HICL

HICL PROCEEDINGS

Editors: Kersten, W., Blecker, T., Ringle, C.M. and Jahn, C. 2019
Artificial Intelligence and Digital Transformation in Supply Chain Management.
ISBN: 978-3-750249-47-9
Digital Transformation in Maritime and City Logistics.
ISBN: 978-3-750249-49-3

Editors: Kersten, W., Blecker, T., Ringle, C.M. and Jahn, C. 2018
The Road to a Digitalized Supply Chain Management.
ISBN: 978-3-746765-35-8
Logistics 4.0 and Sustainable Supply Chain Management.
ISBN: 978-3-746765-36-5

Editors: Kersten, W., Blecker, T., Ringle, C.M. and Jahn, C. 2017
Digitalization in Supply Chain Management and Logistics.
ISBN 978-3-7450-4328-0
Digitalization in Maritime Logistics and Sustainable Supply Chain Management.
ISBN 978-3-7450-4332-7

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.
ISBN 978-3-7375-0341-9
Next Generation Supply Chains.
ISBN 978-3-7375-0339-6
…find more proceedings on hicl.org/publications

Proceedings of the Hamburg International Conference of Logistics 29

Data Science and Innovation in Supply Chain Management

How Data Transforms the Value Chain

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

Edition	1st edition, September 2020
Publisher	epubli GmbH, Berlin, www.epubli.de
Editors	Wolfgang Kersten, Thorsten Blecker and Christian M. Ringle

Cover design	Martin Brylowski
Cover photo	Photo by Markus-Spiske on Unsplash
Layout	Carolin Herberg, Ole Grasse, Marvin Kastner and Martin Brylowski

ISBN	978-3-753123-46-2
ISSN (print)	2635-4430
ISSN (online)	2365-5070

Preface

Data sciences continue to shape the industrial and scientific world opening new opportunities across a wide range of sectors. Artificial intelligence is considered a key driver of data science that has the potential to introduce new sources of growth. The recent advances in machine learning and automation have created a whole new business ecosystem.

This year's edition of the HICL proceedings complements the last year's volume: Artificial Intelligence and Digital Transformation in Supply Chain Management. All entities along the supply chain are challenged to adapt new business models, techniques and processes to enable a smooth transition into an innovative supply chain.

This book focuses on core topics of data science and innovation in the supply chain. It contains manuscripts by international authors providing comprehensive insights into topics such as Supply Chain Analytics, Blockchain, Technology Management or Advanced Manufacturing and provide future research opportunities in the field of supply chain management.

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

Hamburg, September 2020

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

Table of Contents

I.
Innovation and Technology Management

How Disruptive Start-Ups Change the World of Warehouse Logistics

Julia Feldt [1], Henning Kontny[2], and Frank Niemietz[2]

1 – Hamburg University of Applied Science

2 – Swisslog GmbH

Purpose: New technical solutions in logistics change the ways of working within warehouses on different levels, from warehouse layouts and concepts of goods picking to process planning and human resources. Thus, disrupting the previous practice in its core.

Methodology: In order to evaluate the impact of the new technologies on the warehouse operations, the multiple case study approach was used. To gain a deeper understanding of the changes within logistics processes, the results of the deep-dive analysis are summarized using morphologic box methodology.

Findings: Presented solutions such as AutoStore, Kiva and CarryPick can lead to a substantial increase in the speed of order picking while staying very flexible and demanding significantly less of expensive warehouse space. Still, the implementation of these technologies requires a systematic approach with clearly stated goals.

Originality: In contrary to available papers which are concentrating on a single case study with application of one technology at one particular company, the presented paper analyses several solutions comparing them with each other. Additionally, the research evaluates the impact of the technologies on logistic processes and warehouse layouts. Thus, creating value for practitioners looking for solutions to optimize intralogistics.

First received: 6. Mar 2020 Revised: 20. Jun 2020 Accepted: 26. Jun 2020

1 Introduction

Due to the rapid development of e-commerce in the last decade (Statista, 2020b; a), the customer orders became small-sized, low-volume, but more frequent (Battini et al., 2015). Thus making "classic" picking operations, immensely dependent on manual labor (de Koster, Le-Duc and Roodbergen, 2007) and initially created for high-volume B2B picking, highly inefficient and cost-intensive. According to researchers the picking process is the most costly activity in the warehouse and can be responsible for up to 55% of warehouse expenses (D'Souza, Costa and Pires, 2020; de Koster, Le-Duc and Roodbergen, 2007).

Another challenge is increasingly low availability of workers for warehouse operations (BCG, 2014), which inevitably leads to the rise in salaries and thus, warehouse costs.

The rise of digitalization can be used to achieve the positive effects in logistics (Kersten et al., 2015), especially applying robotics for the support of warehouse personnel can lead to higher productivity in combination with lower costs (Robotics Business Review, 2020; Bonkenburg, 2016).

The main aim of this paper is to present short use cases and evaluate available technical solutions for the improvement of picking processes in times of e-commerce growth and personnel scarcity. Thus, supporting warehouse companies in decisions on the application of robotic solutions at their companies.

2 Methodology

To provide a clear structured information on different technologies and thus, creating a basis for further ana-lysis the method of a case study was chosen. According to Boer (2015) case research belongs to one of the most compelling research methods in operations, especially in the design of original theory. He argues that with recent fast developments in technology, researchers should rely more on field-based research methods. Other researchers (Ketokivi and Choi, 2014) add that some of the "breakthrough concepts and theories" (i.e. lean production and servitization) in operations were evolved from case studies. In other disciplines such as management and sociology case research is already acknowledged method and is broadly applied to study organizational behavior and strategy, perform ethnographic and anthropology studies (Karlsson, 2016, p.166).

In recent years case study as a research method gained recognition from experts in operations research. The Journal of Operations Management (JOM) stated in its mission “highest priority is thus given to studies that are anchored in the real world” (Karlsson, 2016). Additionally, researchers (Ketokivi and Choi, 2014; Boer et al., 2015; Yin, 2018) underline that results of a good case study can result in remarkably high impact.

Visualization of the main results was performed using the method of the morphological box, which main advantage is a presentation of different alternatives at the same time (Blecker et al., 2004; Koch, 2015).

The methodology consists of three main steps (Schawel and Billing, 2011) :
Step 1. Problem definition (s. chapter 3).
Step 2. Possible solutions (three case studies described in chapter 4).
Step 3. Evaluation of solutions based on defined dimensions and scores (as presented in chapter 5.1).

3 Problem Definition

Today's warehouse logistics is confronted by following main trends:

Growth of e-commerce sales. According to Statista (2020a)big e-commerce companies has grown substantially from 2009 to 2019, Amazon (worldwide) from 24,51 to 280,52 billion USD and Zalando (German e-commerce company) from 6 million to 6,48 billion USD. The study of DHL confirms that such rapid growth can only be achieved with appropriate warehouse capacities and optimization of all logistics processes (Bonkenburg, 2016).

Customer expectations. Amazon has pushed the expectations of the customers to the limits of possible, promising them next- or even same-day delivery (Bechtsis et al., 2017), putting competitors and warehouse logistics under strong performance pressure (Füßler and Boysen, 2017; Robotics Business Review, 2020).

Labor force shortfalls are predicted by BCG (2014) and based on the demographic risk would cause a considerable deficit of workers (in Germany, the shortage would be around 10 million workers by 2030). Since the "classic" order picking processes are highly dependent on the human workforce, they will suffer under a lack of personnel on the market.

Industry 4.0, digitalization or Internet of Things, which is connecting the processes, machines and even products in (near)-real-time enabling decentralized autonomous decisions (Wagner and Kontny, 2017) as well as adding flexibility and robustness to the system (Monostori, 2018).

The trend of digitalization, on the one hand, puts additional pressure on the companies to improve their processes, systems and spend money on technology in times of economic uncertainty (Feldt, Kontny and Wagenitz, 2019). On the other hand, it can provide solutions to the predicted labor deficit (Bonkenburg, 2016), enabling a high level of customer satisfaction through fast deliveries allowing companies to profit from the e-commerce growth. An additional argument for the implementation of digital solutions in warehouse logistics is the distribution of worker's time, which is according to De Koster (2007; 1999) in "classic" order picking process is shaped by walking and searching (around 70% of total work hours) while picking itself takes only around 15% of the time (s. figure 1). Although there are some robots on the market which could replace the picking part of the process, as described by researchers (Kohl et al., 2019; Mester and Wahl, 2019; Schwäke et al., 2017; Rieder and Verbeet, 2019), presented paper is focused on technologies for replacement of the walking and searching part of the process.

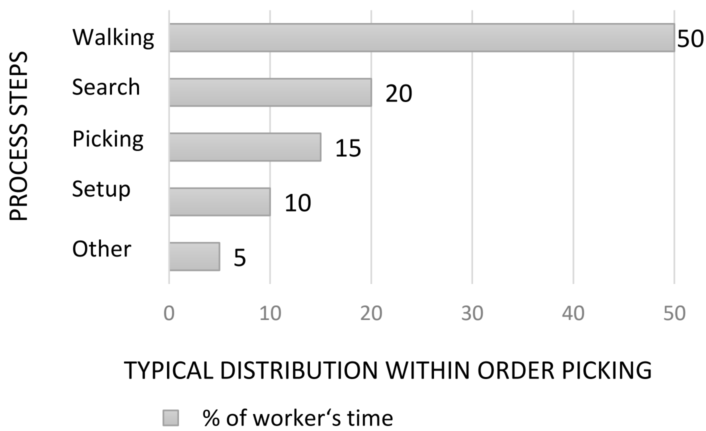


Figure 1: Time distribution within order picking process (according to de Koster, Le-Duc and Roodbergen, 2007)

According to the Robotic Business Review (2020) currently, there are over 50 warehouse automation companies with an overall revenue of 13 billion USD in 2018 with a predicted growth to 27 billion USD by 2025. To compare the automated solutions with the "classic" order-picking process, the focus was narrowed to the following technologies:

- Kiva systems, which were bought by Amazon and renamed to Amazon Robotics[1].
- CarryPick KMP600 AGV from Swisslog and KUKA.
- AutoStore as the most space-efficient goods-to-person storage systems (AutoStoreSystem, 2020).

The reasons for the choice as well as the case description of each technology are described in the respective chapters below.

[1] Since Amazon Robotics contains more than just Kiva systems which are in focus of the research, we will continue to use the term Kiva systems in the paper.

4 Case Studies

4.1 Kiva Systems

In the year 2012, Amazon acquired a start-up company called Kiva Systems, a robot manufacturer, for 775 million USD (The New York Times, 2012). This way, Amazon has differentiated itself from other e-retailers and enabled fast deliveries within one or two days.

The main focus of the KivaSystems is to bring goods to the workers as in contrary to the initial person-to-goods concept, saving up to 10 miles per worker per day and up to 50% of workers time (D'Andrea, 2012). Thus, at that point in time, the KivaSystems used a highly innovative approach to the order-picking process supported by the new technology of autonomous mobile robotics (AMR).

As presented in figure 2, the KivaSystems needs less warehouse space due to narrow gangways and saves at least 50% of picking time of a warehouse worker, since it works

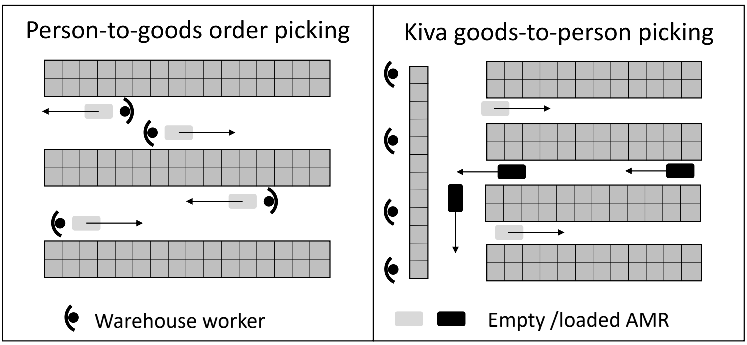


Figure 2: Classic order picking vs Kiva picking

based on a goods-to-person concept in contrary to time-consuming person-to-goods order picking. Due to the reason that Amazon uses KivaSystems exclusively and even renamed it into AmazonRobotics, next product which is available for any company will be evaluated in the next chapter.

4.2 CarryPick

CarryPick system was created for the warehousing and picking operations and can be applied in small or big-size warehouses due to its scalability. Similar to Kivasystem, CarryPick is based on goods-to-person picking concept, uses AMRs (automated mobile robots) to bring racks with goods to warehouse workers. Additionally, a worker is supported by "pick-by-light" technology which allows saving time for the search of the right product (which according to de Koster (2007) takes up to 20% of the overall picking time).

CarryPick system consists of mobile racks, AMRs, workstations for pickers and a warehouse management software for autonomous process steering; thus, the structure of the solution is very similar to the KivaSystems.

One of the most interesting features of the system is its ability for growth. If needed, additional AMRs can be added to an existing system in combination with additional racks for goods storage. Thus, making the system scalable, which is indispensable in times of strong and fast e-commerce growth. According to Swisslog (2020b), the whole racks structure is very efficient and is up to 300% better than a conventional rack system (s. fig.2).

Still, there is even more space-efficient system available, such as AutoStore, which contains no space between racks and can be build up to 5,4 meters high (AutoStoreSystem, 2020) in contrary to 2,5 meters CarryPick racks (Swisslog, 2020a). Thus, using the warehouse space in the best possible way.

4.3 AutoStore

AutoStore system consists of plastic bins, which can be filled with a single product or have up to 36 compartments with max. total weight up to 30 kg (AutoStoreSystem, 2020). The bins are stored in up to 24 different levels (AutoStoreSystem, 2020) in a system and can be transported by robots, which are moving on top of the rack system as shown on fig.3 and can "dive" in order to get the bin (as shown on the right side of fig. 3). The robots are quite fast, they move with a velocity of 13 km/h, which allows them to bring the bin to the "ConveyorPort" from any point of the warehouse within approx. 2 minutes.

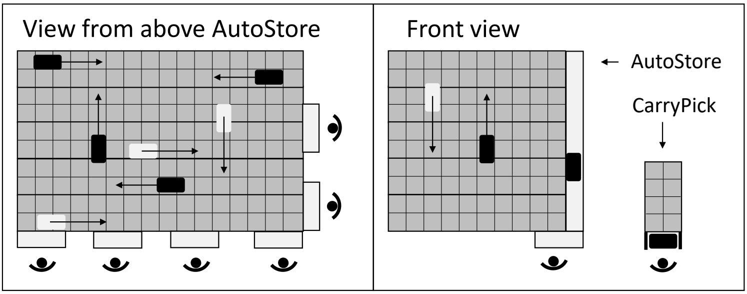


Figure 3: AutoStore view from above and from the front

The workers pick the goods from a bin at ConveyorPort and are additionally supported by pick-by-light and weight control systems. On the right side of figure 3, the difference between CarryPick and AutoStore is visualized and demonstrates the difference in height at AutoStore and thus, even more efficient use of cost-intensive warehouse space. On the other hand, AutoStore is limited to the products with maximal measurement of 649x449x425mm and weight of around 30kg (AutoStoreSystem, 2020).

Since most products which are sold online are still fitting in these constraints, AutoStore can easily be applied for e-commerce. If needed, the combination of both systems can be applied, due to their scalability and flexibility. The comparison of the systems is provided in the next chapter.

5 Results and Discussion

5.1 Morphologic Box

In order to evaluate different technologies and compare them with "classic" order-picking processes, the methodology of the morphologic box was chosen (as described in chapter 2). The scenarios of Kiva and CarryPick were evaluated as one since the differences between them are rather insignificant in comparison to other technologies. The dimensions for the evaluation are based on feedback from industry experts and the importance of those dimensions for the implementation as well as during the whole period of warehouse operation.

Due to the reason, that same value in different dimensions can have the opposite meaning, i.e. low investment in hardware or low personnel cost are rather positive while a low number of picks per hour or low scalability are negative, the dimensions were evaluated on efficiency. For example, low efficiency in warehouse space means that the technology demands extensive warehouse space. At the same time, low efficiency in picks per hour means that the productivity of the technology is lower than the productivity of the technology with high efficiency. This approach allows evaluation under a common denominator, uncomplicated assignment of scores (1 point for low, 2 for medium and 3 for high efficiency), and homogeneous visual mapping.

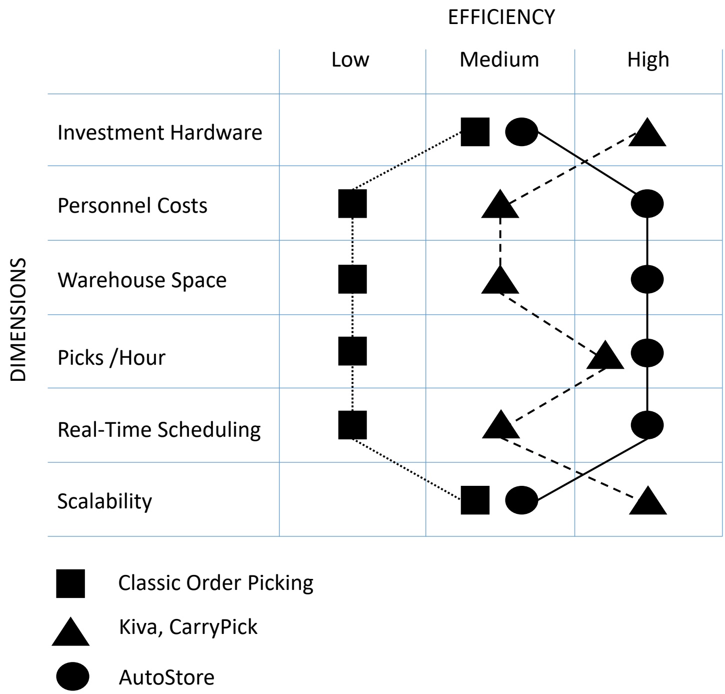


Figure 4: Analysis of Technologies Based on Efficiency in Six Dimensions

As shown in the figure above the "classic" order-picking processes are least efficient; they achieved only 6 out of 18 possible points. Although investment in hardware such as forklifts and warehouse racks could be evaluated as a medium; the high personnel costs, high usage of expensive warehouse space combined with low productivity (due to the extreme long ways up to 10 miles per worker per day for picking goods) as well as inflexible scheduling and thus low flexibility lead to inefficient processes. Considering the fact that e-commerce customers expect their orders to be delivered the next day, and the operations need real-time scheduling which would allow scheduling the customer orders for picking the same day. Otherwise, the order would be picked earliest next day, unnecessarily increasing the duration of the delivery.

Scalability is another crucial dimension of today's warehouse operations. Due to the constant growth of e-commerce each year by approx. 9%, companies need to regularly increase their warehouse capacities, building additional warehouse space, buying hardware, and hiring personnel.

The Kiva and CarryPick technologies demand lower investment in hardware in comparison to the "classic" system, have lower personnel costs (the workers are concentrating on a picking part of the process without "running"). Additionally, those technologies demand less space, due to the reason that the robots move below the racks in comparison to the forklifts which need their fixed "streets". The number of products which could be picked per hour is substantially higher than in "classic" process since in the "classic" process around 2/3 of the time are spent by running through the warehouse while looking for the right storage rack.

Moreover, real-time scheduling allows adapting the schedule for the day to the incoming customer orders, thus, providing additional flexibility to the process. The scalability of the systems is rather high. Hovewer additional robots and racks can cause re-routing of the robots to prevent the situations of the traffic jam as well as mutual lockdown by robots (Füßler and Boysen, 2017). Applying the score system described above, the CarryPick robots earn 15 out of 18 points.

The AutoStore system needs slightly higher investment in the hardware due to higher prices of the racks, which have up to 14 levels in comparison to rather low racks of Carry Pick. For the same reason, the scalability of the

AutoStore under consideration of the required investment is medium, since its efficiency is lower than in case of expansion of CarryPick system. Personnel costs in AutoStore scenario are the lowest, since the workers receive the highest possible support from the automation, thus increasing the number of picks per hour.
At the same time, AutoStore is the most space-efficient way of goods storage, due to the absence of any space between the shelves. Not only the movements of robots are scheduled in real-time modus, but also the customer orders can be translated in picking orders in (near)-real-time modus if needed, making this technology the most flexible and fast. Due to the above reasons, the system was evaluated with the highest score of 16 out of 18 points.
Although new technologies provide substantially higher efficiency to order-picking processes, they also have some limitations in their application, which need to be considered and are described in the next chapter.

5.2 Application Limitations

Despite the numerous advantages of the CarryPick and AutoStore technologies, they have some limitations for their application based on their technical data.
AutoStore can only be used for the products with volume in the same or smaller size as an AutoStore bin (AutoStoreSystem, 2020). Similarly, CarryPick and Kiva systems have restrictions on the volume of the products, although their volume is substantially higher than in AutoStore (based on a rack length and width in comparison to a size of a bin).
Still, even here, products with high-volume, such as furniture or bikes, which can be sold online, cannot be picked by CarryPick. On the other hand,

such high-volume products have, as a rule, different delivery conditions (so-called two-man-handling) and would be sent separately to the small-size orders.
For example, if a customer orders a garden table and decoration to it in the same order in the same online store, he would receive two deliveries: one as a small package delivered by parcel company such as DHL or DPD and the other delivered by a truck company such as Kuehne+Nagel. For that reason, high-volume products can have separate handling in the warehouse and will not disturb high-automated processes of handling of the small and medium volume products.
Due to the above limitations in the application, it is recommended for the companies to perform an analysis of their current product structure and then to decide on the most appropriate system or a combination.

5.3 Discussion of Results

Application of new technologies leads to changes in different areas of warehouse logistics, such as:
Warehouse layouts. On the one hand, the expensive warehouse space can be utilized more efficiently using CarryPick or AutoStore technology, thus promising fast returns on investment. On the other hand, the warehouse layouts need to be re-planned, dividing the areas for human workers from the areas where only robots should move.
Concepts of goods picking. Since the "classic" concept of person-to-goods causes low productivity and is incredibly inefficient(de Koster, Le-Duc and Roodbergen, 2007), it would be replaced on a long-term by the concept of goods-to-person, where robots support warehouse workers by bringing them goods for picking (D’Souza, Costa and Pires, 2020).

Process planning. Reactive scheduling of orders in (near)-real-time modus would completely replace schedu-ling based on demand planning. Although demand planning processes are essential for the strategy of the company, they cannot be applied for the real-time scheduling of picking orders based on same-day customer orders. Thus, the planning processes would become decentralized and autonomous (Feldt and Kontny, 2020).

Human Ressources. Arising technologies such as CarryPick and AutoStore allow reacting to the increasingly low availability of the warehouse personnel (BCG, 2014), at the same time providing existing workers with more human-friendly work environment than initial order-picking systems, thus ma-king the job of warehouse workers more attractive.

5.4 Limitations of the Study and Recommendations for Further Research

Although during the research period different scenarios for the application of CarryPick and AutoStore were elaborated for an e-commerce company in Hamburg, including evaluation of the investment costs and impact of new technology on processes, the results cannot be presented here due to the signed non-disclosure agreement. Thus, limiting the presentation of results to the qualitative analysis.

For this reason, the authors can recommend other researchers to perform applied research on the topic of disruptive start-ups with innovative technological solutions in order to provide demanded support for the practitioners in the area of warehouse logistics.

Additionally, cooperation between practitioners (i.e. e-commerce companies or technology providers) and resear-chers is highly recommended. The researchers can support the practitioners with independent and unbiased (in comparison to commercial providers) results while benefiting from the experience of the company experts. Thus, creating valuable benefits for the participants on both sides.

6 Conclusion

This study contributes to the topic of warehouse logistics in times of e-commerce growth by providing a multiple case study with evaluation of technology systems. Presented morphological box provides practitioners with the dimensions which should be taken into consideration for choice and (re-)design of order-picking warehouse systems. In combination with the description of main trends for the next ten years, it can reveal new perspectives on the operations and motivate companies to invest their financial resources in the same manner as Amazon and Zalando who has shown considerable growth in past years.

Additionally, it must be said that there is no technology which would fit best in every scenario. While looking for a proper solution, a company should perform an analysis of the own data (i.e. product structure, available warehouse area) prior to the investment in one technology over the other. In some cases, the combination of two or three technologies can be most beneficial.

Furthermore, the current development trends, such as tremendous growth of e-commerce, which was accelerated even further by the COVID-19 restraints as well as the expected shortage of the warehouse workers in the next years should be taken into consideration by companies.

References

AutoStoreSystem, 2020. Technical data on bins. [online] Available at: <https://autostoresystem.com/de/bins/> [Accessed 27 May 2020].

Battini, D., Calzavara, M., Persona, A. and Sgarbossa, F., 2015. A comparative analysis of different paperless picking systems. Industrial Management & Data Systems, 115(3), pp.483–503.

BCG, 2014. The Global Workforce Crisis: $10 Trillion at Risk. [online] Available at: <https://www.bcg.com/publications/2014/people-organization-human-resources-global-workforce-crisis.aspx> [Accessed 24 May 2020].

Bechtsis, D., Tsolakis, N., Vlachos, D. and Iakovou, E., 2017. Sustainable supply chain management in the digitalization era: The impact of Automated Guided Vehicles. Journal of Cleaner Production, 142, pp.3970–3984.

Blecker, T., Abdelkafi, N., Kreutler, G. and Friedrich, G., 2004. Product Configuration Systems - State of the Art - Conceptualization and Extensions. p.13.

Boer, H., Holweg, M., Kilduff, M., Pagell, M., Schmenner, R. and Voss, C., 2015. Making a meaningful contribution to theory. International Journal of Operations & Production Management, 35(9), pp.1231–1252.

Bonkenburg, T., 2016. Robotics in Logistics. A DPDHL perspective on implications and use cases for the logistics industry. p.37.

D'Andrea, R., 2012. Guest Editorial: A Revolution in the Warehouse: A Retrospective on Kiva Systems and the Grand Challenges Ahead. IEEE Transactions on Automation Science and Engineering, 9(4), pp.638–639.

D'Souza, F., Costa, J. and Pires, J.N., 2020. Development of a solution for adding a collaborative robot to an industrial AGV. Industrial Robot: the international journal of robotics research and application, [online] ahead-of-print(ahead-of-print). Available at: <https://www.emerald.com/insight/content/doi/10.1108/IR-01-2020-0004/full/html> [Accessed 23 May 2020].

Feldt, J. and Kontny, H., 2020. AIDA 4.0: Architectures of Industry 4.0 demonstrated through application scenarios in business game. In: Dynamics in Logistics. Proceedings of the 5th International Conference LDIC. Bremen.

Feldt, J., Kontny, H. and Wagenitz, A., 2019. Breaking Through the Bottlenecks Using Artificial Intelligence. p.29.

Füßler, D. and Boysen, N., 2017. Efficient order processing in an inverse order picking system. Computers & Operations Research, 88, pp.150–160.

Karlsson, C., 2016. Research Methods for Operations Management. 2nd ed. [online] NY: Routledge. Available at: <https://www.researchgate.net/publication/310280068_Research_Methods_for_Operations_Management> [Accessed 23 May 2019].

Kersten, W., Blecker, T., Ringle, C.M. and epubli GmbH eds., 2015. Sustainability in logistics and supply chain management: new designs and strategies. 1st ed ed. Proceedings of the Hamburg International Conference of Logistics (HICL). Berlin: epubli GmbH.

Ketokivi, M. and Choi, T., 2014. Renaissance of case research as a scientific method. Journal of Operations Management, 32(5), pp.232–240.

Koch, S., 2015. Einführung in das Management von Geschäftsprozessen. [online] Berlin, Heidelberg: Springer Berlin Heidelberg. Available at: <http://link.springer.com/10.1007/978-3-662-44450-4> [Accessed 23 May 2020].

Kohl, M., Malik, B., Lopitzsch, J. and Fottner, J., 2019. Auswahl- und Priorisierungsmodell für Industrie 4.0-Use Cases in der Logistik. Volume 2019, p.Issue 12.

de Koster, R., Le-Duc, T. and Roodbergen, K.J., 2007. Design and control of warehouse order picking: A literature review. European Journal of Operational Research, 182(2), pp.481–501.

de Koster, R., Roodbergen, K.J. and van Voorden, R., 1999. Reduction of Walking Time in the Distribution Center of De Bijenkorf. In: M.G. Speranza and P. Stähly, eds. New Trends in Distribution Logistics, Lecture Notes in Economics and Mathematical Systems. [online] Berlin, Heidelberg: Springer Berlin Heidelberg.pp.215–234. Available at: <http://link.springer.com/10.1007/978-3-642-58568-5_11> [Accessed 24 May 2020].

Mester, J. and Wahl, F., 2019. Robotik in der Intralogistik - Ein Projekt der Unternehmen Fiege und Magazino. In: I. Göpfert, ed. Logistik der Zukunft - Logistics for the Future. [online] Wiesbaden: Springer Fachmedien Wiesbaden.pp.199–211. Available at: <http://link.springer.com/10.1007/978-3-658-23805-6_7> [Accessed 24 May 2020].

Monostori, J., 2018. Supply chains robustness: Challenges and opportunities. Procedia CIRP, 67, pp.110–115.

Rieder, M. and Verbeet, R., 2019. Robot-Human-Learning for Robotic Picking Processes. p.29.

Robotics Business Review, 2020. Warehouse Automation Companies - The Top 50 for 2020 According to LogisticsIQ. [online] Robotics Business Review. Available at: <https://www.roboticsbusinessreview.com/research/the-top-50-warehouse-automation-companies-2020/> [Accessed 23 May 2020].

Schawel, C. and Billing, F., 2011. Top 100 Management Tools: Das wichtigste Buch eines Managers. 3., überarb. Aufl ed. Wiesbaden: Gabler.

Schwäke, K., Dick, I., Bruns, R. and Ulrich, S., 2017. Entwicklung eines flexiblen, vollautomatischen Kommissionierroboters. Volume 2017, p.Issue 10.

Statista, 2020a. E-commerce in Germany. Available at: <https://www.statista.com/study/32414/e-commerce-in-germany-statista-dossier/>.

Statista, 2020b. eCommerce Report 2020. Available at: <https://www.statista.com/study/42335/ecommerce-report/>.

Swisslog, 2020a. CarryPick: flexibles, modulares Kommissioniersystem. [online] Available at: <https://www.swisslog.com/de-de/produkte-systeme-l%C3%B6sungen/automatisierte-lagertechnik-lagersysteme-lagerlogistik/boxes-cartons-small-parts-items/carrypick-automatisches-lager-und-kommissionier-system> [Accessed 27 May 2020].

Swisslog, 2020b. White Paper Mobile Robotics Web. Available at: <https://www.swisslog.com/de-de/search-results-page?q=carrypick>.

The New York Times, 2012. Amazon.com Buys Kiva Systems for $775 Million - The New York Times. [online] Available at: <https://dealbook.nytimes.com/2012/03/19/amazon-com-buys-kiva-systems-for-775-million/> [Accessed 24 May 2020].

Wagner, J. and Kontny, H., 2017. Use case of self-organizing adaptive supply chain. epubli. [online] Available at: <https://tubdok.tub.tuhh.de/handle/11420/1474> [Accessed 30 Apr. 2019].

Yin, R.K., 2018. Case study research and applications: design and methods. Sixth edition ed. Los Angeles: SAGE.

Product Modularization in Integrated Supply Chains: A Product Life-Cycle Phase Specific Concept for Effect Allocation

Martin Brylowski [1], Maximilian Ludwig [2], Wolfgang Kersten [1], and Wolfgang Schultze [2]

1 – Hamburg University of Technology - Institute of Business Logistics and General Management

2 – CEPRA – Center of Performance Research and Analytics

Purpose: Product modularization and supply chain integration have established themselves as efficient methods for complexity management, but a holistic view of their effects has rarely been studied. For this reason, we demonstrate a concept which presents these effects along the product life-cycle phases (PLCP) and the strategic success factor (SSF):

Methodology: We applied a systematic literature review and carried out 13 semi-structured expert interviews to cover the perspective of science as well as practice. Using qualitative content analysis, the effects of product modularization in integrated supply chains is elaborated. The effects were allocated to the appropriate PLCP and subsequently assigned to the affected SSF.

Findings: We found positive and negative modularization effects in each phase of the product life-cycle: development, procurement, production, sales, and after-sales. Within the appropriate PLCP, the effects were allocated to the SSF: cost, time, quality, flexibility, and risk. Scientists as well as practitioners are aware of the positive effects of modularization. Negative effects are largely neglected in both perspectives.

Originality: The developed concept provides a holistic view of product modularization effects under consideration of an integrated supply chain. Besides the PLCP specific effects are assigned to the affected SSF. This enables a structured and categorized assessment of modularization effects in integrated supply chains and reveals hidden as well as undesirable side effects for science and practice.

First received: 6. Mar 2020 Revised: 20. Jun 2020 Accepted: 26. Jun 2020

1 Introduction

In today's competitive environment companies are facing numerous requirements: Customers are becoming more and more demanding regarding the performance and individuality of products, which increases the number and variety of new product launches. At the same time, the more intensive interaction between mechanical and electronic product components leads to an overlapping of different technology and innovation cycles. Lau, Yam and Tang, (2011), consider the electronics industry to be the industry with the shortest product life-cycles, in which product development is often influenced by the degree of modularity of the product. Concerning drive technology, the number of electronic components of products has risen continuously. From a cost perspective, this change requires a separate optimization of the technology and innovation cycles compared with those of traditional hardware (Müller, 2001, p. 52). Modularization enables those functions, that are subject to the same technology or innovation cycle, to be combined in one module (Müller, 2001, p. 52). This simplifies the replacement of modules with different life-cycles since it is no longer necessary to replace the entire product if only individual components need to be adapted (Müller, 2001, p. 52).

Furthermore, modularization is influenced by the increasing cooperation between companies and supply chain management has been established in many places (Schilling, 2000, p. 327). The design of the product architecture has become indispensable for the design of the interfaces between supplier, producer, and customer and has a considerable influence on product life-cycle costs (Schilling, 2000, p. 327). For example, from the procurement side, modular sourcing can be established to reduce development costs and use the development competencies of suppliers (Schilling, 2000, p. 327). In the after-sales area, spare parts management can be mapped more effective, and, from the customer's point of view, switching costs between different suppliers are reduced (Schilling, 2000, p. 327).

These effects represent only a part of the potential of product modularization with regard to product life-cycle costs (Ulrich, 1994, p. 224). Through the physical decoupling of modules and the decoupling of development and production processes, many other effects can be related to internal company procedures and cooperation in supply chains (Ulrich, 1994, p. 224). Along the product life-cycle, in addition to the direct monetary effects, changes in the strategic success factors (SSF) of time, quality, flexibility, and risk also arise, which can be attributed to costs (Kersten, Lammers and Skride, 2011, p. 24). The diversity of potential product modularization effects reflects the complexity that companies face with product modularization projects. While a comprehensive, structured and transparent presentation of the direct and indirect product modularization effects on product life-cycle costs, considering supply chain activities, could serve as a basis for orientation and decision-making, the literature provides only fragmentary approaches for solving this problem.

Product modularization and supply chain integration have established themselves as efficient methods for complexity management, but a holistic view of their effects has rarely been studied. For this reason, we demonstrate a concept which presents these effects along with the product life-cycle phases (PLCP) and discusses the following research question in this paper:

1) Which product life-cycle phase (PLCP) specific product modularization effects result from supply chain integration in the drive technology industry?
2) How do those effects affect the strategic success factors (SSF) of a company in the drive technology industry?

The remainder of the paper is structured as follows. Section 2 describes the methodological approach. Section 3 describes the Product Life-Cycle Phase Specific Concept for Effect Allocation and assigns the main effects of product modularization in integrated supply chains to the appropriate PLCP and SSF. Section 4 shows the results and section 5 completes the article with a conclusion including the managerial implications and advices for further research.

2 Methodological approach

The allocation of product modularization effects in the integrated supply chain to the appropriate PLCP and SSF of a company follows a five-step research design which can be seen in figure 1.

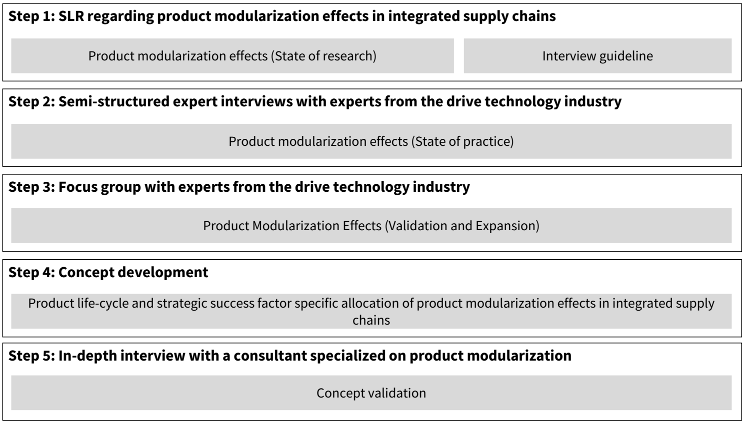


Figure 1: Steps of the methodological approach

First, a systematic literature review (SLR) is applied to extract product modularization effects from scientific publications. This step is also used to develop a guideline for semi-structured expert interviews. One of the aims of this paper is to present the state of the art on the topic of product modularization related to the drive technology industry. Accordingly, the experts participating in the interviews and the focus group are persons exclusively working in this field. Consequently, following the SLR, 13 semi-structured expert interviews are conducted to assess the effects of product modularization in the drive technology industry. The results of both research methods are then discussed in a focus group and extended by further effects. The focus group consists of six experts, all of them previously participated in the expert interviews. The next step is the concept development and thus the allocation of the effects to the appropriate PLCP and SSF of a company. Finally, an in-depth interview is applied to validate research findings. The in-depth interview was conducted with a consultant who is specialized in product modularization. The interviewee has a broad knowledge regarding the effects of product modularization and is therefore ideally suited for the validation of the allocation. The most important person- and company-related information can be found in the appendix. The data generation and validation processes are described in detail in the following chapters.

Step 1: Systematic literature review

In management research, the SLR is an important instrument to manage the diversity of knowledge (Tranfield, Denyer and Smart, 2003, p. 208). Mulrow (1994, p. 597) discusses a variety of arguments why a SLR can be seen as a very efficient method for identifying and evaluating extensive literature. The main difference to traditional research is the introduction of a replicable, scientific, and transparent process that aims to minimize distortions and random errors in systematic literature research (Cook, Mulrow and Haynes, 1997, p. 377). To define uniform steps and to ensure scientific quality, the SLR carried out in this study is based on the procedure described by Tranfield, Denyer and Smart (2003).

At the beginning of the SLR, a review committee should be set up to avoid controversies about the inclusion and exclusion of articles (Tranfield, Denyer and Smart, 2003, p. 214). In the SLR carried out for this work, the review committee consists of the authors that deal with the topic of product modularization for research purposes. After the review committee is set up, the objective of the SLR must be defined (Tranfield, Denyer and Smart, 2003, p. 214). This is already apparent from the motivation and research questions of the present paper.

The identification of relevant research begins with the selection of databases where scientific publications can be found (Tranfield, Denyer and Smart, 2003, p. 215). In this paper "Scopus" and "Web of Science" are selected, which are considered as the largest databases for peer-reviewed literature in various research areas. The data extraction from the databases took place on the 1st of January 2020. Subsequently, keywords and a search string are identified, which are built up from previous preliminary research, literature, and discussions within the review team (Tranfield, Denyer and Smart, 2003, p. 215). The selected search string is divided into three categories with the focus on the keyword "modular*". The search string is used in such a way that each publication found contained modularization in the title, abstract, or keywords. Besides, the keywords "effect", "impact", "implication", and "change" are included, which indicate effects in connection with modularization. This ensured that publications could be found that contained the effects of modularization. Besides, the keywords "supply chain", "supplier", and "value chain" are used to obtain hits linking modularization with the supply chain or value chain perspective. To limit the number of search results and thus exclude irrelevant literature, the search term is reasonably combined using Boolean operators ("AND" and "OR") are illustrated in Figure 2.

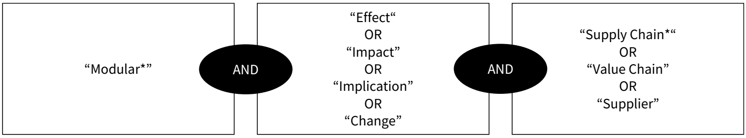


Figure 2: Search string used for the SLR

With those search strings a total of 828 search results were generated on Scopus and Web of Science. After the removal of duplicates, 644 publications remained to be examined. In a next step publications which are not relevant for answering the research question were filtered out (Tranfield, Denyer and Smart, 2003, p. 215). For this purpose, two filter criteria were established. First, all publications that are not written in German or English were filtered out. Second, during title and abstract screening only publications dealing with product modularization in the context of supply chain management were kept. After these steps, 128 relevant publications remained. The subsequent full-text screening was carried out using the same filter criteria, with the addition that product modularization must be treated as a central object of investigation within the studies. A total of 71 publications were identified that meet all filter criteria and thus prove to be suitable for the data extraction. 16 additional publications were added that proved to be relevant in the backward citation. For the final data extraction, 87 articles remained and are shown in detail in the appendix. Figure 3 shows the number of relevant publications after each filter step.

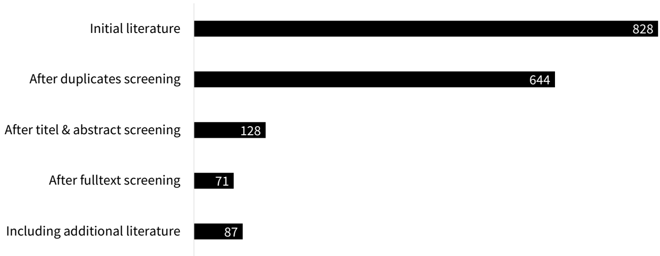


Figure 3: Number of relevant publications

The subsequent extraction and summarization of the data were carried out by using the Citavi 6 software to code and qualitatively analyze all corresponding modularization effects. The literatur analysis was based on Mayring (1994) using the coding method. This contains a summary of identical aspects from the identified publications and their reproduction by a new statement (Mayring, 1994, p. 164). By coding the individual modularization effects, a code structure is created, which is hierarchically structured according to the relationships between the individual modularization effects.

Step 2: Semi-structured interviews

In order to identify product modularization effects in the drive technology industry as comprehensively as possible, 13 expert interviews were conducted within this paper. Those are classified in the category of semi-structured interviews and lasted between 45 and 90 minutes. Besides, these are guideline-based interviews, which differ from open and narrative interviews. An interview guideline contains questions that are asked to the interviewee (Gläser and Laudel, 2010, p. 42). The subsequent extraction and summarization of the data were carried out by following the procedure of

Mayring (1994) and based on a literal transcript. The Citavi 6 software was used to code and qualitatively analyze all corresponding modularization effects.

Step 3: Focus group

The focus group is a moderated, mostly guideline-based discourse process in which a small group of six to twelve people is encouraged to discuss a specific topic by an information input from the researcher. The goal in the course of this group interaction is to collect data, whereby as many different aspects of a topic as possible are to be illuminated (Schulz, 2012, pp. 9–13). Usually, focus groups are not used as a separate method in the research process but are rather integrated into multi-method designs, as is the case in this paper. Nevertheless, the advantages of the interview, such as deeper insights into the experience of the respondents, should not be overlooked. According to Schulz (2012, p. 12), a combination of the two research methods is worthwhile. Therefore, semi-structured interviews and a focus group were applied in this article.
The focus group took place in the format of a one-day workshop after the expert interviews had been conducted and evaluated. The topics and questions of the expert interviews were used to initiate the discussion within the focus group as the goal was to validate and expand the previous research results. There is no uniform procedure for the evaluation of focus groups (Schulz, 2012, p. 12). In this article, a literal transcript is prepared, which was evaluated analogously to the expert interviews using Citavi 6 software and the procedure of Mayring (1994).

Step 4: Concept development

In this step, the previously elaborated results are synthesized. For this purpose, the code structures of the SLR, the semi-structured expert interviews, and the focus group are merged. The result of the synthesis is a three-level pyramid, which hierarchically structures the effects. Based on this pyramid, the effects are allocated to the corresponding PLCP and SSF of a company. The detailed description of the three-level pyramid and its elements as well as the allocation of the effects to the PLCP and SSF take place in the results section of the article.

Step 5: In-depth interview

To validate the effect allocation to the appropriate PLCP and SSF, one in-depth interview has been conducted. In the literature, an in-depth interview is described as a rather unstructured and personal interview with a single respondent. The aim is to reveal in-depth views and assessments on a topic (Frankel, Naslund and Bolumole, 2005, p. 197). The in-depth interview started with a short presentation of the preliminary results and has been conducted at advanced stages of the research process. The in-depth interview lasted for 180 minutes. The validation refers to product modularization effects whose PLCP and SSF precise allocation was previously not possible due to insufficiently specific explanations in the literature and expert interviews or focus group.

3 A product life-cycle phase specific concept for effect allocation

By conducting a systematic literature search, 13 expert interviews and a focus group, a total of 249 modularization effects in integrated supply chains were identified. In the course of extracting the product modularization effects by coding, different effect levels have emerged. This is because some effects, according to the principle of a causal chain, cause the emergence of further effects.

The functional decoupling through reduction of function division and the physical decoupling of modules through interfaces were identified as "first-level effects" in the code structure. Those effects can be interpreted as basic elements of modular product architectures.

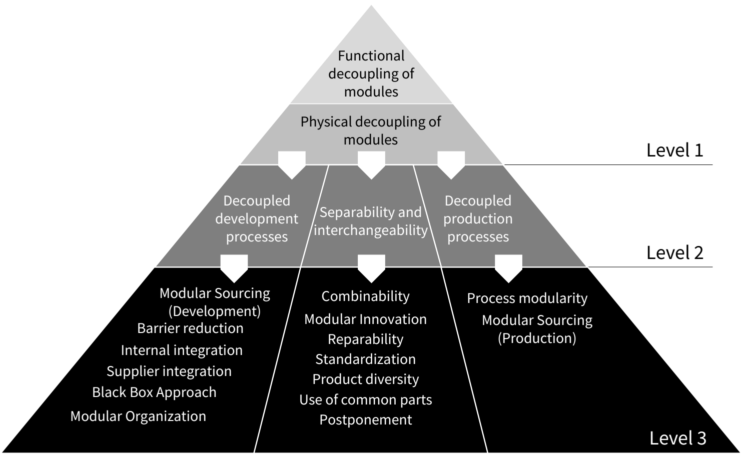


Figure 4: Systematical structure of the modularization effects

Product modularization results from the interaction of these two effects. Consequently, these first-level effects bundle all further modularization effects. In the next step some effects of the second code structure level were also categorzied as "main effects" in order to create transparency and to highlight the most important ones. Those modularization effects that result from the effects of the first level and lead to more than ten further effects each were recorded as "main effects" of the second code structure level. These include the process-related effects of decoupling the development and production processes and the product-related effect of separability and interchangeability (of modules). These main effects are of correspondingly great importance, as they divide all other product modularization effects into three different dimensions.

The approach for highlighting main effects was also applied to all effects beyond the first two levels of the code structure, with the difference that these were categorized as main effects if they bundled more than five further sub-effects each. A total of 20 main effects could be identified through this procedure, of which 11 main effects are attributable to both research and practice. The remaining nine main effects could only be identified within the systematic literature search. Main effects that result exclusively from practice could not be identified. Figure 4 shows a pyramid that structures all identified main effects systematically.

The allocation of the effects to the appropriate PLCP and SSF is based on the 249 identified modularization effects and its expected impacts stated in the literature and expert interviews (or focus group). Every effect was assigned to exactly one PLCP/SSF combination. The result can be seen in Figure 5. A distinction is made between positive (+1) and negative (-1) effects. The allocation of product modularization effects was discussed in the in-depth interview and adjusted at relevant points. This refers to the effects whose precise allocation was previously not possible due to insufficiently specific explanations in the literature and expert interviews (or focus group).

In the following part, the elaborated 20 main effects which cause the shown impacts on the PLCP are described in detail.

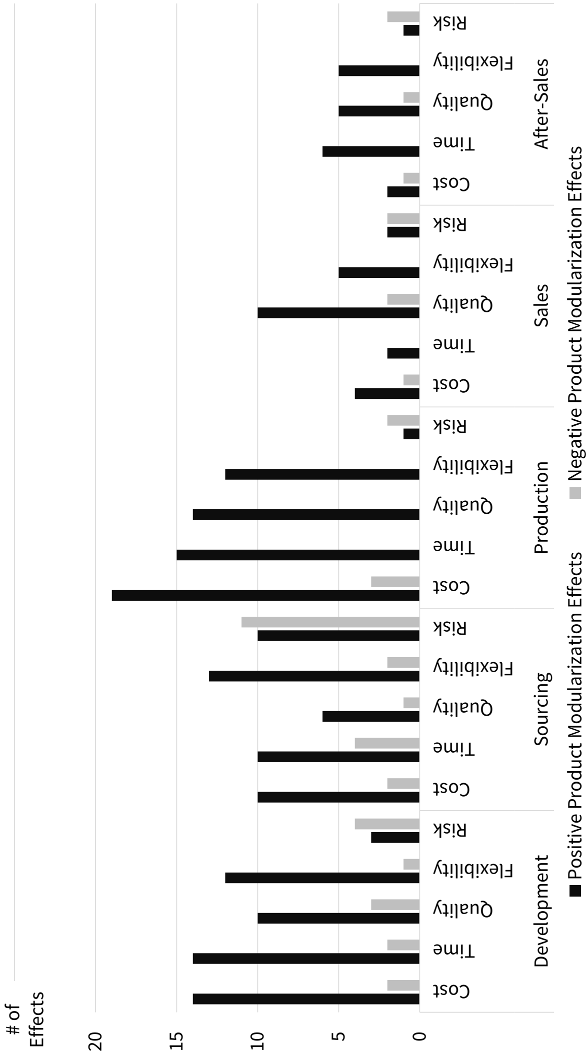


Figure 5: Effect allocation

Functional decoupling of modules

Functional decoupling refers to the reduction of the functional division of components or modules and the resulting independence of modules. Due to the intended 1-to-1 mapping of components (modules) to functions, components (modules) fulfill fewer functions in modular product architectures compared to the integral design. The resulting sub-effects relate to changes in product structure or complexity (Ulrich, 1995, p. 422).

Physical decoupling of modules

Interface definition and standardization creates physical independence from modules by defining decouplable or reversible interfaces (Ulrich, 1995, p. 422). This ensures that the connections between the components within a module remain powerful, while the connections between the modules are relatively weak. The standardization of interfaces across different products or product families or even company boundaries represents the second step, which reinforces the potential of product modularization (Sanchez and Mahoney, 1996, pp. 65–66). As described, physical decoupling allows exploiting the three main effects of "separability or exchangeability", "decoupling of development processes", and "decoupling of production processes", whereby it must be mentioned that these are partly created by the interplay between functional and physical decoupling. Since the literature focuses primarily on physical separability when mentioning the main effects, they are mostly attributed to the main effect of physical decoupling of modules. In this way, a double inclusion of the subordinate main effects as well as their sub-effects could be avoided in the evaluation of the effects on the PLCP.

Decoupled development processes

When the view changes from the modular product to the processes of the modularizing company, the decoupling of development processes can be determined. The decoupling of development processes refers to the possibility of separate and parallel development, which arises when the functions of modules are precisely specified and the interfaces between individual modules and the rest of the product are fully defined. The possibility of decoupling processes results from the functional and physical independence of modules (Sanchez and Mahoney, 1996, p. 64) (Danese and Filippini, 2010, p. 1194). Thus, the coordination of processes can be limited to ensure that the components or modules to be developed correspond to the standardized interfaces (Ulrich, 1994, p. 224). Product development can be divided internally and externally by having different development teams taking over the development of individual modules (Vickery, et al., 2016, p. 755).

Separability and interchangeability

As can already be seen from the explanations above, product modularization results in a decoupling of modules within a product architecture. This decoupling can be transformed into a relatively simple separability of the individual modules. Moreover, in addition to this reversibility, other modules can be easily inserted into the product architecture (interchangeability), if standardization of the corresponding interface is assumed (Fixson, 2005, p. 359) (Sanchez and Mahoney, 1996, pp. 65–66). The primary effects of separability and interchangeability are increased combinability, modular innovation, and reparability. These effects will be discussed in detail later.

Decoupled production processes

Parallel to the decoupling of the development processes, the division of a product into independent modules also enables the decoupling of production processes according to the same principle. Accordingly, the production of the individual modules or subsystems can be carried out independently of each other and parallel to each other, internally and externally, in different plants (Ulrich, 1994, p. 224) (Pashaei and Olhager, 2017, p. 362).

Modular sourcing (Development)

According to Christensen (2011, p. 214), the more efficient coordination in integrating suppliers is reflected in the sourcing of development and production activities. Here, favorable framework conditions are created by combining individual parts into complete functional units (modules) within the framework of "modular sourcing", which are developed, manufactured and pre-assembled by module suppliers before being delivered to the final assembly plants. The possibility of modular sourcing also results due to the independence of individual modules from the rest of the product architecture (Wang and Zhang, 2019, p. 11). Modular sourcing is separated into the spin-off of development activities on the one hand and production activities on the other. These are described at a later stage below.

Barrier reduction

At the beginning of this section, it should be mentioned that within this article no difference is made between different degrees of modularity, but a discrete way of thinking in integral and modular product architectures is assumed. This is of importance since different views dominate in the literature regarding the characteristics of information sharing and the resulting type of supply chain collaboration. According to Howard and Squire (2007), a modular product architecture leads to increased information sharing between buyers and suppliers, from initial design to delivery. This, in turn, leads to increased supply chain collaboration and information sharing.

In contrast, Cammarano, Michelino and Caputo (2019, p. 2) for example, do not make a direct distinction between degrees of modularity and take a much more radical stance by considering modularization and collaboration as opposites. Nevertheless, they do not exclude the integration of suppliers but argue that it is achieved by coordination through standardized interfaces. This means that the cooperative technical development of components or modules between the buyer and suppliers can be minimized as far as possible and handled almost completely autonomously by one of the two parties. Only initial contents such as specifications and communication channels must be defined together in advance. Therefore, the essential requirement to be met is the installment of components or modules with a specific function within the product architecture of the buyer via standardized interfaces.

At the same time, it should be mentioned that the occurrence of completely modular product architectures is rather unlikely (Ulrich, 1995, p. 424). Nevertheless, this idealized view serves to illustrate the maximum potential of product modularity and is therefore suitable for achieving the goals of this article.

Beyond the discussion on the degree of collaboration between buyers and suppliers, a modular product architecture leads to the establishment of a "common language" which simplifies the way a product is described. This also simplifies communication and information flow between the various internal and external business units (Lorenzi and Di Lello, 2001, p. 432). This leads to the dismantling of internal and external communication barriers, thus promoting both supplier and internal integration (Boer and Boer, 2019) (Seyoum and Lian, 2018, p. 857). These subordinate main effects are described below.

Internal integration

Internal integration refers to teamwork and the participation of different internal departments and functions in decision-making, which is increasingly taking place in the context of product modularization (Wang and Zhang, 2019, p. 2). Zhang, et al. (2019), were also able to demonstrate the positive effects of product modularization on internal quality integration. They define internal quality integration as the degree to which an organization structures its policies, practices and procedures into collaborative, synchronized processes to meet the quality requirements of its customers (Zhang, et al., 2019, p. 7). In doing so, they include quality aspects related to production, development and sales processes in their approach (Zhang, et al., 2019, p. 10).

Supplier integration

The term supplier integration can be derived from the definition of supply chain integration, which is described overall as a process of redefining and connecting units or companies through the coordination or exchange of information and resources (Mujuni Katunzi, 2011, p. 106). Supplier integration suggests that suppliers provide information and participate in decision-making. It is characterized by a cooperative relationship between the buyer and the upstream supplier (Petersen, Handfield and Ragatz, 2005, p. 379). Modular product architecture enriches supplier integration by reducing the complexity of communication and interaction with suppliers as far as possible to the interfaces of a module, thus enabling efficient coordination (Seyoum and Lian, 2018, p. 857) (Wang and Zhang, 2019, p. 5). Accordingly, more efficient supplier integration results as a positive effect of modular product architecture compared to integral product architecture.

Black box approach

Two different alternatives to the black box approach have been identified in the literature. The original black box approach represents a radical mechanism compared to supplier integration, where product development is split between a buyer and supplier, with the buyer only defining the basic requirements in terms of design, cost and interface details and transferring the responsibility for delivering the detailed component design, prototyping and production to the supplier. The supplier thus follows the rough framework conditions set by the buyer (Clark, et al., 1987, p.741). In connection with modular products, Cammarano, Michelino and Caputo (2019, pp. 2–4), go one step further and expand this approach by describing an autonomous component or module development by the supplier. In doing so, suppliers develop independent innovations and invest heavily in standardized interfaces that enable embedded coordination, while the buyer has to adapt his activities to the supplier's interfaces to effectively integrate the component or module innovation into products. Basically, in both variants of the black box approach, the interface is predefined by one of the two parties, while the other party must align accordingly. This is the main difference to the more "classic" integration mechanisms, where the interfaces and the design are usually developed or adapted together (Cammarano, Michelino and Caputo, 2019, pp. 2–4).

Modular organization

The theory of the emergence of modular organizations in the course of product modularization originally comes from Sanchez and Mahoney (1996, p. 73), who argue that modular product architectures not only create flexible product designs but also cause the design of loosely coupled, flexible, "modular" organizational structures. The main reason for this is that coordination is embedded in fully specified and standardized component interfaces, which eliminate the need to exercise management authority. If the coordination between buyers and suppliers can be concentrated and reduced to the standardized interfaces, except for possible initial coordination, this results in a reduced need for coordination and collaboration. This increased degree of autonomy means that suppliers can be kept at a certain distance.

Combinability

Combinability results from the fact that modular product architectures create flexible product designs through the interchangeability of individual modules. This implies the possibility of a cross-product "mix and match" of different modules, with standardized interfaces, which can result in new variants (Sanchez, 1995, p. 143).

Modular innovation

Modular innovation refers to the ability to upgrade a product by replacing individual, "obsolete" modules with new, technically more sophisticated modules without affecting the rest of the product structure. This ability is given to modular product architectures by the independence of individual modules as well as the resulting easy interchangeability (Danese and Filippini, 2010, p. 1194).

Reparability

The simplified reparability of modular products compared to integral ones is also made possible by the separability of the individual modules. This allows problems within the product to be identified more quickly (Lau, Yam and Tang, 2007, p. 1053). In addition, the increased exchangeability can lead to a simple replacement of defective modules according to the "plug & play" principle, whereby a disassembly of the entire product or system could be avoided (Droge, Vickery and Jacobs, 2012, p. 253).

Standardization

Because of their combinability, a standardization of modules and components across the product families of a company is encouraged (Zhang, Zhao and Qi, 2014, p. 147). This standardization is possible because the functions of a component or module in the modular design are clearly defined and physically separable. Also, random interactions between a component or module and the rest of the product are minimized. This simplifies the integration of a module within different products if a standardized interface is used (Ulrich, 1994, p. 223). In addition, standardization supports increased use of common parts and postponement capability.

Product diversity

The combinability leads to the fact that through "mix and match", companies can create a significantly higher product variety from a relatively small number of different components (Ulrich, 1994, pp. 223–224).

Use of common parts

The use of common parts is promoted by the fact that standardization enables the effective use of modules in several variants of a product family or over several product generations. The reuse of modules also requires increased use of common parts (Fixson and Clark, 2002, p. 135) (Kohr, Budde and Friedli, 2017, p. 57) (interview 8, minute 55).

Postponement

The postponement strategy refers to the late, customer-specific differentiation of a standard product into different variants. Modularization allows a company to maximize the number of standard components and assemble these components for all possible product options in the earlier stages of the assembly process. The addition of components that differentiate the product from others can be shifted to the later stages of the production process (Feitzinger and Hau, 1997, p. 117).

Process modularity

The understanding of process modularity in the context of this article results from the definition of Tu, et al. (2004, p. 151), who interpret it as the standardization of process modules in production, whereby processes can be rearranged or new process modules added promptly in response to changing product requirements.

Modular Sourcing (Production)

The modular sourcing of production activities follows the same principle as the modular sourcing of development activities described above. Accordingly, a separate description of the effect is not given here, and reference is made to the above explanations on modular sourcing of development activities.

4 Results

This section of the article answers the following research questions:
1) Which product life-cycle phase (PLCP) specific product modularization effects result from supply chain integration in the drive technology industry?
2) How do those effects affect the strategic success factors (SSF) of a company in the drive technology industry?

To be able to present the cost-oriented effects of product modularization on the PLCP transparently, an allocation to the corresponding PLCP and SSF was carried out. An overall view of the product modularization effects on the PLCP has been created by summarizing all the effects per main effect all the way up to the original effects of functional and physical decoupling. Looking exclusively at the effects of product modularization within each PLCP, it is shown that opportunities arise primarily in the development, procurement, and production phases. Especially in the production phase, many positive effects can be assumed with minimal negative influences. In the sales and after-sales phases, on the other hand, meaningfully fewer positive effects were observed, although a clear predominance of positive effects in relation to the negative effects can be observed here too.

If the perspective changes to the effects of product modularization on SSF, there is an almost balanced allocation of effects on cost, time, quality, and flexibility. This applies to both the positive and negative effects. From this, it can be deduced that companies with different strategic orientations can benefit from product modularization. Only the SSF risk shows a surplus of negative effects, that mainly occur in the procurement phase. These negative effects, however, mostly represent potential influences that can be prevented or shifted to other locations by using appropriate approaches.

5 Conclusion

A total of 249 effects of product modularization have been identified, of which 174 were identified from research, 31 from practice, and 44 from both perspectives. Due to the bundeling of a large number of (sub-)effects, 20 of these effects with a correspondingly central character could be highlighted as so-called main effects. The basic elements of functional and physical decoupling of components or modules as well as the standardization of the corresponding interfaces were identified as the origin of all effects. On the second main effect level, the product-related separability and interchangeability, as well as the process-related effects of decoupled development and production activities, have been identified.

5.1 Managerial implications

The main difference between the research and the practical perspective lies in the product-related and the process-related effects. While practitioners focus largely on the product-related effects of product modularization, the process-related effects are neglected. Researchers follow a more holistic perspective, from which it is possible to deduce that the potential of product modularization in the drive technology industry has not yet been fully exploited. It turns out that the possibilities for the integration of suppliers resulting from the decoupling of development and production processes have not yet been exploited in practice. It should be mentioned that the positive effects in this area are associated with a high degree of modularity. Also, the main effects of the development and production process decoupling cause the most negative effects, especially in the procurement phase. For these reasons, the current neglect of the effects of the development and production process decoupling could be explained. Nevertheless, a considerable potential could be demonstrated by these effects, which should compensate for the negative effects of an adequate implementation of product modularization. Consequently, the stronger consideration of the process-related effect dimensions as well as the resulting consequential effects can be derived as a recommendation for action in practice. Besides, the effects associated with product-related separability and interchangeability, such as improved combinability, standardization, product variety, or the enabling of modular innovation, have been identified both in research and in practice. Those effects generate the greatest amount of positive impacts, especially in regard to the conflict between individualization and standardization of products. Negative effects, on the other hand, appear to be strongly neglected both in research and practice. A possible reason for this could be the bias of many researchers and the experts interviewed, who would like to present product modularization as a suitable solution for mastering the increasing complexity in companies and accordingly focus the positive effects stronger than the negative ones.

5.2 Further research

All in all, the current state of research and practice on the maximum potential of product modularization was compiled in both positive and negative aspects. A considerable surplus of positive effects on the PLCP could be identified. Since the effects within this article explicitly represent potentials, some of which can only be generated under certain circumstances, all effects must be individually related to the respective company. This could reduce the shown maximum potential of product modularization because the fulfillment of all conditions is considered unlikely. This also applies to the negative effects, the extent of which should also be evaluated individually.

Appendix

Appendix 1: Relevant publications

#	Authors	Object of investigation
1	Chanaron, 2001	Buyer-Supplier-Relationship
2	Des Doran, 2002	
3	Hoetker, Swaminathan and Mitchell, 2007	
4	Howard and Squire, 2007	
5	Cabigiosu and Camuffo, 2012	
6	Squire, et al., 2009	
7	Furlan, Cabigiosu and Camuffo, 2014	
8	Pero, et al., 2018	
9	Sanchez and Mahoney, 1996	Modular Organization
10	Hoetker, 2006	

#	Authors	Object of investigation
11	Ulrich, 1994	Product design / architecture
12	Ulrich, 1995	
13	Fixson and Clark, 2002	
14	Fixson, 2005	
15	Fixson, 2007	
16	Doran and Hill, 2009	
17	Pil and Cohen, 2006	New Product Development and Innovation
18	Jin and Zong, 2012	
19	Bouncken, Pesch and Gudergan, 2015	
20	Xue-feng and Yan-xia, 2013	
21	Vos, et al., 2018	

#	Authors	Object of investigation
22	Cammarano, Michelino and Caputo, 2019	
23	Hsiao, Tan and Chiou, 2019	
24	Arnheiter and Harren, 2005	
25	Takahiro and Dongsheng, 2006	
26	Abdelkafi, Blecker and Pero, 2010	
27	Danese and Filippini, 2010	New Product Development and Innovation
28	Huang, Stewart and Le Chen, 2010	
29	Pero, et al., 2010	
30	Christensen, 2011	
31	Parente, Baack and Hahn, 2011	
32	Danese and Filippini, 2013	

#	Authors	Object of investigation
33	Ye, et al., 2018	New Product Development and Innovation
34	Vickery, et al., 2016	
35	Arora, Gambardella and Rullani, 1997	Supply Chain Integration
36	Novak and Eppinger, 2001	
37	Hsuan Mikkola and Skjøtt-Larsen, 2004	
38	Lau, Yam and Tang, 2007	
39	Droge, Vickery and Jacobs, 2012	
40	Davies and Joglekar, 2013	
41	Zhou, Gu and Yuan, 2014	
42	Sorkun, 2016	
43	Wang and Zhang, 2019	

#	Authors	Object of investigation
44	Zhang, et al., 2019	Supply Chain Integration
45	C. Y. Baldwin and K. B. Clark, 1997	Implementation / Management
46	Christensen, Raynor and Verlinden, 2001	
47	Bask, et al., 2010	
48	Minartz, 2010	
49	Skirde, Kersten and Schröder, 2016	
50	Kohr, Budde and Friedli, 2017	
51	van Hoek and Weken, 1998	Supply Chain Architektur
52	Lorenzi and Di Lello, 2001	
53	Doran, 2003b	
54	Doran, 2003a	

#	Authors	Object of investigation
56	Lau and Yam, 2005	Supply Chain Architektur
57	Ro, Liker and Fixson, 2007	
58	Zirpoli and Camuffo, 2009	
59	Pashaei and Olhager, 2017	
60	Sanchez and Hang, 2017	
61	Lin, 2003	Supply Chain Performance
62	Lin, 2004	
63	Bush, Tiwana and Rai, 2010	
64	Oh and Rhee, 2010	
65	Pashaei and Olhager, 2015	
66	Rezk, Singh Srai and Williamson, 2016	

#	Authors	Object of investigation
55	Doran, 2005	Supply Chain Performance
67	Seyoum and Lian, 2018	
68	Suh and Lee, 2018	
69	Gualandris and Kalchschmidt, 2013	Supply Chain Risk Management
70	Gualandris and Kalchschmidt, 2015	
71	Ciccullo, Pero and Caridi, 2017	
72	Feitzinger and Hau, 1997	Mass Customization
73	Liao, Deng and Marsillac, 2013	
74	Zhang, Zhao and Qi, 2014	
75	Sanchez, 1995	Company performance
76	Worren, Moore and Cardona, 2002	

#	Authors	Object of investigation
77	Jacobs, Vickery and Droge, 2007	Company performance
78	Eidelwein, et al., 2018	
79	Wurzer and Reiner, 2018	
80	Boer and Boer, 2019	
81	Mee-ngoen, Thongrawd and Jermsittiparsert, 2019	
82	Saeed, Malhotra and Abdinnour, 2019	
83	Pashaei and Olhager, 2019	
84	Fernández and Kekäle, 2005	Reverse Logistics & Sustainability
86	Durand, Telenko and Seepersad, 2010	
87	Sonego, Echeveste and Galvan Debarba, 2018	

Appendix 2: Participants of the empirical study

#	Supply Chain Stage	Function	Inter-view	Focus Group	In-Depth Inter-view
1	Module supplier	HO Develop-ment	X	X	
2	Module supplier	Controller	X		
3	Component and module supplier	HO Develop-ment	X		
4	System supplier	Resource Man-ager	X	X	
5	Component and module supplier	HO Modulari-zation	X	X	
6	Component and module supplier	Project Man-ager	X		
7	System supplier	HO Controlling	X	X	
8	System supplier	HO Controlling	X	X	
9	System supplier	HO Develop-ment	X		
10	Consulting	Project Man-ager	X		X

#	Supply Chain Stage	Function	Inter-view	Focus Group	In-Depth Inter-view
11	System supplier	HO Control-ling	X		
12	System supplier	HO Control-ling	X	X	
13	Component sup-plier	Complexity Manager	X		

References

Abdelkafi, N., Blecker, T. and Pero, M., 2010. Aligning New Product Development and Supply Chains: Development of a Theoretical Framework and Analysis of Case Studies. In: J. Kacprzyk, G. Q. Huang, K. L. Mak, and P. G. Maropoulos, eds. 2010. Proceedings of the 6th CIRP-Sponsored International Conference on Digital Enterprise Technology. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 1399–1419.

Arnheiter, E. D. and Harren, H., 2005. A typology to unleash the potential of modularity. Journal of Manufacturing Technology Management, [e-journal] 16(7), pp. 699–711. http://dx.doi.org/10.1108/17410380510619923.

Arora, A., Gambardella, A. and Rullani, E., 1997. Division of labour and the locus of inventive activity. Journal of Management & Governance, [e-journal] 1(1), pp. 123–140. http://dx.doi.org/10.1023/A:1009993430964.

Bask, A., Lipponen, M., Rajahonka, M. and Tinnilä, M., 2010. The concept of modularity: diffusion from manufacturing to service production. Journal of Manufacturing Technology Management, [e-journal] 21(3), pp. 355–375. http://dx.doi.org/10.1108/17410381011024331.

Boer, H. and Boer, H., 2019. Design-for-variety and operational performance. Journal of Manufacturing Technology Management, [e-journal] 30(2), pp. 438–461. http://dx.doi.org/10.1108/JMTM-03-2018-0065.

Bouncken, R. B., Pesch, R. and Gudergan, S. P., 2015. Strategic embeddedness of modularity in alliances: Innovation and performance implications. Journal of Business Research, [e-journal] 68(7), pp. 1388–1394. http://dx.doi.org/10.1016/j.jbusres.2015.01.020.

Bush, A. A., Tiwana, A. and Rai, A., 2010. Complementarities Between Product Design Modularity and IT Infrastructure Flexibility in IT-Enabled Supply Chains. IEEE Transactions on Engineering Management, [e-journal] 57(2), pp. 240–254. http://dx.doi.org/10.1109/TEM.2010.2040741.

C. Y. Baldwin and K. B. Clark, 1997. Managing in an Age of Modularity. Harvard Business Review, 75(5), pp. 84–93.

Cabigiosu, A. and Camuffo, A., 2012. Beyond the “Mirroring” Hypothesis: Product Modularity and Interorganizational Relations in the Air Conditioning Industry. Organization Science, [e-journal] 23(3), pp. 686–703. http://dx.doi.org/10.1287/orsc.1110.0655.

Cammarano, A., Michelino, F. and Caputo, M., 2019. The purchase of innovative components as an open innovation practice: redefining the boundaries between closed and open innovation. In: . 2019. 2019 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC): IEEE, pp. 1–9.

Chanaron, J. J., 2001. Implementing technological and organisational innovations and management of core competencies: lessons from the automotive industry. International Journal of Automotive Technology and Management, [e-journal] 1(1), p. 128–128. http://dx.doi.org/10.1504/IJATM.2001.000031.

Christensen, C. M., Raynor, M. and Verlinden, M., 2001. Skate to where the money will be. Harvard Business Review, (79), pp. 72–80.

Christensen, T. B., 2011. Modularised eco-innovation in the auto industry. Journal of Cleaner Production, [e-journal] 19(2-3), pp. 212–220. http://dx.doi.org/10.1016/j.jclepro.2010.09.015.

Ciccullo, F., Pero, M. and Caridi, M., 2017. Exploring the hidden potential of product design to mitigate supply chain risk. International Journal of Electronic Customer Relationship Management, [e-journal] 11(1), p. 66–66. http://dx.doi.org/10.1504/IJECRM.2017.086753.

Clark, K. B., Chew, W. B., Fujimoto, T., Meyer, J. and Scherer, F. M., 1987. Product Development in the World Auto Industry. Brookings Papers on Economic Activity, [e-journal] 1987(3), p. 729–729. http://dx.doi.org/10.2307/2534453.

Cook, D. J., Mulrow, C. D. and Haynes, R. B., 1997. Systematic reviews: synthesis of best evidence for clinical decisions. Annals of internal medicine, [e-journal] 126(5), pp. 376–380. http://dx.doi.org/10.7326/0003-4819-126-5-199703010-00006.

Danese, P. and Filippini, R., 2010. Modularity and the impact on new product development time performance. International Journal of Operations & Production Management, [e-journal] 30(11), pp. 1191–1209. http://dx.doi.org/10.1108/01443571011087387.

Danese, P. and Filippini, R., 2013. Direct and Mediated Effects of Product Modularity on Development Time and Product Performance. IEEE Transactions on Engineering Management, [e-journal] 60(2), pp. 260–271. http://dx.doi.org/10.1109/TEM.2012.2208268.

Davies, J. and Joglekar, N., 2013. Supply Chain Integration, Product Modularity, and Market Valuation: Evidence from the Solar Energy Industry. Production and Operations Management, [e-journal] 22(6), pp. 1494–1508. http://dx.doi.org/10.1111/poms.12052.

Des Doran, 2002. Manufacturing for synchronous supply: a case study of Ikeda Hoover Ltd. Integrated Manufacturing Systems, [e-journal] 13(1), pp. 18–24. http://dx.doi.org/10.1108/09576060210411477.

Doran, D., 2003a. An evaluation of value-transfer within a modular supply chain. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, 217(7), pp. 521–527.

Doran, D., 2003b. Supply chain implications of modularization. International Journal of Operations & Production Management, [e-journal] 23(3), pp. 316–326. http://dx.doi.org/10.1108/01443570310462785.

Doran, D., 2005. Supplying on a modular basis: an examination of strategic issues. International Journal of Physical Distribution & Logistics Management, [e-journal] 35(9), pp. 654–663. http://dx.doi.org/10.1108/09600030510632023.

Doran, D. and Hill, A., 2009. A review of modular strategies and architecture within manufacturing operations. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, [e-journal] 223(1), pp. 65–75. http://dx.doi.org/10.1243/09544070JAUTO822.

Droge, C., Vickery, S. K. and Jacobs, M. A., 2012. Does supply chain integration mediate the relationships between product/process strategy and service performance? An empirical study. International Journal of Production Economics, [e-journal] 137(2), pp. 250–262. http://dx.doi.org/10.1016/j.ijpe.2012.02.005.

Durand, J., Telenko, C. and Seepersad, C., 2010. How Does Modularity Affect Green Design? In: . 2010. Volume 6: 15th Design for Manufacturing and the Lifecycle Conference; 7th Symposium on International Design and Design Education: ASMEDC, pp. 405–415.

Eidelwein, F., Piran, F. A. S., Lacerda, D. P., Dresch, A. and Rodrigues, L. H., 2018. Exploratory Analysis of Modularization Strategy Based on the Theory of Constraints Thinking Process. Global Journal of Flexible Systems Management, [e-journal] 19(2), pp. 111–122. http://dx.doi.org/10.1007/s40171-017-0177-1.

Feitzinger, E. and Hau, L. L., 1997. Mass customization at Hewlett-Packard: the power of postponement. Harvard Business Review, (75), pp. 116–123.

Fernández, I. and Kekäle, T., 2005. The influence of modularity and industry clockspeed on reverse logistics strategy: Implications for the purchasing function. Journal of Purchasing and Supply Management, [e-journal] 11(4), pp. 193–205. http://dx.doi.org/10.1016/j.pursup.2006.01.005.

Fixson, S. K., 2005. Product architecture assessment: a tool to link product, process, and supply chain design decisions. Journal of Operations Management, [e-journal] 23(3-4), pp. 345–369. http://dx.doi.org/10.1016/j.jom.2004.08.006.

Fixson, S. K., 2007. Modularity and Commonality Research: Past Developments and Future Opportunities. Concurrent Engineering, [e-journal] 15(2), pp. 85–111. http://dx.doi.org/10.1177/1063293X07078935.

Fixson, S. K. and Clark, J. P., 2002. On the link between modularity and cost-a methodology to assess cost implications of product architecture differences. In: . 2002. IEEE International Engineering Management Conference: IEEE, pp. 131–136.

Frankel, R., Naslund, D. and Bolumole, Y., 2005. The “White Space” of Logistics Research: A Look at the Role of Methods Usage. Journal of Business Logistics, [e-journal] 26(2), pp. 185–209. http://dx.doi.org/10.1002/j.2158-1592.2005.tb00211.x.

Furlan, A., Cabigiosu, A. and Camuffo, A., 2014. When the mirror gets misted up: Modularity and technological change. Strategic Management Journal, [e-journal] 35(6), pp. 789–807. http://dx.doi.org/10.1002/smj.2138.

Gläser, J. and Laudel, G., 2010. Experteninterviews und qualitative Inhaltsanalyse als Instrumente rekonstruierender Untersuchungen. 4th ed. [e-book]. Wiesbaden: VS Verlag. Available at: Gläser, Jochen (VerfasserIn)
Laudel, Grit (VerfasserIn)
Gläser, Jochen (VerfasserIn)
Laudel, Grit (VerfasserIn). <http://d-nb.info/1002141753/04>.

Gualandris, J. and Kalchschmidt, M., 2013. Product and process modularity: improving flexibility and reducing supplier failure risk. International Journal of Production Research, [e-journal] 51(19), pp. 5757–5770. http://dx.doi.org/10.1080/00207543.2013.793430.

Gualandris, J. and Kalchschmidt, M., 2015. Mitigating the effect of risk conditions on supply disruptions: the role of manufacturing postponement enablers. Production Planning & Control, [e-journal] 26(8), pp. 637–653. http://dx.doi.org/10.1080/09537287.2014.955895.

Hoetker, G., 2006. Do modular products lead to modular organizations? Strategic Management Journal, [e-journal] 27(6), pp. 501–518. http://dx.doi.org/10.1002/smj.528.

Hoetker, G., Swaminathan, A. and Mitchell, W., 2007. Modularity and the Impact of Buyer–Supplier Relationships on the Survival of Suppliers. Management Science, [e-journal] 53(2), pp. 178–191. http://dx.doi.org/10.1287/mnsc.1060.0630.

Howard, M. and Squire, B., 2007. Modularization and the impact on supply relationships. International Journal of Operations & Production Management, [e-journal] 27(11), pp. 1192–1212. http://dx.doi.org/10.1108/01443570710830593.

Hsiao, C.-C., Tan, D. and Chiou, J.-S., 2019. Electronic integration and capability widening for OEM suppliers. International Marketing Review, [e-journal] ahead-of-print(ahead-of-print). http://dx.doi.org/10.1108/IMR-02-2018-0071.

Hsuan Mikkola, J. and Skjøtt-Larsen, T., 2004. Supply-chain integration: implications for mass customization, modularization and postponement strategies. Production Planning & Control, [e-journal] 15(4), pp. 352–361. http://dx.doi.org/10.1080/0953728042000238845.

Huang, T.-T. A., Stewart, R. A. and Le Chen, 2010. Identifying key enablers to improve business performance in Taiwanese electronic manufacturing companies. International Journal of Operations & Production Management, [e-journal] 30(2), pp. 155–180. http://dx.doi.org/10.1108/01443571011018699.

Jacobs, M., Vickery, S. K. and Droge, C., 2007. The effects of product modularity on competitive performance. International Journal of Operations & Production Management, [e-journal] 27(10), pp. 1046–1068. http://dx.doi.org/10.1108/01443570710820620.

Jin, Z.-k. and Zong, Y.-z., 2012. The effects of modular production on the module suppliers' willingness to innovate. In: . 2012. 2012 International Conference on Management Science & Engineering 19th Annual Conference Proceedings: IEEE, pp. 651–657.

Kersten, W., Lammers, T. and Skride, H., 2011. Entwicklung eines Kriterienkataloges zur strukturierten Allokation von Effekten der Modularisierung, pp. 14–30.

Kohr, D., Budde, L. and Friedli, T., 2017. Identifying Complexity Drivers in Discrete Manufacturing and Process Industry. Procedia CIRP, [e-journal] 63, pp. 52–57. http://dx.doi.org/10.1016/j.procir.2017.03.290.

Lau, A. K.W., Yam, R. C.M. and Tang, E. P.Y., 2007. Supply chain product co-development, product modularity and product performance. Industrial Management & Data Systems, [e-journal] 107(7), pp. 1036–1065. http://dx.doi.org/10.1108/02635570710816739.

Lau, A.K.W. and Yam, R.C.M., 2005. A case study of product modularization on supply chain design and coordination in Hong Kong and China. Journal of Manufacturing Technology Management, [e-journal] 16(4), pp. 432–446. http://dx.doi.org/10.1108/17410380510594516.

Liao, K., Deng, X. and Marsillac, E., 2013. Factors that influence Chinese automotive suppliers’ mass customization capabilities. International Journal of Production Economics, [e-journal] 146(1), pp. 25–36. http://dx.doi.org/10.1016/j.ijpe.2013.01.014.

Lin, B.-W., 2003. Cooperating for supply chain effectiveness: manufacturing strategy for Chinese OEMs. International Journal of Manufacturing Technology and Management, [e-journal] 5(3), p. 232–232. http://dx.doi.org/10.1504/IJMTM.2003.003412.

Lin, B.-W., 2004. Original equipment manufacturers (OEM) manufacturing strategy for network innovation agility: the case of Taiwanese manufacturing networks. International Journal of Production Research, [e-journal] 42(5), pp. 943–957. http://dx.doi.org/10.1080/00207540310001622449.

Lorenzi, S. and Di Lello, A., 2001. Product modularity theory and practice: the benefits and difficulties in implementation within a company. International Journal of Automotive Technology and Management, [e-journal] 1(4), p. 425–425. http://dx.doi.org/10.1504/IJATM.2001.000050.

Mayring, P., 1994. Qualitative Inhaltsanalyse. In: A. Boehm, ed. 1994. Texte verstehen. Konzepte, Methoden, Werkzeuge. Konstanz: Univ.-Verl. Konstanz, pp. 159–175.

Mee-ngoen, B., Thongrawd, C. and Jermsittiparsert, K., 2019. The impact of product and process strategies on the service performance: The mediating role of supply chain integrations. International Journal of Supply Chain Management, 8(4), pp. 291–301.

Minartz, L., 2010. Standardisierung von Schnittstellen im Rahmen der Produktmodularisierung - Entwicklung eines Kriterienkataloges zur Identifikation von Potenzialen am Beispiel von Antriebsachsen in der Landmaschinenindustrie. Hamburg.

Mujuni Katunzi, T., 2011. Obstacles to Process Integration along the Supply Chain: Manufacturing Firms Perspective. International Journal of Business and Management, [e-journal] 6(5). http://dx.doi.org/10.5539/ijbm.v6n5p105.

Mulrow, C. D., 1994. Rationale for systematic reviews. BMJ (Clinical research ed.), [e-journal] 309(6954), pp. 597–599. http://dx.doi.org/10.1136/bmj.309.6954.597.

Novak, S. and Eppinger, S. D., 2001. Sourcing By Design: Product Complexity and the Supply Chain. Management Science, [e-journal] 47(1), pp. 189–204. http://dx.doi.org/10.1287/mnsc.47.1.189.10662.

Oh, J. and Rhee, S.-K., 2010. Influences of supplier capabilities and collaboration in new car development on competitive advantage of carmakers. Management Decision, [e-journal] 48(5), pp. 756–774. http://dx.doi.org/10.1108/00251741011043911.

Parente, R. C., Baack, D. W. and Hahn, E. D., 2011. The effect of supply chain integration, modular production, and cultural distance on new product development: A dynamic capabilities approach. Journal of International Management, [e-journal] 17(4), pp. 278–290. http://dx.doi.org/10.1016/j.intman.2011.08.001.

Pashaei, S. and Olhager, J., 2015. Product architecture and supply chain design: a systematic review and research agenda. Supply Chain Management: An International Journal, [e-journal] 20(1), pp. 98–112. http://dx.doi.org/10.1108/SCM-12-2013-0487.

Pashaei, S. and Olhager, J., 2017. The impact of product architecture on global operations network design. Journal of Manufacturing Technology Management, [e-journal] 28(3), pp. 353–370. http://dx.doi.org/10.1108/JMTM-11-2015-0108.

Pashaei, S. and Olhager, J., 2019. Product architecture, global operations networks, and operational performance: an exploratory study. Production Planning & Control, [e-journal] 30(2-3), pp. 149–162. http://dx.doi.org/10.1080/09537287.2018.1534267.

Pero, M., Abdelkafi, N., Sianesi, A. and Blecker, T., 2010. A framework for the alignment of new product development and supply chains. Supply Chain Management: An International Journal, [e-journal] 15(2), pp. 115–128. http://dx.doi.org/10.1108/13598541011028723.

Pero, M., Micheli, G., Aiolfi, S. and Pacchiani, D., 2018. Triadic relationships in new product development: Contingent factors and implications for performance. In: . 2018. Proceedings of the 23rd Summer School ""Francesco Turco"" - Industrial Systems Engineering 2018, pp. 263–269.

Petersen, K. J., Handfield, R. B. and Ragatz, G. L., 2005. Supplier integration into new product development: coordinating product, process and supply chain design. Journal of Operations Management, [e-journal] 23(3-4), pp. 371–388. http://dx.doi.org/10.1016/j.jom.2004.07.009.

Pil, F. K. and Cohen, S. K., 2006. Modularity: Implications for Imitation, Innovation, and Sustained Advantage. The Academy of Management Review, [e-journal] 31(4), pp. 995–1011. http://dx.doi.org/10.5465/amr.2006.22528166.

Rezk, R., Singh Srai, J. and Williamson, P. J., 2016. The impact of product attributes and emerging technologies on firms' international configuration. Journal of International Business Studies, [e-journal] 47(5), pp. 610–618. http://dx.doi.org/10.1057/jibs.2016.9.

Ro, Y. K., Liker, J. K. and Fixson, S. K., 2007. Modularity as a Strategy for Supply Chain Coordination: The Case of U.S. Auto. IEEE Transactions on Engineering Management, [e-journal] 54(1), pp. 172–189. http://dx.doi.org/10.1109/TEM.2006.889075.

Saeed, K. A., Malhotra, M. K. and Abdinnour, S., 2019. How supply chain architecture and product architecture impact firm performance: An empirical examination. Journal of Purchasing and Supply Management, [e-journal] 25(1), pp. 40–52. http://dx.doi.org/10.1016/j.pursup.2018.02.003.

Sanchez, R., 1995. Strategic flexibility in product competition. Strategic Management Journal, [e-journal] 16(S1), pp. 135–159. http://dx.doi.org/10.1002/smj.4250160921.

Sanchez, R. and Hang, C. C., 2017. Modularity in New Market Formation: Lessons for Technology and Economic Policy and Competence-Based Strategic Management. In: R. Sanchez, A. Heene, S. Polat, and U. Asan, eds. 2017. Mid-Range Management Theory: Competence Perspectives on Modularity and Dynamic Capabilities: Emerald Publishing Limited, pp. 131–165.

Sanchez, R. and Mahoney, J. T., 1996. Modularity, flexibility, and knowledge management in product and organization design. Strategic Management Journal, [e-journal] 17(S2), pp. 63–76. http://dx.doi.org/10.1002/smj.4250171107.

Schulz, M., 2012. Quick and easy!? Fokusgruppen in der angewandten Sozialwissenschaft. In: M. Schulz, B. Mack, and O. Renn, eds. 2012. Fokusgruppen in der empirischen Sozialwissenschaft. Von der Konzeption bis zur Auswertung. Wiesbaden: Springer VS, pp. 9–22.

Seyoum, B. and Lian, Y., 2018. Market performance implications of modularization: Evidence from global auto firms operating in China. International Business Review, [e-journal] 27(4), pp. 852–866. http://dx.doi.org/10.1016/j.ibusrev.2018.01.008.

Skirde, H., Kersten, W. and Schröder, M., 2016. Measuring the Cost Effects of Modular Product Architectures — A Conceptual Approach. International Journal of Innovation and Technology Management, [e-journal] 13(04), p. 1650017–1650017. http://dx.doi.org/10.1142/S0219877016500176.

Sonego, M., Echeveste, M. E. S. and Galvan Debarba, H., 2018. The role of modularity in sustainable design: A systematic review. Journal of Cleaner Production, [e-journal] 176, pp. 196–209. http://dx.doi.org/10.1016/j.jclepro.2017.12.106.

Sorkun, M. F., 2016. Contrary evidence: product modularity and supplier integration. International Journal of Integrated Supply Management, [e-journal] 10(3/4), p. 283–283. http://dx.doi.org/10.1504/IJISM.2016.081278.

Squire, B., Cousins, P. D., Lawson, B. and Brown, S., 2009. The effect of supplier manufacturing capabilities on buyer responsiveness. International Journal of Operations & Production Management, [e-journal] 29(8), pp. 766–788. http://dx.doi.org/10.1108/01443570910977689.

Suh, C. J. and Lee, I. T., 2018. An Empirical Study on the Manufacturing Firm’s Strategic Choice for Sustainability in SMEs. Sustainability, [e-journal] 10(3), p. 572–572. http://dx.doi.org/10.3390/su10020572.

Takahiro, F. and Dongsheng, G., 2006. The architectural attributes of auto parts and transaction patterns on design drawings. International Journal of Automotive Technology and Management, [e-journal] 6(4), p. 370–370. http://dx.doi.org/10.1504/IJATM.2006.012231.

Tranfield, D., Denyer, D. and Smart, P., 2003. Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. British Journal of Management, [e-journal] 14(3), pp. 207–222. http://dx.doi.org/10.1111/1467-8551.00375.

Tu, Q., Vonderembse, M. A., Ragu-Nathan, T. S. and Ragu-Nathan, B., 2004. Measuring Modularity-Based Manufacturing Practices and Their Impact on Mass Customization Capability: A Customer-Driven Perspective. Decision Sciences, [e-journal] 35(2), pp. 147–168. http://dx.doi.org/10.1111/j.00117315.2004.02663.x.

Ulrich, K., 1994. Fundamentals of Product Modularity. In: S. Dasu, and C. Eastman, eds. 1994. Management of Design. Dordrecht: Springer Netherlands, pp. 219–231.

Ulrich, K., 1995. The role of product architecture in the manufacturing firm. Research Policy, [e-journal] 24(3), pp. 419–440. http://dx.doi.org/10.1016/0048-7333(94)00775-3.

van Hoek, R. I. and Weken, H. A.M., 1998. The Impact of Modular Production on the Dynamics of Supply Chains. The International Journal of Logistics Management, [e-journal] 9(2), pp. 35–50. http://dx.doi.org/10.1108/09574099810805825.

Vickery, S. K., Koufteros, X., Dröge, C. and Calantone, R., 2016. Product Modularity, Process Modularity, and New Product Introduction Performance: Does Complexity Matter? Production and Operations Management, [e-journal] 25(4), pp. 751–770. http://dx.doi.org/10.1111/poms.12495.

Vos, M. A., Raassens, N., van der Borgh, M. and Nijssen, E. J., 2018. Balancing modularity and solution space freedom: effects on organisational learning and sustainable innovation. International Journal of Production Research, [e-journal] 56(20), pp. 6658–6677. http://dx.doi.org/10.1080/00207543.2018.1458165.

Wang, Z. and Zhang, M., 2019. Linking product modularity to supply chain integration and flexibility. Production Planning & Control, pp. 1–15. http://dx.doi.org/10.1080/09537287.2019.1700571.

Worren, N., Moore, K. and Cardona, P., 2002. Modularity, strategic flexibility, and firm performance: a study of the home appliance industry. Strategic Management Journal, [e-journal] 23(12), pp. 1123–1140. http://dx.doi.org/10.1002/smj.276.

Wurzer, T. and Reiner, G., 2018. Evaluating the impact of modular product design on flexibility performance and cost performance with delivery performance as a moderator. International Journal of Operations & Production Management, [e-journal] 38(10), pp. 1987–2008. http://dx.doi.org/10.1108/IJOPM-03-2017-0152.

Xue-feng, L. and Yan-xia, W., 2013. Strategic transformation of Shanzhai firms: Evidence from the Chinese case. In: . 2013. 2013 International Conference on Management Science and Engineering 20th Annual Conference Proceedings: IEEE, pp. 789–797.

Ye, Y., Huo, B., Zhang, M., Wang, B. and Zhao, X., 2018. The impact of modular designs on new product development outcomes: the moderating effect of supply chain involvement. Supply Chain Management: An International Journal, [e-journal] 23(5), pp. 444–458. http://dx.doi.org/10.1108/SCM-01-2018-0021.

Zhang, M., Guo, H., Huo, B., Zhao, X. and Huang, J., 2019. Linking supply chain quality integration with mass customization and product modularity. International Journal of Production Economics, [e-journal] 207, pp. 227–235. http://dx.doi.org/10.1016/j.ijpe.2017.01.011.

Zhang, M., Zhao, X. and Qi, Y., 2014. The effects of organizational flatness, coordination, and product modularity on mass customization capability. International Journal of Production Economics, [e-journal] 158, pp. 145–155. http://dx.doi.org/10.1016/j.ijpe.2014.07.032.

Zhou, S., Gu, Z. and Yuan, J., 2014. Product modularity and supply chain collaboration: An empirical study of firm performance for 221 Chinese manufacturing industries. In: . 2014. 2014 IEEE International Conference on Management of Innovation and Technology: IEEE, pp. 41–47.

Zirpoli, F. and Camuffo, A., 2009. Product architecture, inter-firm vertical coordination and knowledge partitioning in the auto industry. European Management Review, [e-journal] 6(4), pp. 250–264. http://dx.doi.org/10.1057/emr.2009.25http://dx.doi.org/10.1057/emr.2009.25.

Simulating the impact of digitalization on retail logistics efficiency

Dominic Loske [1,2] and Matthias Klumpp [2,3]

1 – UCAM Universidad Católica San Antonio de Murcia, Faculty of Business and Law

2 – FOM University of Applied Sciences, Institute for Logistics and Service Management

3 – Georg-August-University of Göttingen, Faculty of Production and Logistics Management

Purpose: The study uses the results of an efficiency analysis for digitalization within a retail logistics blue-collar work system of professional truck drivers and aims to elaborate an ex-ante efficiency simulation approach for digitalization scenarios.
Methodology: The simulation method combines the efficiency scores of Data Envelopment Analysis (DEA), statistical bootstrapping, and regression analysis. By increasing the original sample size of n=30 truck drivers up to 60,000 samples through 2,000 bootstrap iterations, it is possible to gain a highly significant regression function.
Findings: The mathematical simulation approach can be transferred to alternate scenarios in terms of forecasting efficiency development based on the experience distribution of the workforce.
Originality: As the impact of digitalization on the efficiency of blue-collar work systems is often unknown, this methodology could provide insights for logistics researchers and managers when estimating the efficiency impact of digitalization.

First received: 6. Mar 2020 Revised: 20. Jun 2020 Accepted: 26. Jun 2020

1 Introduction

Recent advances in the areas of computer science, engineering, robotics, and information science have spawned remarkable digital progress in the fields of production as well as transport and logistics. Focusing on operations management, it can be observed that the ongoing digital transformation is changing the competitive frameworks in which companies are operating in, and consequently their core business operations (Koleva, Andreev, 2018; Lanz, Tuokko, 2017; Lu, et al., 2018; Rajput, Singh, 2019; Zangiacomi, et al., 2017; Roscoe, Cousins, Handfield, 2019). Approaches aimed at enhancing operations have brought high innovation potential to operations management and are often discussed connected to the Industry 4.0 concept (Lasi, et al., 2014; Lee, Bagheri, Kao, 2015; Lee, Kao, Yang, 2014; Stock, Seliger, Seliger G., Kohl H., Mallon J., 2016; Wang, et al., 2016). This describes a set of related technologies and digital solutions in OM that aim to support the development and integration of automation (Stadnicka, Antonelli, 2019; Wollschlaeger, Sauter, Jasperneite, 2017; Pérez, et al., 2019), as well as the exchange of real-time data in production processes (Cao, et al., 2017; Chen, et al., 2016; Zeng, et al., 2019). Thus, most digital innovations in OM concentrate on e.g. digital manufacturing and production management (Borangiu, et al., 2019; Giraldo-Castrillon, Páramo-Bermúdez, Muñoz-Betancur, 2019; Kulkarni, Verma, Mukundan, 2019; Roscoe, Cousins, Handfield, 2019; Wang, et al., 2019), additive manufacturing (Hedenstierna, et al., 2019; Emon, et al., 2019; Hamidi, Aslani, 2019; Jiang, Xu, Stringer, 2019; Kleer, Piller, 2019; Pérez, et al., 2019), or predictive maintenance (Antomarioni, et al., 2019; Chehri, Jeon, Zimmermann A., Chen Y.-W., Howlett R.J., Jain L.C., 2019; Liu, et al., 2019; March, Scudder, 2019). However, most approaches towards the described digital transformation have the status of conceptual drafts and the effect of the digital transformation is seldom examined with operations research methods or simulation approaches.

Taking up this research gap, an efficiency analysis was developed and applied to evaluate the effect of changing levels of digitalization within the working systems of professional truck drivers (Loske, Klumpp, 2018). However, this method can only explain the verifiable effects of digitalization from the a posteriori perspective, after the digital changeover has taken place. Therefore, an interesting question for scientist and practitioners, as well as the research question of this publication, is: "How could an a priori simulation tool for empirical DEA results be structured, aiming to enable assessments of varying digital transformation scenarios?".

After this introduction (section 1), the literature review summarizes the technique and results of the efficiency analysis by Loske and Klumpp in 2018, supplemented with further research, including a second efficiency analysis and several regression analyses. Based on these finding, section 4 explains the essentials of a bootstrap approach in nonparametric frontier models (Simar, Wilson, 1998; Simar, Wilson, 2007) applied in the software r and bootstraps the results of one regression analysis presented in the previous section. Furthermore, the effects of bootstrapping are examined from a statistical point of view to test the transferability of the basic data (n=30) on up to 60,000 samples through 2,000 bootstrap iterations. Section 4 closes with the elaboration of the a priori simulation approach. The key findings and further research questions are summarized in section 5.

2 Literature review

This DEA model analyzed the efficiency of truck drivers working in the sector of distribution logistics for a large German food retailing company. The transportation unit is responsible for delivering food and non-food items from the central logistics center to all grocery shops of the relevant delivery area complete and on time as well as for returning recyclable materials plus empty load carriers from the grocery shops back to the logistics center. Focusing the daily business of professional truck drivers and the physical material flows, the work process can be divided in the following steps: (1) Register at the responsible dispatcher in the logistics center, (2) Receive data for delivery tour through mobile device, (3) Load the truck by scanning barcodes on load carriers through mobile device, (4) Receive freight documents from dispatcher, (5) Drive to n grocery shops, (6) Unload cargo at n grocery shops, (7) Return recyclable material and empty load carriers back to logistics center. Aspiring to choose work steps with a maximum of interaction with the digital device, the loading process (2) and (3) were selected for further analysis. Figure 1 presents the applied DEA model.

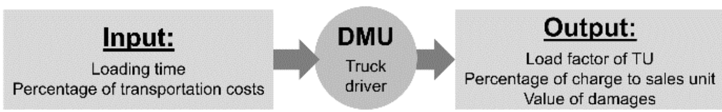


Figure 1: DEA model applied in Loske and Klumpp 2018.

2.1 An empirical analysis for efficiency level in digitalization

A first case analysis (C1) investigated the work system of truck loading for professional truck drivers in retail logistics for 4.5 weeks and aimed to evaluate the efficiency progression of a digital changeover. The analysis contains data of 1,350 delivery tours and focused on a changing level of the digitalized work equipment within retail logistics. Therein, the old mobile devices based on windows mobile software with complex operation principles using a keyboard were replaced by new mobile devices with Android software and a user-friendly full touch display. Another significant modification was the integration of more and new processes into the existing workflow that is handled by the mobile device and has not been included before, e.g., particular application for high-value products like cigarettes, elimination, and digitalization of accompanying documents along with clear menu navigation. The DEA specification constant returns to scale (CRS) is used due to the following reasons: (1) The results of the both models are similar, (2) the analysis does not particularly search for increasing or decreasing returns to scale and (3) it is assumed that the MPSS, the individual performance capability of professional truck drivers, is equal (Banker, Charnes, Cooper, 1984). Figure 2 presents the results of C1.

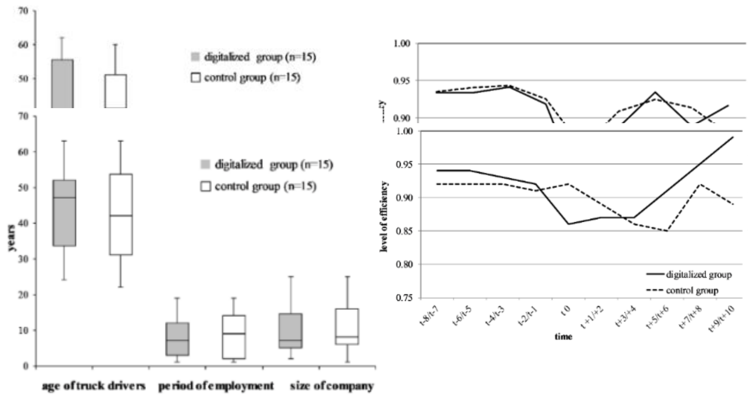


Figure 3: Structure of the study groups and the efficiency curve.

the two examination groups as a longitudinal study, where 4.5 weeks are divided into nine periods with three days each. Through the DEA analysis, it was possible to gain practical knowledge about the development of efficiency when the level of digitalization increased within working systems of retail logistics. Even though the empirical curve progression reflects the theoretical curve progression of Lewin (Lewin, 1947), it was not possible to prove long-term efficiency improvement. Therefore, a second case analysis (C2) was conducted during 9.5 weeks, analyzing data of 2,100 delivery tours. The following figure summarizes the structure of the study groups and the empirical curve progression of C2. Using C2, it was possible to verify the findings of C1 when reflecting the theoretical curve progression presented and furthermore, prove long-term efficiency improvements. Figure 2 presents the results of C2.

2.2 Regression analysis for influencing factors

After elaborating an efficiency analysis for digitalization within blue-collar work systems in retail logistics in the previous chapters, section 3.2. deals with the identification of relevant impact factors for efficiency improvements. Therefore, the data of C2 with the level of efficiency during the digital changeover in t0 is used for nine regression analyses to examine the relationship to exogenous factors integrated into the work system, which are determined as characteristics of the employees: (1) Age (interval scale), (2) Seniority (interval scale), (3) company size (ordinal scale), (4) migration (dichotomous y/n), (5) education (ordinal scale), (6) vocational training (ordinal scale) and (7) job of parents (dichotomous, truck driver y/n). Furthermore, endogenous factors resulting out of the digital changeover, such as (8) satisfaction and (9) motivation (both as interval scale from the questionnaire), are examined. Table 1 summarizes the results of nine regression analyses.

Table 1: Results of regression analysis for influencing factors

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Obs.	30	30	30	30	30	30	30	30	30
R2	.002	.864	.038	.001	.025	.263	.104	.182	.076

	Adj. R2	Re. err.	F Stat.
(1)	-.074	0.116	0.030
(2)	0.854	0.043	18.693***
(3)	-.036	0.114	0.514
(4)	-.076	0.116	0.016
(5)	-.050	0.115	0.338
(6)	.206	0.100	4.643*
(7)	.035	0.110	1.504
(8)	.119	0.105	2.891
(9)	.005	0.112	1.069

Note: *p**p***p<0.01

The results show that the seniority of truck drivers has a high influence on the level of efficiency during a digital changeover ($R2 = 0.864$), whereas the other exogenous factors do not influence this scenario. Regarding the endogenous factors, it can be stated that the truck driver's perception of motivation and satisfaction does not affect the truck driver's performance. These findings are used in the next chapter to develop an a priori efficiency simulation for the impact of digitalization. Figure 4 illustrates the regression analysis for seniority (named "TIME") and efficiency (called "EFF").

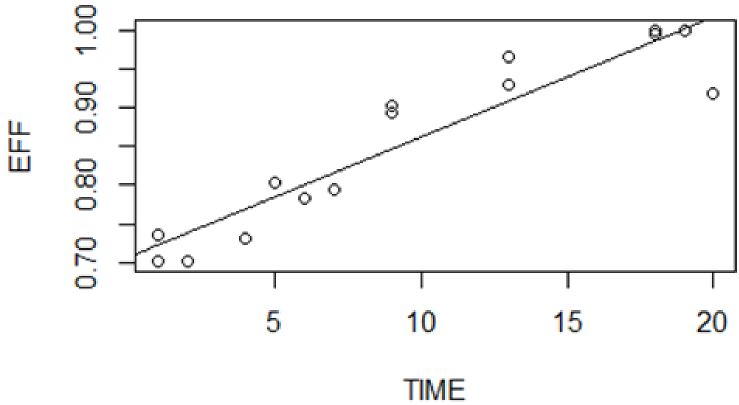


Figure 4: Illustration of regression analysis for seniority and efficiency.

Aiming to ensure that the data is suitable for further investigation, several statistical tests were conducted, including (a) residuals versus fits plot, (b) normal Q-Q, (c) scale location and (d) residuals versus leverage. When conducting a residual analysis, a "residuals versus fits plot" is the most frequently created plot. It is a scatter plot of residuals on the y-axis and fitted values (estimated responses) on the x-axis. The plot is used to detect non-linearity, unequal error variances, and outliers. For (a) it can be determined that the residuals bounce randomly around the 0-line. Therefore, it can be suggested that the assumption of a linear relationship is reasonable. None residual stands out from the basic random pattern of residuals, which indicates that there are no outliers. A Normal Q–Q plot is used to compare the shapes of distributions, providing a graphical view of how properties such as location, scale, and skewness are similar or different in the two distributions. Q–Q plots can be used to compare collections of data or theoretical distributions. Concerning (b), the points form a roughly straight line, indicating a normal distribution. These results are presented in figure 5.

The Scale-Location plot shows whether the residuals are spread equally along with the predictor range, e.g., homoscedastic. On optimum is

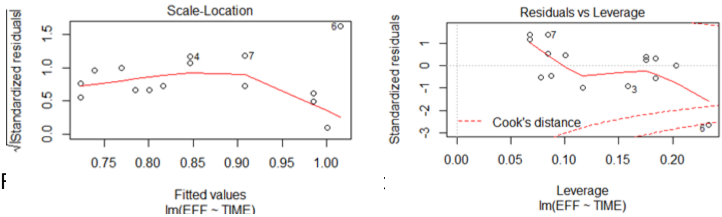
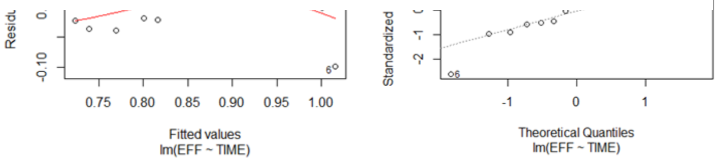


Figure 6: Scale-location and residual versus leverage for regression.



achieved when the line on this plot is horizontal with randomly scattered points on the plot. For (c) this can be observed until an efficiency of 0.95, whereby the data range from 0.96 to 1.00 is not equally spread and DMU6 causes weakness within the regression model. The Residuals versus Leverage plots help to identify critical data points on the model. The points the analysis is searching for are values in the upper right, or lower right corners, which are outside the red dashed Cook's distance line. These are points that would be influential in the model, and re-moving them would likely noticeably alter the regression results. This analysis also indicated that DMU6 causes weakness within the model, also visualized in figure 6.

3 A priori simulation approach

3.1 Basics of statistical bootsrapping

From a statistical point of view, bootstrapping describes a method of testing that relies on random sampling with replacement. The basic idea of the computer-assisted method developed by Efron is to generate n new, wider samples from a given and finite sample. It furthermore allows assigning measures of accuracy in terms of confidence intervals, e.g., α=10%, α=5% or α=1% (Efron, 1979; Efron, 1987; Efron, 1994; Efron, Tibshirani, 2000). The paper entitled "How to Bootstrap in Nonparametric Frontier Models" by Simar and Wilson presents a DEA-applicable approach with up to 1,000 newly generated samples in 1998 and 2007 they introduced a second algorithm which can generate up to 2,000 samples (Simar, Wilson, 1998; Simar, Wilson, 2007). The rDEA package can perform DEA calculations with different assumptions using defined DMUs, input, and output factors and to implement bootstrap calculations with up to 2,000 bootstrap repetitions. The algorithm can be described as follows: dea.robust(X, Y, W=NULL, model, RTS="variable", B=1000, alpha=0.05, bw="bw.ucv", bw_mult=1), whereby:

X a matrix of inputs for observations, for which DEA scores are estimated

Y a matrix of outputs for observations, for which DEA scores are estimated

W a matrix of input prices, only used if model="costmin"

model a string for the type of DEA model to be estimated, "input" for input-oriented, "output" for output-oriented, "costmin" for cost-minimization model

RTS a string for returns-to-scale under which DEA scores are estimated, RTS can be "constant", "variable" or "non-increasing”

B an integer showing the number of bootstrap replications, the default is B=2000

alpha a number in (0,1) for the size of confidence interval for the bias-corrected DEA score

bw a string for the type of bandwidth used as a smoothing parameter in sampling withreflection,"cv"or"bw.ucv" for cross-validation bandwidth,"silverman"or "bw.nrd0" for Silverman’s (1986) rule

bw_mult bandwidth multiplier, default is 1 that means no change

After running the algorithm with the software r, it provides (1) the DEA efficiency scores for the formulated model, (2) the lower bound, meaning the beginning of the confidence interval of α=10%, α=5% or α=1%, (3) the upper bound, indicating the beginning of the confidence interval of α=10%, α=5% or α=1%, as well as (4) the bias-corrected DEA efficiency scores. The following figure 7 illustrates the results of bootstrap with B=2,000 iterations for C2.

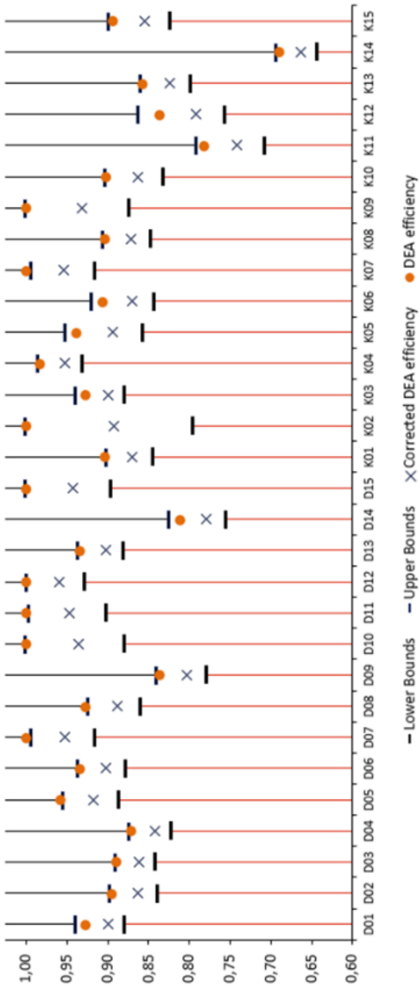


Figure 7: Results of bootsrap with B=1,000 iterations for C2.

3.2 Regression analyses for bootsraps with different iterations

The general idea is to merge the efficiency values of the DEA approach as a dependent variable and the findings of the linear regression analysis, with in-dependent variables, as well as to increase the original sample size nsample for a simulation sample nsim by B bootstrap iterations. As a bootstrap for both variables, the dependent and independent, as well as resampling solely the independent variable, destroys the link of the DMU and its characteristics, bootstrap iterations are conducted on the DEA model and its efficiency values. The efficiency values of period t0 for the digitalization group of case analysis C2 are used with efficiency as the dependent and period of employment as the independent variable. Table 2 opposes the results of 13 regression analyses for 11 bootstraps with the significance levels of $\alpha = 0.05$ and $\alpha = 0.01$. As the number of bootstraps has to be bigger than $1/\alpha$ there is no calculation with less than 50 iterations for $\alpha = 0.05$ and none with less than 100 iterations for $\alpha = 0.01$.

Table 2: Results for 6 bootstrap calculations with α = 0.05 and α = 0.0

	eff.	eff. B=50	eff. B=100	eff. B=200	eff. B=500	eff. B=1000	eff. B=2000
Period employ.	0.015***	0.018***	0.018***	0.018***	0.018***	0.018***	0.018***
	(0.002)	(0.0003)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Const.	0.708***	0.754***	0.753***	0.754***	0.753***	0.754***	0.754***
	(0.020)	(0.004)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)
Observ.	30	750	1,500	3,000	7,500	15,000	30,000
R2	0.864	0.812	0.804	0.795	0.788	0.792	0.792
Adj. R2	0.854	0.811	0.804	0.794	0.788	0.792	0.792
Re. err.	0.015***	0.018***	0.018***	0.018***	0.018***	0.018***	0.018***

	eff.	eff. B=100	eff. B=200	eff. B=500	eff. B=1000	eff. B=2000

Period employ.	0.015***	0.018***	0.018***	0.018***	0.018***	0.018***
	(0.002)	(0.0002)	(0.0002)	(0.0001)	(0.0001)	(0.0001)
Const.	0.708***	0.756***	0.755***	0.754***	0.753***	0.753***
	(0.020)	(0.003)	(0.002)	(0.001)	(0.001)	(0.001)
Observ.	30	1,500	3,000	7,500	15,000	30,000
R2	0.864	0.793	0.784	0.789	0.790	0.790
Adj. R2	0.854	0.793	0.784	0.789	0.790	0.790
Re. err.	0.043	0.060	0.062	0.061	0.061	0.061

Note: *p<0.10, **p<0.05, ***p<0.01

The findings show that the values of the regression analysis stabilize between 500 and 2,000 bootstrap iterations for both levels of significance. Furthermore, the $\beta 0$ and $\beta 1$ values differ marginal between $\alpha = 0.05$ and $\alpha = 0.01$. Due to the higher significance, the linear regression equation $y = 0.753 + 0.0181x$ of $\alpha = 0.01$, which can explain 79% of the regression model's variance, is used for further calculations. To illustrate the effect of bootstrapping calculation on the linear regression model, figure 8 illustrates the linear regression model for 2,000 bootstraps and the development of R2 for increasing iterations with α = 0.05 and α = 0.01.

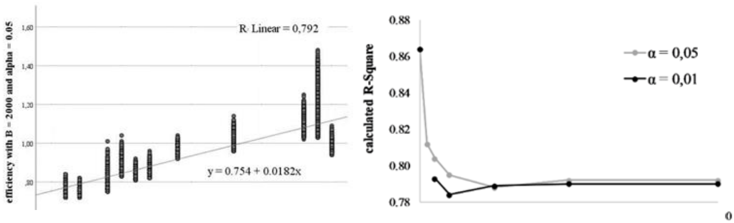


Figure 8: Linear regression model and R2 for increasing iterations.

3.3 Effects of bootstrapping from statistical point of view

Aspiring to shed light on how the statistical bootstrapping and increasing iterations improve the linear regression equation, the developments of the regression analyses are opposed with B=0, B=100, B=200, B=500, B=1,000 and B=2,000 iterations. The residuals versus fitted, the normal Q-Q, the scale location, and the residuals versus leverage are compared by presenting the basic model, as well as the bootstrap models with B=100, B=500, and B=2,000 iterations. The results are visualized in figure 9.

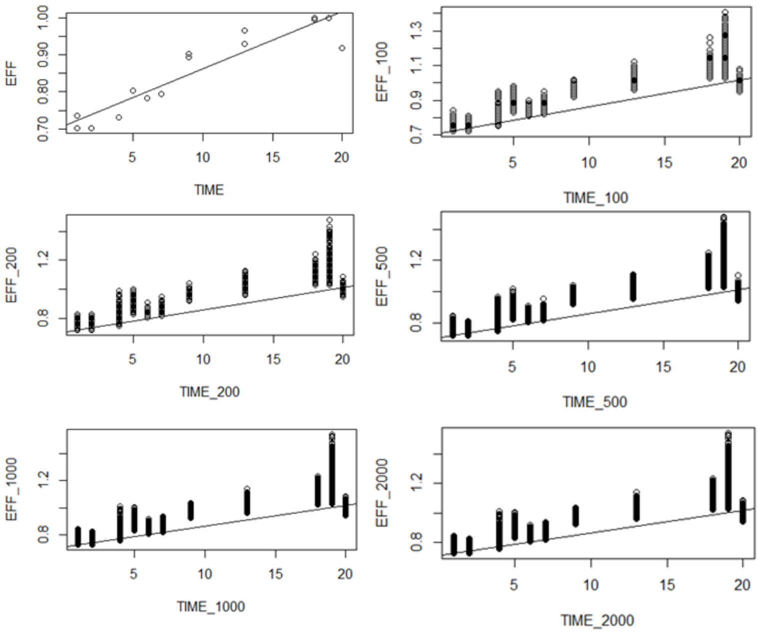


Figure 9: Development of regression analyses.

The regression lines are developing significantly from the basic model to 500 bootstraps, which can also be seen in the R2 values that have been elaborated in the previous chapter. In contrast, the doubling of bootstraps from 1,000 to 2,000 iterations has hardly any notable effect. A further reflection of the bootstrapping results shows that DMUs with an efficiency score of more than 0.90 in the basic model rise into super-efficiency when bootstrapping the results. These DMUs are illustratively separated from the remaining DMUs by a red line. The maximum of 1.40 is already reached with a minimum of B=100 bootstraps, whereas additional bootstraps lower the maximum efficiency on 1.35. Super-efficiency implies the possible capability of a DMU in increasing its inputs and reducing its outputs without becoming inefficient (Chen, Du, Huo, 2013). In the DEA literature, approached focusing super-efficiency examine, e.g. identifying outliers, ranking the extreme efficient DMUs or calculating efficiency stability region. The results are visualized in figure 10.

Examining the development of residuals versus fitted, it can be stated that

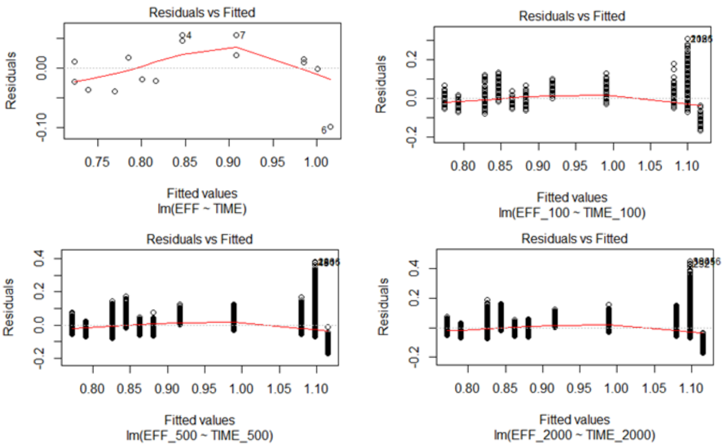


Figure 10: Development of residuals versus fitted.

the residuals approximate around the 0-line when increasing the number of observations by statistical bootstrapping. This underlines the assumption that a line-are relationship is reasonable, which improves with increasing iterations.

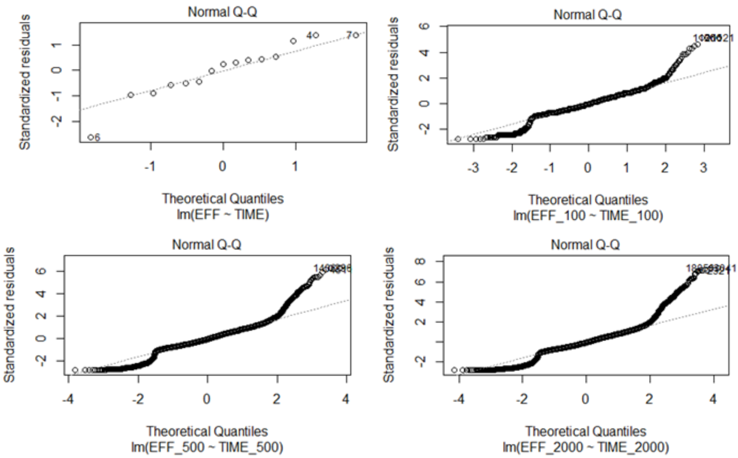


Figure 11: Development of normal Q-Q.

For the basic population, the points form a roughly straight line, indicating a normal distribution. When increasing the samples via bootstrapping the super-efficient DMUs leave this line significantly.

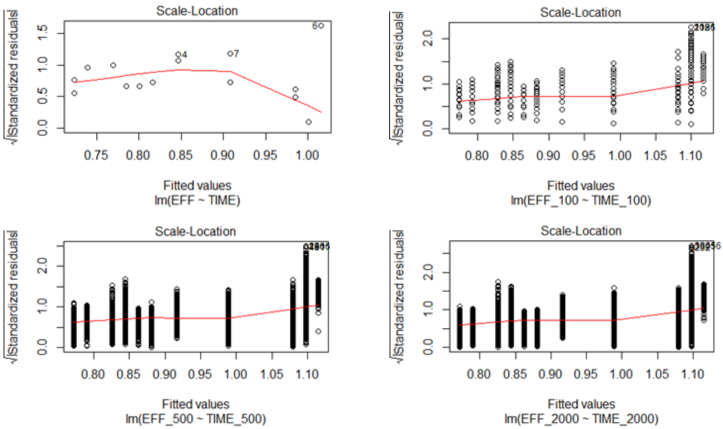


Figure 12: Development of scale location.

The aspired optimum of the scale location, which is a horizontal red line indicating a constant scale-location with randomly spread points on the plot, is reached when increasing the bootstrap iterations. Thereby it seems irrelevant if 100 or 2,000 bootstrap iterations are conducted.

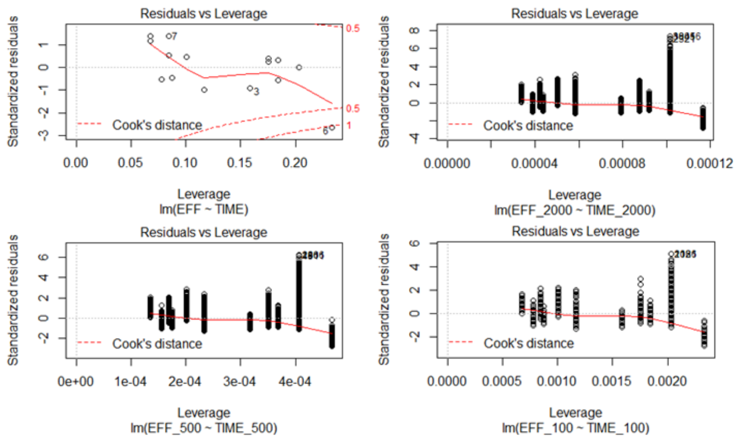


Figure 13: Development of residuals versus leverage.

The influence of the data point DMU6, which has been identified by examining the Cook’s distance line in the basic model, can significantly be lowered when bootstrapping the empirical DEA results. While the increase of bootstraps from 100 to 500 results in an approximation of all data points to the 0-line, further extensions seem not to influence the results. The deviation of data points in the right area of the graphs results from the super-efficient DMUs.

3.4 An a priori simulation approach

With a stable and highly significant linear regression equation, it is now possible to accelerate (1) a managerial approach by focusing on a temporal and an inductive simulation when answering current issues of retail logistic managers e.g. “How is the efficiency level of truck drivers for digital changeovers within our retail logistics sector in 10 years?” or “How will the efficiency curve develop during a digital changeover in another depot” and (2) a methodological approach answering questions e.g. “How can the efficiency level for digital changeovers, concerning all truck drivers in a certain country, be evaluated?”.

For a first managerial approach, the verified linear regression equation efficiency = 0.753 + 0.0181 × seniority is applied to determine the total efficiency of the retailer's depot by an inductive simulating of the basic population with all 173 truck drivers. Whereby the sample (min.= 1; max.= 20; mean= 9.66; sd = 6.758) had an average efficiency of 0.86, the basic population (min.= 1; max.= 27; mean= 9.62, sd = 5.62) shows an average efficiency of 0.88. By applying the same logic to another depot of the retailer, it was possible to simulate the efficiency during a digital changeover for further

123 truck drivers (min. = 1; max. = 38; mean = 10.55, sd = 7.504) with an average efficiency of 0.87. Besides the presentation of the results, it has to be mentioned that it is crucial to apply the linear regression equation to every single DMU. Simply entering the mean value of the depot into a formula disregards the underlying standard deviation which spans the wrong value for the average efficiency. Figure 14 illustrates the histograms of depots used for inductive simulation that were the basis for our analysis.

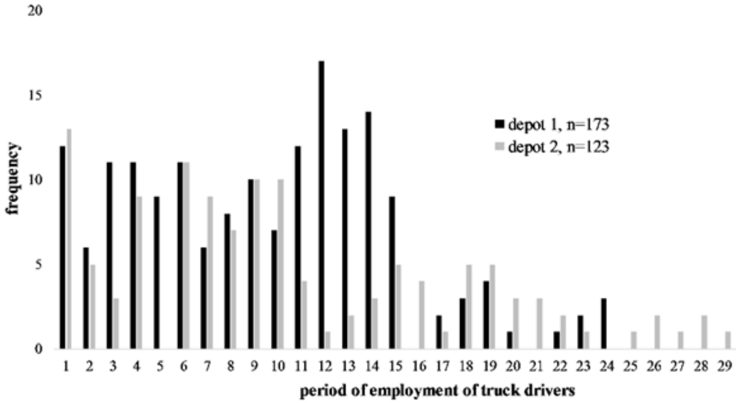


Figure 14: Histograms of depots used for inductive simulation.

A second managerial approach aims to elaborate a temporal simulation that is tested under the following assumptions: (1) The number of DMUs stays constant with n=30, (2) The developed regression model for the digital changeover can be transferred on digital transitions happening in the future and (3) Retiring truck drivers are replaced by drivers with age occurring in the sample. For the simulation, the data of case analysis two is used, and the age of the truck drivers is raised by ten years, causing retirements that are presumed with 60 years of age and marked grey. The age and the period of employment for the new drivers are selected randomly by choosing with repetition out of the occurring ages from the sample set. Table 3 summarizes the results of the temporal simulation.

Table 3: Results of the managerial approach for temporal simulation.

Sample Øeff. = 0.855				Simulation Øeff. =0.916			
DMU	empl.	age	eff.	DMU	empl.	age	eff.
DMU1	4	54	0.73	DMU1	9	38	0.89
DMU2	9	35	0.89	DMU2	19	45	1.00
DMU3	2	53	0.70	DMU3	1	24	0.74
DMU4	9	50	0.90	DMU4	13	47	0.93
DMU5	13	63	0.93	DMU5	5	29	0.84
DMU6	20	28	0.92	DMU6	30	38	1.00
DMU7	13	29	0.96	DMU7	23	39	1.00
DMU8	1	24	0.70	DMU8	11	34	0.95
DMU9	7	47	0.79	DMU9	17	57	1.00
DMU10	18	47	1.00	DMU10	28	57	1.00
DMU11	19	32	1.00	DMU11	29	42	1.00
DMU12	18	51	0.99	DMU12	2	50	0.70
DMU13	6	38	0.78	DMU13	16	48	1.00
DMU14	5	61	0.80	DMU14	1	24	0.74
DMU15	1	37	0.74	DMU15	11	47	0.95

On this basis, the simulation calculates the efficiency values for all DMUs where the period of employment does not occur in the sample (DMU6,

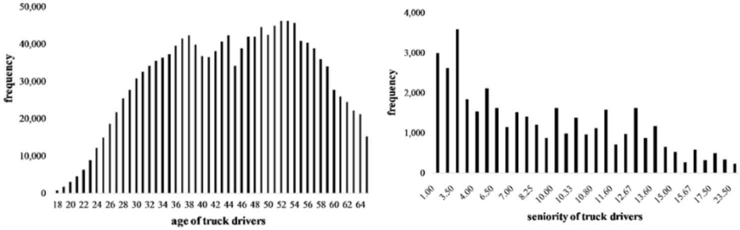


Figure 15: Histograms for the distribution of parent population.

DMU7, DMU8, DMU9, DMU10, DMU11) by using the linear regression function. The temporal simulation predicts an average level of efficiency of 0.916 for a digital changeover within the examined retailer's depot in 10 years (t0=0.855). To address a methodological advancement, the connection between efficiency and period of employment, expressed by efficiency = 0.753 + 0.0181 × time of employment, is applied to a parent population. Therefore, the dataset "GB Driving Licence Data" issued by the Driver and Vehicle Licensing Agency (DVLA) of Great Britain (GB) containing information about age and type of license for 1,512,167 license holders was used. Relevant data was selected by choosing the truck driver license categories C and CE, licenses and exclude pre-driving test learner licenses. To generate a dataset for the seniority of truck drivers, the average seniority per age extracted from the retailer's depots dataset, which was used previously, is applied. The total efficiency of 0.89 is then calculated by applying the linear regression line in the distribution of seniority and weighting them with the total number of driving licenses per period of employment.

Figure 16 summarizes the a priori simulation approach by illustrating the framework of requirement taken from (Loske, Klumpp, 2018), the method

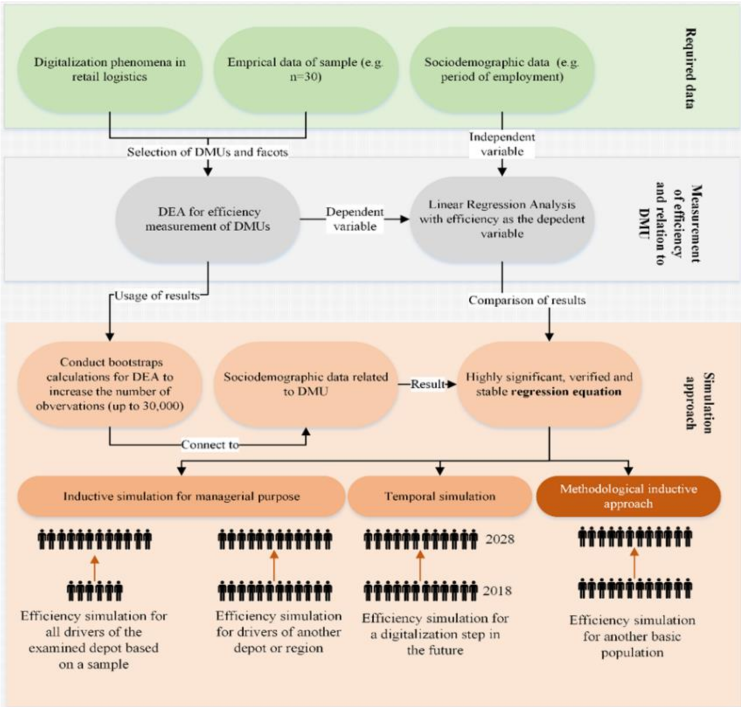


Figure 16: Requirements and outcomes for the simulation.

for measuring the relative efficiency by applying DEA as well as the combination of empirical efficiency values, bootstrapping and regression analysis. The a priori simulation approach can have the character of (1) an inductive simulation for managerial purpose, (2) a temporal simulation and (3) a methodological inductive approach.

4 Conclusion

Based on the efficiency scores of retail truck drivers, a regression analysis stated a strong statistical linear impact of seniority on the efficiency during digital changeovers, which was used to develop an inductive simulation approach. The combination of DEA, statistical bootstrapping, and regression analysis enabled the development of a significant regression function for the relationship of seniority and efficiency due to 60,000 simulation samples. Concerning the ongoing digital transformation, this inductive simulation approach can potentially be adapted to gain anticipative insights regarding the digitalization phenomenon for scientists and logistics managers. Future research would have to address among others the following points: (1) A possible simulation approach based on nonlinear regression, (2) A further simulation approach based on nonlinear regression with multiple variables and (3) A simulation approach for alternative digitalization scenarios in logistics, e.g. order picking or cargo handling.

References

Ahrens, D., 2016: Neue Anforderungen im Zuge der Automatisierung von Produktionsprozessen: Expertenwissen und operative Zuverlässigkeit, Arbeits- und Industriesoziologische Studien, 9(1), pp. 43–56.

Antomarioni, S. u. a., 2019: Defining a data-driven maintenance policy: an application to an oil refinery plant, International Journal of Quality and Reliability Management, 36(1), pp. 77–97.

Avent, R., 2014: The third great wave, The Economist, Special Report(1), pp. 1–14.

Banker, R.D., Charnes, A., Cooper, W.Wagner, 1984: Some models for estimating technical and scale inefficiencies in Data Envelopment Analysis, Management Science, 30(9), pp. 1078–1092.

Bauer, W., Schlund, S., 2015Wandel der Arbeit in indirekten Bereichen: Planung und Engineering, in: Hartmut Hirsch-Kreinsen/Peter Ittermann/Jonathan Niehaus (Eds.), Digitalisierung industrieller Arbeit, 2015pp. 54–69.

Borangiu, T. u. a., 2019: Digital transformation of manufacturing through cloud services and resource virtualization, Computers in Industry, 108, pp. 150–162.

Brynjolfsson, E., McAfee, A., 2014: The second machine age: Work, progress, and prosperity in a time of brilliant technologies: W.W. Norton & Company, New York.BM14

BVL, 2017: Logistik als Wissenschaft: Zentrale Forschungsfragen in Zeiten der vierten industriellen Revolution, Positionspapier Bundesvereinigung Logistik (BVL), 1(1), pp. 1–20.

Cao, W. u. a., 2017: Real-time data-driven monitoring in job-shop floor based on radio frequency identification, International Journal of Advanced Manufacturing Technology, 92(5-8), pp. 2099–2120.

Chehri, A., Jeon, G., Zimmermann A., Chen Y.-W., Howlett R.J., Jain L.C., 2019: The Industrial Internet of Things: Examining How the IIoT Will Improve the Predictive Maintenance, Smart Innovation, Systems and Technologies, 145, pp. 517–527.

Chen, H.Q. u. a., 2016: Cloud-based data management system for automatic real-time data acquisition from large-scale laying-hen farms, International Journal of Agricultural and Biological Engineering, 9(4), pp. 106–115.

Chen, Y., Du, J., Huo, J., 2013: Super-efficiency based on a modified directional distance function, Omega, 41(3), pp. 621–625.

Dombrowski, U., Riechel, C., Evers, M., 2014Industrie 4.0 (Industry 4.0): Die Rolle des Menschen in der vierten industriellen Revolution (The role of humans in the fourth industrial revolution), in: Wolfgang Kersten (Ed.), Industrie 4.0 (Industry 4.0), 2014pp. 129–153.

Efron, B., 1979: Bootstrap methods: Another look at the jackknife, The Annals of Statistics, 7(1), pp. 1–26.

—, 1987: Better bootstrap confidence intervals, Journal of the American Statistical Association, 82(397), pp. 171–185.

—, 1994: The jackknife, the bootstrap and other resampling plans, 6. Aufl.: Society for Industrial and Applied Mathematics, Philadelphia.Efr94

Efron, B., Tibshirani, R.J., 2000: An introduction to the bootstrap: Chapman & Hall, Florida.ET00

Eisenmann, M., Ittermann, P., 2017: Hybride Dienstleistungen und Wandel der Arbeit: Herausforderungen und Perspektiven in der Logistik, Soziologisches Arbeitspapier, 50(1), pp. 1–46.

Emon, M.O.F. u. a., 2019: Multi-material 3D printing of a soft pressure sensor, Additive Manufacturing, 28, pp. 629–638.

Giraldo-Castrillon, F.-A., Páramo-Bermúdez, G.-J., Muñoz-Betancur, J.-M., 2019: Monitoring of machining in the cloud as a cost management service and follow of cutting parameters: Environment developed with IoT tools, International Journal of Manufacturing, Materials, and Mechanical Engineering, 9(3), pp. 26–41.

Hamidi, F., Aslani, F., 2019: Additive manufacturing of cementitious composites: Materials, methods, potentials, and challenges, Construction and Building Materials, 218, pp. 582–609.

Hedenstierna, C.P.T. u. a., 2019: Economies of collaboration in build-to-model operations, Journal of Operations Management, , Hirsch-Kreinsen, H., 2015Gestaltungsperspektiven von Produktionsarbeit bei Industrie 4.0, in: Christopher Schlick (Ed.), Arbeit in der digitalisierten Welt, 2015

Hirsch-Kreinsen, H./Ittermann, P./Niehaus, J. (Eds.), 2015Digitalisierung industrieller Arbeit: Die Version Industrie 4.0 und ihre sozialen Herausforderungen, Baden-Baden: Nomos Verlagsgesellschaft.

— (Eds.), 2015Digitization of industrial work: The version Industry 4.0 and its social challenges, Baden-Baden: Nomos Verlagsgesellschaft.

Hirsch-Kreinsen, H. u. a., 2018„Social Manufacturing and Logistics“: Arbeit in der digitalisierten Produktion, in: Steffen Wischmann/Ernst Hartmann (Eds.), Zukunft der Arbeit, 2018

Huchler, N., 2016: Die ‚Rolle des Menschen' in der Industrie 4.0: Technikzentrierter vs. humanzentrierter Ansatz, Arbeits- und Industriesoziologische Studien, 9(1), pp. 57–79.

Jiang, J., Xu, X., Stringer, J., 2019: Optimization of process planning for reducing material waste in extrusion based additive manufacturing, Robotics and Computer-Integrated Manufacturing, 59, pp. 317–325.

Kagermann, H., Lukas, W.-D., Wahlster, W., 2011: Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution, VDI Nachrichten, 13,

Kersten, W. (Ed.), 2014Industrie 4.0 (Industry 4.0): Wie intelligente Vernetzung und kognitive Systeme unsere Arbeit verändern (How intelligent networking and cognitive systems change our work), Berlin: Gito.

Kleer, R., Piller, F.T., 2019: Local manufacturing and structural shifts in competition: Market dynamics of additive manufacturing, International Journal of Production Economics, 216, pp. 23–34.

Klumpp, M., 2018: Automation and artificial intelligence in business logistics systems: Human reactions and collaboration requirements, International Journal of Logistics Research and Applications, 21(3), pp. 224–242.

Koch, V. u. a., 2014: Chancen und Herausforderungen der vierten industriellen Revolution: Pwc und Strategy, Frankfurt, München.KGK14

Koleva, N., Andreev, O., 2018: Aspects of Training in the Field of Operations Management with Respect to Industry 4.0, International Conference on High Technology for Sustainable Development, HiTech 2018 - Proceedings, , Kulkarni, S., Verma, P., Mukundan, R., 2019: Performance landscape modeling in digital manufacturing firm, Business Process Management Journal, 25(3), pp. 533–552.

Lanz, M., Tuokko, R., 2017: Concepts, methods and tools for individualized production, Production Engineering, 11(2), pp. 205–212.

Lasi, H. u. a., 2014: Industry 4.0, Business and Information Systems Engineering, 6(4), pp. 239–242.

Lee, J., Bagheri, B., Kao, H.-A., 2015: A Cyber-Physical Systems architecture for Industry 4.0-based manufacturing systems, Manufacturing Letters, 3, pp. 18–23.

Lee, J., Kao, H.-A., Yang, S., 2014: Service innovation and smart analytics for Industry 4.0 and big data environment, Procedia CIRP, 16,

Lewin, K., 1947: Frontiers in Group Dynamics, Human Relations, 1(1), pp. 5–41.

Liu, Q. u. a., 2019: Single-machine-based joint optimization of predictive maintenance planning and production scheduling, Robotics and Computer-Integrated Manufacturing, 55, pp. 173–182.

Loske, D., Klumpp, M., 2018: Efficiency Analysis for Digitalised Working Systems of Truck Drivers, Hamburg International Conference of Logistics, , pp. 99–119.

Lu, G. u. a., 2018: Addressing endogeneity in operations management research: Recent developments, common problems, and directions for future research, Journal of Operations Management, 64, pp. 53–64.

March, S.T., Scudder, G.D., 2019: Predictive maintenance: strategic use of IT in manufacturing organizations, Information Systems Frontiers, 21(2), pp. 327–341.

Markillie, P., 2012: A third industrial revolution, The Economist, Special Report(1), pp. 1–10.

Pérez, B. u. a., 2019: Impact of macronutrients printability and 3D-printer parameters on 3D-food printing: A review, Food Chemistry, 287, pp. 249–257.

Pérez, L. u. a., 2019: Industrial robot control and operator training using virtual reality interfaces, Computers in Industry, 109, pp. 114–120.

Rajput, S., Singh, S.P., 2019: Industry 4.0 − challenges to implement circular economy, Benchmarking, , Rifkin, J., 2011: The third industrial revolution: How lateral power is transforming energy, the economy and the world: Palgrave Macmillan, New York.Rif11

Roscoe, S., Cousins, P.D., Handfield, R., 2019: The microfoundations of an operational capability in digital manufacturing, Journal of Operations Management, ,

Schlick, C. (Ed.), 2015Arbeit in der digitalisierten Welt: Beiträge der Fachtagung des BMBF 2015, Frankfurt am Main: Campus.

— (Ed.), 2015Arbeit in der digitalisierten Welt: Beiträge der Fachtagung des BMBF 2015, Frankfurt am Main: Campus.

Simar, L., Wilson, P.W., 1998: Sensitivity analysis of efficiency scores: How to bootstrap in nonparametric frontier models, Management Science, 44(1), pp. 49–61.

—, 2007: Estimation and inference in two-stage, semi-parametric models of production processes, Journal of Econometrics, 136(1), pp. 31–64.

Stadnicka, D., Antonelli, D., 2019: Human-robot collaborative work cell implementation through lean thinking, International Journal of Computer Integrated Manufacturing, 32(6), pp. 580–595.

Stock, T., Seliger, G., Seliger G., Kohl H., Mallon J., 2016: Opportunities of Sustainable Manufacturing in Industry 4.0, Procedia CIRP, 40,

Stowasser, S., Jeske, T., 2015Arbeitswelt der Zukunft, in: Christopher Schlick (Ed.), Arbeit in der digitalisierten Welt, 2015

van Eck, N.Jan, Waltman, L., 2010: Software survey: VOSviewer, a computer program for bibliometric mapping, Scientometrics, 84(2), pp. 523–538.

Wang, J. u. a., 2019: Digital Twin for rotating machinery fault diagnosis in smart manufacturing, International Journal of Production Research, 57(12), pp. 3920–3934.

Wang, S. u. a., 2016: Towards smart factory for industry 4.0: A self-organized multi-agent system with big data based feedback and coordination, Computer Networks, 101, pp. 158–168.

Wee, D. u. a., 2015: Industry 4.0: How to navigate digitization of the manufacturing sector: McKinsey & Company, München u. a.WKC15

Will-Zocholl, M., 2016: Die Verlockung des Virtuellen: Reorganisation von Arbeit unter Bedingungen der Informatisierung, Digitalisierung und Virtualisierung, Arbeits- und Industriesoziologische Studien, 9(1), pp. 25–42.

Windelband, L., Dworschak, B., 2015Arbeit und Kompetenzen in der Industrie 4.0: Anwendungsszenarien Instandhaltung und Leichtbaurobotik, in: Hartmut Hirsch-Kreinsen/Peter Ittermann/Jonathan Niehaus (Eds.), Digitization of industrial work, 2015pp. 71–86.

Wischmann, S./Hartmann, E. (Eds.), 2018Zukunft der Arbeit: Eine praxisnahe Betrachtung, Berlin: Springer Vieweg.

Wollschlaeger, M., Sauter, T., Jasperneite, J., 2017: The future of industrial communication: Automation networks in the era of the internet of things and industry 4.0, IEEE Industrial Electronics Magazine, 11(1), pp. 17–27.

Wrobel-Lachowska, M. u. a., 2018: The role of the lifelong learning in logistics 4.0, Advances in Intelligent Systems and Computing, 596, pp. 402–409.

Zangiacomi, A. u. a., 2017: The implementation of digital technologies for operations management: a case study for manufacturing apps, Production Planning and Control, 28(16), pp. 1318–1331.

Zeng, P. u. a., 2019: Time-slotted software-defined Industrial Ethernet for real-time Quality of Service in Industry 4.0, Future Generation Computer Systems, 99, pp. 1–10.

Zuboff, S., 2010: Creating value in the age of distributed capitalism: McKinsey Quarterly.Zub10

A Procedural Model for Exoskeleton Implementation in Intralogistics

Carsten Feldmann [1], Victor Kaupe [2], and Martin Lucas [3]

1 – University of Applied Sciences Münster

2 – BASF Coatings GmbH

3 – University of Applied Sciences Hamm-Lippstadt

Purpose: Exoskeletons are robotic devices worn on the human body which mechanically support the operator's muscle skeleton. This study answers the following research question: Given insights drawn from a comprehensive literature analysis and two case studies which concern success factors for deployment projects, how can a systematic procedural model be used to support exoskeleton implementations in intralogistics?

Methodology: This study follows the design-science research process developed by Peffers et al. (2006). The research gap was identified based on a systematic and comprehensive review of literature which reflects the current state of research. Insights gained via this process were compared with empirical data from pilot installations at two case companies: a Swedish market leader in the furniture industry and a leading German coatings manufacturer.

Findings: A procedural model was designed to systematically consider success factors for an implementation which involves (1) workplace context; (2) human context and exoskeleton selection; (3) economic context; (4) pilot testing, evaluation, and maintenance; (5) deployment and training; and (6) go-live and support. It addresses technical, commercial, and social domains. The latter is critical to success, as it ensures staff acceptance.

Originality: Exoskeletons can contribute to solving challenges such as demographic transitions and skills shortages in logistics. The procedural model closes a research gap from a scientific perspective and enables practitioners to exploit the potentials of successful exoskeleton introduction. Case studies in two different branches ensure practical relevance and significantly expand the state of research regarding the efficient achievement of implementation goals.

First received: 6. Mar 2020 Revised: 20. Jun 2020 Accepted: 26. Jun 2020

1 Introduction

Intralogistics refers to planning and controlling the flow of goods within a company site, such as a plant or distribution center (Arnold, 2007). Three prime factors pave the way for the dissemination of exoskeletons in this domain. First, demographic changes are leading to labour shortages (Garloff and Wapler, 2016; Sahashi et al., 2018). Second, monotonous, repetitive movements and postural stress result in musculoskeletal disorders among workers, thereby causing 22% of all sick days in Germany (Meyer et al., 2019). Third, the proportion of manual work in intralogistics is relatively high in many companies. On the one hand, there is a trend towards the automation of processes and workplaces (Mikušová et al., 2017). On the other hand, not all human work can be easily replaced with technology if the space is limited or the job requires complex gestures, precise gripping or dexterity (Dahmen et al., 2018a; Sylla et al., 2014). Moreover, the costs of automation solutions are often prohibitively high compared to the costs associated with human workers (Bogue, 2018).

As ergonomic-assistance systems, industrial exoskeletons provide a way to improve both ergonomics and work performance. Exoskeletons are mechanical structures which are worn on the human body to support the user's muscle skeleton for certain movements and postures, thereby addressing ergonomic needs for the upper and lower extremities and/or the trunk (Bogue, 2018; De Looze et al., 2016; Fox et al., 2019) while performing tasks such as lifting and carrying goods. Exoskeletons are associated with potential ergonomic benefits for workers such as enhanced strength and endurance (Bogue, 2018), reduced physical strain and stress (Butler, 2016;

Fox et al., 2019; Hensel and Keil, 2018), decreased disorders of the musculoskeletal system and other occupational injuries. Thus, exoskeletons can result in a reduction of employee sick days (Schmidtler et al., 2015; Sylla et al., 2014). Exoskeletons can help employees who have physical limitations and are in the process of inclusion or occupational reintegration (Hensel and Keil, 2018).

From a business perspective, such improvements imply increased productivity (Butler, 2016; Schmidtler et al., 2015), lower costs (Bogue, 2018; Dahmen et al., 2018a; Todorovic et al., 2018), higher quality (Butler, 2016; Dahmen et al., 2018a; Spada et al., 2017; Todorovic et al., 2018) and greater flexibility (Constantinescu et al., 2015). However, the level of dissemination in companies is relatively low (ABI Research, 2019). To date, there is no tested procedural model which can help practitioners implement exoskeletons in intralogistical processes.

The research question of this study can be summarized as follows: Given insights drawn from a comprehensive literature analysis and two case studies which concern success factors for deployment projects, how can a systematic procedural model be used to support exoskeleton implementations in intralogistics?

The following section provides an overview regarding the state of the research from which the research gap can be derived. Next, Section 3 spells out the research methodology. Subsequently, sections 4 through 7 follow the phases of the design-science research process. In the concluding section, the findings of this study are summarized and implications for research and practice are discussed.

2 State of the field and the research gap

To sharpen the research agenda, the current state of research had to be determined by an extensive literature review following the framework by Vom Brocke et al. (2009). Relevance is enhanced by avoiding repeated analysis of what is already known (Baker, 2000), and rigor is derived from an effective use of the existing knowledge base (Hevner et al., 2004). A preliminary evaluation of article titles and abstracts reduced the number of publications from 3,248 from 10 databases to a sample of 54 articles based on the following criteria: currency, relevance, authority, accuracy, and purpose. To ensure the high quality of the sources, the focus was placed on publications in scholarly journals and proceedings of conferences.

Many papers examine the influence of exoskeletons on workplace ergonomics, often with a narrow scope of specific application scenarios: e.g., working overhead or supporting particular body parts with a specific exoskeleton type (Baltrusch et al., 2018; Bosch et al., 2016; Butler, 2016; Ebrahimi, 2017; Graham et al., 2009; Picchiotti et al., 2019; Poon et al., 2019; Rashedi et al., 2014; Rogge et al., 2017; Schmidtler et al., 2015; Steinhilber et al., 2018; Sylla et al., 2014). Studies in the industrial context mainly address assembly tasks in manufacturing (Fox et al., 2019; Staub and Anderson, 2019; Sylla et al., 2014)—in particular, in the automotive industry (Constantinescu et al., 2015; Dahmen et al., 2018a; Hyun et al., 2019; Spada et al., 2017). In contrast, exoskeletons in intralogistics is an applied research area that has received relatively little attention in the literature (Hensel and Keil, 2018; Schmidtler et al., 2015; Winter et al., 2019). Few studies focus on the economic implications of utilizing industrial exoskeletons (Dahmen et al., 2018a; Schmidtler et al., 2015; Todorovic et al., 2018).

The available studies are very heterogeneous in terms of research methods and the empirical database, so that the results are not strictly comparable. Research is often limited to general-level analysis (Todorovic et al., 2018) and case studies (Butler, 2016; Steinhilber et al., 2018; Sylla et al., 2014). Due to a low number of test persons and laboratory conditions, the findings of many empirical studies do not go beyond a proof of concept (Hensel and Keil, 2018). Some findings are documented in the form of single (experimental) case studies (Butler, 2016; Sylla et al., 2014), which cannot be used for a valid induction because of their limited sample scope. In addition, their constructs and indicators are often not sufficiently validated. However, such studies are essential to determining cause-effect relationships in a scientifically accurate manner. Dahmen et al. (2018a) present a holistic-planning method for exoskeleton implementation in manufacturing which is based on a set of assessments. Hensel and Keil (2018) provide hints for implementation in industrial practice. However, there is no comprehensive, generalizable procedural model in the literature which considers intralogistics requirements.

The issues can be summarized as follows: There is no holistic procedural model for implementing exoskeletons in intralogistics. Structured information about the success factors of exoskeleton deployment is weak. For practitioners, it is difficult to understand how investments in exoskeletons contribute to value creation. Accordingly, two research questions were addressed:

RQ1: Given the success factors identified in literature, how can a systematic procedural model be used to structure the implementation process for exoskeletons in intralogistics?

RQ2: Which goals should be pursued with which methods in each phase of the procedural model to increase the probability of success of an exoskeleton-implementation project?

3 Research methodology

Design science provides a suitable methodological framework for construction-oriented research projects (Zelewski, 2007). This study follows the design-science research process presented by Peffers et al. (2006), which is comprised of six steps: problem identification and motivation, objectives for a solution, design and development, evaluation, and communication (see Figure 1). The methodology is oriented towards Peffers et al. (2006) and the guidelines of Hevner et al. (2004). While the procedure of Peffers et al. (2006) describes the research logic of a design-science approach, the recommendations of Hevner et al. have become established in the publication practice for documentation of the scientific nature of such an approach (Zelewski, 2007).

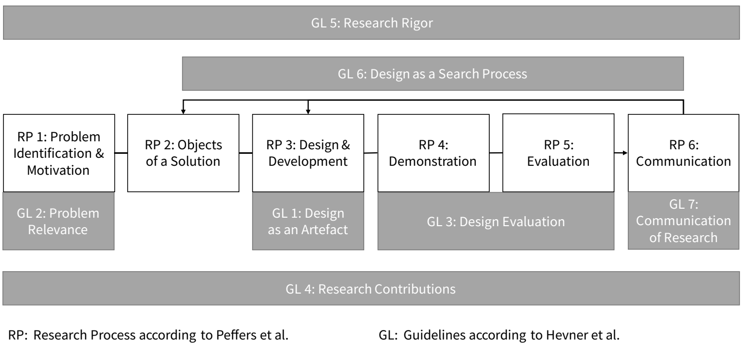


Figure 1: Design-science research process and guidelines, following Zellner (2015).

First, to capture and analyze the state-of-the-research completely, systematically, and comprehensibly, the research gap was identified based on a comprehensive literature review, following Vom Brocke et al. (2009). Second, the findings were compared with insights gained from two case companies. Two research objectives were pursued. On the one hand, a qualitative-explorative goal was achieved: the capture of subjective assessments and interpretation patterns with which to compare the situation-specific contextual conditions. Semi-structured interviews and questionnaires were used to identify the individual perspectives and patterns that are lost in the variances of quantitative group studies. On the other hand, the goal of empirically validating the theoretical findings was pursued: Case studies have a validating function when theory-based research hypotheses are compared with the results of the case evaluation. Because they are used to identify industry specifics, the case studies comprise pilot implementations at a German coatings manufacturer and a leading Swedish company in the furniture industry. The artifactual solution developed in this study is a procedural model for the implementation of exoskeletons in intralogistics. A procedural model is a representation of the activities to be carried out within the framework of an overall task (Schütte, 1998).

4 Problem identification and motivation

There is no holistic procedural model available in the literature for guiding practitioners in implementing exoskeletons in intralogistics processes (see Section 2). This lack may lead to a higher risk of poor decisions, avoidable costs, and excessively long project duration. Moreover, it is difficult for practitioners to understand in detail how investments in exoskeletons contribute to improvements in productivity and quality and to decreasing disorders of the musculoskeletal system. A procedural model in the form of a standardized process would structure the fulfilment of the overall task so that progress can be tracked and documented during the implementation project. Moreover, such a procedural model could promote a common understanding of the process and cross-functional cooperation between the departments involved.

5 Objectives for a solution

The first objective is to concisely identify the main impacts of exoskeletons in intralogistics processes. The second aim is to help companies implement exoskeleton solutions. Therefore, this paper develops a procedural model for systematically structuring the deployment process. In the procedural model, the overall task is divided into modular activities and is structured systematically in a logical and chronological sequence (Schütte, 1998). In this respect, a procedural model represents the essential elements of a process (e.g., activities, tools) and the mapping of their interrelationships. It reduces the risk of wrong decisions which might otherwise result in unnecessarily high project costs and project duration and a suboptimal solution in operations. Motivation of project participants increases as they understand the benefits of exoskeletons. The bundling of success factors from the literature analysis and empirical data streamlines the implementation of the best possible solution.

6 Design and development

6.1 Overview

A model is a simplified representation of a complex system whereby the real world is represented in terms of elementary levels and laws (Adam, 1997). The object—the implementation process of an exoskeleton solution—is systematically described in a model to create important properties comparable to real counterparts (Börner et al., 2012). The artifact to be designed is a procedural model: a systematic framework for the temporal and logical structuring of the activities to be performed within an exoskeleton implementation. The following section describes the design principles applied. The succeeding sections outline the overall set-up of the procedural model and describe its individual phases in detail.

6.2 Design principles

Modeling is a design process in which designers build a model according to a user's needs (Vom Brocke, 2007). The model should be suitable as a guideline whereby practitioners can facilitate exoskeleton deployment in the application domain of intralogistics. The target group comprises project managers and team members of exoskeleton-deployment projects and logistics-process owners. The prerequisites for applicability by such users include comprehensibility, simple applicability, and practical relevance. The quality of a model shall be ensured by following the principles of proper modelling (Becker et al., 1995).

6.3 Procedural model

6.3.1 Overview

The procedural model comprises six phases: (1) workplace context; (2) human context and exoskeleton-type selection; (3) economic context; (4) pilot-testing, evaluation, and maintenance; (5) deployment and training; and (6) go-live and support (see Figure 2).

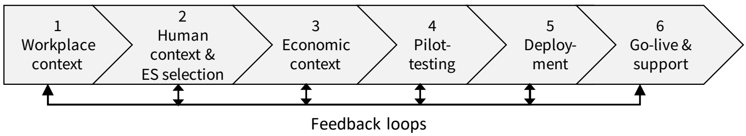


Figure 2: Procedural model for exoskeleton implementation in intralogistics

An exoskeleton implementation aims at increasing economic efficiency while reducing physical stress for workers. Its benefits, measured in terms of ergonomics and improved work performance, are jointly determined by a number of factors. Some of these factors are interdependent, so they should be determined simultaneously. To make the model manageable for practitioners, these interdependencies are partly fragmented. Thus, iterative solutions or recursions are required at some points in the procedural model. For example, a workplace limits the selection of a potential exoskeleton. However, there may be also restrictions with regards to exoskeleton selection due to the physical characteristics of individual workers. Figure 3 presents an overview of the contextual factors and key interdependencies addressed in the following sections. Outcomes per phase will be looped back to preceding phases to optimize the configuration of the human-machine interface (HMI).

Ergonomists, company physicians, occupational safety persons, work councilors and above all affected workers and supervisors should be involved in the selection, piloting and roll-out of the exoskeletons at an early stage (Hensel and Keil, 2018; Rogge et al., 2017).

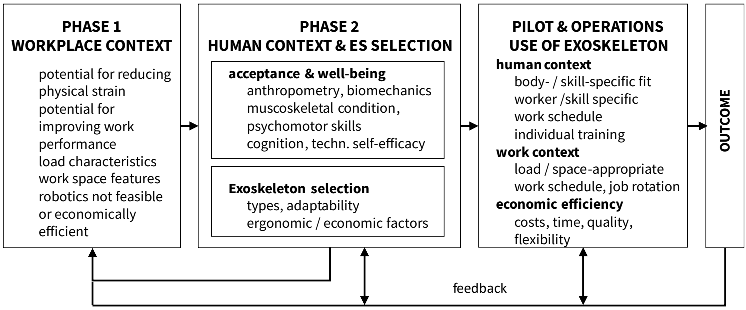


Figure 3: Overview of selected contextual factors and their interdependencies

6.3.2 Phase 1: workplace context

The context for exoskeleton use is determined both by the activities of a workplace and by the individual characteristics of its workers. The objective of the first phase is to pre-select suitable workplaces. The human context—i.e., the individual requirements a worker has for an exoskeleton—are addressed in Phase 2.

There are a large number of "paper and pencil" methods for the ergonomic assessment and categorization of workplaces. These include EAWS (European Assembly Worksheet) and OCRA (Occupational Repetitive Actions), which are used to analyze loads, postures, and/or repetitions in a process (Daub, 2017). Against the background of their inaccuracy, biomechanical measurements based on kinematics and kinetics data are preferable. Electromyography measurements provide information about which muscle areas are particularly stressed (Sahashi et al., 2018).

The following criteria point to the potential suitability of a workplace for the use of an exoskeleton and can be utilized as a pragmatic quick check:

1. There are (monotonous, repetitive) movements or postures which cause physical strain of workers, e. g., while lifting or lowering heavy loads (Dahmen et al., 2018b; Daub, 2017; Winter et al., 2019), and there is a potential for improving ergonomics. Sufficient space for working with the exoskeletons is available.
2. Load characteristics—such as the shape, weight, and kind of goods to be handled—are suitable (Fox et al., 2019).
3. Safety-related legal and occupational requirements can be met (Dahmen et al., 2018b).
4. The potential exists for improving work performance with respect to time, costs, flexibility, or quality (Dahmen et al., 2018a; Todorovic et al., 2018). There are few occasions for walking long distances, thus compensating the positive impact on economic efficiency (Fox et al., 2019). The cost of alternative robotics solutions is too high (Sylla et al., 2014).
5. Operation is not suitable for robotics in terms of feasibility, speed or flexibility. For example, activities require complex gestures, precise gripping, dexterity or sensory inputs, or the available space is limited (Dahmen et al., 2018a; Fox et al., 2019; Sylla et al., 2014). Wide and frequent variations of activities and goods to be handled are caused by uncertain demand and dynamic customer requirements.

6.3.3 Phase 2: human context and exoskeleton type selection

On one hand, the ergonomic parameters of exoskeleton use are to be set so that the physical strain on workers is reduced. Exoskeletons should help staff work safely and ergonomically, reducing fatigue and stress. On the other hand, work performance should be improved with respect to economic efficiency (see Phase 3). Both improvements result from a variety of partly interdependent factors. Besides the workplace requirements (Phase 1), the task-specific selection of an adequate exoskeleton type and the individual characteristics of a worker determine the success of exoskeleton operations. In what follows, the selection criteria for exoskeleton types are outlined first; then the worker-specific criteria are presented.

A variety of exoskeleton types exist. Fox et al. (2019) have identified eight different types, which are categorized in terms of the body part assisted, sources of support, and sources of power. Daub (2017) provides common classifications (following Bai and Christensen, 2017; Bosch et al., 2016; Bueno et al., 2016; Lee et al., 2012; Rogge et al., 2016):

a) Application: rehabilitation, assistive robots, human amplifier, combined use.

b) Human body part being supported: limbs, trunk, or the whole body.

c) Effect mechanism (deviating from Daub, 2017): (1) passive, (2) active, and (3) hybrid exoskeletons. (1) Passive exoskeletons support the wearer by means of mechanical aids, such as a spring or cable, which absorb any loads which occur like a counterweight and thus convert them into energy to support a posture or a motion (Fox et al., 2019). (2) Active exoskeletons (wearable robotics) also provide external-force support via sensors and ac-

tuators such as electric motors or pneumatic systems. (3) Hybrid exoskeletons are active exoskeletons that are controlled by nerve signals and bioelectric sensors (Stewart et al., 2017).
d) Power-transmission methods: gear drive, cable drive, linkage mechanism or other.
e) Alignment of the degree of freedom between human and robotic joints: anthropomorphic vs. quasi-anthropomorphic and non-anthropomorphic.
f) Control methods and sensor infrastructure: cognitive human-robot interaction, wherein the interaction occurs via human cognitive processes versus (physical human-robot interaction, which involves physical interaction.
The critical movements or postures identified in Phase 1 should be assisted by the exoskeletons. Exoskeletons usually support specific regions of the body, such that the concrete-load situation and the affected physical-constriction areas ultimately determine the selection of the system. The factors mentioned in Phase 1, the "workplace context", should be assessed in conjunction with a specific exoskeleton (e.g., whether escape routes can be used when wearing the exoskeletons). The ease with which an exoskeleton can be put on and taken off should also be checked (change-over time, see Phase 3). Dahmen and Constantinescu (2020) present a scoring-based model for preselecting a suitable exoskeleton for a specific workplace.
When selecting an exoskeleton, the risks of its use must also be considered. Rigid systems that support specific body parts restrict and weaken other parts (Daub, 2017). The worker who operates in an exoskeleton has a limited degree of freedom and movability (Schmidtler et al., 2015). Heavy and motion-limiting exoskeletons in particular reduce the ability to cover long distances (Fox et al., 2019). Accordingly, the weight and dimensions of the exoskeleton are another selection criterion. The physical strain on workers

might be high, as workers suffer from load shifts to different parts of the body. So far, there are hardly any reliable findings from longitudinal studies in occupational science regarding the possibly negative long-term consequences of exoskeleton use (Hensel and Keil, 2018; Steinhilber et al., 2018). This research gap results in ergonomic and legal risks that are difficult to assess.

Besides the activities at a specific workplace (Phase 1) and the selection of an adequate exoskeleton type to support a particular task, the fit to the characteristics of an individual worker also determines the success of applying an exoskeleton. On the one hand, *success* refers to human acceptance and well-being achieved by reducing physical strain. On the other hand, success is determined by improving work performance with respect to time, costs, or quality. The factors of the human context are comprised of a workers' individual anthropometry, biomechanics, musculoskeletal condition, psychomotor skills, plus the cognition and self-confidence needed to cope with the new technology (Fox et al., 2019; Schmidtler et al., 2015; Sylla et al., 2014). These person-specific factors need to be considered when selecting (and if necessary, adapting) an exoskeleton type to ensure a sufficient fit between the individual characteristics of a worker, his or her workplace, and the task to be performed (Daub, 2017; Hensel and Keil, 2018). Since these factors—the workplace (and its tasks), the selection of an exoskeleton type (or its adaptation), and the characteristics of a worker—are strongly interdependent, the fit between them is ideally determined by IT-based simulations (Sylla et al., 2014; Constantinescu et al., 2016). If the technical means or skills are not available for this, the fit should be sought in iterative feedback cycles in real-life set-ups.

In the literature, human-exoskeleton interactions are generally evaluated by defining indices of performance for a specific application scenario (such as joint velocity) or by measuring interaction forces (Schmidtler et al. 2015; Sylla et al., 2014). Moreover, sensor data such as electromyographic measurements (EMG) and time-synchronized video recordings are also used (Winter et al., 2019). However, "soft" factors, such as subjective perceptions of discomfort, must be considered when evaluating exoskeleton scenarios, as these are key to increasing the workers' acceptance (Daub, 2017; Rogge et al., 2017; Winter et al., 2019) and thus constitute a critical success factor. In one case study, worker acceptance was severely affected by workplace bullying through condescending remarks regarding the presumed low performance and visual appearance of an exoskeleton system. Involving employees voluntarily from the beginning of the project and actively engaging them in shaping their work context (for example, by allowing them to review trial runs) promotes acceptance of the exoskeleton solution. The same applies to intuitive adjustment of the device to the individual body measurements.

6.3.4 Phase 3: economic context

Phase 3 addresses the evaluation of an investment in exoskeleton capabilities with regards to economic efficiency. Table 1 provides an overview of the potential factors to be considered for the analysis (Bogue, 2018; Butler, 2016; Dahmen et al., 2018a; Schmidtler et al., 2015; Todorovic et al., 2018). To ensure the value orientation of an exoskeleton investment, assessment of the economic impact should be based on the economic-value-added (EVA) concept, which is widely accepted as a financial metric for measuring value (Young and O'Byrne, 2001). The EVA shows how much value is added to the capital employed in each year of the forecast, thereby supporting a dynamic perspective. To ensure relevance for logistics operations, the EVA model should be based on the approach of Feldmann and Pumpe (2017).

6.3.5 Phase 4: pilot testing, evaluation and maintenance

Testing is a process of executing a system with the intent of finding errors or potentials for improvement. For an example, consider any activity which

Table 1: Potential factors for analyzing impacts on the economic efficiency

Impact area	Factors and assumed direction of effect
Time	(-) Decrease of cycle time for a task (higher throughput due to improved ergonomics, stable quality, higher motivation) (+) Increase of set-up time, e. g. for putting on and taking off the ES or battery charging of active ES (+) Increase of time needed for covering distances on foot
Costs one-time	(+) Acquisition costs or development costs for in-house development (+) Training (-) Integration of impaired workers
Costs ongoing	(+) Rental or license fees (+) Depreciation (+) Maintenance, repair (+) Storage (+) Energy (+) Space required (-) Sick days (-) Financial consequences associated with occupational injuries (-) Overtime
Flexibility	(+) Employability of worker and workplace (+) Capabilities with regards to variant diversity / work assignment
Quality	1. Process quality (+) Precision (+) Error prevention, embedded Poka Yoke (+) Stable workflow 2. Product quality (+) Degree of accuracy (+) Scratch protection

is aimed at evaluating an attribute or capability of a system to determine whether it performs as required (Mathur and Malik, 2010). A pilot setting should be used for initially testing, with regards to ergonomic and economic requirements, interactions between the workplace, the task to be performed, and the worker using the exoskeleton. First, the technical requirements of the solution with regards to the workplace context (Phase 1) and the exoskeleton ergonomics must be validated. At present, there are no standardized testing methods available (Rogge et al., 2017). A holistic assessment should combine subjective, biomechanical, and mechanical testing methods, thereby building on available orthopedic examination tools. Dahmen and Hefferle (2018) have identified 36 scientific-assessment methods. Hensel and Steinhilber (2018) see added value in the combined observations of laboratory and field studies. The authors propose a test cycle analogous to that used in software development, which is based on the advanced V-model by Mathur and Malik (2010), featuring unit, integration, system, user acceptance, and performance testing.

Second, the acceptance and well-being of the workers (Phase 2) must be ensured. For a successful implementation, practical aspects such as comfort, usability, security, and user acceptance should be considered (Hensel and Steinhilber, 2018). Due to inherent hazards to the health and safety of workers, a risk assessment based on the relevant guidelines and a declaration of conformity by the manufacturer is essential (Hensel and Keil, 2018). To assess the subjective perception of workers, Hensel and Keil (2018) recommend measuring strain relief, discomfort, usability, and user acceptance. Third, economic efficiency (Phase 3) must be evaluated by a profitability analysis.

On the one hand, an exoskeleton potentially reduces physical strain on workers. On the other hand, negative effects may also occur, which may restrict its applicability and acceptance. These may include (following cited in Fox et al., 2019) balance problems (Kim et al., 2018), friction and pressure at fixation and support points (Bosch et al., 2016; Huysamen et al., 2018; Rogge et al., 2017; Winter et al., 2019), or unpredictable loading (Picchiotti et al., 2019; Weston et al., 2018). Special attention should be given to usability and economic efficiency in workplaces which require that long distances be covered on foot (Winter et al., 2019).

The usability of the exoskeletons plays an important role in practical use, both in the execution of the supported activity and in secondary activities such as driving a forklift truck and donning and removing the exoskeleton. With decreasing usability and increasing discomfort, user acceptance decreases; thus, the probability of sustainable use also decreases. Some exoskeletons reach their limits when moving in confined spaces and overcoming distances on foot. Upper-body-supporting exoskeletons are often designed for only one activity such as lifting such that workers may feel uncomfortable and lack maneuverability when walking and sitting. In intralogistics, however, many workplaces are characterized by alternating activities.

Initial pilot testing and ongoing maintenance work together to achieve a high quality, reliable, and efficient solution. In addition to tasks like cleaning, maintenance involves modifying an existent exoskeleton system—which is comprised of the workplace, tasks, human workers, and exoskeletons—to correct faults and exploit potentials for improvement. For example, load carriers or routes may have to be adjusted or an exoskeleton tailored to fit the body of a specific worker, work plans are aligned with the skills of different workers, and confidence may be improved through task-specific job training (Fox et al., 2019). Iterative feedback loops must continuously convert the insights gained both from initial pilots and ongoing operations into improvements in ergonomic- and economic-target dimensions (see Figure 3).

6.3.6 Phase 5: deployment and training

Phase 5 encompasses deployment testing and training as the final activities of the implementation project before transition to the daily operation of the line organization. Deployment testing verifies that the correct system elements, functionalities, and procedures are defined and implemented in the operational environment (Mathur and Malik, 2010). Moreover, it assures that the responsible persons in the line organization are enabled to run, maintain, and support the system. Training is the process of learning the physical and cognitive skills needed to perform specific tasks in an exoskeleton work context, which include knowing safety instructions.

6.3.7 Phase 6: go-live and support

Phase 6 comprises the "go-live" and support. At go-live, the exoskeleton solution is formally available to workers in regular operations. A support plan outlines a detailed on-site support strategy for a solution’s "go-live" and post-"go-live" periods. It identifies the tasks and roles required to facilitate the exoskeleton solution, outlines the escalation process and issue resolution, and assigns staff to the support roles. Ongoing care and occupational health monitoring of exoskeleton users is essential (Daub, 2017). The risk of atrophic muscle diseases caused by using an orthosis over a long period of time and psychological effects due to stigmatization must be identified in a timely manner so that countermeasures can be taken (Hensel and Keil, 2018).

7 Demonstration and evaluation

To demonstrate and evaluate the efficacy of the artifact used to solve the problem, case studies were conducted at two companies: a Scandinavian market leader in the furniture industry and a leading German coatings manufacturer. The findings were integrated into the development of the procedural model such that the following description provides only a rough outline.

7.1 Use case 1: furniture industry

7.1.1 Situation

The first case company is a furniture-store chain with worldwide distribution networks. Pilot runs were conducted at a German distribution site. A broad spectrum of loads (in terms of dimensions, weights, and packaging variants) had to be handled. Loads packed in cartons or films weighed between 0.2 to 30 kg. The units' dimensions ranged from 20 mm (L) x 20 mm (B) x 10 mm (H) to a length of up to 2,500 mm and breadth/height of up to 1,000 mm.

The two application scenarios were manual-order picking processes for store replenishment and picking of customer orders, particularly focusing on the differences between a goods-to-person versus a person-to-goods set-up. The first case employed a goods-to-person picking scenario: An electric overhead rail conveyor (EORC) transports articles on loading units from a high-bay warehouse to stationary picking stations and—after the articles have been picked directly from the hangers of the EORC, as the source pallet—takes away the emptied loading units for downstream handling. To reduce the grasp depth, the provisioning is arranged parallel to the long side of the loading units, thereby realizing a maximum grasp depth of 800 mm. The grasp height ranges from +500 mm to +1,650 mm. The entire process uses DIN EN 13698-1 flat pallets as loading units. At the end of the picking process, the target pallets are taken away to stationary staging points.

The second application scenario tested person-to-goods picking. The articles to be picked are available on stationary source pallets located at floor level and on the first tier of a racking system. In stand-on operations which use a horizontal order picker, the worker moves from one rack bay to the next to gather the items. The items are removed from the racks, either by first alighting from the horizontal order picker or by reaching over for them directly without dismounting. The target pallets are carried on the forks of the horizontal order picker. With the loading units stored in the racking systems with their narrow sides facing the aisles, the grasp depth can be as much as 1,500 mm and the grasp height between 0 mm (floor level) and +2,550 mm. The DIN EN 13698-1 flat pallets and overlong pallets orientated towards DIN EN 13698-1 are used as loading units.

7.1.2 Methodology

Active and passive exoskeletons were assessed regarding work performance and ergonomics—especially wearing comfort. Two field trials validated work processes in two-shift operations over a one-week period using seven experienced workers with an average age of 46. Following a participatory approach, the exoskeleton users provided subjective evaluations. To assess the subjective perception of workers, ratings of strain relief, discomfort, usability and user acceptance were taken following Hensel and

Keil (2018). The assessments were done via questionnaire-based surveys in cooperation with the workers' council.

7.1.3 Evaluation

The metric “order lines picked per time unit” served to evaluate the work performance of the picking process. No performance improvements were observed. On the contrary, in the second scenario, a slight reduction of performance was measured which resulted from the restricted freedom of movement on the horizontal order picker. After a short familiarization phase, the times required for putting on and taking off the exoskeletons could be reduced to just a few seconds without assistance. Increased flexibility was not observed. For the overhead grasping required in the second scenario with a grasp height of >1,800 mm, some workers reported that the exoskeleton was a hindrance.

The wearing comfort of the exoskeletons was generally described as not bothersome. However, sweating at the exoskeleton contact points with the body was frequently mentioned as a cause for discomfort. Ergonomic and healthcare parameters could not be analyzed due to the short observation period and the data-collection approach. Nevertheless, the majority of workers reported that their back muscles at the end of the shift did not feel strained. The influence of exoskeletons on motivation and workplace esteem was assessed positively.

7.2 Use case 2: coatings manufacturer

7.2.1 Situation

The second case company develops and produces coatings for the automotive industry and decorative paints. The pilot run took place in the finished-goods warehouse at the German headquarters. Its operations include pallet movements, picking of goods, packing of goods, and loading of trucks. The main handling unit is the industry pallet (1,200 mm x 1,000 mm, CP1). Intermediate bulk containers placed on pallets are also common. The loads analyzed were distinguished by the size and weight of the packaging units. The category "big packagings" was used for loads ranging from 10 to 35 kg. Typical load units include containers, barrels, hobbocks, drums, and cans. The process follows the principle of person-to-goods. Handling aids such as vacuum lifters help the workers with material handling. The category "small packagings" encompassed loads below 10 kg, while carton boxes comprising two units can have a total weight of up to 20 kg. For this load category, the goods-to-person principle is applied.

Three application scenarios were analyzed. The first scenario is a workplace for picking goods in which loads are lifted and carried from stored pallets at a picking platform following the goods-to-person principle. The units handled are cartons, cans, and boxes weighing from one to 10 kg. The main movements and postures were bending over, cutting straps, lifting the load, turning and placing the load on a conveyor belt. The second scenario is a workplace for packing goods from chutes to mixed pallets for outbound shipments. It deals with the same loads as above and follows the goods-to-person principle. The activities covered include taking the goods from the chute from a sideward position, turning towards the pallet, placing the goods on the pallet, wrapping the pallet in foil, and utilizing a forklift to move the pallet. The third workplace deals with packing goods according to airfreight requirements based on the person-to-goods-principle. Handling units include cartons, cans and hobbocks ranging from one to 20 kg. The workers have to walk from a packing table to a storage location, lift the goods to a pallet, pull the pallet close to the packing station with a lift truck, take the goods from the pallet, pick up a folded carton and unfold it, place the goods inside the carton and fill it with padding chips, and finally close and strap the carton before placing it in a staging area.

7.2.2 Methodology

An active exoskeleton was tested intensively for one day by four test persons. Six probands tested a passive exoskeleton over a period of two months. The test persons were experienced workers with an average age of 36. The subjective feedback of the test persons was obtained via semi-structured interviews.

7.2.3 Evaluation

All interviewees confirmed that exoskeletons support the physical handling of goods and increase the ergonomics in intralogistics operations, especially when bent forward during picking and packing. Participants suggest that back strain and associated pain are mitigated by the passive exoskeletons. In contrast, the active exoskeletons caused back pain in one test person due to its weight. The active exoskeletons limited the workers' mobility more than the passive exoskeletons due to the size and weight of the former. For the same reason, both exoskeletons were considered more suitable for use in workplaces which employ the goods-to-person principle. Particularly in the case of the person-to-goods set-up, the bulkier active exoskeleton was a hindrance in overcoming walking distances. The most frequently highlighted disadvantage of both exoskeleton types was its limited usability on the forklift truck. Moreover, the active exoskeletons could not be worn on an industrial truck due to the dimensions of the lateral mounted engines. Its applicability in workplaces with limited space was constrained for the same reason. Most test persons perceived the passive exoskeletons as easy to put on and comfortable to wear in terms of pressure points and friction. However, the heat development was widely perceived as disadvantageous. Two workers reported problems in adjusting the exoskeletons to their individual needs.

Operational staff plays a significant role in successfully deploying new technologies. Accordingly, the workers must be involved at an early stage. By bringing in ideas, defining requirements, and evaluating the performance, they are committed to sustainably using the solution. At both case companies, the workers appreciated the early integration and ongoing support. 75% of the test persons would like to integrate exoskeletons permanently into their processes. The majority of test persons expressed a desire for smaller, lighter, and tighter-fitting exoskeletons that are easier to put on and take off and do not restrict their movability—especially with regard to changing activities with fork-lift trucks, among others. However, most employees did not show any interest, as only 5% and 10% (for active exoskeletons and passive exoskeletons, respectively) of the regular staff in the finished-goods warehouse took part voluntarily. Potential reasons for this include anxiety regarding testing procedures, lack of pre-injuries, lack of knowledge about the exoskeleton's benefits, and fear of derogatory comments from fellow employees.

8 Communication

8.1 Conclusions

8.1.1 Principal conclusions

This paper aimed at supporting practitioners in deploying exoskeletons. It makes two contributions which address two gaps in the current literature. The first contribution is to provide a systematic procedural model with which to help intralogistics practitioners implement exoskeletons, given the insights provided by a comprehensive literature review and two case studies. This is relevant, as extant studies typically focus on specific exoskeleton types and application scenarios—mainly in manufacturing. The second contribution is to provide frameworks, methods, and success factors for each phase of the procedural model, thereby to increase the probability of success of an exoskeleton deployment. This is essential, as practitioners need simple and comprehensible guidelines if they are to succeed.

8.1.2 Implications for research

Due to their skills and flexibility, human workers will continue to be a success factor in the future of intralogistics. Exoskeleton solutions can contribute to solving current challenges in intralogistics such as demographic transitions and competitive pressures to increase productivity. This explorative study has pursued the goal of generating inductively derived findings and developing a new theoretical concept from them. This was accomplished based on a comprehensive literature review and two case studies. The result is the procedural model, which expands the state-of-research. However, some limitations of the presented model should be mentioned. The framework is to be interpreted in view of the specific context of a particular company and the particular goods analyzed. The cause-and-effect relationships between exoskeleton utilization and the business targets could not be quantified in monetary values. Detailed case studies which focus on a specific exoskeletons and industry are desirable, using the presented framework for systematic analysis.

There are various starting points for further developing the presented framework. On the one hand, gaps in the applied methods and concepts can be closed. On the other hand, new methods and concepts can be added. Potential extensions comprise a differentiation with regards to specific exoskeleton types and industry requirements. It is desirable to quantify the economic impacts for a specific intralogistics process. In addition, other target areas can be integrated into the model, such as motivational aspects or potential impacts on health costs for society. Potentially negative effects of exoskeleton use—e.g., with regard to psychological effects and the risk of atrophic muscle diseases when using an orthosis over a long period of time—should be identified through field studies and occupational physiology studies (Hensel and Keil, 2018).

Understanding how sensor data from exoskeletons can be aggregated on Internet-of-things platforms for drawing insights regarding the optimizing of ergonomics and work performance could promote the integration of exoskeletons into overall Industry 4.0 solutions (ABI Research, 2019). Moreover, we should consider whether the increased availability of robotics-as-a-service operating models (i.e., leasing robotic devices rather than purchasing the equipment) would lead to an increased dissemination of exoskeletons.

8.1.3 Implications for practioniers

Exoskeletons offer opportunities with which to address the challenges of mass customization, an ageing workforce, and cost pressures without investing in automation technology that is not yet fully capable of replacing the flexibility of human workers. The procedural model supports efficient exoskeleton implementation. It closes a relevant research gap, helping structured decision-making implement the most appropriate solution. Relevant guidelines and success factors are systematically explained to advise the practitioner on how to proceed. Pilot applications in two different branches ensure practical relevance. Expectations from a commercial perspective, such as increased efficiency, have not been confirmed in the case studies. In particular, the covering of long distances by employees may compensate for potential productivity advantages in picking processes.

Qualitative feedback from users and supervisors gave clear indications of the barriers to implementing technological innovations in practice. Implementing the technology alone is not enough; the social domain forms a critical basis for a successful exoskeleton implementation by ensuring acceptance by the staff. A structured change-management process with early employee involvement has proven to be a crucial step in ensuring sustainable success. When they are allowed to bring in ideas, define requirements, evaluate the performance and decide if the technology is beneficial or not, employees become committed to the future solution. A successful implementation of exoskeletons has the potential to prevent occupational injuries associated with physical stress and increase economic efficiency in intralogistics processes.

References

ABI Research, 2019. The Exoskeleton Market Is Picking Up: US$5.8 Billion in Global Reve-nue Projected for 2028. [online] Available at: <https://www.abiresearch.com/search/?q=the+exoskeleton+market+is+picking+up> [Accessed 26 February 2020].

Adam, D., 1997. Planung und Entscheidung: Modelle - Ziele - Methoden. 4th edition. Wiesbaden: Gabler.

Arnold, D. (Ed.), 2007. Intralogistik: Potentiale, Perspektiven, Prognosen. Heildelberg, Berlin, Heidelberg, New York: Springer.

Bai, S. and Christensen, S., 2017. Biomechanical hri modeling and mechatronic design of exoskeletons for assistive applications. In Human Modelling for Bio-Inspired Robotics, pp. 251-272. Academic Press.

Baker, M., 2000. Writing a Literature Review. The Marketing Review 1:219.

Baltrusch, S. J., Van Dieën, J. H., Van Bennekom, C. A. M. and Houdijk, H., 2018. The effect of a passive trunk exoskeleton on functional performance in healthy individuals. Applied Ergonomics, 72, pp. 94-106.

Becker, J., Rosemann, M. and Schütte, R., 1995. Grundsätze ordnungsmäßiger modellierung. Wirtschaftsinformatik, 37(5), pp. 435-445.

Bogue, R., 2018. Exoskeletons - a review of industrial applications. Industrial Robot, 45(5), pp. 585-590.

Börner, K., Boyack, K. W., Milojević, S. and Morris, S., 2012. An Introduction to Modeling Science: Basic Model Types, Key Definitions, and a General Framework for the Comparison of Process Models. In Models of Science Dynamics: Encounters Between Complexity Theory and Information Sciences (A. Scharnhorst, Editor). Berlin, Heidelberg: Springer.

Bosch, T., van Eck, J., Knitel, K. and de Looze, M., 2016. The effects of a passive exoskeleton on muscle activity, discomfort and endurance time in forward bending work. Applied ergonomics, 54, pp. 212-217.

Bueno, L., Brunetti, F., Frizera, A., Pons, J. L. and Moreno, J., 2008. Human-robot cognitive interaction. Wearable Robots: Biomechatronic Exoskeletons, 1, pp. 87-126.

Butler, T. R., 2016. Exoskeleton Technology: Making Workers Safer and More Productive. Professional Safety, 61(09), pp. 32-36.

Constantinescu, C., Muresan, P. C. and Simon, G. M., 2016. JackEx: the new digital manufacturing resource for optimization of Exoskeleton-based factory environments. Procedia CIRP, 50, pp. 508-511.

Constantinescu, C., Popescu, D., Muresan, P. C. and Stana, S. I., 2015. Exoskeleton-centered process optimization in advanced factory environments. Procedia CIRP, 41, pp. 740-745.

Dahmen, C. and Constantinescu, C., 2020. Methodology of Employing Exoskeleton Technology in Manufacturing by Considering Time-Related and Ergonomics Influences. Applied Sciences, 10(5), 1591.

Dahmen, C. and Hefferle, M., 2018. Application of Ergonomic Assessment Methods on an Exoskeleton Centered Workplace.Proceedings of the The XXXth Annual Occupational Ergonomics and Safety Conference Pittsburgh, USA.

Dahmen, C., Hölzel, C., Wöllecke, F. and Constantinescu, C., 2018a. Approach of optimized planning process for exoskeleton centered workplace design. Procedia 51st CIRP Conference on Manufacturing Systems, 72, pp. 1277-1282.

Dahmen, C., Wöllecke, F. and Constantinescu, C., 2018b. Challenges and possible solutions for enhancing the workplaces of the future by integrating smart and adaptive exoskeletons. Procedia CIRP, 67, pp. 268-273.

Daub, U., 2017. Evaluation aspects of potential influences on human beings by wearing exoskeletal systems. In 17. Internationales Stuttgarter Symposium, pp. 1331-1344. Springer Vieweg: Wiesbaden.

De Looze, M. P., Bosch, T., Krause, F., Stadler, K. S. and O'Sullivan, L. W., 2016. Exoskeletons for industrial application and their potential effects on physical work load. Ergonomics, 59(5), pp. 671-681.

Fox, S., Aranko, O., Heilala, J. and Vahala, P., 2019. Exoskeletons: Comprehensive, comparative and critical analyses of their potential to improve manufacturing performance. Journal of Manufacturing Technology Management.

Garloff, A. and Wapler, R., 2016. Labour Shortages and Replacement Demand in Germany. The (Non-) Consequences of Demographic Change. Graham, R. B., Agnew, M. J. and Stevenson, J. M., 2009. Effectiveness of an on-body lifting aid at reducing low back physical demands during an automotive assembly task: Assessment of EMG response and user acceptability. Applied Ergonomics, 40(5), pp. 936-942.

Ebrahimi, A., 2017. Stuttgart Exo-Jacket: an exoskeleton for industrial upper body applications. 10th IEEE International Conference on Human System Interactions, pp. 258-263.

Feldmann, C. and Pumpe, A. (2017). A holistic decision framework for 3D printing investments in global supply chains. Transportation research procedia, 25, pp. 677-694.

Hensel, R. and Keil, M., 2018. Subjektive Evaluation industrieller Exoskelette im Rahmen von Feldstudien an ausgewählten Arbeitsplätzen. Zeitschrift für Arbeitswissenschaft, 72, pp. 252–263.

Hensel, R. and Steinhilber, B., 2018. Bewertung von Exoskeletten für industrielle Arbeitsplätze. In: Weidner, R., and Karafillidis, A., Technische Unterstützungssysteme, die die Menschen wirklich wollen. Hamburg, 11 December 2018.

Hevner, A. R., March, S. T., Park, J. and Ram, S., 2004. Design Science in Information Systems Research. MIS Quarterly 2004(28), pp. 75–105.

Huysamen, K., de Looze, M., Bosch, T., Ortiz, J., Toxiri, S. and O'Sullivan, L.W., 2018). Assessment of an active industrial exoskeleton to aid dynamic lifting and lowering manual handling tasks. Applied Ergonomics, Vol. 68, pp. 125-131.

Hyun, DJ, Bae, K., Kim, K., Nam, S. and Lee, D., 2019. A light-weight passive upper arm assistive exoskeleton based on multi-linkage spring-energy dissipation mechanism for overhead tasks. Robotics and Autonomous Systems, 122, pp. 1-9.

Kim, S., Nussbaum, M. A., Esfahani, M. I. M., Alemi, M. M., Alabdulkarim, S. and Rashedi, E., 2018. Assessing the influence of a passive, upper extremity exoskeletal vest for tasks requiring arm elevation: Part I, Part II. Applied ergonomics, 70, pp. 315-330.

Mathur, S. and Malik, S., 2010. Advancements in the V-Model. International Journal of Computer Applications, 1(12), pp. 29-34.

Meyer, M., Maisuradze, M. and Schenkel, A. (2019). Krankheitsbedingte Fehlzeiten in der deutschen Wirtschaft im Jahr 2018–Überblick. In Fehlzeiten-Report 2019, pp. 413-477. Berlin, Heidelberg: Springer.

Mikušová, N., Čujan, Z., & Tomková, E. (2017). Robotization of logistics processes. In MATEC Web of Conferences, Vol. 134, EDP Sciences, p. 38.

Peffers, K., Tuunanen, T., Rothenberger, M. A. and Chatterjee, S., 2007. A design science research methodology for information systems research. Journal of management information systems, 24(3), pp. 45-77.

Picchiotti, M. T., Weston, E. B., Knapik, G. G., Dufour, J. S., & Marras, W. S., 2019. Impact of two postural assist exoskeletons on biomechanical loading of the lumbar spine. Applied ergonomics, 75, pp. 1-7.

Poon, N., van Engelhoven, L., Kazerooni, H. and Harris, C. (2019, November). Evaluation of a Trunk Supporting Exoskeleton for reducing Muscle Fatigue. In Proceedings of the Human Factors and Ergonomics Society Annual Meeting (Vol. 63, No. 1, pp. 980-983). Sage CA: Los Angeles, CA: SAGE Publications.

Rashedi, E., Kim, S., Nussbaum, M. A. and Agnew, M. J., 2014. Ergonomic evaluation of a wearable assistive device for overhead work. Ergonomics, 57(12), pp. 1864-1874.

Rogge, T., Daub, U., Ebrahimi, A. and Schneider, U., 2016. Der interdisziplinäre Entwicklungsprozess von aktiv angetriebenen, körpergetragenen Exoskeletten für die oberen Extremitäten am Beispiel des „Stuttgart Exo-Jacket “. Technische Unterstützungssysteme, die die Menschen wirklich wollen, 213.

Rogge, T., Daub, U., Ebrahimi, A. and Fraunhofer IPA, 2017. Status demonstration of the interdisciplinary development regarding the upper limb exoskeleton "Stuttgart Exo-Jacket”. In: M. Bargende, H.-C. Reuss, J. Wiedemann (eds.), 17. Internationales Stuttgarter Symposium, Proceedings, pp. 479-491.

Sahashi, K., Murai, S., and Takahashi, Y., 2018. Power Assist Control Based on Learning Database of Joint Angle of Powered Exoskeleton Suitable for Wearer’s Posture. In: M. Antona and C. Stephanidis (eds.): UAHCI 2018, LNCS 10908, pp. 340–346.

Schütte, R., 1998. Grundsätze ordnungsmäßiger Referenzmodellierung - Konstruktion konfigurations- und anpassungsorientierter Modelle. Wiesbaden: Gabler.

Schmidtler, J., Knott, V., Hölzel, C. and Bengler, K., 2015. Human Centered Assistance Applications for the working environment of the future. Occupational Ergonomics, 12(3), pp. 83-95.

Spada, S., Ghibaudo, L., Gilotta, S., Gastaldi, L. and Cavatorta, M. P., 2017. Investigation into the applicability of a passive upper-limb exoskeleton in automotive industry. Procedia Manufacturing, 11, pp. 1255-1262.

Staub, J. and Anderson, N., 2019. The resilient factory. Supply Chain Management Review, 6, pp. 48-49.

Steinhilber, B., Seibt, R., & Luger, T., 2018. Einsatz von Exoskeletten im beruflichen Kontext–Wirkung und Nebenwirkung. In: Arbeitsmedizin–Sozialmedizin–Umweltmedizin, 53, pp. 662-664.

Sylla, N., Bonnet, V., Colledani, F. and Fraisse, P., 2014. Ergonomic contribution of ABLE exoskeleton in automotive industry. International Journal of Industrial Ergonomics, 44(4), pp. 475-481.

Todorovic, O., Constantinescu, C. and Popescu, D., 2018. Foundations for economic evaluation of exoskeletons. Acta Technica Napocensis, Series: Applied Mathematics, Mechanics, and Engineering, 61(special), pp. 221-230.

Vom Brocke, J., 2007. Design principles for reference modeling: reusing information models by means of aggregation, specialisation, instantiation, and analogy. In Reference modeling for business systems analysis, pp. 47-76. IGI Global.

Vom Brocke, J., Simons, A., Niehaves, B., Niehaves, B., Reimer, K., Plattfaut, R. and Cleven, A., 2009. Reconstructing the giant: on the importance of rigour in documenting the literature search process. ECIS 2009 Proceedings. http://aisel.aisnet.org/ecis2009/161.

Weston, E. B., Alizadeh, M., Knapik, G. G., Wang, X. and Marras, W. S., 2018. Biomechanical evaluation of exoskeleton use on loading of the lumbar spine. Applied ergonomics, 68, pp. 101-108.

Winter, G., Felten, C. and Hedtmann, J., 2019. Testing of Exoskeletons in the Context of Logistics - Application and Limits of Use, in: C. Stephanidis (ed.), HCII 2019, CCIS 1033, pp. 265–270.

Young, D.S. and O'Byrne, S.F. EVA and value-based management. New York: McGraw Hill; 2001

Zelewski, S., 2007. Kann Wissenschaftstheorie behilflich für die Publikationspraxis sein? Eine kritische Auseinandersetzung mit den "Guidelines" von Hevner et al. In: Lehner, F., Zelewski, S. (Eds.): Wissenschaftstheoretische Fundierung und wissenschaftliche Orientierung der Wirtschaftsinformatik. GITO: Berlin 2007, pp. 74-123.

Zellner, P., 2015. Entwicklung einer Methode zur intraorganisationalen Prozessstandardisierung, Dissertation at the Faculty of Economics and Business Administration of the Technical University of Dresden.

Blockchain Technology – Integration in Supply Chain Processes

Tan Guerpinar [1], Sophie Harre [1], Michael Henke [1], and Farah Saleh [2]

1 – Chair of Enterprise Logistics, TU Dortmund University

2 – Digix

Purpose: Supply chain networks face an increasing demand to integrate globally distributed customers and suppliers. As supply chain processes are deemed to lack sufficient transparency and security, blockchain solutions are piloted to offer an IT infrastructure covering these needs. This paper aims to bring current projects one step further and evolves a model for integrating blockchain solutions into supply chain processes.

Methodology: In order to get an overview of existing models for technology integration, an exploratory research study is conducted. In addition, requirements for the specific integration of blockchain solutions are gathered and categorized in a systematic content analysis. Based on these requirements, the models are evaluated, compared and utilized for the development of a new model.

Findings: Since none of the presented models fully meet the specific blockchain-based requirements, the existing models must be further developed. Specifically, increases in the number of supply chain partners and external stakeholders involved in blockchain-based systems are not supported by current models, and need to be integrated systematically.

Originality: In this paper, an integration model is developed that is particularly suitable for blockchain integration into supply chain processes. In order to give starting points for a validation of the model, a case study is conducted in the field of blockchain-based payment gateway solutions.

First received: 6. Mar 2020 Revised: 20. Jun 2020 Accepted: 26. Jun 2020

1 Introduction

Today's complex supply chain networks demand for advanced technologies that establish information systems between growing numbers of supply chain partners. In 2019, Capgemini Consulting conducted a study on the topic of digital transformation, which reports that approximately 70% of global change management projects are focused on the integration of advanced technologies (Capgemini Consulting, 2019, pp. 14-16). In this globalized economy, cooperation and competition are increasing in the sense of co-opetition to achieve the next level of innovation (Henke, 2002). Advanced technologies, such as blockchain technology, are gaining in importance as they can establish trustful and traceable relations between multiple organizations. The German federal government has announced its own blockchain strategy in summer 2019. Even though the technology emerged from the finance sector, experts believe that the greatest opportunities lie in redesigning and optimizing business processes. Currently, 10% of all companies piloting blockchain solutions mention that "closer collaboration within their supply chain" can be seen as a main purpose and benefit. (Bitkom, 2019)

The goal of this paper is to develop a model for the integration of blockchain technology into supply chain processes of organizations. The following research questions are utilized to guide the research:

1. "Which requirements do blockchain technology and its use in supply chain processes place on integration models?"

2. "Which existing integration models can be utilized for our purposes?"

3. "What model do we need to specifically address the integration of blockchain technology in supply chain processes?"

To address the research questions above, the terms supply chain management and -processes, as well as blockchain technology are defined and explained briefly in the next section. In order to identify models that are suitable for the integration of IT technologies, a literature research is conducted and analyzed subsequently. For the purpose of analysis, requirements of blockchain technology and its application area are identified by means of the requirements engineering. To fully meet the identified requirements, a new concept will be developed based on selected existing models. Finally, the findings are summarized and recommendations for future research are presented.

2 Background

In literature, the concepts of supply chain management and blockchain technology have been defined in different ways. In this section, relevant definitions are presented to reach a common understanding.

2.1 Supply Chain Management and -Processes

Following Cooper et al. (1997), *supply chain managment* is defined as "the integration of business processes from the end user to the original supplier, who provides products, services and information that add value for the customer". Subsequently, *supply chain processes* are defined as key business processes that "run the length of the supply chain and cut across firms and functional silos within each firm" (Croxton et al., 2001). In this paper, supply chain processes are further understood to consider "material-, information- and value flows over the entire value-added process" (Arndt, 2008). In order to interlink the participants of todays' supply chains and enable a transparent but secured exchange within the mentioned material, information and value flows, new approaches, and technologies are needed. Yet there are several hurdles to overcome. First, during information construction, software and hardware costs are high, risks are difficult to mitigate, and the implementation cycle can be time consuming. Second, the participants of multi-party supply chains are often inhibited to provide relevant information. Therefore, they may suffer from issues such as poor supplier coordination, lack of accountability, or inability to monitor partner activities in real time. (Saberi et al. 2019, p. 2117 ff.). Blockchain solutions that are designed particularly for supply chain management promise to address these problems will be described in the next chapter.

2.2 Blockchain in Supply Chain Management

Blockchain technology by definition is a "technical concept that does not store data in a central database, but rather distributes data to the user's systems using cryptographic methods" (Burgwinkel, 2016, p. 1). The data is therefore stored in individual blocks that are sequentially connected to form a chain so that both the chronological order and the data integrity of the entire data stock are ensured. Manipulations of the data stock are detectable and data can only be appended in the form of a block at the end of the existing blockchain (Burgwinkel, 2016, pp. 5-6).

One advantage of using blockchain technology is having an increased transparency of processes and transactions throughout the whole supply chain. Every user of the blockchain, as soon as rights are granted, can observe specific transactions or processes, which makes it easier to create trust between individual partners. Moreover, data can be stored in a decentralized and immutable manner eliminating single points of failure, providing proof or issue certificates on the basis of untampered data (Bogart and Rice, 2015, pp. 9-12).

However, the technology also brings challenges. Considering the human factor, companies that want to integrate blockchain solutions have to train their employees with high time exposure (BMWi, 2016, p. 69). From a technical point of view, the interconnectivity of blockchain solutions and handling of different data formats still need to be investigated (Acatech, 2018, p. 59). Due to its novelty, the technology also has effects on security aspects and demands the consideration of new kinds of security mechanisms (Bitkom, 2019, p.39). Furthermore, from an organizational point of view, interdisciplinary problems can arise due to the required collaboration of different departments and disciplines (Gürpinar et al., 2019, p. 607). Also, governmental and legal regulations affect the development of blockchain solutions and have to be considered carefully (Reyna et al., 2018, pp. 182-183). Finally, another challenge for the technology integration is the difficulty in assessing its business value and concrete statement for potential cost savings (Fechtelpeter et al., 2019, p. 21).

As a result, a lot of blockchain projects remain in a proof of concept stage and need guidance to achieve the integration of their blockchain solution (Pai et al., 2018). There are some approaches that provide guidance on that topic. Fridgen et al. (2017) develop a process model guiding the reader from an understanding of the technology to the prototype stage. Also Wüst and Gervais (2018) focus on the part of understanding the technology and provide a flow chart to decide whether or not to use a blockchain solution. However, these approaches lack the consideration of an actual integration approach after the positive decision. Apart from that, Panarello et al. (2018), Reyna et al. (2018) and Gonczol et al. (2020) have presented work related to the integration of blockchain solutions, considering either an IoT environment or supply chain processes. However, their outcomes are comprised of integration benefits, challenges and considerations about technical characteristics without presenting integration models. Finally, Niehues and Guerpinar (2019) present a holistic integration model for disruptive technologies and highlight the need for a model that is aimed at blockchain solutions in particular.

3 Methodology

Because sufficient integration models for blockchain technology could not be found, a literature research on and an analysis of integration models for general IT technologies is conducted. Therefore, blockchain related requirements are developed and utilized to evaluate the identified models.
The procedure of the literature research is based on Van Wee and Banister (2016), as well as Durach et al. (2017). Scopus, Elsevier, IEEE, Google Scholar und Springer Link are used as a data sources to find concepts for the integration of IT technologies. Using the pyramid system, further relevant articles are identified and further specified with filter functions. Peer-reviewed articles are given priority in the selection of the articles, but in order to obtain a wider range of practice-relevant models, grey literature is also included.

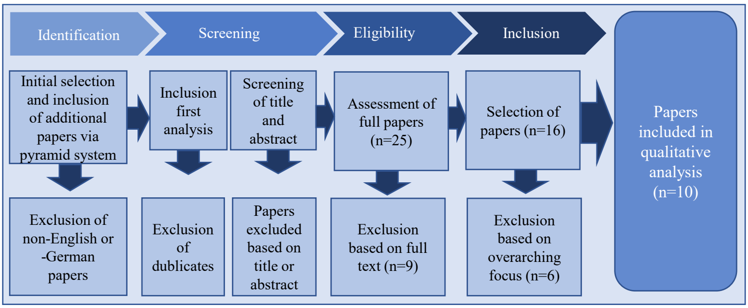


Figure 1: Literature Selection Procedure, based on Casino et al., 2019, p. 59

The selection of models (see Figure 1) is divided into four steps. First, articles that are not written in German or English language are excluded. Second, during the title check, articles that do not sufficiently refer to the integration of IT technologies are excluded. Third, the remaining papers are analyzed to ensure suitable integration models can be presented. Fourth, papers that are too generic or specific are excluded as well. Finally, ten models are selected for the analysis. The four most important ones are described in the next section.

3.1 Existing Integration Models

The **Accelerated SAP Model** (ASAP) represents a phase model with five main phases. In the first phase, the project preparation and organization take place. The second phase "Business Blueprint" defines the business requirements. In the third phase, the basis system is configured, system administrators are set up, interfaces are planned and data is converted. In the fourth phase, final system tests are carried out and the employees are trained. The final phase represents the system check and continuous support (Gulledge and Simon, 2005, pp. 715-719).

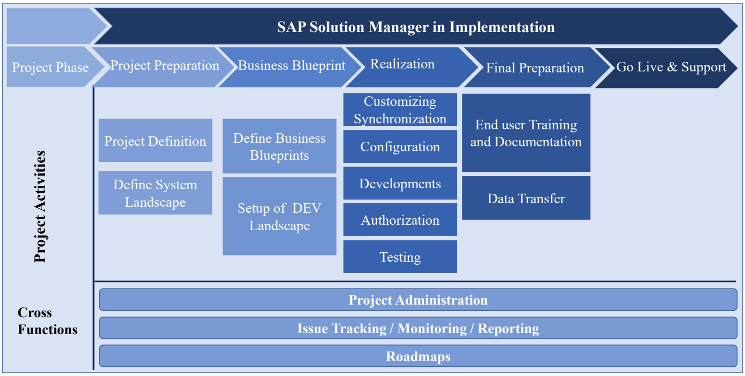


Figure 2: Accelerated SAP Model, based on (Gulledge & Simon, 2005, p. 720)

Scholl's cycle is based on the spiral model. First of all, the problem is concretized and the tasks are defined. Then, the stakeholders and their needs are considered. Next, Pre-studies are carried out, followed by a detailed analysis of business processes and data organization, which are then redesigned. The information system is then developed, integrated and tested. The first run concludes with the evaluation. The project team and management decide whether a further run is necessary. (Scholl, 2004, pp. 286-287) Stakeholders play an important role in the development of this cycle. By focusing on this stakeholder group, a better understanding between the project team and stakeholders is achieved. (Scholl, 2004, p. 298)

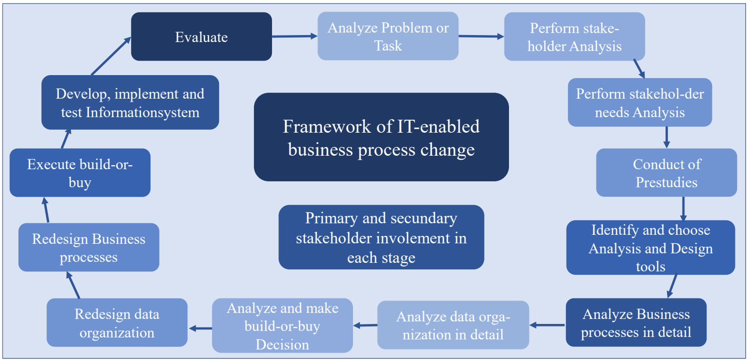


Figure 3: Scholl's cycle of IT-supported change of business processes, based on (Scholl, 2004, p. 286)

Nedbal's process model is based on a literature review. The phases of the model are not linear, but they overlap and are flexible in their order. In the first phase, the initial situation is analyzed and the primary objectives are defined. In the second phase, the current situation is determined by analyzing information systems, existing business processes and technical infrastructures. The third phase focuses on the selection of suitable concepts and tools. In the fourth phase, this is when the technical implementation takes place. The integration approach is introduced and the ready-to-use integration solution is created. In the final phase, the team evaluates the integration solution. Continuous monitoring ensures continuous and sustainable development. (Nedbal, 2013, pp. 162-168)

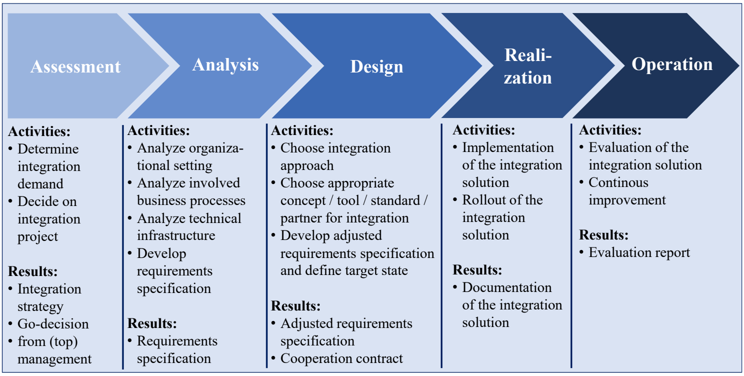


Figure 4: Nedbal's process model, based on (Nedbal, 2013, p. 163)

The **framework of Qu et al.** deals with value creation, business processes, functional structure, information flows, data flows and knowledge management. (Qu et al., 2018, p. 2) The model is divided into three phases: AS-IS model, TO-BE model and analysis of feasibility. In the AS-IS model, business processes, information systems and the management situation are analyzed. In the TO-BE model, information systems and business processes are redesigned. As far as possible, a flat, decentralized organizational structure is preferred and business processes are replaced by synchronized inter-organizational procedures. In the feasibility analysis, the information system is tested using quantitative methods to ensure the efficiency of the new system. (Qu et al., 2018, pp. 7-11)

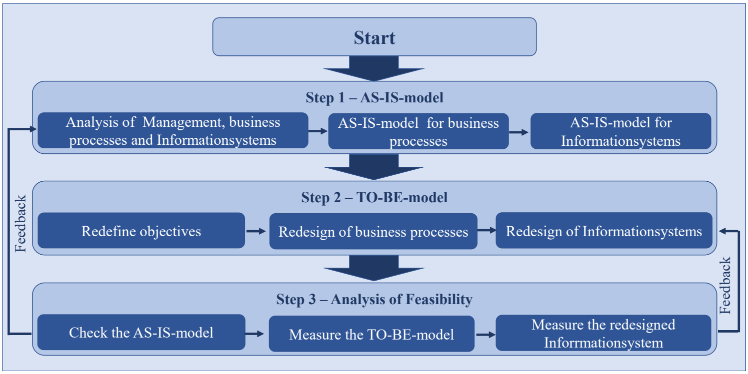


Figure 5: Qu et al.'s framework, based on (Qu et al., 2018, p. 7)

3.2 Requirements for Blockchain Integration

After models for the integration of IT technologies have been selected, requirements related to blockchain technology are developed. To do this, the requirements engineering developed by Pohl and Rupp (2015) is used. The requirements engineering has the task of "determining the requirements of the stakeholders, documenting them appropriately, checking and coordinating them and managing the documented requirements throughout the entire life cycle of the system". (Pohl and Rupp, 2015, p. 4) The following figure illustrates these steps.

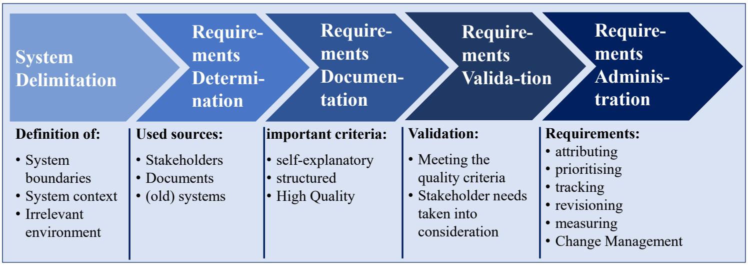


Figure 6: Rupp's requirements engineering, based on (Pohl and Rupp, 2015)

The first step in requirements engineering is the separation of the developed system from its environment. In this study, the focus is on blockchain technology and the requirements that this technology places on integration models. In addition, business processes and supply chain processes with their influencing factors and interfaces are relevant. The second step is the requirements determination for important requirement sources that are used including the consideration of stakeholders and documentation procedures of the existing IT systems. A further literature research is carried out to determine the requirements. The findings are then collected and documented. (Pohl and Rupp, 2015, pp. 21-23) The third step is the requirements documentation. The goal for this is to summarize and structure the requirements to make them easier and understandable. This step results in eight requirements that blockchain technology places on an integration model. These will be elaborated in the next steps. (Pohl and Rupp, 2015, p. 51) In the fourth step, the defined requirements are checked to ensure their quality, the needs of the stakeholders are considered and errors in content are resolved. The following types of errors are examined: completeness, traceability, correctness, consistency, verifiability and necessity. (Pohl and Rupp, 2015, pp. 97-98) In this step, two requirements can be combined. In the fifth step the requirements are managed. In this step the requirements are prioritized to determine the order of utilization. According to Rupp, the following criteria is used for prioritization: implementation costs, risk, damage in case of unsuccessful implementation, volatility, importance and duration of implementation. (Pohl and Rupp, 2015, pp. 123-129) In this step, one requirement is excluded as it does not contribute to the objectives of the integration project. The procedure results in the following six requirements a blockchain-centered integration model for supply chain processes needs to take into account:

(1) The stakeholders with their needs, requirements and wishes in order to enable a successful integration (Fechtelpeter et al., 2019, pp. 18-19);

(2) The consideration of the existing information systems and examination from different perspectives in order to create an intact system architecture (Kahloun and Ghannouchi, 2016, p. 1018);

(3) The company and the environment in order to avoid additional adaptation processes (Matthes, 2011, p. 25);

(4) Data management and the control mechanisms to be provided (Gupta Gourisetti et al., 2019, pp. 208-211);

(5) The monetary consideration of integration costs and benefits at the beginning of the integration process in order to ensure financial stability (Bosu et al., 2019, pp. 2653-2654);

(6) The quality and complexity of the integration model. The model must be easy to understand, versatile and of high quality (Nedbal, 2013, p. 162).

4 Evaluation

In order to evaluate the selected integration models for IT technologies along the developed requirements, the utility analysis is used as a method. The utility analysis is frequently used for multi-criteria decision problems on a qualitative and semi-quantitative level. It helps with reducing complexity and can easily be adapted to special cases. Also, individual aspects can be removed or reinserted easily. (Stuhr, 2013)

The first phase of utility analysis is dedicated to the definition of the evaluating requirements. This has already been done. In the second phase, a target tree is developed to weight the evaluating requirements. For this purpose, the requirements are assigned to two main categories: internal and external factors. In the third phase, possible characteristics are defined for the respective requirements. For this purpose, the verbal response options are assigned to numerical values of the utility value scale. (Example: requirement not considered in the model = 0; requirement strongly considered = 6) (Stuhr, 2013, p. 112) In the fourth phase, each integration model is evaluated regarding the individual requirements by forming partial utility values. In the fifth phase, the total utility of the respective model is calculated according to the weighting factors. The result is checked by plausibility and sensitivity analysis. In the last phase, the ranking is established. For this purpose, the total benefits are put in a sequence so that the best alternatives can be highlighted. (Stuhr, 2013, pp. 88-93) In Figure 7, the four best ranked models Scholl's cycle, the ASAP model, Nedbal's process model and the Qu et al. framework can be seen.

models	requirements						overall benefit	ran-king
	Quality & Com-plexity (20 %)	Control mechanism & data ma-nagement (15 %)	Mone-tary expense (10 %)	Busi-ness context (15 %)	structure of Informa-tionsys-tems (20 %)	Stake-holders & system users (20 %)		
Royce, Fairley: Waterfall model	6	4	2	4	6	0	3,8	7
Boehm: spiral model	6	4	2	4	6	0	3,8	7
Microsoft: MSF	6	4	2	4	6	0	3,8	7
TOGAF	6	2	2	6	6	4	4,6	5
ASAP & SAP Solution Manager	6	4	4	4	6	6	5,2	2
Ortiz et al: IE - GIP	4	6	2	6	2	4	4,0	6
Scholls cycle	4	6	6	6	6	6	5,6	1
Pilorget: MIIP	0	4	2	6	6	4	3,7	8
Nedbals process model	6	4	4	6	6	4	5,1	3
Qu et al.s framework	2	6	4	6	6	6	5,0	4

Figure 7: Total benefits of the integration models

Scholl's cycle is characterized by the special position of the stakeholders in this model. Stakeholders are analyzed intensively in order to fulfil their interests and wishes. Due to the small steps in the procedure, the model fulfils many of the defined requirements in the best possible way. A weakness is the complexity and usability of the model.

The ASAP model is characterized by a simpler structure. This ensures an easy understanding of the procedure and provides a good overview of the project progress. However, the control mechanisms could be a weakness for blockchain integration in this case.

Nedbal clearly divides his process model in activities and results, which simplifies goal-oriented project work and enables stakeholders to be proactively informed about the progress. However, for blockchain integration, more focus should be placed on data management.

The framework by Qu et al. is characterized by an intensive analysis of the initial situation and the existing information system's structure. Even though it is structured into three phases, it is more complex and harder to apply than the other models.

The TOGAF model analyzes intensively the structure of the information systems and the business context. (Lankhorst, 2017, pp. 139-140) Nevertheless, it has no sufficient control mechanisms in place. The IE-GIP model has a particularly high score in the category Stakeholder & System User. However, the monetary context and the existing information systems structure are hardly considered. The model has a simple structure and deals intensively with data management. (Ortiz et al. 1999, pp. 169-170) The waterfall model stands out for its simple structure and its intensive examination of the existing information systems structure but lacks flexibility. (Scharch, 2016, pp. 19-20) Boehm's spiral model is characterized by its low complexity. Data management and control mechanisms are also considered in each cycle. (Scharch, 2016, pp. 31-32) The MSF has a simple structure, a low complexity and deals intensively with the existing information systems structure. Like the waterfall and spiral model, stakeholders and system users are not taken into account. (Campbell et al., 2003, p. 7) Pilorget's model is very complex due to the 64 defined process dependencies and the 17 MIIP processes. (Pilorget, 2010, pp. 1-2) Although this model achieves good values in other categories, this model is ranked last as it is hard to handle.

5 Findings

In the previous section, four relevant models for technology integration were selected and further analyzed in terms of strengths and weaknesses by means of developed blockchain-specific requirements. In this chapter, a new model for the specific integration of blockchain technology in supply chain processes is introduced. During the development of the model, priority is placed on fulfilling all requirements and to find a balance between simple and complex visualization.

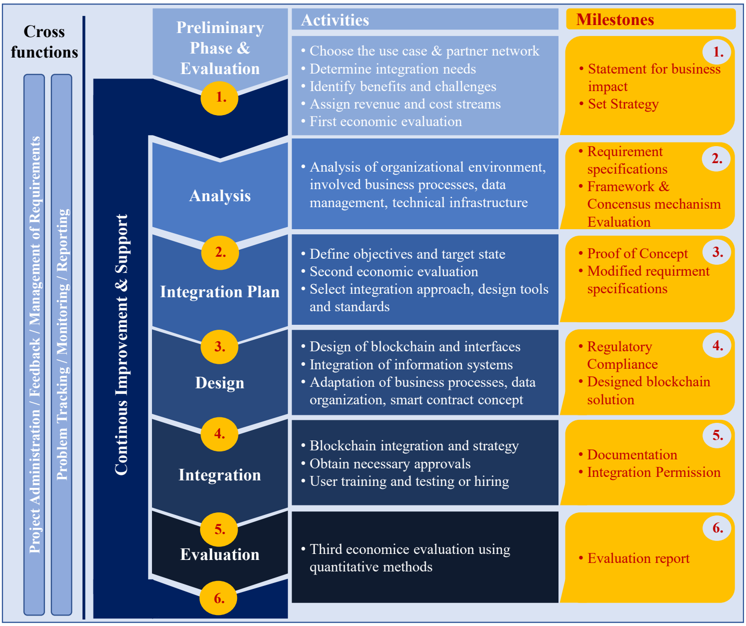


Figure 8: Model for integrating blockchain technology in supply chain

The new model is divided into six phases. It starts with the preliminary and evaluation phase, which initiates the integration project and is only run once. This first phase is followed by six subsequent processes, which can be run cyclically to ensure that user feedback and necessary changes are considered and regular quality checks conducted. Furthermore, the cyclical structure ensures that new requirements can be identified and integrates flexibly. This way, a long-term functioning system is guaranteed. In order to reach the next phase of the model, milestones have to be fulfilled. A milestone specifies certain criteria necessary to start the next phase and divides the project into manageable sections. (Scharch, 2016, p. 12)
The model also presents the following cross functions: project administration, consideration of feedback and management of requirements, problem tracking, monitoring, and reporting. By centrally anchoring these aspects, new requirements can be registered and documented immediately to be considered in the next development cycle. Also, requirements specified by stakeholders can be considered in this way. Furthermore, continuous project and problem tracking ensure that irregularities and errors are recorded and eliminated, before they can have serious consequences for the overall project. The documentation and reporting make the integration process traceable for management and also serve as an important basis of discussion with blockchain partners. The generated learnings can also be used for further blockchain projects or to report to other stakeholders on the project progress. (Gulledge and Simon, 2005, p. 729)
In the preliminary and evaluation phase, the blockchain use case, its application area, and potential partners are determined. Also benefits and challenges of a blockchain integration are raised and associated to potential revenue and cost streams. Through this and together with the methods for

economic evaluation, a first statement about the business impact is produced. Finally, an integration strategy with primary goals and needs is issued and agreed upon already with relevant stakeholders.

After that, the cyclical main phase of the integration model begins. In the first phase, the analysis is based on components of the selected models. Namely, the analysis of the organizational environment and determination of project members, as well as of business processes, data management and the technical infrastructure. The findings of this analysis phase form the basis of a requirements specification and are consolidated in the end. In this phase, it is important to identify all organizational areas and respective business processes that are affected by a blockchain integration. Also, this phase has a strong technical focus, as the specifications of the blockchain framework and respective consensus mechanism have to be chosen with respect to data integrity and security.
In the integration planning phase, the requirement specifications are adapted. The goal of this phase is to find a suitable integration approach and to select appropriate tools for the integration. Therefore, the integration approach is determined, broken down in smaller elements that get prioritized and selected. The integration approach must include the consideration of affected business processes, middleware, information systems and data types. Also, supporting tools and standards as well as security mechanisms are selected at this point. Finally, the economic evaluation from step one can be enriched with more business process details and all findings from this phase can be incorporated into a documented requirement specification, which represents a milestone.

In the design phase, the technical system is designed. The value-added processes, data and information flows, functional structure, and knowledge management must be taken into account here. If necessary, the business processes, their data organization, and the handling of existent information systems have to be adapted or redesigned. The project team then sets up the system and plans the interfaces and necessary data conversions. Also, a concept for the use of smart contracts has to be installed here, which includes the decision of what data would be kept onchain or off-chain. Finally, the regulatory compliance hast to be ensured and the schedule for the start of operations determined. The milestone of this phase is the final documented design of the blockchain solution with the assigned responsibilities for all involved partners.

In the integration phase, the blockchain solution is integrated into the considered business processes. For this purpose, the system must be tested in advance and during the whole integration process. Besides organizational aspects, this phase focuses on the human factor. Trainings have to be conducted not only for end users but for all employees that have to deal with adapted business processes, especially for management that has to consider strategic consequences. In this phase, all necessary permissions are obtained for the system to go live. Once the permits have been granted, the blockchain solution can finally be tested. The milestone of this phase is the approval of the ready-to-use blockchain solution.

In the evaluation phase, the blockchain solution is further tested. At this point we also get more quantitative data for evaluation purposes and consider operational benefits and costs, project risks, the strategic importance and the internal resource requirements in our third economic evaluation. To do so, Qu et al. (2018) propose the use of quantitative methods to ensure the technology's effectiveness. The aim of the evaluation is to ensure that the business environment is fully considered and supported. This includes the validation of business processes, technical parameters, and the survey of end users. The milestone of this phase is the evaluation report, which documents the success of the blockchain integration project.

Once the system has been fully evaluated, the phase of support and continuous change follows. The concept of continuous change improves the integrated blockchain solution over time. In our model, this last phase represents the transition to the analysis phase because the cyclical arrangement allows newly arising requirements to be recorded and incorporated immediately. Thus, the blockchain integration is part of a recurring cycle of continuous improvement.

6 Case Study

In order to give starting points for a validation of the developed model, in this section a case study to consider practical aspects is introduced. With the COVID-19 pandemic we have seen a significant increase in demand for streamlined cashless payment systems, which is one reason why blockchain-based payment gateway solutions are piloted. Apart from public variants, there are also private solutions that are used with merchants and their partners to perform automatized purchases and verify the provenance of assets. These solutions are deemed to offer cheaper transaction costs, more transparency, and also disruptive opportunities like activity-based payments via smart contracts.

The Singaporean blockchain provider Digix develops such solutions with its Proof of Provenance (PoP) protocol. The PoP protocol utilizes the Ethereum platform and the Inter Planetary Files System (IPFS) to track assets through its chain of custody. Digix also offers an API allowing other applications to be built on top of their solution. In the following, we examine the methodical approach of the integration model and enrich it with aspects to be considered during the integration approach of a blockchain-based payment gateway solution at Digix as our case study.

1. Preliminary Phase

First, opportunities and challenges of the blockchain solution are gathered, possible revenue and cost streams on a monetary basis are not yet associated. Subsequently, all opportunities and challenges are compared to traditional payment solutions. The most important opportunity to be considered in our case is the enhanced transparency of the payment processes.

This includes the verification of identities and allows multiple parties to interconnect on a trustful basis. The most important challenge is to establish the consortium of partners.

2. Analysis Phase

In relation to the second phase, the project team considers specifications of the existing business processes and evaluates different blockchain platforms. Most of the public solutions for PoP are built on Ethereum platform, especially if there are multiple external parties involved. To keep transactions private in a B2B setting, private protocols are also considered. In this case, the Hyperledger Fabric protocol is commonly used. In the case of private blockchains, participants are known to one another and jointly decide to participate in the network. For this reason, they have to be provided with suitable credentials to be part of the network. Also, based on the preliminary profitability statement, they have to be provided with information about expected opportunities and challenges when participating. For this reason, in our case study, a lot of time is invested to specify organizational and technical opportunities and challenges for different partners.

3. Integration Planning

In the third phase, management has to decide if the software solution is to be developed in-house or development is outsourced to an external company. In the former, team members have to be selected or hired with respect to the right skillsets such as smart contract development. Also, the adaptability and scalability of a technology stack has to be evaluated to ensure core processes can be carried out with minimal distractions. The integration model also refers to design tools being considered. In our case this would be with regard to where the data is placed and stored in the architecture. This can be an on-chain data store of a private blockchain. Alternatively, data can also be stored off-chain using a third party tool such as IPFS. For the consideration of data security, in our case study, securing mechanisms like the chainpoint protocol can be selected to ensure that embedded data is secured.

4. Design

In the design face of a payment gateway, the use of complex smart contracts and micropayments have to be considered, which often come in an either/or relationship. As such, the project team has to evaluate how to design smart contracts and whether or not advanced rules are integrated into the templates. Throughout this phase, it is important to have all involved parties be able to respond and provide their input whenever they are triggered. Another aspect for consideration in the design phase is data governance. All parties must decide what parties share and own data and what data is enough for mutual agreement. In this phase, user interfaces of the blockchain solution must be developed to drive ease of adoption and usage with minimal distraction. Processes involved need to be assessed and streamlined and business functions have to be engaged in all phases. Lastly, the compliance with international, regional and country's respective regulations must be considered to reach the milestone. In this case, it is the Monetary Authority of Singapore Regulation (MAS). The regulations determine how the integration processes will be performed in detail and eventually lead to how interoperability such as exchanges between data need to be managed.

5. Integration

In the integration phase, the blockchain solution is to be tested. In our case study, because blockchain integrations tend to fail due to partner willingness, high importance is placed on understanding the partners' goals and showing that the product fulfills them. In this stage, the project team also needs to consider the interconnections between their chosen consensus mechanism and the system's modularity ensuring data integrity and scalability of the solution. Also, the integration model refers to trainings at this point, which are very important. Also, external parties involved such as partners and merchants need to be trained to get familiar with blockchain terms and terminologies to increase their confidence and competency to perform their tasks in the transparent network. Internal employees or newly hired development teams need to scale up their technical skillsets to ensure the product can be developed based on best practices. In this case study, the usability of go language for smart contract development plays an important role. At the same time, business functions such as marketing, procurement and compliance teams have to be trained to analyze blockchain data in order to perform their tasks.

6. Evaluation

The integration model suggests to conduct a final evaluation of the integration project. In this case study, the following positions would need to be evaluated.

(1) Partner acquisition costs: This can be related to marketing costs or expenses that occurred to drive partner's adoption such as training or compliance with regulations.

(2) Influence on IT infrastructure and maintenance: A good infrastructure regardless of a centralized or decentralized system has to be considered to ensure 99.99% uptime and its ability to scale up when the number of on-

boarded partners grows, or the size of data and network throughput increases.

(3) System interfaces: As the blockchain solution needs interfaces to existing systems, the ease of integrating the solutions also with partners' infrastructure needs to be evaluated.

(4) Data governance and analytics: Consensus relies on the parties making rational decisions. Controls such as transaction monitoring can be explored to ensure that no party is performing any illegal tasks and the wallet addresses used are whitelisted.

7 Conclusion

Since blockchain technology is increasingly crossing into various supply chain processes of organizations, but in some cases remains in proof of concept phases, an extensive literature research to identify suitable models for technology integration is conducted. In a second literature research, requirements that blockchain technology places on the integration models are collected. For this purpose, the requirements engineering following Pohl and Rupp is utilized. This way, six requirements are developed: The consideration of stakeholders & system users, as well as of existing information systems, the business context, control mechanisms & data management, monetary expenses as well as quality and complexity of the integration models. Together with these requirements, all models are evaluated by means of a utility analysis. As a result, four technology integration models emerged to be used as a basis. We then developed a new model that meets all the predefined requirements for blockchain integration and conducted a case study to ensure plausibility.

In summary, in this paper, an integration model was developed that is particularly suitable for blockchain integration into supply chain processes. Nevertheless, limitations have to be considered. First, all of the selected papers in the literature research have a focus on IT technologies. Other scientific approaches like innovation, or strategic management are not considered. Second, the integration model is not specified on a certain blockchain use case. Application areas in supply chain management might vary from one another, and therefore, additional case specific integration requirements need to be considered.

It should be noted that there are only few approaches dealing with the integration of blockchain technology into supply chain processes and a holistic model is needed to guide organizations in their attempts of fully utilizing the technology and overcome proof of concept phases. Hence, as further research need, the validation of our model along with a live case study can be suggested. Only this way, unconsidered aspects can be identified and practical applicability can be ensured. In addition, further models focusing on the economic evaluation of blockchain technology should be developed and integrated in order to reach the overall goal of scalable and profitable blockchain solutions in supply chain processes.

References

Acatech, 2018. Blockchain. Deutsche Akademie der Technikwissenschaften München/Berlin.

Allweyer, T., 2005. Geschäftsprozessmanagement: Strategie, Entwurf, Implementierung, Controlling. Herdecke: W3l-Verlag.

Bundesministerium für Wirtschaft und Energie (BMWi), 2016. Monitoring-Report Wirtschaft Digital 2016. Berlin.

Bitkom e. V., 2019. Blockchain in Deutschland – Einsatz, Potenziale, Herausforderungen. Studienbericht 2019. Berlin.

Bogart, S. and Rice, K., 2015. The Blockchain Report: Welcome to the Internet of Value. In: Needham & Company, 21.10.2015, S. 1-57.

Bosu, A., Iqbal, A., Shariyar, R., et al., 2019. Understanding the motivations, challenges and needs of Blockchain software developers: a survey. In: Empirical Software Engineering, 24 (2019) 4, S. 2636-2673.

Broad, J., 2013. System Development Life Cycle (SDLC). In: J. Broad (Hrsg.): Risk Management Framework. A Lab-Based Approach to Securing Information Systems. Rockland, USA: Syngress Publishing Elsevier, S. 39-45.

Burgwinkel, D., 2016. Blockchaintechnologie und deren Funktionsweise verstehen. In: D. Burgwinkel (Hrsg.): Blockchain Technology. Einführung für Business- und IT Manager, Berlin, Boston: De Gruyter Oldenbourg, S. 3-50.

Capgemini Consulting, 2019. Auf dem Sprung - Wege zur organizsational Dexterity. Change Management Studie 2019. Offenbach am Main.

Campbell, D., Lory, G. and Robin, A., 2003. Microsoft Solutions Framework v3 Overview. In: Microsoft (Hrsg.): Microsoft Solutions Framework – White Paper, 2003, S. 1-30.

Casino, F., Dasaklis, T. K. and Patsakis, C., 2019. A systematic literature review of blockchain-based applications: Current status, classification and open issues. In: Telematics and Informatics, 36 (2019), S. 55-81.

Croxton, K. & Garcia-Dastugue, S. & Lambert, D. & Rogers, D., 2001. The Supply Chain Management Processes. International Journal of Logistics Management, The. 12th, pp. 13-14.

Durach, C., Kembro, J. and Wieland, A., 2017. A New Paradigm for Systematic Literature Reviews in Supply Chain Management. In: Journal of Supply Chain Management, 53 (2017) 4, S. 67-85.

Fechtelpeter et al., 2019. Vorstudie zur Entwicklung einer bedarfs- und nutzergerechten Unterstützung von KMU bei der Einführung und Anwendung von Industrie 4.0. In: Acatech (Hrsg.): Forschungsbeirat Plattform Industrie 4.0. 2019, München.

Fridgen, G., Radszuwill, S., Schweizer, A., et al., 2017. Entwicklung disruptiver Innovationen mit Blockchain: Der Weg zum richtigen Anwendungsfall. In: Wirtschaftsinformatik & Management, 9 (2017) 5, S. 52–59.

Gonczol, P. & Katsikouli, P. & Herskind, L. & Dragoni, N., 2020. Blockchain Implementations and Use Cases for Supply Chains – A Survey. IEEE Access.

Guerpinar, T.; Straub, N.; Kaczmarek, S.; Henke, M., 2019. Blockchain-Technologie im interdisziplinären Umfeld. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb.

Gulledge, T. and Simon, G., 2005. The evolution of SAP implementation environments: a Case study from a complex public sector project. In: Industrial Management & Data Systems, 105 (2005) 6, S. 714-736.

Gupta Gourisetti, N., Mylrea, M. and Patangia, H., 2019. Application of Rank-Weight Methods to Blockchain Cybersecurity Vulnerability Assessment Framework. In: 9th Annual Computing and Communication Workshop and Conference (CCWC), vom 07. bis 09.01.2019 in Las Vegas, USA, IEEE: S. 206-213.

Hanser, E., 2010. Agile Prozesse: Von XP über Scrum bis MAP. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg.

Kahloun, F. and Ghannouchi, S. A., 2016. Quality Criteria and Metrics for Business Process Models in Higher Education Domain: Case of a Tracking of Curriculum Offers Process. In: Procedia Computer Science, 100 (2016), S. 1016-1023.

Henke, M., 2003. Strategische Kooperationen im Mittelstand. Potentiale des Coopetition-Konzeptes für kleine und mittlere Unternehmen (KMU). Zugl.: München, Techn. Univ., Diss., 2002 u.d.T.: Henke, Michael: Strategische Kooperationen kleinerer und mittlerer Unternehmen (KMU) unter besonderer Berücksichtigung des Coopetitions-Ansatzes. Verl. Wiss. & Praxis, Sternenfels.

Lankhorst, M., 2017. Enterprise Architecture at Work. Modelling, Communication and Analysis. 4. Aufl., Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg.

Matthes, D., 2011. Enterprise Architecture Frameworks Kompendium. Berlin, Heidelberg: Springer Verlag Berlin Heidelberg.

Nedbal, D., 2013. A process model to guide the integration of business processes and services within and across organisations. In: International Journal of Services, Economics and Management, 5 (2013) 1, S. 154-177.

Niehues S., Guerpinar, T., 2019. Disruptive technologies : integration in existing supply chain processes. In: Hamburg International Conference of Logistics (HICL) 2019.

Ortiz, A., Lario, F. and Ros, L., 1999. Enterprise Integration - Business Processes Integrated Management: a proposal for a methodology to develop Enterprise Integration Programs. In: Computers in Industry, 40 (1999) 2-3, S. 155-171.

Pai et al., 2018. Does blockchain hold the key to a new age in supply chain transparency and trust? https://www.capgemini.com/wp-content/uploads/2018/10/Digital-Blockchain-in-Supply-Chain-Report.pdf., accessed at: 01.05.2020

Panarello, A. & Tapas, N. & Merlino, G. & Longo, F. & Puliafito, A., 2018. Blockchain and IoT Integration: A Systematic Survey. Sensors.

Pilorget, L., 2010. MIIP: Modell zur Implementierung der IT-Prozesse. Wiesbaden: Vieweg+Teubner Verlag.

Pohl, K. and Rupp, C., 2015. Basiswissen Requirements Engineering. Aus- und Weiterbildung nach IREB-Standard zum Certified Professional for Requirements Engineering Foundation Level. 4. Aufl., Heidelberg: dpunkt Verlag.

Qu, Y., Ming, X., Ni, Y. et al., 2018. An integrated framework of enterprise information systems in smart manufacturing system via business process reengineering. In: Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 233 (2018) 11, S. 2210-2224.

Reyna, A., Martin, C., Chen, J. et al., 2018. On blockchain and its integration with IoT. Challenges & opportunities. Future Generation Computer Systems, 88.

Saberi, S.; Kouhizadeh, M.; Sarkis, J., et al., 2019. Blockchain technology and its relationships to sustainable supply chain management. In: International Journal of Production Research, 57 (2019) 7, pp. 2117 ff.

Scharch, M., 2016. Vorgehensmodelle in der Software-Entwicklung. In: Professur BWL – Wirtschaftsinformatik, Justus-Liebig-Universität Gießen (Hrsg.): Arbeitspapiere WI, 4 (2016), S. 1-67.

Scholl, H. J., 2004. Involving Salient Stakeholders. Beyond the technocratic view on change. In: Action Research, 2 (2004) 3, S. 281-308.

Stuhr, H. J., 2013. Untersuchung von Einsatzszenarien einer automatischen Mittelpufferkupplung. Dissertation, Technische Universität Berlin.

Van Wee, B. and Banister, D., 2016. How to Write a Literature Review Paper? In: Transport Reviews, 36 (2016) 2, S. 278-288.

Vogel-Heuser, B., 2003. Systems Software Engineering. Angewandte Methoden des Systementwurfs für Ingenieure. München: Oldenbourg Wissenschaftsverlag.

Wüst, K. and Gervais, A., 2018. Do you Need a Blockchain? In: (Hrsg.): 2018 Crypto Valley Conference on Blockchain Technology. CVCBT 2018 : 20-22 June 2018, Zug, Switzerland : proceedings. Piscataway, NJ: IEEE, S. 45–54.

Zimmermann, O., Schlimm, N., Waller, G. et al., 2005. Analysis and design techniques for service-oriented development and integration. In: INFORMATIK 2005 - Informatik LIVE! Band 2.

Application of agile methods in traditional logistics companies and logistics start-ups – First results from a German Delphi Study

Malena Zielske [1] and Tobias Held [1]

1 – Hamburg University of Applied Sciences

Purpose: To meet rapidly changing requirements and increasing product complexity, a growing number of traditional companies and startups increases their agility by using agile methods. The logistics industry in particular is known to be a comparatively slow adapter to changes in general, but especially to new organizational innovations. The objective of the Delphi study conducted is to assess how traditional logistics companies and logistics startups use agile methods in their IT departments to deal with fast changing internal and external influences and how they respond to change.

Methodology: A Delphi study will be conducted over several complementary rounds as an iterative expert judgement process. After the analysis of the first results, insights can be gained on the following points covering traditional logistics companies and logistics startups: a) The selection of agile methods and practices, b) the benefits that these methods and practices offer and c) the challenges of applying these methods and practices.

Findings: The first results of the Delphi study show that traditional logistics companies as well as logistics startups use agile methods and practices to deal with a high degree of market uncertainty and change, and reveal what advantages and challenges they face.

Originality: This originality of the Delphi study presented lies in its contribution to the largely unexplored area of agility in traditional logistics companies and logistics startups.

First received: 6. Mar 2020 Revised: 20. Jun 2020 Accepted: 26. Jun 2020

1 Introduction

Digitization raises the demand for software products such as platforms and (mobile) applications, also for sectors that have not (predominantly) made money with software products in the traditional sense. The aim is to look at how other industries, such as the logistics industry, deal with this demand for software products and whether logistics companies use agile methods originating from software development in order to digitize their products and align them in the best possible way with the customer.
In the last few years, the use of agile methods and practices has become increasingly popular not only for software companies (Laanti, Salo and Abrahamsson, 2011). Agile methods and practices such as Scrum and Kanban are used to deal with increasing product development and project complexity, evolving customer expectations, uncertainties in the business model, complex technological decisions, or other changing external influences, such as those that occur at a company's suppliers (Beck, 2000; Cockburn and Highsmith, 2001). Agile methods and practices promise to deliver business value in a timely manner and in short iterations. This is made possible by an incremental and empirical approach (Abbas, Gravell and Wills, 2008; Larman and Basili, 2003).
Since the 1980s, the concept of agility itself has evolved from a concept that encompasses flexibility and leanness to a value-based concept (Conboy, 2009). Agility focuses not only on customer value, but also on individuals, cooperation and interaction to achieve flexibility and leanness (Conboy, 2009) and depends strongly on the way all employees think (Beck et al., 2001). The concept of agility is still a complex concept today and is interpreted in many ways in research and practice (Conboy, 2009).

This study focuses on how the conservative logistics industry - known as a "slow adapter" (Kupp, Marval and Borchers, 2017) - deals with agility and how established logistics companies and logistics startups use agility to deliver innovative (software) products that are appreciated by customers (Vogel and Lasch, 2018). Many logistics companies seem to have difficulties in delivering the right customer value and this gives the impression that they cannot keep up with the startups or the speed of innovation within the industry (Beck et al., 2001; Delfmann et al., 2018; Newkirk, 2002). There is an increasing number of partnerships to promote the exchange between traditional logistics companies, logistics start-ups and also IT consultancies. One example is the Digital Logistics Hub, of which Lufthansa Industry Solutions GmbH & Co. KG is one of the partners.

The goal of this Delphi study is to identify agile methods and practices used in traditional logistics companies and logistics startups. The objective is to understand the advantages logistics companies gain from the use of agile methods, but also the difficulties they face when using them.

The research questions (RQ) asked are listed below:

- RQ1: Which agile methods and practices do traditional logistics companies and logistics startups use?
- RQ2: How do traditional logistics companies and logistics startups benefit from the use of agile methods?
- RQ3: What difficulties do traditional logistics companies and logistics startups face concerning the adoption of agile methods and practices?

The Delphi study is conducted based on established guidelines (Dalkey and Helmer, 1963; Linstone and Turoff, 2002; Diamond et al., 2014).

The paper is structured as follows: Section 2 gives a brief overview of the underlying definitions of agile methods and practices as well as an overview of related work. Section 3 presents the applied research method and describes the study design of the iterative judgement process. Section 4 summarizes the findings of the first round of the Delphi study and discusses both their meaning and limitations. Finally, Section 5 concludes this study and provides some perspective for future research.

2 Background

In the following the scientific background of agile methods as well as related Delphi studies are presented.

2.1 Agile methodologies

The concept of agility has developed from a concept of flexibility and leanness to a value-based concept since the 1980s (Conboy, 2009). Agility concentrates not only on customer value, but also on individuals, interaction and collaboration to achieve flexibility and leanness (Conboy, 2009). The term agility is a multifaceted concept and is still widely interpreted in research and practice (Conboy, 2009). Conboy and Fitzgerald offer a general definition of the term and characterize agility as "the ability of an entity to proactively, reactively or inherently embrace change in a timely manner, through its internal components and its relationships with its environment" (Conboy and Fitzgerald, 2004, p.39; Pikkarainen and Wang, 2011). They thus define the basic values of agile process models, especially the willingness to change and to cooperate (Cohn, 2009).
Agility is not limited to one functional area, but "can be addressed in different business competence areas" (see Figure I) (Kettunen, 2009).
The concept of agility was first established in organizational theory and the social sciences as corporate agility to effectively address change in an uncertain world. Brown and Agnew first described agility in 1982 as "the capacity to react quickly to changing circumstances" (Brown and Agnew, 1982). They not only mention flexibility, but also the commitment of essential resources, especially human resources, to output-oriented goals (Schirrmacher and Schoop, 2018). The use of agility was concretized in the

Lehigh Report, which was published in 1991 and describes agile manufacturing (Hooper, Steeple and Winters, 2001; Nagel and Dove, 1991). Hooper characterizes agile manufacturing as "manufacturing system with extraordinary capabilities (internal capabilities: hard and soft technologies, human resources, educated management, information) to meet the rapidly changing needs of the market […]" (Davarzani and Norrman, 2015; Yusuf, Sarhadi and Gunasekaran, 1999).
In 1995, Goldman et al. broadened the Lehigh Report and noted that agility

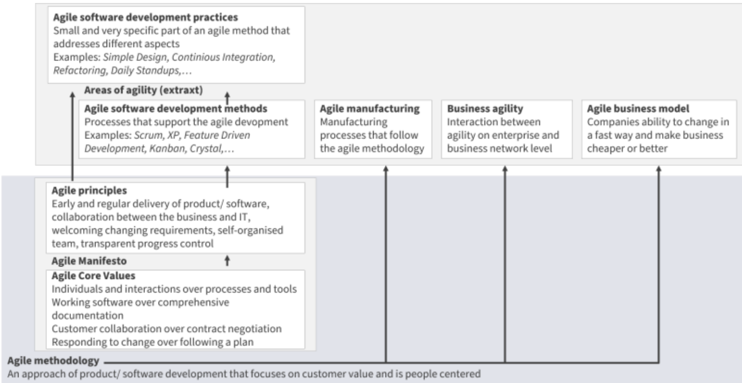


Figure 1: Agile business competence areas and their relationship (Own representation based on (Daniels, 2014; Helaakoski et al., 2006; Kettunen, 2009; van Oosterhout, Waarts and van Hillegersberg, 2005)

is also relevant for other organizational units such as marketing, production, design, organization and management (Goldman et al., 1995). The uncertainty of changing requirements also impacts IT and software development, where the need for agility is increasing as well due to the dynamic circumstances of the other business and technology areas mentioned above. In 2001, the so-called "Agile Manifesto" of software development projects was first introduced (Beck et al., 2001), after agile and iterative process models such as Rational Unified Process and methods such as Scrum and Extreme Programming (XP), Feature Driven Development and Kanban had evolved since the 1980s (Anderson, 2004; Beck, 2000; Kruchten, 1998; Palmer and Felsing, 2002; Takeuchi and Nonaka, 1986; Schwaber, 1997).

The Agile Manifesto consists of four values and twelve principles and aims to optimize the software development process and collaboration with and within teams. With a focus on creating customer value, many agile methods and practices have also been designed that can be applied to other non-IT areas (Highsmith, 2010; Parente, 2015). Practices are linked to a method, but can also be used in combination with other methods. The most common agile methods are Scrum, Kanban, Extreme Programming (XP), Feature Driven Development (FDD) and Crystal (Abrahamsson et al., 2003; Beck, 2000; Schwaber, 2004; VersionOne CollabNet, 2019; Palmer and Felsing, 2002). Examples for agile practices are Daily Standups, Retrospectives, Visualization, Limit Work in Progress, Feedback Cycles, and Refactoring.

The use of agile methods is particularly suited for complex product development or project situations characterized by fast and frequent changes (Stacey and Mowles, 2015). Agile methods aim to decrease complexity by accelerating reaction time, improving collaboration (Kaim, Härting and Reichstein, 2019) and strengthening trust between team members as well as with the customer. Simpler processes, lower change costs and less time spent on changes also lead to increased productivity and a lower error rate (Prater, Biehl and Smith, 2001). This enhances product quality and minimizes complexity (Anwer et al., 2017).

The aim of this Delphi study is to assess the use of agile methods and practices in traditional logistics companies and logistics startups.

2.2 Related work

There are related studies in the literature that use the Delphi approach in the field of agility and in the field of logistics. Table I shows an overview of the reported benefits of the Delphi approach.

Table 1: Overview of Delphi studies in the field of agile methods and the field of logistics

Paper	Aim of the study	Reason for the selection of the Delphi approach
(Akkermans et al., 2003)	Identify supply chain management trends	Structured group communication process: Individuals express effectively views on complex issues Theory-building research method that allows receiving feedback on comments of other experts
(Conboy and Fitzgerald, 2007)	Review the current state of agile method tailoring.	Reliable consensus obtained from an expert group Combining the knowledge of a large expert group to have a better chance of getting closer to the truth Complex problems can often only be solved by pooling opinions
(von der Gracht, Kauschke and Ruske, 2009)	Energy efficiency and speed in the supply chain	Overcome the ‘bandwagon’ and ‘halo’ effect High inclusion of expertise to systematically develop a consensus of expert opinion on future trends Experts can look at the views of their colleagues (anonymously) and possibly rethink their own answers

Paper	Aim of the study	Reason for the selection of the Delphi approach
(Deschene, Don Gottwald and Clifford, 2016)	Identify agile methods to increase acceptance for software security considerations	Separate questioning of selected experts Segregation of experts to ensure anonymity, reduce the risk of group opinion and limit the influence of dominant experts Structured, guided, iterative approach that seeks to arrive at a consensus on a particular research topic.
(Schön et al., 2017)	Identify most important challenges in agile RE	Anonymity prevents the influence by other experts Iterative approach with controlled feedback Use learnings from previous rounds to carry out the following ones

Analyzing the related work, it can be stated that the Delphi approach is used in particular for anonymous, iterative research where complex problems are addressed.

Akkermans et al. use the Delphi approach in their study on future supply chain management, as it enables them to structure a group communication process, so that experts can give their assessments of complex problems and receive feedback from other experts during the study, for example via comments (Akkermans et al., 2003). It is also a theory-building research method.

Conboy and Fritzgerald want to benefit from the fact that the combination of the judgement gives a large number of people a better chance to come closer to the truth (Conboy and Fitzgerald, 2007).

Von der Gracht et al. have designed their Delphi study in such a way that surveyed experts can immediately identify data trends and thus take into account the views of their colleagues (anonymously) to possibly rethink their own answers (von der Gracht, Kauschke and Ruske, 2009).

Deschene has chosen the Delphi method for her study on agile methods in relation to software security policies because it offers a qualitative, guided and iterative approach to bring experts to a consensus (Deschene, Don Gottwald and Clifford, 2016).

Schön et al. have also chosen the Delphi approach in order to be able to proceed in an iterative way and to use the learnings from the previous rounds (Schön et al., 2017).

To this end, the aim of this study is to find out which agile methods and practices are used by traditional logistics companies and logistics startups, why they are used and what difficulties they encounter. To the best of our knowledge, there is currently no study that examines this by means of a qualitative study with practicing experts in agile methods in logistics.

3 Research methodology

Originally, the Delphi method was used to reach a consensus within the expert group on the research topic. Various metrics such as Fleiss' Kappa (Fleiss, 1971) or Kendall's concordance coefficient (Legendre, 2005) are used for this purpose. However, recent studies show that even the definition of consensus is ambiguous (Diamond et al., 2014). Therefore, the ultimate goal of this Delphi study is not to reach consensus but to find valuable insights on the current use of agile methods and practices. For this purpose, the questionnaire is adapted to the research questions between the individual rounds. Therefore the Delphi approach was modified (Dalkey and Helmer, 1963; Diamond et al., 2014; Linstone and Turoff, 2002) and used to carry out an iterative expert assessment process (Dalkey, 1969) to evaluate the use of agile methods and practices in traditional logistics companies and logistics startups in four stages (see Figure II).

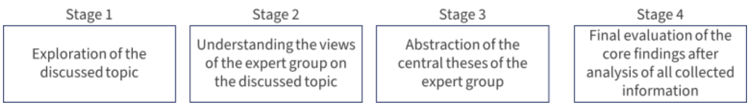


Figure 2: Stages of a Delphi study

Within the questionnaire, qualitative questions are combined with quantitative ones. In-depth insights can be gained through qualitative controlled opinion feedback (Dalkey and Helmer, 1963; Fletcher and Marchildon, 2014) which can be quantified in the following rounds of quantitative questions and evaluated without distortion. The feedback on the results of the preliminary round enables the experts' opinions to be sharpened (Vijayasarathy and Turk, 2012).

3.1 Description of the study design

The study will be conducted in several successive rounds. Figure III gives an overview of the procedure. In each round a questionnaire is created and optimized by several pretests. Afterwards, an e-mail with an invitation and link to the online questionnaire is sent to the participating experts. Results of the first round are used to develop the subsequent questionnaires. However, this paper considers only the results of the first round, as at the time of writing the second round had not yet been completed. The participants had two weeks to answer the questionnaire. Afterwards, the results were evaluated with two other researchers. The study was conducted with questionnaires in German and English. These were checked in advance for consistency.

Figure 3: Process of the Delphi study

We used Google forms for the first round of the Delphi study. In general, it was decided to use 7-point Likert items because it has been shown to be the best choice to avoid interpolation (Finstad, 2010). In some cases a 5-point Likert item was used to reduce complexity for the experts in the answer choices (Cummins and Gullone, 2000). In addition, the quality criteria proposed by Diamond et al. were considered (Diamond et al., 2014) to ensure the quality of this study.

In the first round, invitations were sent out to 37 experts. 29 experts participated in the study. For reliable results, the literature recommends a minimum number of 10-15 panelists (Lilja, Laakso and Palomäki. J., 2011; Dalkey, 1969). Accordingly, the first round met the requirement of reliability.

3.2 Selection of experts

For this Delphi study expert participants are expected to have a deep knowledge on the use of agile methods and practices in the IT departments of traditional logistics companies and logistics startups (Okoli and Pawlowski, 2004). As expertise is difficult to assess a systematic classification is conducted (Clayton, 1997; Sackman, 1975). Participants are selected based on their expertise in the specific field of logistics and more specifically, for their experience with agile methods and practices. The experts who participated in the Delphi study are practitioners in the areas of logistics and IT consultation in the area of logistics. In total the panel consisted of 29 experts working in 29 different companies with headquarters in Germany.

45% of the companies were founded within the last 10 years and are therefore classified as startups (see Figure IV). In total, 14 out of 29 participants were from logistics companies. More than 25% of all participating companies were founded within the last three years. On the other hand, about

55% of the companies were founded more than 10 years ago. The details can be found in the following diagram.

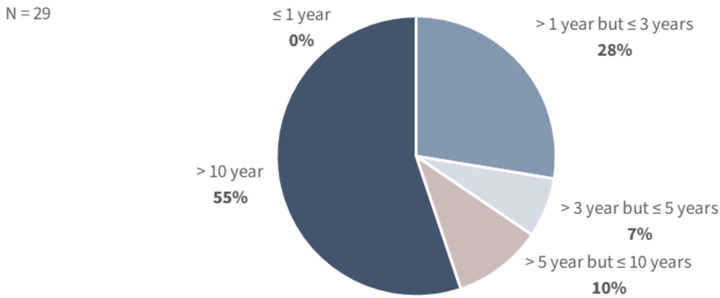


Figure 4: Age of the logistics companies

About 50% of the participants come from companies with more than 500 employees. In comparison, about 30% of the participants come from companies with less than 30 employees (see Figure V). There is only one logistics company younger than 10 years that has more than 500 employees. Conversely, all companies older than 10 years have more than 500 employees.

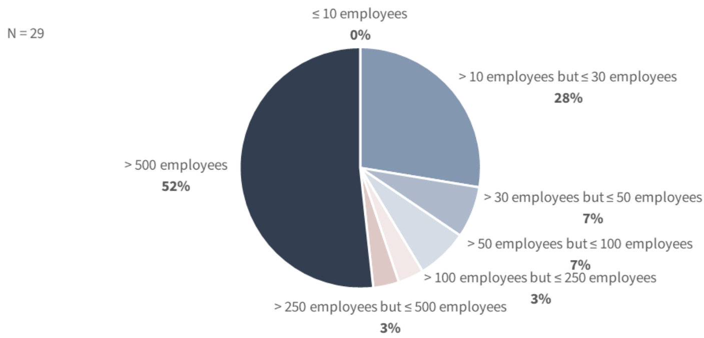


Figure 5: Number of employees

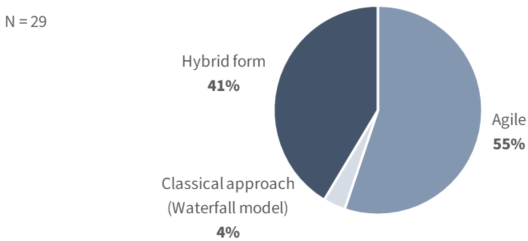


Figure 6: Team organization

Participants stated, that only little work is done purely according to the waterfall model, often the hybrid approach is followed or even worked completely agile.

Looking at the experience of the participants in the logistics industry, 45% have more than five years of experience in the logistics industry. Another 45% have between one and five years of experience.

In the first round of the Delphi study, mainly members of the top management (7 participants), project leaders (6 participants) and agile coaches/ scrum masters (5 participants) took part. Other participants work as head of department, software developer, product lead and business analyst. To deepen the results of this study a broad selection of experts took place (Okoli and Pawlowski, 2004) so that a variety of different views can be included.

The participating experts were also asked to assess their prior knowledge with regard to agile methods. 20 out of 29 participants, close to 70%, rated their prior knowledge on a scale from one to seven as five or higher (see Table II). 16 of the 29 participants have three or more years of experience with the use of agile methods and practices.

Table 2: Expertise of experts (N = 29) in agile methods rated by themselves (1 = No know-how, 7 = Very extensive know-how)

Scale	1	2	3	4	5	6	7
Number of participants	0	1	2	6	6	13	1

Figure VII shows the type of process models that experts have worked with. It is worth mentioning that most experts have experience with both sequential, classical approaches and with agile approaches.

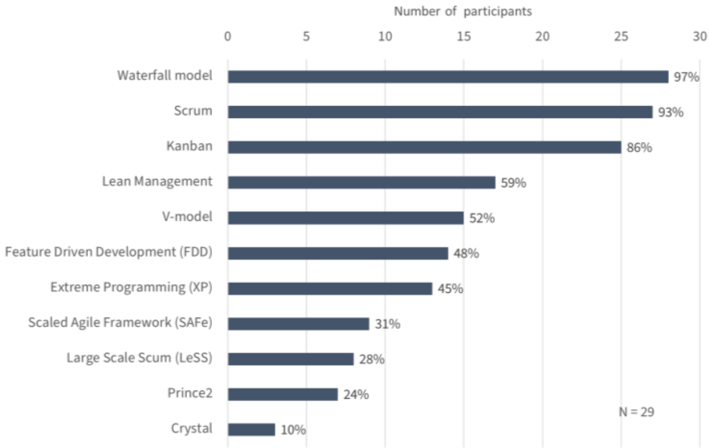


Figure 7: Process models used by percentual share of experts

Experts are aware of the membership of the expert panel. This is necessary to prevent that experts have the feeling that they can say anything as accountability is removed due to anonymity of experts in this study (Sackman, 1975).

4 Results and limitations

In the first round it was possible to find out which agile methods and practices are used in traditional logistics companies and logistics startups. In addition, participants were asked about the benefits of using agile methods and practices and the challenges applying them.

4.1 RQ1: Agile methods and practices used

To answer the first RQ, the study participants were asked which agile methods and practices are used.

The agile method Scrum is used most by traditional logistics companies as well as by logistics startups (see Figure VIII). This is followed by Kanban, Lean Startup, XP and FDD. It is noticeable that startups use the older agile methods such as XP and FDD more often than traditional logistics companies. More than 80% of the participants state that they want to use additional agile methods - especially methods for scaling Scrum such as Scaled Agile Framework (SAFe) and Large Scale Scrum (LeSS). Logistics companies, especially the logistics startups, seem to plan their scaling of their agile teams.

These results can be compared with the results of the 13th State of Agile Reports (VersionOne CollabNet, 2019). The State of Agile Report is conducted by CollabNet VersionOne and collects responses from more than 1000 participants worldwide from various industries and company sizes on the use of agile methods. Following the results of the State of Agile report, Scrum is also the most widely used methodology. However, this is followed

by Scrumban and mixtures of an agile and a waterfall approach. The methods Lean Startup and XP are only mentioned there in 2% and 1% respectively as the methods used.
For scaling agile teams the State of Agile report stated that most companies use SAFe, Scrum of Scrum or LeSS among others (VersionOne CollabNet, 2019).

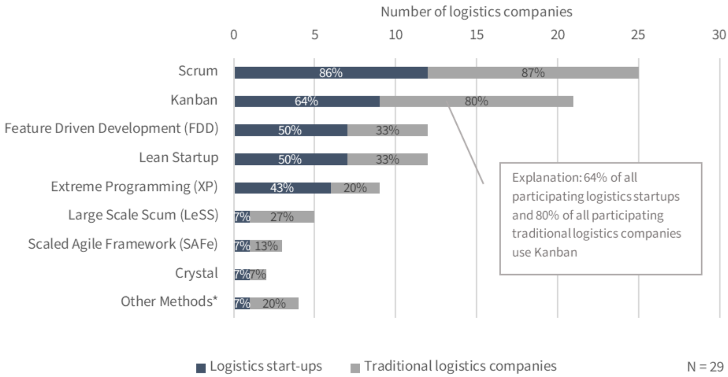


Figure 8: Overview of the agile methods used

Looking at the agile practices, Daily (Scrums) followed by a close exchange within the agile team and reviews and retrospectives are used most often (see Figure IX). Looking at logistics startups in more detail, based on the results of the first round, minimum viable products are especially important, as well as joint team planning through Daily (Scrums) and Sprint Planning sessions. For traditional logistics companies the use of task boards like Kanban boards, the close exchange within the team and the feedback from the customer are especially important.

Agile practices are in theory a subset of the complete agile method. The results of this Delphi study show that often single practices are used, but not the complete agile method. For example, in 100% of the cases Daily (Standups) are performed in logistics startups and traditional logistics companies. However, only 92% of logistics startups and 87% of traditional logistics companies use the associated agile method scrum. The effect is even stronger with more technical agile practices such as refactoring and pair programming. These are used individually much more often than the complete agile method Extreme Programming. Other studies have already discovered this finding (Diebold and Dahlem, 2014; Jalali and Wohlin, 2010; Pikkarainen et al., 2008).

Comparing this with the results of the 13th State of Agile Report, it is also evident that daily (standups), sprint planning, retrospectives and the iterative collection of customer feedback are the most important practices (VersionOne CollabNet, 2019). The logistics industry seems to behave similarly to other industries.

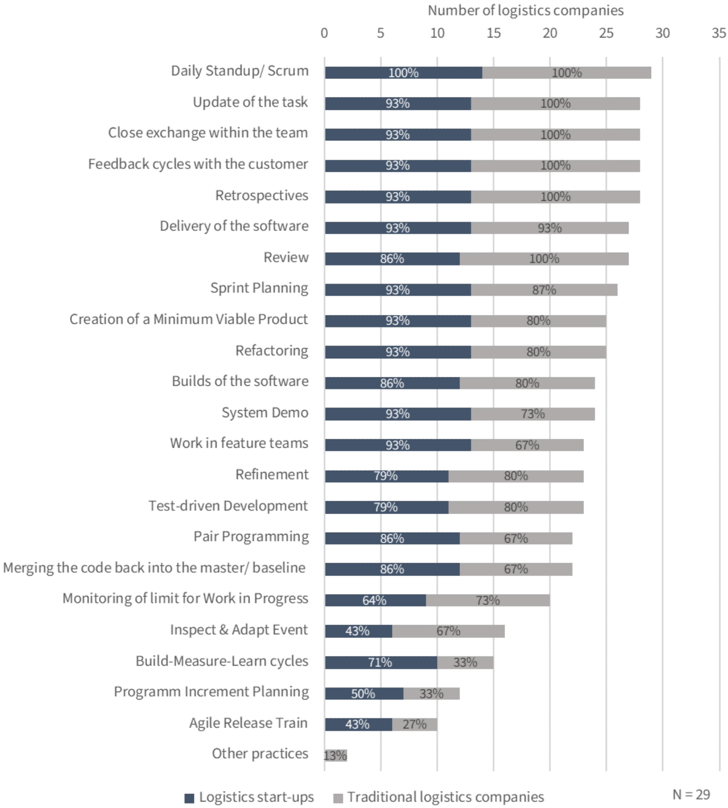


Figure 9: Overview of the agile practices used

4.2 RQ2: Benefits from the use of agile methods

The reasons why participants use agile methods are largely the same in logistics startups and traditional logistics companies. It is mainly about the responsiveness to changing priorities/ demands, the acceleration of (product) delivery and more intensive coordination between IT and business departments (see Figure X).

Regardless of the size of the company, very similar benefits seem to be sought through the use of agile methods. If you compare this with the 13th State of agile Report, you will see that this does not only apply to the logistics industry. Also in other industries, the most important advantages of the use of agile methods are the ability to react to changing requirements, fast product/software delivery, increased quality and improved coordination between IT and the business (VersionOne CollabNet, 2019).

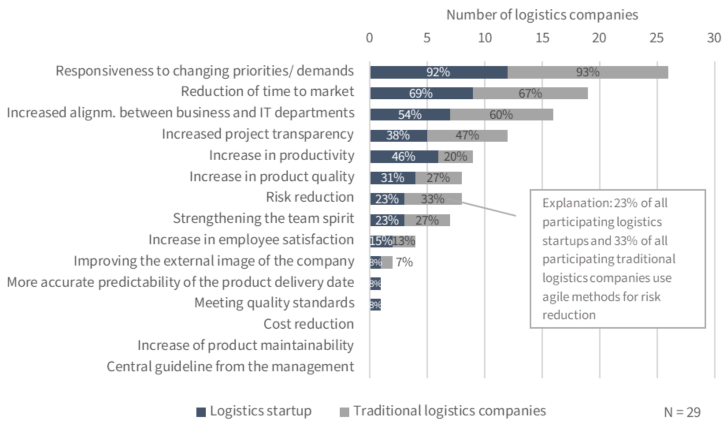


Figure 10: Reasons for the use of agile methods and practices

4.3 RQ3: Difficulties adopting agile methods and practices

Overall, there is a rather similar distribution between the challenges faced by logistics startups and traditional logistics companies when using agile methods. Looking at traditional logistics companies in more detail, they rather have a problem with the organizational culture and lack of willingness for change. Participants from logistics startups stated that their employees/ colleagues do not have so much of a problem with change but with the unbalanced distribution of knowledge in the agile teams. Both types of companies see the partial lack of knowledge about agile methods as a challenge.

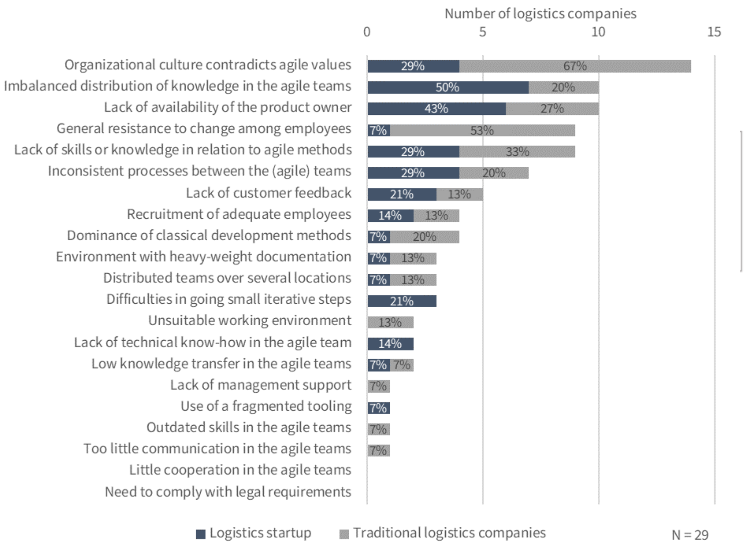


Figure 11: Challenges of startups and traditional logistics companies using agile methods and practices

Agile Coaches and Scrum Master see especially the organizational culture, the lack of knowledge about agile methods and resistance to change as challenges. In comparison, the unbalanced distribution of knowledge within teams, the lack of availability of product owners and the lack of commitment of the customer regarding feedback are challenges that top management and department heads see in the use of agile methods.

4.4 Limitations

As the design of a questionnaire is important for the data collection process, several pre-tests were conducted with participants who correspond to the expert profile. Nevertheless, it cannot be ruled out that nuances in the answers may be lost through this type of online survey. Therefore, the participants had the possibility to complement their answers to closed questions in a free text field. Following the first round of questioning, a report on the results was prepared by the authors of this paper. Decisions were made on the selected points of interest. This may lead to distortions in the opinion-forming process of the panel in the following rounds. An attempt was made to minimize this effect by means of a very precise data analysis and the involvement of two additional researchers.

Finally, it should be mentioned that a survey can of course only be used to investigate whether logistics companies and logistics startups use agile methods. For a more detailed investigation of the manner of the application of agile methods, a case study may have to be conducted in the future.

5 Conclusion and implications for future research

This paper has focused on the identification of the agile methods and practices used by traditional logistics companies and logistics startups and has discussed the benefits and challenges of using agile methods. For this purpose an iterative expert assessment process was carried out. This process consists of several complementary rounds. This paper reflects the results of the first round. It was written during the realization of further rounds. Our panel consisted of 29 experts working in 15 traditional logistics companies and 14 logistics startups who are familiar with the use of agile methods and practices. By identifying the most important methods and practices as well as the benefits and challenges, we contributed to the body of knowledge in the field of logistics. Scrum and Kanban were identified as the most important methods, Daily (Standups), use of task boards such as Kanban boards and the close exchange within the team and with the customer were identified as the most important practices. The main goal of using agile methods is to be able to react to changes and reduce time to market. The biggest challenges are the organizational culture, which contradicts the agile values and an unbalanced distribution of knowledge in agile teams.

Future research can use a case study to find out how well the agile methods and practices are applied in logistics companies and startups. It could also be questioned to what extent the organizational culture of startups is more compatible with the use of agile methods than in traditional logistics companies. The organizational culture and the fear of change are the biggest challenges for traditional logistics companies.

References

Abbas, N., Gravell, A.M. and Wills, G.B., 2008. Historical Roots of Agile Methods: Where Did "Agile Thinking" Come From? In: Agile Processes in Software Engineering and Extreme Programming. Springer, Berlin, Heidelberg.pp.94–103.

Abrahamsson, P., Warsta, J., Siponen, M.T. and Ronkainen, J., 2003. New directions on agile methods: a comparative analysis. In: 25th International Conference on Software Engineering, 2003. Proceedings. Portland, OR, USA: IEEE.pp.244–254.

Akkermans, H.A., Bogerd, P., Yücesan, E. and Van Wassenhove, L.N., 2003. The impact of ERP on supply chain management: Exploratory findings from a European Delphi study. European Journal of Operational Research, 146(2), pp.284–301.

Anderson, D., 2004. Making the business case for agile management: Simplifying the complex system of software engineering. In: Motorola S3 Symposium. pp.1–13.

Anwer, F., Aftab, S., Waheed, U. and Muhammad, S.S., 2017. Agile Software Development Models TDD, FDD, DSDM, and Crystal Methods: A Survey. International Journal of Multidisciplinary Sciences and Engineering, 8(2), pp.1–10.

Beck, K., 2000. Extreme programming eXplained: embrace change. Boston, MA, USA: Addison-Wesley.

Beck, K., Beedle, M., Bennekum, A. van, Cockburn, A., Cunningham, W., Fowler, M., Grenning, J., Highsmith, J., Hunt, A., Jeffries, R., Kern, J., Marick, B., Martin, R.C., Mellor, S., Schwaber, K., Sutherland, J. and Thomas, D., 2001. Agile Manifesto. [online] Available at: <https://agilemanifesto.org/>.

Brown, J. and Agnew, N., 1982. Corporate agility. Business Horizons, 25(2), pp.29–33.

Clayton, M.J., 1997. Delphi: A technique to harness expert opinion for critical decision-making tasks in education. Educational Psychology, 17(4), pp.373–386.

Cockburn, A. and Highsmith, J., 2001. Agile Software Development: The People Factor.

Cohn, M., 2009. Succeeding With Agile: Software Development Using Scrum. 1st ed. Boston, Massachusetts: Addison-Wesley Professional.

Conboy, K., 2009. Agility from first principles: Reconstructing the concept of agility in information systems development. Information Systems Research, 20(3), pp.329–354.

Conboy, K. and Fitzgerald, B., 2004. Toward a conceptual framework of agile methods. In: Proceedings of the 2004 ACM workshop on Interdisciplinary software engineering research. pp.37–44.

Conboy, K. and Fitzgerald, B., 2007. The views of experts on the current state of agile method tailoring. In: IFIP International Federation for Information Processing. pp.217–234.

Cummins, R. and Gullone, E., 2000. Why we should not use 5-point Likert scales: The case for subjective quality of life measurement. In: International Conference on Quality of Life in Cities. Singapore: National University of Singapore.pp.74–93.

Dalkey, N., 1969. An experimental study of group opinion: The Delphi method. Futures, 1(5), pp.408–426.

Dalkey, N. and Helmer, O., 1963. An Experimental Application of the Delphi Method to the Use of Experts. Management Science, 9(3), pp.458–467.

Daniels, K.E.S., 2014. The New Venture Manifesto: Redefining the Success Standards of New Ventures with the Agile Methodology. Florida State University.

Davarzani, H. and Norrman, A., 2015. Toward a relevant agenda for warehousing research: literature review and practitioners' input. Logistics Research, 8(1), pp.1–18.

Delfmann, W., Ten Hompel, M., Kersten, W., Schmidt, T. and Stölzle, W., 2018. Logistics as a Science - Central Research Questions in the Era of the Fourth Industrial Revolution. Logistics Research, 11(9), pp.1–13.

Deschene, M., Don Gottwald, W. and Clifford, C., 2016. Embracing security in all phases of the software development life cycle: A delphi study. Capella University.

Diamond, I.R., Grant, R.C., Feldman, B.M., Pencharz, P.B., Ling, S.C., Moore, A.M. and Wales, P.W., 2014. Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies. Journal of Clinical Epidemiology, 67(4), pp.401–409.

Diebold, P. and Dahlem, M., 2014. Agile practices in practice - A mapping study. In: ACM International Conference Proceeding Series. Association for Computing Machinery.

Finstad, K., 2010. Response Interpolation and Scale Sensitivity: Evidence Against 5-Point ScalesJUS. Journal of Usability Studies, 5(3), pp.104–110.

Fleiss, J.L., 1971. Measuring nominal scale agreement among many raters. Psychological Bulletin, 76(5), pp.378–382.

Fletcher, A.J. and Marchildon, G.P., 2014. Using the Delphi Method for Qualitative, Participatory Action Research in Health Leadership. International Journal of Qualitative Methods, 13(1), pp.1–18.

Goldman, S., Nagel, R., Preiss, K. and Iacocca, L., 1995. Agile competitors and virtual organizations: strategies for enriching the customer. Van Nostrand Reinhold. New York: Van Nostrand Reinhold.

von der Gracht, H., Kauschke, P. and Ruske, K.-D., 2009. How will supply chains evolve in an energy-constrained, low-carbon world?: Transportation & logistics 2030: Publications: Transportation & logistics: Industries: PwC. Wiesbaden.

Helaakoski, H., Iskanius, P., Peltomaa, I. and Kipina, J., 2006. Agile Business Model in the Steel Product Industry Sector. In: 2006 IEEE International Conference on Management of Innovation and Technology. IEEE.pp.1010–1014.

Highsmith, J.A., 2010. Agile project management: Creating innovative products. Boston: Addison-Wesley.

Hooper, M.J., Steeple, D. and Winters, C.N., 2001. Costing customer value: an approach for the agile enterprise. International Journal of Operations & Production Management, 21(5/6), pp.630–644.

Jalali, S. and Wohlin, C., 2010. Agile practices in global software engineering - A systematic map. In: Proceedings - 5th International Conference on Global Software Engineering, ICGSE 2010. IEEE Computer Society.pp.45–54.

Kaim, R., Härting, R.C. and Reichstein, C., 2019. Benefits of agile project management in an environment of increasing complexity—A transaction cost analysis. In: Smart Innovation, Systems and Technologies. Springer Science.pp.195–204.

Kettunen, P., 2009. Adopting key lessons from agile manufacturing to agile software product development—A comparative study. Technovation, 29(6–7), pp.408–422.

Kruchten, P., 1998. The rational unified process. Boston, Massachusetts, United States: Addison-Wesley.

Kupp, M., Marval, M. and Borchers, P., 2017. Corporate accelerators: fostering innovation while bringing together startups and large firms. Journal of Business Strategy, 38(6), pp.47–53.

Laanti, M., Salo, O. and Abrahamsson, P., 2011. Agile methods rapidly replacing traditional methods at Nokia: A survey of opinions on agile transformation. Information and Software Technology, 53(3), pp.276–290.

Larman, C. and Basili, V.R., 2003. Iterative and incremental developments. a brief history. Computer, 36(6), pp.47–56.

Legendre, P., 2005. Species associations: The Kendall coefficient of concordance revisited. Journal of Agricultural, Biological, and Environmental Statistics, 10(2), pp.226–245.

Lilja, K., Laakso, K. and Palomäki. J., 2011. Using the Delphi method. In: Technol. Technology Management in the Energy Smart World. Portland, OR, USA.pp.1–10.

Linstone, H.A. and Turoff, M., 2002. The Delphi Method: Techniques and Applications. Journal of Marketing Research, JSTOR.

Nagel, R. and Dove, R., 1991. 21st Century Manufacturing Enterprise Strategy-an Industry led View. Darby, PA, USA: DIANE Publishing.

Newkirk, J., 2002. Introduction to agile processes and extreme programming. In: Proceedings of the 24th international conference on Software engineering - ICSE '02. New York, New York, USA: ACM Press.p.695.

Okoli, C. and Pawlowski, S.D., 2004. The Delphi method as a research tool: An example, design considerations and applications. Information and Management, 42(1), pp.15–29.

van Oosterhout, M., Waarts, E. and van Hillegersberg, J., 2005. Assessing Business Agility: A Multi-Industry Study in The Netherlands. Springer, Boston, MA.pp.275–294.

Palmer, S. and Felsing, J., 2002. A practical guide to feature-driven development. Prentice Hall PTR.

Parente, S., 2015. Bridging the Gap: Traditional to Agile Project Management 1. PM World Journal, IV(IX), pp.1–12.

Pikkarainen, M., Haikara, J., Salo, O., Abrahamsson, P. and Still, J., 2008. The impact of agile practices on communication in software development. Empirical Software Engineering, 13(3), pp.303–337.

Pikkarainen, M. and Wang, X., 2011. An investigation of agility issues in scrum teams using agility indicators. In: Information Systems Development: Asian Experiences. pp.449–459.

Prater, E., Biehl, M. and Smith, M.A., 2001. International supply chain agility Tradeoffs between flexibility and uncertainty. International Journal of Operations and Production Management, 21(5–6), pp.823–839.

Sackman, H., 1975. Delphi Critique: Expert Opinion, Forecasting and Group Process. 1st ed. Lexington, MA, USA: DC Heath.

Schirrmacher, A. and Schoop, M., 2018. Agility in Information Systems - A Literature Review on Terms and Definitions: Lehrstuhl für Wirtschaftsinformatik 1.

Schön, E.M., Winter, D., Escalona, M.J. and Thomaschewski, J., 2017. Key challenges in agile requirements engineering. In: Lecture Notes in Business Information Processing. Springer Verlag.pp.37–51.

Schwaber, K., 1997. SCRUM Development Process. In: Business Object Design and Implementation. London: Springer.pp.117–134.

Schwaber, K., 2004. Agile Project Management with Scrum | Microsoft. Microsoft Press, (March), p.192.

Stacey, R.D. and Mowles, C., 2015. Strategic management and organisational dynamics: The challenge of complexity to ways of thinking about organisations.

Takeuchi, H. and Nonaka, I., 1986. The new new product development game: Stop running the relay race and take up rugby. Harvard Business Review, 64, pp.137–146.

VersionOne CollabNet, 2019. The 13th annual state of agile Report. CollabNet VersionOne, Alpharetta, GA, USA.

Vijayasarathy, L. and Turk, D., 2012. Drivers of agile software development use: Dialectic interplay between benefits and hindrances. Information and Software Technology, 54(2), pp.137–148.

Vogel, W. and Lasch, R., 2018. Complexity drivers in product development: A comparison between literature and empirical research. Logistics Research, 11(7), pp.1–42.

Yusuf, Y., Sarhadi, M. and Gunasekaran, A., 1999. Agile manufacturing: The drivers, concepts and attributes. International Journal of Production Economics, 62(1–2), pp.33–43.

II.
Risk and Security Management

Building a Virtual Maritime Logistics Cybersecurity Training Platform

Harri Pyykkö [1], Jarkko Kuusijärvi [1], Sami Noponen [1], Sirra Toivonen [1], and Ville Hinkka [1]

1 – VTT Technical Research Center of Finland Ltd.

Purpose: This paper proposes how cyber ranges, which are simulation environments and platforms, can be used for cybersecurity training to reduce the vulnerability surface of the maritime supply chain caused by cyberthreat challenges. An additional benefit to conducting exercises for personnel with realistic environments is that unseen problems can be detected when training with different scenarios.

Methodology: This study aims to create a holistic model for a cyber range training environment customized for the port/maritime logistics sector by simulating the actual operational environment. The research combines cybersecurity and risk management with the special requirements of maritime logistics. The methods used were a literature review and a workshop and interview setup with cybersecurity, risk management and maritime professionals.

Findings: The demand for high-level resilience in global maritime supply chains, in addition to better business continuity management, is becoming increasingly important as global markets seek rapid responses to change. There are various new emerging technologies in the pipeline, which are rapidly gaining popularity in the logistics and supply chain management context. Cybersecurity preparedness is therefore essential.

Originality: Organizational and individual cybersecurity preparedness can be improved when individuals have access to hands-on training with realistic cyber exercise scenarios that cover different levels of interactions and triggers/injects in the actual environment. The training scheme focuses on training both technical and non-technical staff to provide extensive coverage of cyber awareness.

First received: 20. Mar 2020 Revised: 25. Jun 2020 Accepted: 8. Jul 2020

1 Introduction

The maritime sector relies heavily on complex Information and Communication Technology (ICT) and Industrial Control Systems (ICS). There are various new emerging technologies in the pipeline which are rapidly gaining popularity in the logistics and supply chain management context. This makes cybersecurity vitally important for the general operability of organizations and it should be deeply entrenched in organizational strategies. However, several recent studies (e.g., ENISA 2019, Ahokas & Laakso 2017) indicate that currently the maritime sector suffers from insufficient cyberthreat preparedness and poor awareness of general cybersecurity. Since ports are part of the critical infrastructure and maritime supply chains form the backbone of global trade, it is essential to increase cybersecurity and cyberthreat awareness and robustness against cyberattacks.

As technological development evolves at an accelerating rate, continuous training is essential for both professionals (cybersecurity experts, ICT experts, etc.) and non-technical personnel working within the maritime logistics cluster (Alcaide & Llave, 2020). This paper aims to determine how this training should be organized.

There are different options for organizing training. We focus on the possibilities of using cyber ranges (CRs), which are simulation environments and platforms for cybersecurity training, to reduce the maritime supply chain vulnerability surface caused by cyberthreat challenges. A further benefit of conducting exercises for personnel in realistic environments is that unseen problems can be discovered while training with different scenarios. This can allow overall processes, technical functionalities and integrations between systems to be improved, increasing the overall efficiency of operations in normal conditions as well.

The starting point of this study is that cyber awareness will progress once individuals throughout the organization (not limited to IT-department or cybersecurity experts) can have actual hands-on training with realistic cyber exercise scenarios in the actual environment (Pyykkö et al. 2020). A CR can be used to conduct realistic cyber exercisers with industrial control systems reflecting typical features of maritime information technology/operations technology networks. It will also provide the counterparts to decision support in terms of cybersecurity procedure improvements and the need for further investments in corporate risk management tools. For training technical staff, detailed data such as alerts and logs are required with appropriate views. For training non-technical staff, a more holistic and easily understandable view, e.g. a dashboard, can be provided on the current cybersecurity situation. Both of these have to be included in the technical features of the CR.

This study aims to create a holistic model to build a CR training environment especially customized for the port/maritime logistics sector and simulating the actual operational environment. The research has a multidisciplinary approach, combining cybersecurity with the special requirements of maritime logistics. The methods used are a literature search and interviews with cybersecurity and maritime professionals.

2 Methodology

The methodology of this paper has two phases: 1) a literature search of cybersecurity threats in the maritime sector and 2) interviews with maritime logistics, risk management and cybersecurity professionals, including a workshop.

The main purpose of the literature search was to find out how the current academic literature considers cybersecurity threats in supply chain management and especially in maritime logistics. We were also interested in knowing what previous studies have found on how organizations view cyber risks compared to other risks.

The purpose of the interviews and workshop was to combine the expertise of different disciplines. The same people participated in both. The interviews were conducted before and after the workshop using an open discussion format in which interviewees could freely share their viewpoints. The workshop was a whole day event at VTT's cybersecurity lab, during which VTT's cybersecurity experts organized exercises demonstrating the vulnerabilities of existing information systems and how a CR could be used for training. The exercises were followed by discussions on the applicability of CRs for training in the maritime logistics sector. There were eight experts, three representing the maritime logistics sector, three cybersecurity, and two risk management.

3 Operational environment and particular features of maritime logistics

Maritime transportation is a vital link in global trade, and in the European Union area alone there are more than 1,200 active seaports. Each of these seaports has its own operational networks, organization, and physical and cyber infrastructure. (Enisa 2019) In addition to the fact that virtually all ports need customized solutions to fully meet their individual requirements, the rising level of digitalization is bringing new challenges for cybersecurity in both Information Technologies (IT) and Operation Technologies (OT) (Enisa 2019). ECSO (2020a) defines cyberspace as "the domain of information flow and communication between computer systems and networks and includes physical as well as purely virtual elements." In order to fully comprehend the cyberspace of the maritime logistics environment, a comprehensive overview is needed of the special features and complexities affecting this domain. Polatidis et al. (2018) underline that "Maritime port infrastructures rely on the use of information systems for collaboration, while a vital part of collaborating is to provide protection to these systems."

The holistic environment of maritime logistics contains multiple layers and various types of interconnections between numerous stakeholders. The literature review on maritime logistics networks (e.g. Dellios & Papanikas 2014) shows that generally, the maritime environment has two categories: the physical environment and the cybernetic environment, as shown in Table 1. The former includes stakeholders such as authorities, maritime, terminal and insurance companies, labour, and facilities including the port infrastructure. The cybernetic maritime environment contains the port infrastructure, ICT systems such as computer and telecommunications systems and networks, hardware, data, services and users (Dellios & Papanikas 2014; Polemi 2018).

Table 1: Division between physical and cybernetic maritime environments (Dellios & Papanikas 2014; Polemi 2018)

PHYSICAL ENVIRONMENT	CYBERNETIC ENVIRONMENT
Port infrastructure, facilities	Infrastructure, such as buildings and ships
Port authorities	Platforms such as servers and databases
Maritime and insurance companies	Telecommunication systems
Shipping and cargo industry	Software and manuals
Government ministries	E-services, such as applications
Related transport infrastructure	External users, such as maritime companies
Human resources	Internal users, such as personnel

In ports there are both IT and OT systems operating, but cybersecurity efforts have generally focused on the former, forgetting that physical operations controlled via OT systems need taking into account as well (Tam et. al. 2019). As described in Table 1, the overall operability of maritime supply chains and ports depends both on the physical environment and on existing infrastructures within the port areas, but also on continuous functionality of the cybernetic environment (Papastergiou et al. 2015).

The complexity of various IT/OT systems creates a system-of-systems that requires numerous types of interfaces connecting them together. According to ECSO (2020a), this is one of the key elements of cyberthreats in the maritime industry. The ports are a vital part of maritime supply chains, and the information systems are closely linked to each other. Maritime end-to-end supply chain networks are highly complex, involving different types of international organizations that exchange information and data via their own information systems (Polatidis et. al. 2018).

3.1 Risk Management in maritime logistics

Ports play a major role as a global supply enabler, and they are often the key connection point for other transportation modes. The security of ports has been a key part of port management already for the last 20 years, since the global International Ships and Port Facilities Security (ISPS) Code became operational. Initially, the development focused on physical security, but in recent years cybersecurity and resilience management have gained increasing attention in response to a clear need arising from digitalization of port operations and processes and management of supply chains. However, digitalization poses major challenges to ports, as many of them still lack a digital culture in the port ecosystem. As a result, in many ports awareness regarding cybersecurity is still poor, and training, allocated budgets and resources lag behind what are considered real needs. Perhaps because of this, ports have been a prime target of cyberattacks in recent years, and stakeholders from many sides of the business have started taking serious steps toward managing cyberthreats. (Enisa, 2019) Chang et al. (2019) identified the following four major cyberthreats to the maritime industry: lack of training and experts, use of outdated IT systems, hacktivism, and fake websites and phishing emails. The International Maritime Organization (IMO) Resolution MSC.428(98) on Maritime Cyber Risk Management in Safety Management Systems (SMS) states that SMS should consider cyber risk management, and encourages “Administrations to ensure that cyber risks are appropriately addressed in safety management systems no later than the first annual verification of the company's Document of Compliance after 1 January 2021” (IMO, 2017). A holistic cybersecurity risk management, analysis and actions are therefore crucial for the maritime sector, ship operators and owners in the coming years.

The current demand-based market structure and lean supply chains have increased the supply chain complexity. The network is a target of many kinds of risk that have to be addressed efficiently. The investments made in security management have reduced supply chain disruptions. Conversely, the threat landscape has shifted towards cyberattacks and data breaches, and they have more often been mentioned as the main causes of disruptions (Elliot et al., 2019; Singh et al., 2019). As ports are major transportation network nodes, the cyberthreat is evident.

3.2 Supply chain resiliency and key performance indicators / KPIs

To succeed, a company’s supply chain should be resilient and its performance should be assessed accordingly. To guarantee timely action, cybersecurity should be clearly addressed in the ports' key performance indicators (KPIs). (Greenberg, 2018) Traditional supply chain resilience KPIs — which include measures for e.g. robustness, agility, visibility, IT capacity/information sharing, supply chain risk management (SCRM) culture, market position, risk control/revenue sharing, velocity and security — may address the cyber requirements for ports too generally. (Singh et al., 2019)

The frequency of port cyberattacks through e.g. malware, phishing, identity fraud, ransomware, man-in-the-middle attacks or data theft and their consequences is estimated to be greater than reported (Miranda Silgado, 2018). The current frameworks support identification, protection, detection, response and recovery in the risk management cycle to build operational resilience against cyberthreats. (International Maritime Organization, 2017). In addition to IT resources, the role of human resources and processes form important cybersecurity measures. (Mraković & Vojinović, 2019).

Because of the difficulty assessing return on investment (RoI) for security as well as for cybersecurity measures, there is no definitive consensus on KPIs. (Onwubiko & Onwubiko, 2019). At company level, the framework for cyber KPI metrics has been proposed to include the number of foiled (prevented, detected and intercepted) attacks, number of vulnerabilities and threats discovered, overage of business assets being monitored by the cyber management, human and process capabilities regarding managing, monitoring and reporting cyber incidents, monitoring capacity and capability of both technical and operational perspectives and incident detection capability. (Onwubiko & Onwubiko, 2019). Awareness and knowledge among port management, employees and the port network are key to timely control-measure actions. CR-enabled risk and security assessment enables ports to discover their weaknesses and vulnerabilities, assess mitigation measures, or evaluate, predict and practise the effectiveness of cyber risk management measures in general. (Polatidis et al., 2018)

4 Cyber range simulation set up

Cyber ranges are simulation environments and platforms for various purposes (ECSO, 2020b). They consist of multiple technologies that are used to construct an environment that has specific functionalities for end users. CRs are mostly used for security testing, security research and enhancing cyber capabilities and competence. A CR can be a general training platform for various aspects, or it can be a digital twin of a specific network environment. The size of a range varies; it can either be a cyber competition platform for up to thousands of users, or a training platform for a handful of participants. When the range is built for cybersecurity training purposes it is usually built or configured around a specific scenario and targeted set of users. Targeted users are usually pre-defined and the level of technical knowledge they possess has to be estimated in order to customize the training for them. Often the scenarios are targeted for ICT and cybersecurity professionals, but also for executive level or non-technical people who are essential when a real cyber incident takes place.

The basic building blocks of a CR are the same for any environment that is to be simulated inside the CR. The CR is composed of hardware (HW) and software (SW) components building up to the scenarios developed for a specific training scenario. Usually, the work required to create a new cyber exercise in a CR is focused on the specific new scenario and the related machines that need to be configured for it. Figure 1 shows how the workload is divided for specific parts related to a CR when constructing a new training (or even the first training); usually the customization and scenario building takes up most of the work for the CR/training organizers. Naturally, if the new scenario is close to a previously built one, the workload drops significantly.

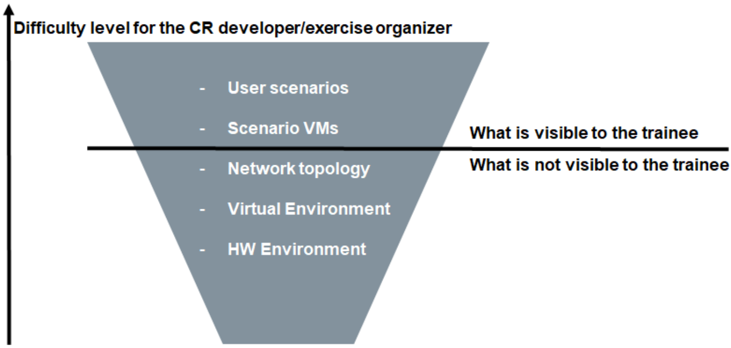


Figure 1: CR, what is visible to the participants, and the effort required to build the scenario.

VTT's CR has been built for organizing small cyber exercises on specific themes. It is hosted on a rack server, the network side is virtualized, and the computers used in the exercises are running in virtual machines. It enables the simulation of cyberattacks and defences, identification of threats and vulnerabilities, traffic monitoring and in-depth analysis. It consists mainly of customized workflows for setting up the scenarios with virtualized systems. Participants use a remote desktop or similar for connecting to the environment. Organizers can use remote or local connections to set up scenarios and control specific training sessions. Figure 2 shows the basic building blocks of a CR operated by VTT, emphasizing components that usually need tailoring according to scenario-specific needs, such as monitoring, situational awareness and obviously the specific machines (virtual systems) for a given maritime scenario.

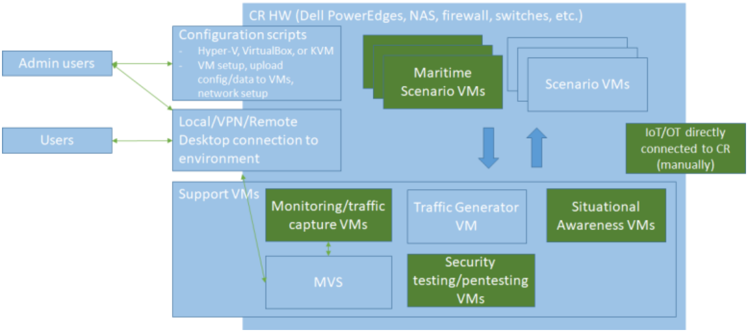


Figure 2: Building blocks of a CR for maritime cybersecurity training

4.1 How to adjust cyber range simulations for the maritime cyber domain

The knowledge of how to build the specific modules used in a scenario is heavily based on the user and operational requirements. Depending on the scenario, the IT/OT devices of the specific scenario, the CR will have to introduce various different network segments and machines located in these network segments. Usually, in a maritime specific scenario, the inclusion of OT devices is obvious. These OT devices can be included into the environment by adding real HW devices that are connected to the virtual environment, or they can be introduced by including virtual OT devices into the virtual environment. The goal of the whole CR scenario work is that the environment (software systems and tools) used by the people in the CR environment is as close to the real environment as possible. This enables to educate and train the people according to the various cyber-related risks/attacks that may occur in their specific environment and how to react to them.

Additionally, we can use the CR environment to test out a new system(s) in a realistic setting without introducing it into the normal operational environment. In addition to covering normal user guidance and testing of functionalities, we can test the system for any cyber-related incidents that may be introduced by integrating it into the current operational environment. Combining two or more functional systems may not always result in one functional operational system, especially in terms of cybersecurity, as there may be some compromises that have to be made in order to integrate systems that might be noticed only during 'normal operations'. The whole purpose of using a CR is to train the operators of the system(s) in the abnormal situations occurring while using the systems. Thus, organizing a CR cybersecurity exercise/training introducing a new system may well introduce some technical and/or (cybersecurity) process-related issues that can then be solved before actually taking the system into everyday use.

The port logistics system running in the CR does not have to be replicated as an exact twin of the real system. It is usually enough that the simulated components provide meaningful functionality for the scenario. For example, a component can be simulated just by replaying relevant traffic into the CR network. Training scenarios often include a simulated cyberattack that can be executed by the organizers or participants playing as a red team. The attacks are often scripts that execute malicious files or inject traffic into the system. Participants have to detect the attacks with the provided tools and react accordingly.

The following list of components provides examples of what can be virtualized in a CR for maritime/port logistics specific scenarios:

- Ship location tracking (GPS, AIS)
- Weather data and forecasts
- Electronic cargo and passenger manifest systems
- Cranes and other container handling systems
- Container tracking systems
- Human-machine interfaces
- Remote diagnostics and maintenance

Situational awareness of the exercise is an important topic for the participants to see what is happening in the environment. Situational awareness can be coarsely divided to two views, depending on the user's needs: high-level and low-level views. During the exercise it is possible to display data of different aspects for people with different competences. For example, technical cybersecurity professionals would be presented with e.g. detailed log data, Intrusion Detection System alerts and network data packets. Different data would be presented for the non-technical people, e.g. risk-analysis, operational status of SCADA systems, or textual descriptions.

4.2 Implementation of a cyber range-based training platform

Defining learning goals for the participants is an important part of planning the pedagogical side of the training. The learning goals are set out in the planning phase, carried out in the implementation (exercise) phase, and finally recapped in the feedback phase after the exercise (Karjalainen et al., 2019). Karjalainen et al. (2019) also argue that specific technical phenomena may distract the users from achieving the actual learning goals that are being targeted for the users. Our approach to tackling this gap is to gather knowledge about the participants' background knowledge, weaknesses and strengths, in order to customize the training around the discovered learning goals. After the CR environment including all the required components and the training scenarios has been developed, preparations for organizing the training session can begin. As maritime logistics involves a large number of different stakeholders, especially at ports where all the different stakeholders come together and interface with each other, it is important to gradually train the stakeholders in their own environments first. After the personnel have been trained to successfully operate, protect and react to possible cyber incidents in their relevant operational environments, the stakeholders can also participate in a wider training/cyber exercise where especially communications skills and co-operation with the relevant other stakeholders can be trained. The following lists possible roadmap steps in realizing this overall training scheme, building up from gathering the existing knowledge, building the scenarios, and ending at a collaboration exercise between selected stakeholders that interface with each other. It should be noted that, depending on the learning objectives and skills of the participants, the CR can be utilized in one or all of the steps listed.

Step1: Online questionnaires/exercises. The purpose of this step is to ascertain the overall skill level of the people participating in the training. Simple exercises can also be done online in a Moodle or even in the CR.

Step 2: Online security awareness training. The purpose of this step is to train the people before jumping to the CR environment, in case they are new to cybersecurity and/or need/want to train themselves beforehand.
Step3: Specific CR exercises for separate groups. The purpose of this step is to organize specific training sessions for different personnel groups. These groups can range from non-technical people to cybersecurity professionals. The target is to train their cyber skills and combine their knowledge while they are working together on specific scenarios. This is targeted to one or more specific operational parts and cybersecurity aspects.
Step4: Intra-company-wide CR exercise/training. The purpose of this step is to have a more large-scale cyber training/exercise with most of the people from the organization taking part. The aim is to train and try out the company's cybersecurity policies during a cyber incident. It will also help to exercise communication between the key roles in the company in case of an incident; who will handle what, who to contact in case of incidents, etc.
Step5: Inter-company-wide CR exercise/training. This is an optional final step, in case e.g. the port authority can organize a larger exercise that includes people from multiple stakeholders. It should also have a scenario in which all of the stakeholders would operate their own systems as in reality and train how a cyber incident is communicated and how it is handled in co-operation between all the relevant stakeholders. This type of training can also include non-technical trainings, such as how to communicate the incident to the outside, like media (incident reporting to CERT/CSIRT is part of the technical part). Figure 3 shows in what relation the different proposed steps are located compared to the exercise/CR preparation work

(feedback is about the CR exercises, otherwise feedback should obviously be available after each step).

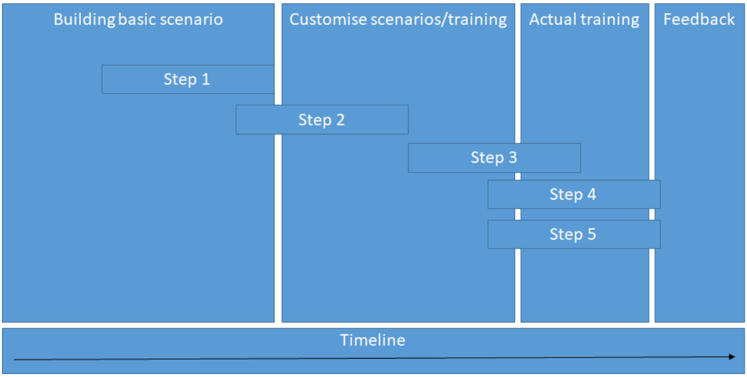


Figure 3: Training steps and CR development/usage phases.

5 Conclusions

As the general level of digitalization and automation of operations continues its rapid growth, also in maritime logistics, it is crucial for overall cybersecurity preparedness that maritime organizations guarantee their personnel appropriate and thorough training, ranging from IT specialists to basic end-users of the systems. As long as there are human factors affecting system usage, not even highly advanced cybersecurity technologies can alone bring sufficient cyber-protection coverage against cyberattacks.

The starting point of the study and related workshop was to combine cybersecurity research with the particular features of maritime logistics, in order to gain a holistic model which can then be utilized when designing the CR training platform. A multidisciplinary approach is needed to close the knowledge and communication gaps between cybersecurity and maritime logistics research and create a mutual learning process. Increasing implementations of new emerging technologies to existing maritime processes will also increase the need for comprehensive cybersecurity simulations and tailored training before the new implementations can be taken into operational use.

The complexity of the maritime logistics environment and general lack of cybersecurity standards is generating pressure for individual maritime organizations and ports to guarantee that cybersecurity preparedness and technological competencies of their own systems, interfaces and personnel are continuously up to date in order to decrease the cyber risks. When creating the CR training scenarios, it is also important to recognize the diversity of different contextual settings and participants' individual skills.

Developing the baseline and the first training scenarios in the CR are the most time-consuming tasks when creating a training for a new context, such as maritime logistics/ports. Once the target core systems and first detailed scenarios are developed, adding new scenarios based on the existing systems and/or introducing a similar system to the CR is a much lighter task. The scenarios and related situational awareness implementations can be reused extensively when moving the training into a new similar environment, e.g., a new port with a different set of systems in use. Obviously, any new system has be to implemented/replicated into the CR if it is crucial for achieving the training goals, but the overall scenarios mostly stay the same. Once the maritime organizations have a validated risk management set up, it should possible to recognize the weakest points of systems/operations. This is valuable information to be given to the training organizers/operators of the CR. The requirements management process in the organizations has to consider these cybersecurity-related requirements/risks as well and how these could be mitigated. The EU Directive on security of network and information systems/NIS (pl, art.3) highlights that cybersecurity should not be considered purely as a technological but also as a strategic issue that the organizations themselves are accountable for (NIS 2016).

6 Discussion

The European Cyber Security Organization (ECSO, 2020a) estimates that globally only around half of existing ports have a sufficient level of understanding in terms of their own cybersecurity aspects, which translates into an urgent need for improvement. The demand for a high level of resilience in global maritime supply chains is an increasingly important aspect of this, alongside business continuity management as global markets consistently require fast responses to change. The common trend is for cargo flows to be as seamless as possible to avoid warehousing of goods. In general, this means that manufacturing companies will have very limited buffer stocks in case of disruptions in the supply chain, while at the same time being ever more dependent on ICT systems. These advances create pressure for manufacturing companies, logistics service providers and ICT companies worldwide to put additional effort into their supply chain operability taking into account potential disturbances in normal material flows.

Training designed for the most technically skilled cybersecurity professionals is certainly not something to challenge normal users of the systems with. Pedagogically, the training must be tailored to the student — start with the basics, then move towards the more complicated learning goals that require prior knowledge. One hurdle to cross in cybersecurity (hands-on) trainings/exercises is that not everyone attending may be right for the level of difficulty of that specific exercise. Some may be highly skilled at cybersecurity while others are at the start of their learning curve. If the exercise is not effective for most of those participating in it, it helps neither the participants nor those running it. Therefore, we emphasize the importance of selecting appropriate participants for specific exercises and trainings.

The most suitable solution would be to conduct a pre-exercise quiz or small-scale online exercise to assess skill levels, allowing the organizers to focus the exercise on the specific weaknesses of the participants. Better yet, they could suggest that the organization willing to educate their personnel divide the participants into one or multiple groups based on training needs. This decision is, of course, up to the organization joining the exercise.

Acknowledgment

This work has received funding from The European Union's Horizon 2020 research and innovation program under grant agreement No. 833389.

References

Ahokas, I., Laakso, K., 2017. Delphi study on safety and security in the Baltic Sea Region ports. Publications of the HAZARD Project. Available at: <https://blogit.utu.fi/hazard> Accessed 30 April 2020].

Alcaide, J.I. and Llave, R.G., 2020. Critical infrastructures cybersecurity and the maritime sector. Transportation Research Procedia, 45, pp. 547-554.

Chang, C.H., Wenming, S., Wei, Z., Changki, P. and Kontovas, C.A., 2019. Evaluating cybersecurity risks in the maritime industry: a literature review. In Proceedings of the International Association of Maritime Universities (IAMU) Conference.

Dellios, K, Papanikas, D., 2014. Deploying a Maritime Cloud. IT Professional, 16(5), pp. 56-61.

ECSO 2020a. ECS WG5 PAPER Understanding Cyber Ranges: From Hype to Reality. Available at: <https://www.ecs-org.eu/documents/uploads/understanding-cyber-ranges-from-hype-to-reality.pdf> [Accessed 12 May 2020].

ECSO 2020b, Transportation Sector Report 03/2020, Cybersecurity for road, rail, air and sea, WG3 / Sectoral Demand. Available at: <https://ecs-org.eu/documents/publications/5e78cb9869953.pdf> [Accessed 12 May 2020].

Elliot R., Muhammad, K., Reece, D., 2019. Supply Chain Resilience. 10 Year Trend Analysis. BCI. Available at: <https://www.thebci.org/uploads/assets/uploaded/6bd728bd-bf0e-4eb7-b15fa67164eb9484.pdf> [Accessed 22 May 2020].

ENISA (2019), Port Cybersecurity - The good practises for cybersecurity in the maritime sector, October 2019

Greenberg A. (2018) The Untold Story of NotPetya, the Most Devastating Cyberattack in History. Wired August 22, 2018. Available at: <https://www.wired.com/story/notpetya-cyberattack-ukraine-russia-code-crashed-the-world/> [Accessed 10 May 2020].

International Maritime Organization, 2017. Guidelines on maritime cyber risk management, MSC-FAL.1/Circ.3. Available at: <http://www.imo.org/en/OurWork/Security/Guide_to_Maritime_Security/Documents/MSC-FAL.1-Circ.3%20-%20Guidelines%20On%20Maritime%20Cyber%20Risk%20Management%20(Secretariat).pdf> [Accessed 10 May 2020].

IMO, 2017. Resolution MSC.428(98), Maritime Cyber Risk Management In Safety Management Systems, 2017. Available at: < http://www.imo.org/en/OurWork/Security/Guide_to_Maritime_Security/Documents/Resolution%20MSC.428(98).pdf> [Accessed 10 May 2020].

Karjalainen, M., Kokkonen T. and S. Puuska, S., 2019. Pedagogical Aspects of Cyber Security Exercises. In *2019 IEEE European Symposium on Security and Privacy Workshops (EuroS&PW)*, Stockholm, Sweden, pp. 103-108,

Miranda Silgado, D., 2018. Cyber-attacks: a digital threat reality affecting the maritime industry. World Maritime University Dissertations. 663.

Mraković, I. and Vojinović, R., 2019. Maritime Cyber Security Analysis–How to Reduce Threats?. Transactions on maritime science, 8(1), pp. 132-139.

NIS (2016), The Directive on security of network and information systems, p1, art. 3., Directive (EU) 2016/1148 of the European Parliament and of the Council.

Onwubiko, C. and Onwubiko, A., 2019. Cyber KPI for Return on Security Investment. In International Conference on Cyber Situational Awareness, Data Analytics And Assessment (Cyber SA), Oxford, United Kingdom, 2019, pp. 1-8.

Papastergiou, S., Polemi, N. and Papagiannopoulos, I., 2015. Business and threat analysis of ports' supply chain services. In International Conference on Human Aspects of Information Security, Privacy, and Trust (pp. 642-653). Springer, Cham.

Polatidis, N., Pavlidis, M., Mouratidis, H., 2018. Cyber-attack path discovery in a dynamic supply chain maritime risk management system. Computer Standards & Interfaces, 56, pp. 74-82.

Polemi, N., 2018. Port Cybersecurity - Securing Critical Information Infrastructures and Supply Chains. Elsevier

Pyykkö, H., Kuusijärvi, J., Silverajan, B., Hinkka, V., 2020, The Cyber Threat Preparedness in the Maritime Logistics Industry, Research Arena 2020, Helsinki, Finland, 27-30 April, 2020. (Conference cancelled)

Singh, C.S., Soni, G. and Badhotiya, G.K., 2019. Performance indicators for supply chain resilience: review and conceptual framework. Journal of Industrial Engineering International, Vol. 15, pp. 105–117.

Tam, K., Jones, K., Forshaw, K., 2019. Cyber-SHIP: Developing Next Generation Maritime Cyber Research Capabilities. International Conference on Marine Engineering and Technology (ICMET), Oman.

Impact of notification time on risk mitigation in inland waterway transport

Johannes Gast [1], Rebecca Wehrle [2], Marcus Wiens [2], and Frank Schultmann [2]

1 – 4flow AG

2 – Karlsruher Institute of Technology - Institute for Industrial Production

Purpose: Transport infrastructures form the backbone of today's interconnected real economy. Interruptions in the availability of these critical infrastructures occur, among other things, due to maintenance operations. Since companies and Supply Chains are dependent on planning security, an adequate notification time in advance of such interruptions is required. Otherwise, insufficient notification time limit available mitigation strategies.

Methodology: First, the authors conduct a workshop concept to obtain expert knowledge from stakeholders to identify critical thresholds of notification times, which affect maintenance and logistics operations in inland waterway transport. Second, this research analyses the notification time of closures on an exemplary real-world network of inland navigation.

Findings: The research reveals a high impact of notification times on logistics operations and determines the planning reliability for all parties involved. Data analysis found that the notification time for the majority of the considered closures is below the identified critical threshold. Efficient planning must address this as they pose threat to Supply Chains operations.

Originality: This research is innovative as there is little analysis on inland waterways, even though there exist accessible historical data. This research contributes to this account by linking critical infrastructure, expert knowledge, and supply chain operations. Quantitative methods extend the base of qualitative knowledge gained from interdisciplinary research. Stakeholders can account for notification time in their risk mitigation strategies.

First received: 20. Mar 2020 Revised: 25. Jun 2020 Accepted: 12. Jul 2020

1 Introduction

Due to the Corona Pandemic, Supply Chain Risk Management (SCRM) receives significant attention in the first half of 2020. Organisations of Supply Chains (SCs) are under pressure "to recognise what needs to be done to assure production at certain levels" (Faertes, 2015). The availability of transport infrastructure is of special interest in the context of SCRM (Li et al., 2016; Hosseini, Ivanov and Dolgui, 2019). Within this context and besides the factors impact, probability, and resilience, another factor comes into focus: risk communication about the enaction and extent of risk mitigation measures by public authorities. In the area of risk communication between the operator and user of infrastructure, the term *notification time* is introduced. Notification time describes the time between the notification from the operator about an impending restriction of a transport way and the actual start of the restriction. For risks that can be identified well before their realisation, stakeholders have enough time to prepare mitigation strategies within this time. This paper introduces the aspect of notification time from the perspective of SCRM and discusses its effect on SCRM strategies.

Notification time concerning events that restrict the navigability and operational readiness of inland waterway transport is the object of study using the example of the West-German canal network. This canal network handles the second most transport volume on inland waterways in Germany following the river Rhine (see Statistisches Bundesamt, 2019). It consists of four canals: the "Wesel-Datteln-Kanal" (WDK), the "Rhein-Herne-Kanal" (RHK), the "Datteln-Hamm-Kanal" (DHK), and the "Dortmund-Ems-Kanal" (DEK). Furthermore, this paper considers two industries that meet their supply primarily through inland waterway transport and depend on the waterway navigability.

1.1 Motivation

Inland waterway transport is an efficient mode of transport to supply large-scale chemical parks, power stations and to transport bulk goods. It provides capabilities for the handling of certain dangerous and bulky goods (like a gas turbine with a weight of 600t). Albeit industries depend on the navigability of the waterways, which is not continuously given: the chemical company BASF SE lost over EUR 245 million during the river Rhine's low water tides in 2018 because the supply by inland waterway transport became disrupted (BASF SE, 2019; Reuters, 2019). The port in Marl, among other ports, could not be accessed for almost two weeks due to ice-coverage of the canal "DHK" in February 2012, inducing significant loss of production capacities to the connected chemical industry park (see ELWIS-database, 2019; Workshops, 2019/2020).
The examples above highlight the dependency of specific SCs on the availability of inland waterways. SC disruptions can propagate downstream of the disrupted SC resulting in risk consequences for additional companies, too (Merz et al., 2009). These consequences are particularly relevant in the case of the (petro-)chemical industry as its products are plentiful and used across industries. For example, a disruption at the chemical park mentioned above caused a shortage of a necessary component for the global automotive industry in 2012. Therefore Yan et al. (2015) identify this park as a highly relevant supplier hidden in various multi-tier SCs due to the global effects of the local disruption.

Furthermore, in the field of risk and disaster management, mitigation, prevention and preparedness as part of the pre-disaster phase are highly relevant (Coetzee and van Niekerk, 2012). Therefore, timely and effective early warnings can enable powerful measures and promote the need to identify early warning times (Todd and Todd, 2011). In the considered field of infrastructure failures, this aspect is about time to prepare for disruptions in SCs, such as those caused by scheduled and notified maintenance closures. A prominent example is the port of Dortmund, which could not be accessed by waterway for six weeks in 2019 and will not be again for six weeks in 2020 due to a lock which is permanently under maintenance (ELWIS-database, 2019)

1.2 Research Objective

This paper aims to investigate the relationship between notification time about restrictions to inland waterway navigability as an enabler for industries to deploy risk mitigation measures. The waterway authority (WSV) announces the restrictions which are targeted to shippers. This allows industries to reorganise their transports, which requires preparation time and enhances the effectiveness of available mitigation strategies to alleviate the effects of the restriction on their affected SCs if necessary. This relationship has not been examined in literature so far.
Assessing the impact of the notification time to SCRM due to restrictions of transport infrastructure is complex because the impact depends on available risk mitigation strategies at the current state of the SC (Tomlin, 2006). Therefore, a mixed-methods approach is suitable. This paper investigates the effects using an exemplary real-world network by obtaining expert

knowledge of stakeholders involved in operating the infrastructure. Furthermore, experts of industries are stakeholders who participated in held workshops. The acquired expert knowledge is then compared with the historical notifications about restrictions in the canal system with means of data collection and analysis. This approach allows the authors to draw conclusions about the preparation time of mitigation strategies and to derive an estimate about how logistics operations become affected by the notification time.

Overall, the paper aims to answers the question of what an appropriate level of notification time is. The criterion for this is the possible implementation of measures to ensure SC operations against the risk of infrastructure unavailability. Moreover, this paper defines the critical threshold of notification times at which stakeholders can deploy further mitigation strategies for the unfolding disruptions.

1.2.1 Outline

This paper addresses the research question in five sections as follows: First, this paper maps the relevance of notification time into the concepts of risk management and SCRM, thereby describing related and existing works to introduce the topic. Then, the paper establishes its mixed-methodology by setting up the workshop concept firstly. Secondly, the findings of the workshop regarding notification time and their consequences for SC operations are compared to the found situation in the West-German canal system by analysing data of the issued notifications from the authorities. In the following two sections, the paper presents and discusses the obtained results. Finally, the authors link the results to the perspective of SCRM and outline further research steps.

1.2.2 Definition

The scientific literature rarely takes into account the discussed notification times. Similar aspects are regarded within the field of disaster management, for example as part of early warning systems. There, the term warning time is more present and is related to the fact that short warning times do not allow effective measures, concerning disasters like natural hazards, to "be implemented in the time available for preventive action and are, therefore, very critical" (Krausmann et al., 2011). To distinguish large-scale disasters from the interruptions considered here, the authors speak of notification times within the research scope. This term transfers the warning time and concepts of disaster management research to the field of SCRM.

2 Literature Review

The dependencies between SCRM, underlying transport infrastructure and risk management are investigated in their respective areas of research. The following section first briefly outlines these interdisciplinary approaches before the concept of notification time is classified from disaster management approaches.

2.1 Supply Chains and Inland Waterway Transport

Inland waterway transport explicitly in the scope of Supply Chain Management (SCM) is considered in one paper (Achmadi, Nur and Rahmadhon, 2018) and one dissertation (Caris, 2011). Pant, Barker and Landers (2015) quantify the consequences of disruptions of inland waterway ports serving multiple industries with waterway connections to multiple regions by calculating the economic losses of industries. More often, the direct risk associated with navigation of inland cargo vessels is analysed (i.e., Xin et al., 2019; Zhang et al., 2014; Yang, Xing and Shi, 2020). Since the literature on waterway transport seldomly considers the supply chain management perspective and does not consider warning or notification times of possible disruptions, the following two sections elaborate on these aspects.

2.2 Supply Chain Risk Management

Risk management is becoming increasingly important in the area of SCM. SC Risk Management (SCRM) is identified as necessary for the agility and robustness of a company and is gaining importance with increasing risks (Wieland and Wallenburg, 2012). Since a SC comprises companies that want to improve their efficiency and effectiveness by integrating and coordinating the flows of materials, goods, information, knowledge and finance, efficient risk management is of need (Bowersox, 2013). This need reflects risks from SC disruptions, which can be neglected by focussing primarily on cost reductions (Khan et al., 2008).

Tomlin (2006) identifies the significance of mitigation strategies for managing SC disruption risks. Therefore, several research attempts deal with the robustness of SCs (Hosseini et al., 2019; Shukla et al., 2011) as well as with the direct analysis of disruptive effects in SCs (Käki et al., 2015; Kleindorfer and Saad, 2005; Sawik, 2019). Further attempts investigate SC robustness and disruption risks in SCs on the background of a natural disaster (Fujimoto, 2011; Park et al., 2013). Whereas most of this research is focusing on the topology of the SC like single or multi-sourcing structures (Yu et al., 2009), Hosseini and Barker (2016) also analyse timely effects which lead to the resilience of infrastructures. In the latter case, the timely effects are limited to the time after a disruption occurs and therefore does not consider the time before it occurs. The following section examines time aspects of the pre-disaster phase from disaster management. The concept of notification time is associated with early warning systems, which are also becoming increasingly important in SCs.

Referring to early warning systems, the connection between what is particularly present in the area of natural disasters and the briefly discussed SCRM does not seem that obvious at first sight. Nevertheless, few early warning systems are currently present in SCs. They aim at identifying negative trends or operational risks for SCs as early as possible to prevent a reduction in sales, damage or even bankruptcy. Therefore, both qualitative and quantitative methods can be used, for example, for long-term forecasts of structural changes, with the crucial question being how much time is lost until the measures become effective (Romeike and Brink, 2006).

2.3 Notification time in risk management

The field of risk management uses disaster management cycles to explain and manage the impacts of disasters (e.g. Baird, 1975; Coetzee and van Niekerk, 2012; Khan et al., 2008). Their three key stages are namely the pre-disaster phase, the disaster occurrence and the post-disaster phase. They comprise all activities, programmes and measures aimed at preventing a disaster, reducing its impact or recovering from its losses (Khan et al., 2008). Apart from this, many attempts of more precise disaster management cycles exist, in which, partly due to the various characteristics of disasters, the phases may overlap and be hard to distinguish (Neal, 1997). As an example, figure 1 depicts an early attempt.

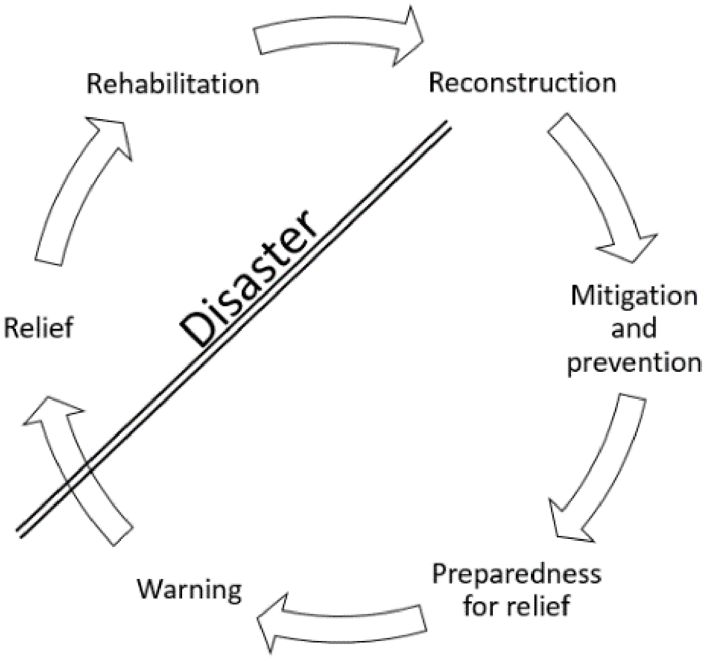


Figure 1: Disaster management cycle (adapted from Baird, 1975)

The pre-disaster phase is significant since it deals with the predictability of the occurrence of disasters. This mostly includes their unpredictable and precise location, timing, or severity and can include measures like plans for timely and effective early warnings (Todd and Todd, 2011). As phases that need to be considered before the occurrence of a disaster, figure 1 shows the aspects of mitigation, prevention, and preparedness as part of the pre-disaster phase (Coetzee and van Niekerk, 2012). Moreover, the cycle shows a phase of warning, which should be taken into account in the management of disasters (Baird, 1975).

In summary, the research about SCRM mostly neglects the aspect of warning times or notification times, which is why the concept of disaster management is predominantly used instead. The source knowledge from primary literature has to be extended to connect these concepts through the defined notification time and be able to elaborate on the impact of notification time on SC operations.

3 Methodology

Expert knowledge is necessary to assess the minimum level as a critical threshold of notification times for inland waterway transport as there are no concepts in SCM about it. However, they may be subject to cognitive or motivational bias, which must be addressed by the concept and methods of gaining reliable expert knowledge (Miles, Huberman and Saldaña, 2014). These insights from the contributory expertise of the experts can be linked-to in the analysis of empirical data from historical disruptions. This also diminishes the potential bias of the experts due to a quantitative methodology. The workshop and the data analysis together form the mixed-methodology of this paper.

3.1 Workshop

Expert knowledge has to be extracted and used to identify appropriate levels of notification time and to be able to deploy SCRM mitigation strategies in case of infrastructure restrictions. Therefore, an interdisciplinary workshop concept is developed by considering an interdisciplinary workshop as an openly structured working meeting with participants from different disciplines, in which different questions can be worked on together by using appropriate techniques (Niederberger and Wassermann, 2015).

The development of the workshop concept must meet certain conditions to benefit from interdisciplinary workshops. These conditions concern, among others, a suitable location and a positive working atmosphere as well as a clear definition of the topic or objective. The composition of the participants also plays an essential role since it influences the arrangement of the points mentioned above (Beermann et al., 2015; Lipp and Will, 2008). One aim was to identify appropriate notification times for infrastructures and, to be suitable for causal research, identify their dependency on reasons for the infrastructure closure. Expert interviews within the held workshop should allow identifying critical thresholds of notification times, which affect maintenance and logistics operations.

Two separate workshops took place ten months apart. The contributions regarding the mentioned sub-target took about half a day each. Six invited participants from all relevant stakeholders attended both workshops; this includes experts from public authorities, science and industry. The groups of participants overlapped but were not identical.

The first workshop served to identify predominantly qualitative correlations. Through open discussions and group work, insights could be gained and manifested, which are essential for the risk assessment of the infrastructures under consideration, including the need to examine the question of appropriate notification times. Interactive discussions and an attempt at gamification were developed and applied to address the risk assessment within the second workshop. In particular, the approach of gamification could manifest insights into the possible mitigation measures that differ in the perspectives of the stakeholders.

Overall, open discussions contributed to identifying essential relationships and processes. Subsequently, the experts were confronted with scenarios and conclusions based on these, which could be falsified, validated, or extended by the methods used in the workshop.

3.2 Data Analysis

In addition to the workshops, this research elaborates on the relation of the notification time by conducting data analysis about the situation in inland waterway transport. This contributes quantitative insights into the qualitative relationships obtained by the experts.

The notification time for restrictions to inland waterway transport is determined by an analysis of 'Notifications to Skippers', which is in the following abbreviated as NtS, which are issued by the WSV and are accessible online (ELWIS-database, 2019). NtS are usually targeted to all vessels at the waterway and inform about changes of valid regulations or navigational charts. They also contain temporary directives from the WSV or shipping police that affect navigability and thus are of interest.

NtS contain information about the issuing instance, the date of issuing, the date of validity and date of expiry. Also, the variable *interval* indicates whether the restriction is valid throughout or only at particular time intervals of a day. The data includes the *types of restriction* to navigability, the *affected group* and states a *reason*. Furthermore, a NtS refers to an affected waterway *infrastructure object* and its *waterway*. This enables the analysis of the *notification time* in which stakeholders can reorganise scheduled transports. Moreover, NtS contain further information, which allows data drill-downs, like the mean of communication, the range of restriction, the reporting obligation, version number, the issuing instance, and additional information provided by the issuing instance.

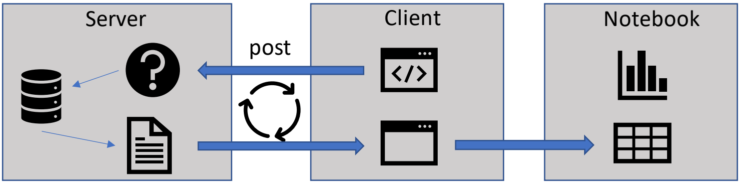


Figure 2: Schema of the data collection process

Figure 2 depicts the whole process: The authors collected the NtS individually through the ELWIS-web interface with the python-requests module by using a post-request to the "ELWIS"-*server* which returns the NtS-document from the database. The document is then fragmented into data entries that are transformed to variables at the *client*-side with python. The created record has a uniform syntax on the *client*-side that is appended to the dataset. The dataset is indexed by the ID of the NtS as well as the locations the NtS refers to. The analysis is then performed on this dataset using a jupyter®-notebook.

The database contains scattered NtS since 2001, albeit continuously since 2007. Overall, the dataset contains 47,425 records and 27 variables. As one NtS-ID can refer to multiple locations, the unique number of NtS totals 39,964. In a first step, only the NtS for the waterways of the West-German canal system is used, dropping the number of records to 3,838.

The records contain information described above and further details separated into the record variables shown in figure 3. Most NtS contain a field for *additional information* specifying the notifications or instructions given

by the waterway authorities. The dataset is mostly complete, as seen in figure 3: Collected data are depicted in dark grey, whereas missing values in the dataset are depicted in white (design by Bilogur, 2018).
Missing information could be completed with further assumptions, which

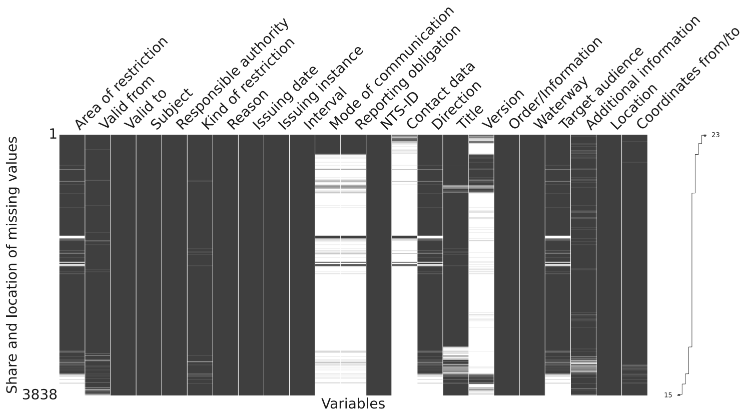


Figure 3: Overview of variables and completeness of the dataset

are backed up by the expert knowledge gained from the workshops discussed in section 3.1. These are namely the following: The NtS are published as notifications with implication on inland waterway transport and not for informational purposes only, which were dropped before. A missing value of the variable *version* indicates NtS without further changes to the notification issued by the authority, meaning a version number of 1. If not otherwise stated, the NtS are released by radio (the value is "UKW"). If not otherwise stated in the column *Interval*, the NtS are valid continuously from the starting date (*Valid from*) until the date of expiry (*Valid to*). Twenty-seven records were deemed not relevant.

NtS purely being issued as an informational note or NtS that were being revoked by the WSV are also dropped. This is indicated either in the title or is identified by value mapping and analysis of the types of restrictions. This eventually drops the relevant dataset to 3,332 records. The distribution of the counts of records for the waterways in the West-German canal network over the years is shown in figure 4. Not many NtS were issued for the DHK, and there are differences in the number of records across the years. The periodicity of records seems to correlate indicating relationships between the canals. The composition of the findings is stated in section 4.2.

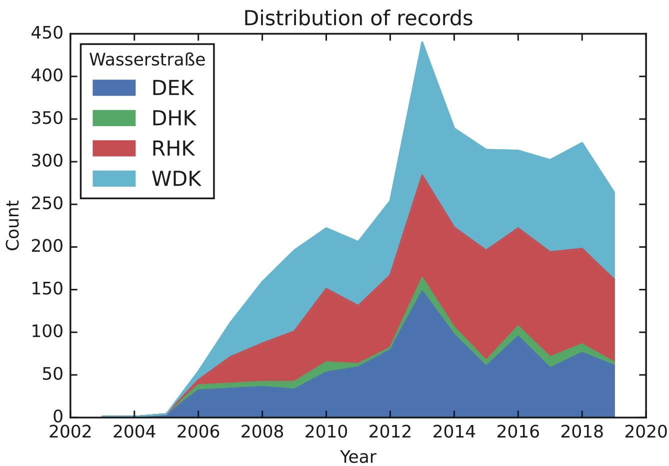


Figure 4: Distribution of NtS records (ELWIS)

4 Findings

By using the described mixed-methods approach, several findings could be extracted and validated with different approaches. In the following, the mostly qualitative results of the workshop are highlighted first. Then, the results of the data analysis are presented.

4.1 Workshop

The findings of the workshops are referenced to by Workshop I (2019) and Workshop II (2020). One of the findings of the workshop implementation was that the possibilities of the industry as a stakeholder are limited and dependent heavily on the notification time. This is partly due to a bottleneck in the transport capacity of alternative modes of transport. Another restricting factor is the storage capacity, which varies for industries. Therefore, the possible stock level and production capacity are identified as further limitation factors. Since those identified limitation factors are finite physical values, they are assumed as fixed values for the analysis of the parameter notification time.
Given those fixed values, an average required minimum notification time of two weeks could be identified, as this is likely to enable the procurement of capacities of rail cargo transport. The consequences of long-term disruptions with a notification period of less than this critical threshold contain significant impacts on businesses in the industry surveyed, which is highly dependent on the functioning of inland waterways. This includes supply bottlenecks up to a complete stop of production. The latter is particularly

critical if the industry concerned is part of critical infrastructures such as public utilities.

No significant pressure in logistics operations is given if the notification time is more than 28 days. This applies to short-term and average restrictions. Whereby restrictions that are in effect for less than a day are considered *short-term,* and average restrictions are manageable by SC operations since valid risk mitigation strategies can still be deployed in time.

The definition of the duration of average restriction differ between industries and business because their SCs have different vulnerabilities to infrastructure closures. Power plants have large storage ranges of up to months so that an early notification time allows for adjusted stockpiling and production planning. Also, road cargo is a possible, albeit costly option. This is not the case for the chemical industry: The storage ranges are within days, and storage is used by both supply and finished products. Hence, this industry needs to maintain a minimum level of access to inland waterway transport during times of temporary restrictions. The information about the interval of the restriction is found in the NtS. Early notification allows for scheduling daily logistics operations more easily to the unrestricted intervals. The strategy of restriction intervals to allow a minimum level of navigability is utilised by the WSV.

The mixed-methods approach shows that some of the restrictions have less relevance for inland waterway transport, like closures due to special caution. However, the workshops revealed that even minor delays of less than one hour potentially stack up because the unloading crew at a port might not be able to clear cargo this day anymore, which leads to further delays. Further findings from the workshops reveal that the direct effects of weather are neglectable in waterway canals. Thus, the limiting factor of inland waterway transport through the canal network are the restrictions communicated by the waterway authorities.

4.2 Data Analysis

The data analysis of the NtS that are communicated by the waterway authorities supports the aforementioned findings: The duration of most restrictions is less than a day and therefore, still provides timeframes for navigability. The types of restriction and their average notification, as well as the duration of closures, are reported for the 3,332 NtS in table 1. It is depicted that the reported mean of notification times for closures is about 22 days and meets the two-week threshold but not the 28 days. However, the median is way below (7 days), suggesting that logistics operations become affected even more (see 4.1). The variable *Time to repair* indicates how long the restriction remains. Further findings are outlined in the figures below.

Table 1: Restrictions of the West-German canal system

		Notification time [d]		Time to repair [d]	
Restriction	Count	mean	Median	mean	median
Closure	1781	22.08	7.0	6.39	0.0
Special caution	535	17.26	4.0	17.23	1.0
Partial closure	369	13.41	5.0	8.16	0.0

		Notification time [d]		Time to repair [d]	
Restriction	Count	mean	Median	mean	median
One-way only	198	14.02	4.0	59.56	6.0
Restrictions	117	2.50	3.0	5.72	1.0
Operations restricted	78	3.26	0.0	49.67	2.0
Docking ban	71	19.22	3.0	16.9	3.0
Maximum Ship length/width	62	32.40	10.5	80.25	8.0
Delays	49	14.86	6.0	28.94	1.0
Operations changed	46	0.13	0.0	295.3	1.0
Operations closed	26	15.19	5.0	7.77	1.0

The availability of inland waterway transport is mainly dependent on the locks and the canals itself which 2,909 records refer to. The statistics of their respective notification times are depicted in the violin graphs in figure 5 and figure 6, which are scaled by the count of records for each category at the x-axis (Design by Waskom et al., 2017).

The blue-coloured violins represent the records where the *Time to repair* [TTR] was less than a day; the brown-coloured violins depict the remaining records. Figure 5 illustrates that the median notification time for closures is about eight days and that 50% of observed values are between zero and 24 days. For closures that last for longer than a day, the average notification time is 25 days. The average notification time for full and partial closures lasting less than a day is significantly lower. This relationship between the medians (white dots) and averages (the middle of the black box of the interquartile ranges) is opposite to the category "Special caution" and the other types of restrictions. This opposite relationship is also partly true for the distribution bandwidth (less kurtosis of the brown-coloured violin for the former categories, significantly more for the latter categories). Furthermore, closures due to special cautions and other reasons have much lower notification days of just about four days. The category "other" in figure 5 mainly features "one-way-only" directives and rather unspecified restrictions as pictured in table 1 above.

Differences exist between the records according to the *reason of restriction*, which is emphasised in the scaled violin plot in figure 6. Figure 6 examines the full closures lasting longer than a day. Here, the interruptions mainly occur due to repairments, which have a shorter average notification time than maintenance operations or scheduled events. The category "other" in figure 6 mainly features inspections and construction operations.

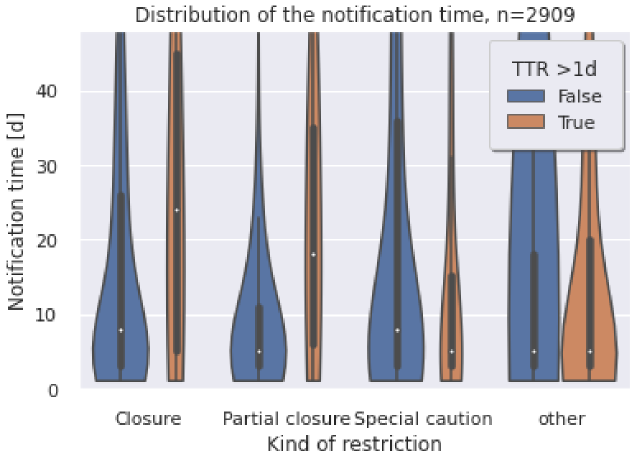


Figure 5: Distribution of the notification time regarding the type of restriction

Figure 6: Distribution of notification time regarding the reason for restriction

Surprisingly, the sound assumption that a longer *Time to repair* would be notified more in advance could not be met based on the underlying data. Even though relationship tests, which included correlation and hypothesis testing, were conducted between the variables *Notification time* and *Time to repair*, the results show no significance for the entire time scale. This is explained, at least partially, by the large variance of closure times caused by accidents which required repairs lasting over a year. Accidents understandably have a notification time of zero, whereas most disruptions of the waterway infrastructure with varying notification times were fixed within hours.

5 Discussion

The presented research outlines an innovative approach to analyse notification time and impact on logistics, which is rarely considered in the literature so far. Whereas expert knowledge within a targeted workshop concept led to findings of processes, industries and mitigation measures, the analysis of historical data could deepen the overall analysis by contributing quantitative findings referring to the notification time. Further relationships between the infrastructure restrictions, the fixing infrastructure operators, and affected industries, show the significance of respecting possible notification times.

The mixed-methods approach reveals that some of the restrictions have less relevance for inland waterway transport, like closures due to special caution. Furthermore, ships in the West-German canal system often drive a roundabout to the seaports, which limits the possibility of earlier procurement, as transport capacities are in transit.

Limitations of the presented research exist primarily in the dependence on the data quality, which regards to both applied methods. Since the quality of the expert knowledge collected in the workshops depends on many factors like personal involvement, these must be considered in order to obtain usable data quality. Furthermore, the data quality and accessibility have a big influence on the results, as well as the quality of assumptions met to complete the incomplete records. These issues were accounted for in the data processing steps and lead, among others, to a reduced number of observations. Overall, it can be stated that the data situation for this conducted research is solid.

All potential sources of interference that could affect the implementation and evaluation of the workshop concept were considered. Moreover, further implications of the extracted expert knowledge supported the data analysis to be able to summarize the types of restrictions to the categories depicted in figure 5 and figure 6.

6 Conclusion

The research reveals a high impact of the notification time on logistics operations in inland waterway transport and reveals the planning reliability for all parties involved. Restrictions that heavily affect navigability, closures, are either tried to be limited to hours at a day or notified in advance. The mixed-methods approach found that the notification time for most of the short-term partial and full closures is below the identified critical threshold. As these pose threats to SC operations, SC planning must account for these restrictions.

This research is innovative as there is little analysis on inland waterway transport as outlined in section 2.1, even though accessible historical data exists, and inland waterway transport is crucial for the chemical and energy industry covered above. This research contributes to the literature by linking critical infrastructure, expert knowledge, and SC operations. Quantitative methods provide the base of broad possibilities for interdisciplinary research. Furthermore, the presented analyses can be used to support SC and infrastructure monitoring processes to account for different risk mitigation strategies depending on the notification time.

Further research could integrate the notification time in the anticipation stage of the concept of SC resilience, as the two concepts are related like the disaster management cycle in figure 1 suggests. SC resilience covers the time aspect concerning *recovery time* already. Also, further research could investigate changes in SC operations due to notification time or the restrictions itself by data analysis of inland AIS-data, which tracks ship movements.

Acknowledgements

The authors want to thank the partners in the joint research project PREVIEW. The project is funded by the security research fund of transportation infrastructure (SIFO) of the German Federal Ministry of Education and Research (BMBF). Special thanks go to the WSV Duisburg-Meiderich, which shared their expertise, thereby supporting this research.

References

Baird, A. "Towards an Explanation and Reduction of Disaster Proneness." PhD Thesis, Bradford University, 1975.

BASF SE. "BASF Report 2018," February 2019. www.basf.com/cz/documents/BASF_Report_2018.pdf.

Beermann, Susanne, Eva Augart, and Monika Schubach. Workshops: Vorbereiten, Durchführen, Nachbereiten. Haufe TaschenGuide. Freiburg: Haufe-Lexware GmbH & Co. KG, 2015. https://www.wiso-net.de/document/HAUF,AHAU__9783648077443127.

Bilogur, Aleksey. "Missingno: A Missing Data Visualization Suite." The Journal of Open Source Software 3, no. 22 (February 27, 2018): 547. https://doi.org/10.21105/joss.00547.

Bowersox, Donald J. Supply Chain Logistics Management. 4. ed. New York, NY: McGraw-Hill, 2013. http://www.loc.gov/catdir/enhancements/fy1205/2011030996-d.html.

Caris, An. "Simulation and Optimisation of Intermodal Barge Transport Networks." 4OR 9, no. 2 (June 2011): 211–14. https://doi.org/10.1007/s10288-010-0142-8.

Coetzee, Christo, and Dewald van Niekerk. "Tracking the Evolution of the Disaster Management Cycle: A General System Theory Approach." Jàmbá: Journal of Disaster Risk Studies 4, no. 1 (2012). https://doi.org/10.4102/jamba.v4i1.54.

ELWIS-database. “Nachrichten Für Die Binnenschifffahrt (NfB).” Wasserfahrt und Schifffahrtsverwaltung des Bundes, 2019. www.elwis.de/DE/dynamisch/mvc/main.php?modul=nfb.

Faertes, Denise. "Reliability of Supply Chains and Business Continuity Management." Procedia Computer Science 55 (2015): 1400–1409. https://doi.org/10.1016/j.procs.2015.07.130.

Fujimoto, Takahiro. Supply Chain Competitiveness and Robustness: A Lesson from the 2011 Tohoku Earthquake and Supply Chain \textquotedblVirtual Dualization\textquotedbl, 2011.

Hosseini, Seyedmohsen, Dmitry Ivanov, and Alexandre Dolgui. "Review of Quantitative Methods for Supply Chain Resilience Analysis." Transportation Research Part E: Logistics and Transportation Review 125 (May 2019): 285–307. https://doi.org/10.1016/j.tre.2019.03.001.

Käki, Anssi, Ahti Salo, and Srinivas Talluri. "Disruptions in Supply Networks: A Probabilistic Risk Assessment Approach." Journal of Business Logistics 36, no. 3 (2015): 273–287. https://doi.org/10.1111/jbl.12086.

Khan, Himayatullah, Laura Giurca Vasilescu, and Asmatullah Khan. "Disaster Management Cycle – a Theoretical Approach." Management and Marketing Journal 6, no. 1 (2008): 43–50.

Kleindorfer, Paul R., and Germaine H. Saad. "Managing Disruption Risks in Supply Chains." Production and Operations Management 14, no. 1 (2005): 53–68. https://doi.org/10.1111/j.1937-5956.2005.tb00009.x.

Krausmann, E., V. Cozzani, E. Salzano, and E. Renni. "Industrial Accidents Triggered by Natural Hazards: An Emerging Risk Issue." Natural Hazards and Earth System Sciences 11, no. 3 (2011): 921–929. https://doi.org/10.5194/nhess-11-921-2011.

Lipp, Ulrich, and Hermann Will. Das Große Workshop-Buch: Konzeption, Inszenierung Und Moderation von Klausuren, Besprechungen Und Seminaren. 8., überarbeitete und erweiterte Auflage. Reihe Beltz Weiterbildung. Weinheim and Basel: Beltz Verlag, 2008. http://deposit.d-nb.de/cgi-bin/dokserv?id=3049802&prov=M&dok_var=1&dok_ext=htm.

Miles, Matthew B., A. M. Huberman, and Johnny Saldaña. Qualitative Data Analysis: A Methods Sourcebook. Third edition. Thousand Oaks, Califorinia: SAGE Publications, Inc, 2014.

Neal, David. "Reconsidering the Phases of Disaster." International Journal of Mass Emergencies and Disasters 15, no. 2 (1997).

Niederberger, Marlen, and Sandra Wassermann, eds. Methoden Der Experten- Und Stakeholdereinbindung in Der Sozialwissenschaftlichen Forschung. Wiesbaden: Springer VS, 2015. https://doi.org/10.1007/978-3-658-01687-6.

Pant, Raghav, Kash Barker, and Thomas L. Landers. "Dynamic Impacts of Commodity Flow Disruptions in Inland Waterway Networks." Computers & Industrial Engineering 89 (November 2015): 137–49. https://doi.org/10.1016/j.cie.2014.11.016.

Park, YoungWon, Paul Hong, and James Jungbae Roh. "Supply Chain Lessons from the Catastrophic Natural Disaster in Japan." Business Horizons 56, no. 1 (2013): 75–85. https://doi.org/10.1016/j.bushor.2012.09.008.

Reuters. "BASF Says It Has Prepared for Any Repeat of Low Rhine Water Levels - Reuters," May 2019. www.reuters.com/article/us-basf-results-rhine/basf-says-it-has-prepared-for-any-repeat-of-low-rhine-water-levels-idUSKCN1S90LZ.

Romeike, Frank, and Gerrit Jan Brink. “Frühwarnindikatoren: Kritischer Faktor Spätwarnung: Erkennung von Trends Und Frühen Signalen Im Risikomanagement.” RISIKO MANAGER, no. 13 (2006): 4–10.

Sawik, Tadeusz. "Disruption Mitigation and Recovery in Supply Chains Using Portfolio Approach." Omega 84 (2019): 232–248. https://doi.org/10.1016/j.omega.2018.05.006.

Shukla, Aviral, Vishal Agarwal Lalit, and Venkat Venkatasubramanian. "Optimizing Efficiency–Robustness Trade–Offs in Supply Chain Design under Uncertainty Due to Disruptions." International Journal of Physical Distribution & Logistics Management 41, no. 6 (2011): 623–647. https://doi.org/10.1108/09600031111147844.

Statistische Bundesamt, 2019. Fachserie Binnenschifffahrt. In: statistische Datenbank, Fachserie Binnenschifffahrt (monatlich). [online] Available at: <genesis.destatis.de>.

Todd, David, and Todd, Hazel. "Natural Disaster Response." World Bank Publications, 2011.

Tomlin, Brian. "On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks." Management Science 52, no. 5 (2006): 639–657. https://doi.org/10.1287/mnsc.1060.0515.

Waskom, M. et al., 2017. mwaskom/seaborn: v0.8.1 (September 2017), Zenodo. Availa-ble at: https://doi.org/10.5281/zenodo.883859.

Wieland, Andreas, and Wallenburg, Carl Marcus. "Dealing with Supply Chain Risks." International Journal of Physical Distribution & Logistics Management 42, no. 10 (2012): 887–905. https://doi.org/10.1108/09600031211281411.

Workshop I, 2019. Project: PREVIEW, www.preview-projekt.de. Karlsruhe, 01.-02.04.2019.

Workshop II, 2020. Project: PREVIEW, www.preview-projekt.de, Karlsruhe, 17.-18.02.2020

Yang, Lupeng, Zhiwei Xing, and Te Shi. "Risk Assessment of Ship Navigation Collision in Inland Waterway Transportation System Based on Bayesian Method." IOP Conference Series: Materials Science and Engineering 780 (April 10, 2020): 062018. https://doi.org/10.1088/1757-899X/780/6/062018.

Yu, Haisheng, Amy Z. Zeng, and Lindu Zhao. "Single or Dual Sourcing: Decision-Making in the Presence of Supply Chain Disruption Risks." Omega 37, no. 4 (2009): 788–800. https://doi.org/10.1016/j.omega.2008.05.006.

Zhang, Di, Xinping Yan, Zaili Yang, and Jin Wang. "An Accident Data–Based Approach for Congestion Risk Assessment of Inland Waterways: A Yangtze River Case." Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability 228, no. 2 (April 2014): 176–88. https://doi.org/10.1177/1748006X13508107.

Improving Risk Assessment for Interdependent Urban Critical Infrastructures

Sandra König [1]

1 – Austrian Institute of Technology

Purpose: Urban critical infrastructures are highly interdependent not only due to their vicinity but also due to the increasing digitalization. In case of a security incident, both the dynamics inside each infrastructure and interdependencies between them need to be considered to estimate the overall impact on a city.
Methodology: An existing high-level model of dependencies between critical infrastructures is extended by incorporating more details on the individual infrastructure's behavior. To this end, a literature review on existing models for specific sectors is conducted with a special focus on machine learning models such as neural networks.
Findings: Existing models for the dynamics of specific urban infrastructures are reviewed and integration in an existing dependency model is discussed. A special focus lies on simulation models since the extended model should be used to evaluate consequences of a security incident in a city.
Originality: Existing risk assessment approaches typically focus on one type of critical infrastructures rather than on an entire network of interdependent infrastructures. However due to the increasing number of interdependencies, a more holistic view is necessary while the dynamics inside each infrastructure should also be considered.

First received: 27. Feb 2020 Revised: 22. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

The benefit of models and simulation in systems of critical infrastructures in security has long been recognized (McLean et al., 2011). Existing simulation approaches may support risk assessment of interconnected critical infrastructures, as in an urban environment. Any holistic risk assessment of urban critical infrastructures should comprise two major parts: a model of all involved infrastructures and a description of the interdependencies between them. The latter is typically an abstract high-level model, e.g., a representation of the network of critical infrastructures as a graph where the critical infrastructures are represented as nodes and the interdependencies as edges. The description of the individual infrastructures depends on the amount of available information. In the simplest case, the functionality is measured on a qualitative scale. The dynamics that yield to changes of the functionality need to be investigated for each infrastructure individually and thus the specific infrastructure models require detailed information and domain knowledge. Risk managers rarely have both a good overview and a deep knowledge of all relevant processes in different infrastructures. One way to approach this problem is to integrate existing simulation models into the high-level dependency model, which is the topic of this article. The proposed method uses neural networks imitating existing domain-specific simulations to enable, or at least simplify, combination of the local views to a simulation model for the entire network of infrastructures.

2 Domain-Specific Simulation Models

This section provides a short overview on domain-specific simulation models that might be integrated into a high-level model of interdependent critical infrastructures. The focus is on transport, energy and water, where a lot of research has already been done, but also food and media are investigated considered relevant when analyzing security of urban infrastructures. Details can be found in the cited papers.

2.1 Transport

Simulation tools for specific transportation systems have been developed and used during the last decades, e.g. for railway, underground and roads. The increased use of traffic simulation has led to guidelines on their application (Olstam and Tapani, 2011).

The network simulation tool OpenPowerNet (Institute of Railway Technology, 2020) focuses on railway power supply networks. It allows simulation of common power supply systems while taking into account the electrical network structure (Stephan, Jacob and Scheiner, 2008). In the UK, railway simulation modeling software has been applied to design baggage transfer (Yeung and Marinov, 2017).

The open source package SUMO (Simulation of Urban MObility) allows simulation of traffic in large scale networks. An overview on recent developments and application of the tool is given in (Lopez et al., 2018).

A model similar to the one we propose here for general infrastructures already exists for the transportation domain: artificial neural networks are used to forecast onboard passenger flows on metro lines and support control and management strategies on transportation systems (Gallo et al., 2019). The model describes the passenger flows as a function of the number of passengers at stations, counted at turnstiles. Training data for the neural network are gained from existing simulation data of a dynamic loading procedure or the rail line.

2.2 Energy Sector

A powerful simulation environment is Gridlab-D (Chassin, Schneider and Gerkensmeyer, 2008; GridLAB-D Wiki, 2020), which is especially applicable to smart grids. Further notable simulation tools include MYNTS (Fraunhofer SCAI, 2020), an extension to the network simulator ns-3 (Wu, Nabar and Poovendran, 2011) or the combined simulation framework for energy and gas systems (Erdener et al., 2014).
An overview on simulation tools for smart grid is given in (Bindner and Marinelli, 2013) and a review of modelling tools for energy and electricity systems with a focus on renewables is provided in (Ringkjøb, Haugan and Solbrekke, 2018).
Interactions between power systems and ICT are investigated in (Müller et al., 2018), models for electricity and gas systems in (Erdener et al., 2014).

2.3 Water

Simulation models are applied in many different parts of water utilities, ranging from water quality (Ziemińska-Stolarska and Skrzypski, 2012) to water distribution systems (Paluszczyszyn, Skworcow and Ulanicki, 2015). Simulation models of urban water management are reviewed in (Peña-Guzmán et al., 2017) and an overview on water resource software is discussed in (Borden, Gaur and Singh, 2016).

2.4 Food

The use of simulation in the area of food supply is relatively new. A discrete event simulation has been used to investigate sustainable delivery of food (Leithner and Fikar, 2019) und simulations have been used to optimized the economic effect of producers (Tundys and Wiśniewski, 2020) and both approaches are particularly paying attention to the supply chain for organic products. Agent-based models may be used for efficient crop production supply chain redesign (Borodin et al., 2014) to simulate agri-food supply chains (Utomo, Onggo and Eldridge, 2018).

2.5 Media

Some countries such as Germany specify media as crucial for society and thus put effort in protecting it (Federal Ministry of the Interior, 2009). Especially social media have the potential to significantly influence consequences of events or attacks such as the one in Munich in 2016 (the local, 2016). Numerous simulation models exist for spreading of rumors through twitter (Serrano, Iglesias and Garijo, 2015).

3 Interdependent Urban Critical Infrastructures

A network of interdependent critical infrastructure is conveniently described by a two-layer model - a high-level "outer" model describing the interdependencies and more detailed "inner" models of the different infrastructure nodes. The interdependencies are vividly representable by a directed graph where nodes represent critical infrastructures and edges correspond to dependencies. Dependencies of any kind should be taken into account, ranging from physical or logical dependencies to geographic proximity, which is an essential factor in urban infrastructures.
A core part of risk assessment in infrastructure networks is risk evolution, i.e., understanding impacts of reduced availability of one or more infrastructure on the others. In alignment with the recommendation of a qualitative risk management (Münch, 2012) it is useful to represent the level of functionality of each infrastructure on a finite scale, e.g., ranging from 1 (properly working) to 5 (not working). How a critical infrastructure changes from one state to another depends on its neighbors, e.g. a hospital might be affected by limited availability of power, as well as on the internal dynamics of the infrastructure, e.g., the number of available emergency generators. Manifold methods exist to describe the dynamics inside the critical infrastructures. The actual model choice is strongly influenced by the availability of information on the individual infrastructure. If a conditional likelihood for each change can be assigned, a Markov model might be used for a conservative estimation of the overall functionality (König and Rass, 2018). If the reactions to an external incident can be described more explicitly, automata models can be used (König et al., 2019). In both cases, data from simulations or from domain experts can support statistical estimation

of respective parameters; it is even possible to use machine learning to train other machine learning models (Rass and Schauer, 2019).
Training such models is not always possible due to limited data. Individual models for the various domains often exist but are typically not compatible. One way to integrate existing simulation methods, as presented in the last section, is to mimic their behavior by re-modelling them as neural networks. The various nets can then be connected in order to simulate the entire network. The remainder of this section describes the integration into the high-level network model. The approach is illustrated in Figure 1.

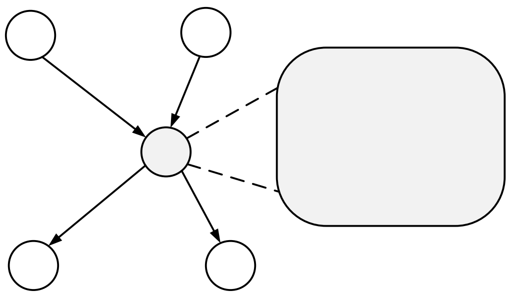


Figure 1: High-level view of dependency model

The main challenge is the combination of potentially many different infrastructure models. One approach is to allow edges of the dependency graph to be used for communication between nodes, transmitting two pieces of information: (a) the current state of a CI, and (b) parameters refining this risk situation (these will determine the reaction of the dependent CIs). For example, if a power supplier CI reports a state "problem" (represented by 2) to a water provider, this information is extended by information on the current (reduced) level of energy supply, which causes the pumps of the water supplier to run at lower performance. In the dependency graph the edge from the power supply to the water provider signalizes the level of functionality and augments this information with data relevant for the dependent CI. The simulation model of the water provider will in turn be used under an adapted setting due to the messages from the energy provider. Such communication between components works best when the components are represented by homogeneous models. To that end, machine learning techniques may be applied to mimic the behavior of a CI, i.e., machine learning systems such as (deep) neural networks may be trained with data from the identified simulation models. Connecting these digital twins into an overall co-simulation model is then a matter of "connecting" software modules accordingly, that is, the output parameters of one deep neural network are input to the neural network.

4 Conclusion

Integrating existing simulation models of critical infrastructures into a dependency model is one way to support risk assessment of interdependent urban critical infrastructures. The main issues to be investigated in future work are the choice of suitable simulations methods and details on the co-simulation, e.g. avoiding oscillation in the network.
While assemble existing software pieces may be challenging, artificial intelligence (AI) and machine learning may be an alternative, e.g. when used in a heterogeneous co-simulation environment. Their high flexibility enables cross-domain co-simulation and incorporation of existing simulation methods. It overcomes the shortcomings of most machine learning techniques, namely the huge amount of training data and the missing expalinability. Training data are generated by the underlying simulation models and these models provide, to some extent, knowledge about the specific domain, i.e., the domain knowledge may help explaining the internal behavior. Further, the proposed method allows cause analysis in the big picture, i.e., identification of infrastructures that may trigger cascading effects. Overall, the combination of AI and simulation for risk management appears as a promising direction of further research.

Acknowledgement

This work was supported by the research project ODYSSEUS ("Simulation und Analyse kritischer Netzwerk-Infrastrukturen in Städten") funded by the Austrian Research Promotion Agency under Grant No. 873539.

References

Anon 2020. GridLAB-D Wiki. [online] Available at: <http://gridlab-d.shoutwiki.com/wiki/Main_Page> [Accessed 15 May 2020].

Bindner, H.W. and Marinelli, M., 2013. Overview of Simulation Tools for Smart Grids. European Energy Research Alliance.

Borden, J.C., Gaur, A. and Singh, C., 2016. Water resource software : application overview and review. Available at: <http://documents.worldbank.org/curated/en/279391467995445292/Water-resource-software-application-overview-and-review>.

Borodin, V., Bourtembourg, J., Hnaien, F. and Labadie, N., 2014. An application of the discrete event simulation for efficient crop production supply chain re-design. 10th International Conference on MOdeling, Optimization and SIMla-tion. Nancy, France.

Chassin, D.P., Schneider, K. and Gerkensmeyer, C., 2008. GridLAB-D: An open-source power systems modeling and simulation environment. In: 2008 IEEE/PES Transmission and Distribution Conference and Exposition. [online] Exposition. Chicago, IL, USA: IEEE.pp.1–5. Available at: <http://ieeexplore.ieee.org/document/4517260/> [Accessed 15 May 2020].

Erdener, B.C., Pambour, K.A., Lavin, R.B. and Dengiz, B., 2014. An integrated simulation model for analysing electricity and gas systems. International Journal of Electrical Power & Energy Systems, 61, pp.410–420.

Federal Ministry of the Interior, 2009. National Strategy for Critical Infrastruc-ture Protection. [online] Berlin. Available at: <https://www.bmi.bund.de/SharedDocs/downloads/EN/publikationen/2009/kritis_englisch.pdf?__blob=publicationFile&v=1>.

Fraunhofer SCAI, 2020. Multiphysical network simulator MYNTS. [online] Sankt Augustin, Germany. Available at: <https://www.scai.fraunhofer.de/en/business-research-areas/network-evaluation-technologies/products/mynts.html> [Accessed 9 Jul. 2020].

Gallo, M., De Luca, G., D'Acierno, L. and Botte, M., 2019. Artificial Neural Net-works for Forecasting Passenger Flows on Metro Lines. Sensors, 19(15), p.3424.

Institute of Railway Technology, 2020. OpenPowerNet. [online] Dresden. Availa-ble at: <https://www.openpowernet.de/>.

König, S. and Rass, S., 2018. Investigating Stochastic Dependencies Between Critical Infrastructures. International Journal on Advances in Systems and Measurements, 11(3 & 4), pp.250–258.

König, S., Rass, S., Rainer, B. and Schauer, S., 2019. Hybrid Dependencies be-tween Cyber and Physical Systems. In: Intelligent Computing. Computing Conference. Cham: Springer Nature Switzerland.pp.550–565.

Leithner, M. and Fikar, C., 2019. A simulation model to investigate impacts of facilitating quality data within organic fresh food supply chains. Annals of Operations Research. [online] Available at: <http://link.springer.com/10.1007/s10479-019-03455-0> [Accessed 6 May 2020].

Lopez, P.A., Wiessner, E., Behrisch, M., Bieker-Walz, L., Erdmann, J., Flotterod, Y.-P., Hilbrich, R., Lucken, L., Rummel, J. and Wagner, P., 2018. Microscopic Traffic Simulation using SUMO. In: 2018 21st International Conference on In-telligent Transportation Systems (ITSC). [online] 2018 21st International Conference on Intelligent Transportation Systems (ITSC). Maui, HI: IEEE.pp.2575–2582. Available at: <https://ieeexplore.ieee.org/document/8569938/> [Accessed 15 May 2020].

McLean, C., Lee, Y.T., Jain, S. and Hutchings, C., 2011. Modeling and Simulation of Critical Infrastructure Systems for Homeland Security Applications. NIST.

Müller, S.C., Georg, H., Nutaro, J.J., Widl, E., Deng, Y., Palensky, P., Awais, M.U., Chenine, M., Kuch, M., Stifter, M., Lin, H., Shukla, S.K., Wietfeld, C., Rehtanz, C., Dufour, C., Wang, X., Dinavahi, V., Faruque, M.O., Meng, W., Liu, S., Monti, A., Ni, M., Davoudi, A. and Mehrizi-Sani, A., 2018. Interfacing Power System and ICT Simulators: Challenges, State-of-the-Art, and Case Studies. IEEE Transactions on Smart Grid, 9(1), pp.14–24.

Münch, I., 2012. Wege zur Risikobewertung. In: P. Schartner and J. Taeger, eds. DACH Security 2012. syssec.pp.326–337.

Olstam, J. and Tapani, A., 2011. A Review of Guidelines for Applying Traffic Simu-la-tion to Level-of-service Analysis. Procedia - Social and Behavioral Sciences, 16, pp.771–780.

Paluszczyszyn, D., Skworcow, P. and Ulanicki, B., 2015. Modelling and Simula-tion of Water Distribution Systems with Quantised State System Methods. Procedia Engineering, 119, pp.554–563.

Peña-Guzmán, C.A., Melgarejo, J., Prats, D., Torres, A. and Martínez, S., 2017. Urban Water Cycle Simulation/Management Models: A Review. Water, 9(4), p.285.

Rass, S. and Schauer, S., 2019. Refining Stochastic Models of Critical Infrastruc-tures by Observation. In: Proceedings of the 56th ESReDA Seminar, European Atomic Energy Community, JRC Publications. [online] Publications Office of the European Union.pp.212–223. Available at: <https://ec.europa.eu/jrc/en/publication/critical-services-continuity-resilience-and-security-proceedings-56th-esreda-seminar>.

Ringkjøb, H.-K., Haugan, P.M. and Solbrekke, I.M., 2018. A review of modelling tools for energy and electricity systems with large shares of variable renewa-bles. Renewable and Sustainable Energy Reviews, 96, pp.440–459.

Serrano, E., Iglesias, C.A. and Garijo, M. eds., 2015. A Survey of Twitter Rumor Spreading Simulations. In: Lecture Notes in Computer Science. [online] 7th International Conference, ICCCI 2015, Madrid, Spain, September 21-23, 2015. Cham: Springer International Publishing. Available at: <http://link.springer.com/10.1007/978-3-319-24069-5> [Accessed 18 May 2020].

Stephan, A., Jacob, M. and Scheiner, H., 2008. OpenPowerNet – simulation of railway power supply systems. [online] COMPRAIL 2008. Toledo, Spain.pp.449–459. Available at: <http://library.witpress.com/viewpaper.asp?pcode=CR08-044-1> [Accessed 5 May 2020].

the local, 2016. Social media a blessing and a curse in Munich shooting. Availa-ble at: <https://www.thelocal.de/20160724/social-media-a-curse-and-a-blessing-in-munich-shooting>.

Tundys, B. and Wiśniewski, T., 2020. Benefit Optimization of Short Food Supply Chains for Organic Products: A Simulation-Based Approach. Applied Scienc-es, 10(8), p.2783.

Utomo, D.S., Onggo, B.S. and Eldridge, S., 2018. Applications of agent-based modelling and simulation in the agri-food supply chains. European Journal of Operational Research, 269(3), pp.794–805.

Wu, H., Nabar, S. and Poovendran, R., 2011. An Energy Framework for the Net-work Simulator 3 (ns-3). In: Proceedings of the 4th International ICST Confer-ence on Simulation Tools and Techniques. [online] 4th International ICST Conference on Simulation Tools and Techniques. Barcelona, Spain: ACM. Available at: <http://eudl.eu/doi/10.4108/icst.simutools.2011.245534> [Accessed 15 May 2020].

Yeung, H.K. and Marinov, M., 2017. A state of the art on railway simulation mod-elling software and its application to designing baggage transfer service. RailExchange conference 2017. Newcastle upon Tyne: Springer.

Ziemińska-Stolarska, A. and Skrzypski, J., 2012. Review of Mathematical Models of Water Quality. Ecological Chemistry and Engineering S, 19(2), pp.197–211.

III.
Supply Chain Analytics and Artificial Intelligence

Product Lifecycle Optimization by Application of Process Mining

Marco Meßner [1] and Johannes Dirnberger [2]

1 – HOERBIGER Service-Gmbh

2 – FH JOANNEUM – Institute of Industrial Management

Purpose: Active product life cycle management contributes to supply chain optimization. However, in nowadays industry the high number of variants and backward loops complicate tracing the entire product lifecycle in an ERP system. Consequently, product lifecycle and corresponding process-organizational optimizations are difficult to implement using established analysis. The aim is to challenge process mining as an alternative to address these aspects.

Methodology: This paper, therefore, applies process mining to the ERP data of a component manufacturer in the metalworking industry. For this purpose, optimization potentials are derived from a literature research and subsequently validated by the application of process mining. Thereby, the data sample comprises 202 products with 15,000 corresponding activities, which were accumulated in the period 2017 to 2019.

Findings: Process mining reveals the product lifecycles and allows to take different analysis perspectives, such as a market or product category view. Firstly, potentials in a variant-driven business for PLM will be elaborated. Secondly, process-organizational recommendations for the product management are developed. Thus, this paper offers a concrete approach to mapping and analyzing the product lifecycle by application of process mining.

Originality: On the one hand, current analysis tools used in ERP systems merely assess the products actual status. On the other hand, PLM systems are regarded as costly due to the complexity but also a continuous process view is not its main focus. Nevertheless, there is little literature on alternatively using process mining in this context.

First received: 2. Apr 2020 Revised: 5. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

Effective data management is a prerequisite for large manufacturing companies that have to "handle considerable amounts of data" due to broad product ranges with numerous complex products that are tailored to the customer (Saaksvuori and Immonen, 2008, p.5.). One concept for meeting this challenge is Product Lifecycle Management (PLM) (Saaksvuori and Immonen, 2008, p.3.). Stark (2017, p.13) defines PLM as "the business activity of managing, in the most effective way, a company's products all the way across their lifecycles; from the very first idea for a product all the way through until it is retired and disposed of". Stark (2020, p.6) further specifies the phases that a product goes through in its life cycle from the perspective of a manufacturing company as *Ideation*, *Definition*, *Realization*, *Service* and *Retirement*.

The origins of PLM lie in the Engineering Data Management (EDM) and Product Data Management (PDM) of the late 1980s, where the aim was handling the increasing number of Computer Aided Design (CAD) drawings (Saaksvuori and Immonen, 2008, p.2). The objectives of PLM today, however, are strongly focused on process optimization for the purpose of financial performance, time reduction, quality improvement and business improvement as Stark (2020, p.17) shows. As examples of business objectives, he cites the extension of product life to increase revenues, reduce development costs, reduce time to market, reduce customer complaints and increase the product release rate.

Special systems exist to support PLM. However, there exist some challenges in this context. Before benefiting from a PLM system, the initial setup is the first obstacle. PLM systems are complex and accompanied by certain dependence on the software provider, especially when problems arise. Furthermore, investment costs of around € 500,000, such as those incurred by an engineering firm with 220 employees, also illustrate a financial issue. (Hansen, 2008)

It finally turns out that the spread of PDM and PLM software is not yet as widespread as a telephone survey conducted in 2017 with 505 managers interviewed, from German industrial companies with at least 20 employees who are responsible for digitization in their company shows. While CAD software is used by 92% and 5% are planning to use it, only 41% use PDM or PLM software and only 8% are planning to use it. (Bitkom Research and Autodesk, 2017)

An alternative way to analyze product life cycles is to analyze activities, digital footprints, in the Enterprise Resource Planning (ERP) system, that are tied to the material master information. In an ERP System, materials are created, changed and used in system applications: In SAP, for instance, the material master is created using transaction MM01 (Frick, et al., 2008, p.59). The material status is then maintained in the basic data sheet and to remain with the SAP example, this is done in transaction MM02 (Benz and Höflinger, 2008, p.88). This status indicates whether restrictions exist for the usability of a material and what these restrictions are. For example, a material can be in development or a discontinued material (SAP Help Portal). Thereby, the selection options for determining the respective material status can be defined as company-specific. All those changes and activities that are executed in an ERP System are stored and allow to analyse product life cycles with ERP data.

However, in nowadays industry the high number of materials and backward loops complicate tracing the entire product lifecycle in an ERP system using established analysis. Therefore, product lifecycle and corresponding process-organizational optimizations are difficult to implement. Since process mining is already applied for other typical process analyses (e.g. purchase-to-pay or offer-to-cash) in an ERP system, it can be an effective alternative for life cycle tracking. The reason is that process mining allows to analyze large amounts of data from the ERP system in a chronological context, based on timestamps (Van der Aalst, 2011, pp.10-13). To examine the suitability of process mining for product life cycle analyses, the following research question arises in this paper:

Which optimization potentials can be identified by the analysis of product life cycles applying process mining on ERP data?

Therefore, the goal of this paper is to apply process mining in a practical use case on the data set of an industrial manufacturing company for the analysis of product life cycles, document the results and thus answering the research question. For this purpose, 202 materials that reached the end of the product life cycle have been selected from a manufacturer's make to order business model. The data comes from the ERP system SAP. The analysis is carried out with Celonis process mining software, which is accessible for academic purposes (Celonis SE, 2020).

2 Process Mining for the ex-post Analysis of as-is Processes

In order to optimize processes in companies, two steps must be carried out beforehand. First, it is necessary to know the processes. For this purpose, data regarding as-is processes is collected. This can be done, for example, by means of widely used methods such as observations, interviews, workshops or the analysis of existing documents or information from IT systems. Secondly, processes are systematically analyzed to identify weaknesses. (Brunner et al., 2017, pp.25-27 and 45f)

The process analysis is the decisive step in the preparation of decisions and, therefore, described in the following.

2.1 Process analysis

The systematic analysis of weaknesses is often done with checklists according to certain perspectives, which also help to identify the causes of problems that have occurred (Best and Weth, 2010, p.85).

These qualitative considerations are reviewed and supplemented by quantitative calculations and simulations. The quantitative process analyses can be divided into ex-ante, real-time and ex-post analyses, depending on the time of the process analysis. Real-time analyses as process monitoring, take place in real time, as the name suggests. Ex-ante analyses are performed before the actual process execution, for planning purposes. An example is process simulation with plan data. Ex-post analyses are carried out after process execution. This allows problem areas such as long lead times to be identified retrospectively. A well-known ex-post analysis method is process mining. (Kühn and Bayer, 2013, p.137f).

Van der Aalst (2011, p.8f) describes process mining as "the idea (…) to discover, monitor and improve real processes (i.e., not assumed processes) by extracting knowledge from event logs readily available in today's systems". According to him, the process-relevant data is scattered across different Process Aware Information Systems (PAIS), such as classic ERP systems and many more. In view of analyzing the product life cycle, it is relevant, as described in the introduction, that the material status is maintained in the ERP system. The changes in the material status are the results of operative processes, which are documented in the ERP system. In addition, ERP systems directly provide the event logs relevant for process mining (van der Aalst, 2011, p.8f). For this reason, process mining is a suitable process analysis technique for retrospectively analyzing the actual life cycle of products, thereby uncovering potential for improvement in the processes. Thus, Process Mining is described in the following.

2.2 Process Mining

Process mining is a relatively young field. In the beginning, small amounts of data were available. Therefore, the algorithms were not very useful in practice. Currently, however, process mining is of great importance in process management theory and practice. (Van der Aalst, 2016, p.20)
Nowadays, the data available in PAIS support whole processes and not individual activities. In addition to ERP systems well-known representatives of PAIS are Customer Relationship Management (CRM) systems, Workflow Management (WFM) systems, Business Process Management (BPM) systems, call center software, high-end middleware and many more. These systems are aware of the process as the completion of one activity triggers

another activity, for example. Secondly, however, there are information systems that only execute individual steps in the process. These include, among others, database systems, mail programs or spreadsheet programs. These informations systems cannot be actively involved in the management or orchestration of the process, because they store process-relevant information in unstructured form. These information systems store process-relevant information in unstructured form. For example, event data is scattered over many tables. In such cases, event data does exist, but is required to be extracted. This data extraction is crucial for process mining. And to make this data from any operational process usable, process mining bridges the gap between data science and process science (Van der Aalst, 2016, p.27f and 32). Regarding process pining techniques, a distinction is made between three types: *Discovery*, *Conformance* and *Enhancement* (Van Der Aalst et al., 2011, pp.172-174).
Van der Aalst (2016, p.33) defines *Discovery* as a technique that "takes an event log and produces a model without using any a-priori information." Essentially, according to him this involves presenting and analyzing the actual process with all its variants. In terms of *Conformance* he speaks of a technique where "an existing process model is compared with an event log of the same process. Conformance checking can be used to check if reality, as recorded in the log, conforms to the model and vice versa. For instance, there may be a process model indicating that purchase orders of more than one million Euro require two checks. Analysis of the event log will show whether this rule is followed or not." Finally, *Enhancement* means to "extend or improve an existing process model using information about the actual process recorded in some event log. Whereas conformance checking

measures the alignment between model and reality, this third type of process mining aims at changing or extending the a-priori model. One type of enhancement is repair, i.e., modifying the model to better reflect reality" (van der Aalst, 2016, p. 33).

The current situation with regard to process mining shows that although it is an important prerequisite that the business processes are mapped in IT systems, incompleteness can be increasingly compensated for. Existing analysis tools can already reconstruct complete process flows from rudimentary or incomplete electronically recorded processes and thus create process models. (Hierzer, 2017, p.87)

At the same time, the selection of relevant data sources is still regarded as crucial for addressing current topics such as the integration of sensor-based, Internet-enabled devices in business processes (Thiede, et al., 2018, p.914).

Even if there are still challenges, the above definitions show the potential that process mining has in theory. Our goal is to use this potential and to apply process mining to a product's life cycle. The use case implemented with real-world data is described in the following chapter.

3 Application of Process Mining for Product Life Cycle Analysis

The basis for the analysis in this paper is a dataset from a make to order business model with high complexity and diversification and is linked to an SAP S4 HANA System. In order to depict the whole process chain there are 202 materials that are at the time of the analysis in the material specific status "End of Life”. The timeframe of the analysis is representing three years. This means no further actions in the system should be executed. At first the *data set***,** then the used *tool* and finally the process mining *analysis* is described in the following.

Description of the Data Set

The first step is to gather material related information from the ERP System. Within this process, the material creation date and all material master changes are extracted. To conduct drill down analysis, more information among sales, purchase and production orders are selected. Specifically, relevant in that case is the creation date of such. In the next step the dataset is prepared for the process mining software in a .csv file, which will be upload to the process mining software.

Applied Process Mining Tool Celonis

With the execution of the analysis a tool has to be selected. The academic aspect of this research allows to use Celonis as a powerful but flexible tool to execute the rather unusual process mining approach. This tool includes the functionality to upload a modified .csv data file. With the right formatting and uploading sequence the data is converted by the process mining engine into the correct format. This builds the process model, the basis for the following analysis.

Analysis

By conducting process analysis or even optimizing processes, there must be an ideal process flow (target process), that functions as the benchmark. The ideal case for our selected dataset looks as follows and represents the lifecycle of a single material. The lifecycle of the material starts with the creation, followed by a workflow to approve the material. The next step is to set the material in the status of a *prototype*. Once the prototype was successful, the material can be set to *supply chain active*. In this stage, sale orders and subsequent purchase or production orders can be created. Once the material reached the peace in sales the material life cycle enters the *phase out* and lastly the *end of life*. The target process is shown in figure 1.

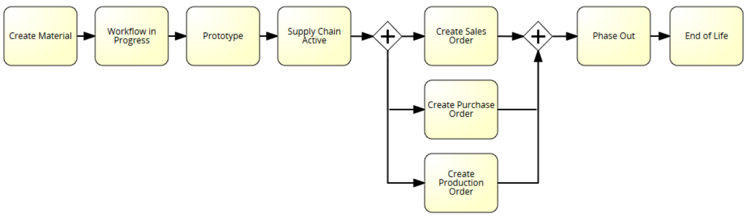


Figure 1: Representation of the company-specific target process

However, process mining technologies reveal the real process flow (as-is process), allow to outline throughput times, find the executed activities and their sequence as well as number of activity executions along the process model. The analysis result reveals the truth behind the process and is shown in figure 2.

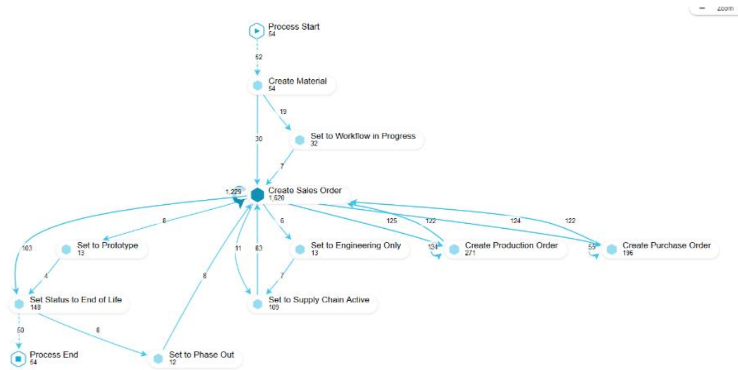


Figure 2: As-is process of the material life cycle

At the example of material lifetime, the first glance of the data shows that this process is not as linear as the target process was described. Materials skip activities, do not follow the path at all, or change the sequence randomly. This picture at the moment does not create value yet. To gain valuable information and derive business decisions, the dataset is needed to be analyzed in detail.

4 Results

The results and focus points are retrieved from typical issues in the day to day business, but do not intend to be exhaustive. In particular, the large amount of data gives seeming endless analysis directions.

The first step in the analysis is to understand the data from a higher level. Viewing the first diagram on the left, the number of materials that followed given paths is represented. In this case only 97 of 202 Materials follow the path of *Set to Workflow in Progress* and *Set to Supply Chain Active*.

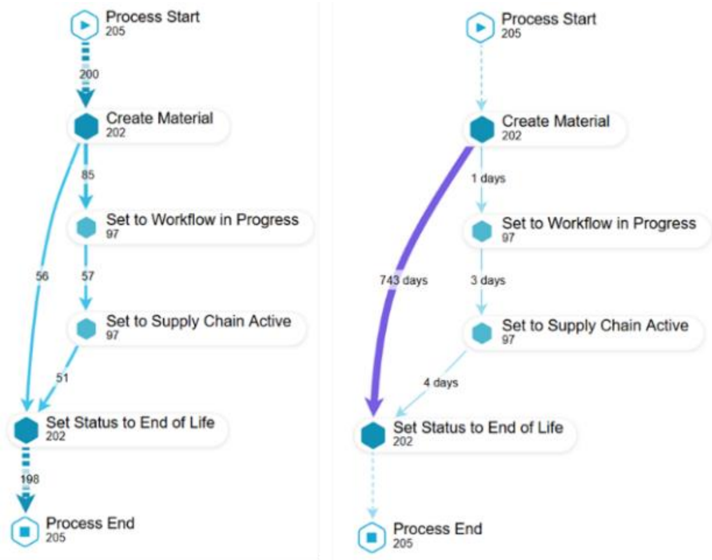


Figure 3: Details of process sequence in throughput time and quantity

One optimization potential might be seen already by switching to the throughput time. To serve the customer as fast as possible, the material

must be set to supply chain active first and the workflow must be finished before a sales order can be create. The throughput time analysis shows already that the workflow execution takes 3 days on median. The variation of this process flow leads to the need for a deeper drilldown.
This view makes the shortcoming of an ideal customer satisfaction more visible. One would be the throughput time overall from the creation of the material to the first sales order creation (41 days median). Others the activities that are executed between those activities, because those drive longer lead times. To show that potential another view that level gives the process flow in the following figure.

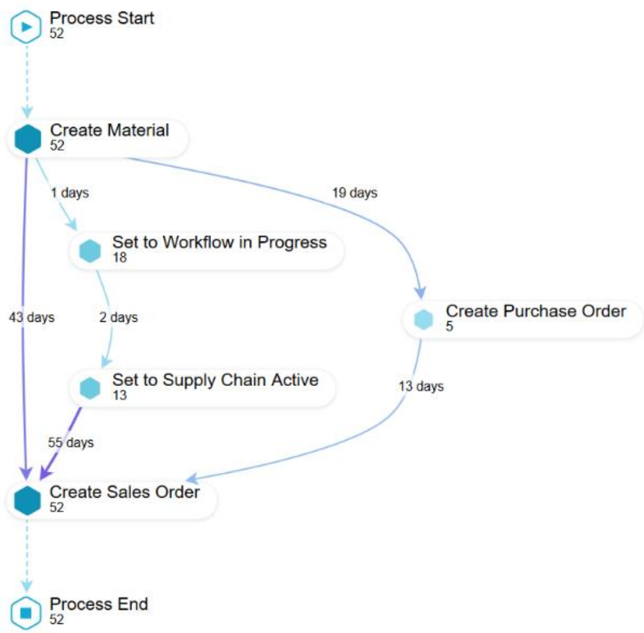


Figure 4: Lead time analysis to serve customers faster

Here several insightful information is hidden, the set workflow activity indeed leads to a longer lead time (18 cases). In 5 cases there is a purchase order created before the sales order was created but this did not affect the throughput time negatively.

Subsequently this information leads to a business research to investigate the real process behind this workflow. Process mining in that case provides the research direction and lists the materials that were affected, but does not give a reason for this.

Focus on Material Status Sequence Violation

The process flow violation in the previous analysis gives an indication that there would be more cases that do not follow the ideal process model.

Another significant process violation to our ideal model is that in 10% of all cases the material status “Prototype” is set after a sales order is created. This has a significant impact on business as the pricing strategy as well as the costing run for the material might not be done yet. The result is a negative impact on the pricing in the future, as the customer might not except price rises in the future anymore.

Focus End of Life

According to the data model the status is set to end of life when there are no further actions taken and the material is not sold or produced in the future. Nevertheless, a process mining based PLM Analysis shows the bare reality.

Those connections to other process steps are found after the status *End of Life* is set:

phase out 3%, set supply chain active 15% and even 4% of materials that have reached their end of life there were sales orders created. To summarize this, more than 20 % of the materials got changed back to another status after it was already set to *End of Life.*

The reason why this can cause concerns for companies is that it keeps the complexity high and drives inventory. For example, if the material reached already the end of life status there should be no material left, the inventory for this product related components should be 0. So whenever there is a sales order created in this status, purchasing must source the components again, possibly to a higher price not in the right quantity or from new vendors. Production must set their machinery up again. In general, the sales of an end of life material cause subsequent non-value adding activities as well as a confusion among departments.

Focus: Changes in a Lifetime

As ERP systems tend to work more autonomously and on a higher level of automation, the number of manual changes is another key performance indicator process mining presents. In the lifetime of 202 Materials, there are 9,880 changes tracked. Hence, this information does not let management perform business decisions. Also in this case a drilldown is needed.

Meaningful are changes of the material description or the purchasing value key, as those count 987 changes and can typically be automated. Modeling this information into quantitative effort and considering each change takes about 3 minutes, the result is that there are about 494 hours spent on changing information in the material master over 3 years of the evaluation timeframe.

Focus: Sales Price Development

With a proper setup of the data model, every change on the material master reveals valuable information. For example, the standard price which is changed over a period of 3 years 515 times and not neglecting this is an essential KPI for the cost tracking. The drilldown to one material reveals even more information. The theory would indicate that product costs and the sales prices go down as the product gets more mature. By applying process mining the reality can be demonstrated in facts and figures: On 156 of 202 materials changes of the standard price are executed. To see if this had a positive or negative impact on business, the development of standard prices is analyzed. The result is that 36 materials show an actual uptrend in costs.

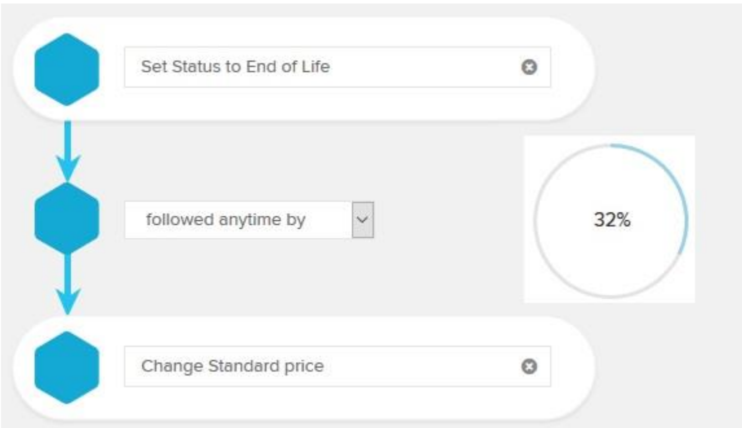


Figure 5: Analysis of process sequence

This information combined with the product life cycle shows that in 32% or on 11 materials those rises were executed after the material status was set to end of life. This supports also the thesis that costs and efforts rise when inactive materials are being touched and foremost used again.

5 Conclusion

The aim of this research was to evaluate if the application of process mining technology in the area of the product life cycle reveals valuable information. When tracing the lifecycle from the creation of the material until it reached the end of life status, using the example of 202 selected materials, the number of activities add up to about 15.000 data points that were executed in the ERP system. The prototypical approach with this real-world data sample shows that process mining technology primarily traces the digital footprints from materials along their lifetime. This reveals facts about the activities that are executed in an ERP System. The resulting product life cycle from the business sample elaborates optimization potential not only in the process flow and the processing time, but also reveals details within process stages. In particular, the development of financial KPIs such as sales price and costs of goods sold has gained attention. Looking at data analytics there might be the claim that other ways to get this information are already established. Nevertheless, the prominent benefit in this analysis is the connection to a timeline. The timeline of a real-world material life cycle provides deeper insights into the development of the KPI. It reveals the details of the changed information, for example the time of the change, whether it was a reoccurring change or a single event as well as the values that were maintained.

However, depending on the business case and the analysis goal, the data model must be adapted and prepared accordingly. In order to apply that to a corporation wide standard, for example, there must be a stable data connection that allows continuous monitoring with real time data. Also, in this extract the scope was limited to selection of materials and a predefined time frame. Further research can be executed by adding more data points. This means other relevant material management systems can be added to gain more data. Besides that, the executed analysis in this paper can be extended and combined with common business use cases including data management.

Using process mining has shown that the technology creates full transparency of the whole material life cycle in an ERP System and allows a wide range of analysis by considering a time series-based development of a material. On the one hand, PLM systems might still be the choice to store and manage product data. On the other hand, when the goal is analyzing the material lifetime stages and the according attributes, process mining is an effective alternative.

References

Benz, J., Höflinger, M., 2008. Logistikprozesse mit SAP®. Springer.

Best, E., Weth, M., 2010. Process Excellence: Praxisleitfaden für erfolgreiches Prozessmanagement. 4., überarb. und erw. Aufl. sl: Gabler Verlag.

Bitkom Research, Autodesk., 2017. Welche der folgenden Arten von Software für technische Anwendungen sind in Ihrem Unternehmen im Einsatz bzw. plant Ihr Unternehmen zukünftig einzusetzen?. Statista. Statista GmbH. [online] Available at: <https://de.statista.com/statistik/daten/studie/785353/umfrage/einsatz-von-software-fuer-technische-anwendungen-in-unternehmen/> [Accessed 21 May 2020]

Brunner, U., Gabriel, M., Bischof, C., 2017. Grundzüge des Prozessmanagements. NVW, Wien Graz.

Celonis SE, 2020. Process Mining Platform. [computer program] Academic Edition. Available at: <https://www.celonis.com/academic-signup> [Accessed 12 July 2020].

Frick, D., Gadatsch, A., Schäffer-Külz, U.G., 2008. Grundkurs SAP ERP.

Hansen, A., 2008. Product Lifecycle Management. Von der ersten Idee bis zur letzten Ruhestätte. Handelsblatt. [online] Available at: <https://www.handelsblatt.com/unternehmen/mittelstand/product-lifecycle-management-von-der-ersten-idee-bis-zur-letzten-ruhestaette/3047284.html> [Accessed 21 May 2020]

Hierzer, R., 2017. Prozessoptimierung 4.0: den digitalen Wandel als Chance nutzen. Haufe-Lexware.

Kühn, H., Bayer, F., 2013. Quantitative Analyse und Planung von Prozessen, in: Prozessmanagement Für Experten. Springer, pp. 137–157.

Saaksvuori, A., Immonen, A., 2008. Product lifecycle management. Springer Science & Business Media.

SAP Help Portal. Available at: <https://help.sap.com/viewer/e79854f090014378a89d74024923dbab/6.00.31/de-DE/858d4c28-debe-46d1-b7a3-b2cc9f851d0d.html> [Accessed 26 May 2020].

Stark, J., 2020. Product Lifecycle Management (PLM), in: Product Lifecycle Management (Volume 1). Springer, pp. 1–33.

Stark, J., 2017. Product lifecycle management (volume 3): the executive summary. Springer.

Thiede, M., Fuerstenau, D., Barquet, A.P.B., 2018. How is process mining technology used by organizations? A systematic literature review of empirical studies. Business Process Management Journal.

Van Der Aalst, W., 2016. Data science in action, in: Process Mining. Springer, pp. 3–23.

Van Der Aalst, W., 2011. Process mining: discovery, conformance and enhancement of business processes. Springer.

Van Der Aalst, W., Adriansyah, A., De Medeiros, A.K.A., Arcieri, F., Baier, T., Blickle, T., Bose, J.C., Van Den Brand, P., Brandtjen, R., Buijs, J., others, 2011. Process mining manifesto, in: International Conference on Business Process Management. Springer, pp. 169–194.

Supply Chain Planning in the food industry

David Stüve [1], Robert van der Meer [1], Matthias Lütke Entrup [2], and Mouhamad Shaker Ali Agha [1]

1 – University of Strathclyde

2 – International School of Management (ISM)

Purpose: Advanced Planning Systems (APS) can contribute to improved decision-making and enhanced efficiency along complex food supply chains. This paper presents a systematic literature review of supply chain planning (SCP) in the food industry. In particular, the literature on three increasingly important planning tasks supported by APS is examined, namely Supply Chain Network Design, Sales & Operations Planning and Production Planning & Scheduling.
Methodology: A literature review is conducted by systematically collecting the existing literature published between 1998 and 2020 and classifying it based on three planning tasks supported by APS modules (Supply Chain Network Design, Sales & Operations Planning and Production Planning & Scheduling). Furthermore, research papers are categorized according to the product under consideration, geographic region and method.
Findings: Multiple models for SCP practices have been developed. The modelling literature is fragmented around specific challenges faced in food supply chains. Empirical literature including case studies on the implementation of APS is sparse. The findings suggest that developed models for the three examined planning tasks are only implemented to a limited extent in practice.
Originality: This paper focuses on three planning tasks that are of increasing relevance for the food industry. The literature review can help practitioners within the food industry to get insights regarding the opportunities offered by the three software modules examined in this paper. Further research should be conducted in these areas to make literature on SCP more practically relevant for managers.

First received: 13. Mar 2020 Revised: 16. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

Supply chain management (SCM) in the food industry is complex. In contrast to other industries, the quality of products continuously deteriorates as the products move along the supply chain (Akkerman, Farahani and Grunow, 2010). Food characteristics such as perishability and cooling requirements need to be considered to satisfy the quality requirements of consumers and to prevent food waste. Consumer attitudes are constantly changing, leading to mass customization and a growing amount of product variants (Trienekens, et al., 2012). Consumer demand fluctuates depending on weather and other factors. Therefore, supply chain planning (SCP) is essential for food companies to retain an overview of the supply chain (Ivert, et al., 2015). Planning problems faced by food companies can be expressed in mathematical models and solved by dedicated software tools. Advanced planning systems (APS) support long-term, mid-term and short-term decision-making and ensure efficient use of resources along the supply chain (Neumann, Schwindt and Trautmann, 2002). However, despite the positive impact of APS on operational efficiency, research indicates that software tools for SCP are only implemented to a limited extent in practice (Vlckova and Patak, 2011; Jonsson and Ivert, 2015). Likewise, Jonsson and Holmström (2016) diagnose a gap between research and practice in the literature of SCP.

Corresponding to the complexity of food supply chains and the resulting need for SCP, the purpose of this paper is to improve the understanding of SCP in a specific context, namely the food industry. To achieve this aim, the study seeks to systematically review the modelling research for SCP in food companies as well as the literature on APS implementation to support SCP practices. The literature review particularly considers the context of application of proposed methods for SCP, indicating the practical relevance of research. This should provide insights into the opportunities of SCP within different food supply chains. In addition, it is examined to what extent the use of APS supporting long-term, mid-term and short-term decisions is covered and facilitated by research. Research on APS implementation is critical as effective SCP requires support by specific software tools. In particular, the study will focus on three different planning tasks that become increasingly relevant for food companies, namely supply chain network design, sales & operations planning (S&OP), and production planning & scheduling. Similar literature reviews have been conducted by Ahumada and Villalobos (2009) and Akkerman, Farahani and Grunow (2010). The former review concentrates on planning models for the agriculture industry; furthermore, modelling approaches are distinguished based on decision variables, and not based on APS modules. The latter review is focused on models for food distribution emphasizing sustainability and food quality.

The remainder of this paper is structured as follows: In the next section APS is introduced to the reader and it is argued why the three mentioned modules are of increasing relevance for the food industry. Subsequently, the research approach for the literature review is specified. After that, selected research papers on SCP in the food industry are categorised based on the three planning tasks and the application context is presented. Thereafter, research papers on APS implementation are investigated. The literature review is followed by a discussion. Lastly, findings are summarized in the conclusion and recommendations for further research are provided.

2 Advanced Planning Systems

The application of APS can address the complexity of food supply chains and conflicting objectives faced by managers of the industry. APS comprise different software modules involving different functionalities and planning tasks, respectively. Figure 1 gives an overview of software modules covered by APS. The framework distinguishes between software modules based on the respective dimensions of planning horizon (from transaction to long-term) and supply chain process (from procurement to sales). At the strategic level, long-term decisions about the configuration of the supply chain are met (e.g. production and warehouse locations). At the tactical planning level, demand forecasts and mid-term production planning are synchronized. Inventory planning is also carried out at this level. At the operational level, the mid-term plans are broken down into concrete production and distribution plans. Supplier relationship management and order management modules serve as interfaces to suppliers and customers for integrated planning along the entire supply chain. Risks in the supply chain are identified, assessed and reported by means of a risk management module. In addition, software solutions in the area of supply chain visibility and business analytics can enhance transparency along the supply chain and visualize the performance of the entire supply chain using selected KPIs.

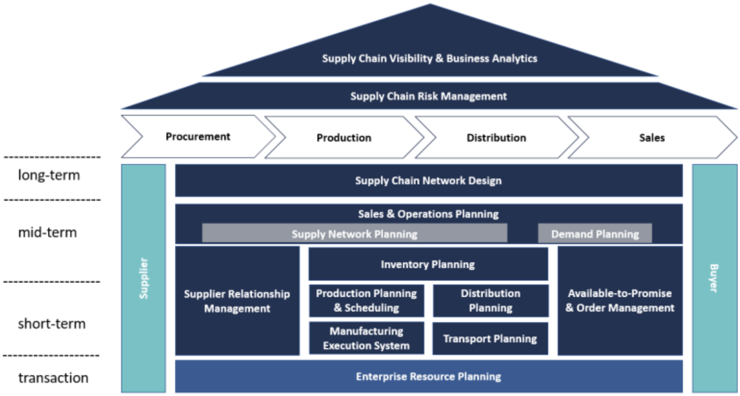


Figure 1: Supply chain planning & navigation framework

By means of these tools, mathematical models of operations research for long-term, mid-term and short-term SCP can be speedily solved. Moreover, APS ensure increased flexibility in case of deviations from original plans and capture interdependencies of planning decisions (Stadtler and Kilger, 2002).

The present paper focuses on three APS modules, namely supply chain network design, S&OP, and production planning & scheduling. Typical functionalities of the respective modules are depicted in Table 1. The importance of strategic decision-making has been growing in recent years. Food supply chains have become global networks responding to consumers' demand for year-round availability of products. Food products are increasingly produced, processed and distributed across different countries (Ahumada and Villalobos, 2009). Consequently, decisions regarding the physical structure of the supply chain are essential for food companies.

Responding to frequent new product developments, demand fluctuations and supply uncertainties, food producers require a well-functioning S&OP process to coordinate the demand- with the supply-side (Ivert, et al., 2015). Moreover, products and raw materials may perish if demand is not well matched with production, reducing overall profitability (Patak and Vlckova, 2012). The process can be supported by either separate demand and supply network planning modules or an integrated version.

Furthermore, complexity in production planning and scheduling is amplified due to increased product variety as a consequence of mass customization (Trienekens, et al., 2012). For instance, products may have different setup times and production equipment may need to be cleaned after production blocks (Bilgen and Günther, 2010).

Table 1: Functionalities of APS modules for supply chain network design, sales & operations planning and production planning & scheduling (Lütke Entrup, 2005)

Module	Functionalities
Supply chain network design	Determination of product strategy: Includes number and main characteristics of products as well as markets to be served. Determination of manufacturing strategy: Includes number and location of plants, sourcing strategy, investment decisions and supplier selection. Determination of logistics strategy: Includes number, locations and echelons of distribution centers, sourcing strategy and investment decisions.

Module	Functionalities
	Determination of investment/divestment decisions: Includes in-/outsourcing, acquisitions/mergers and new technology introduction.
Sales & operations planning	Demand planning module comprises: Statistical forecasting: Assist the planner in making estimations derived from historical data. Incorporation of judgmental factors: To correct and improve statistical forecast (e.g. by consensus of experts). Collaborative/consensus-based decision process: Assures that input for the demand planning process can be collected from all involved departments. Accuracy measurement: Accuracy measures such as the Mean Absolute Percentage Error (MAPE) or the Mean Absolute Deviation (MAD) can be used to track and evaluate forecast accuracy. Supply network planning module comprises: Creation of unrestricted operations plan: Calculation of net demand considering inventory and comparison of production quantities with available capacities. Bottleneck resolution: In case of bottlenecks, automated generation of a feasible plan (e.g. by building up inventory or scheduling additional shifts).

Module	Functionalities
Production planning & scheduling	Dynamic lot-sizing: Definition of quantity of an item to manufacture in a single production run. Automated scheduling: Algorithm-based scheduling and sequencing of production orders. Manual scheduling: To correct and improve production schedules by input of dispatchers etc. Shop floor control: Comprises methods and systems to prioritize, track, and report against production orders and schedules. Rescheduling of orders: Enabled by drag & drop functionality in an interactive planning board.

3 Research Approach

A systematic literature review is conducted to better understand the efforts to support more efficient food supply chains through supply chain network design, S&OP and production planning & scheduling. The review approach pursued in this paper comprises four sequential steps (Mayring, 2003). Firstly, the research papers are collected. Studies for review are obtained through Scopus and Google Scholar databases, and snowballing of citations in relevant papers. Keywords used are “food industry”, “supply chain planning”, “advanced planning systems”, “supply chain network design”, “strategic network planning”, “sales & operations planning”, “S&OP”, “demand planning”, “supply network planning”, “production planning & scheduling”, “production planning” and “production scheduling”. Studies published between 1998 and 2020 in peer-reviewed journals are considered; in 1998 SAP APO was introduced as software for integrated business planning. Only papers addressing SCP practices of food companies that can be associated with supply chain network design, S&OP and production planning & scheduling are selected. Secondly, collected studies are examined based on year of publication, author, and publishing journal. Thirdly, studies are categorized according to the three mentioned fields of SCP. Lastly, the individual modelling approaches for SCP of the collected research papers are presented. Characteristics of the targeted food supply chain, including the product and country under consideration, are depicted to indicate the practical relevance of the selected modelling research. Moreover, the methods underlying the respective models are determined. The review further includes an analysis of the literature covering the implementation of APS to support SCP in food companies, as modelling approaches for SCP are normally solved by specialized software modules. Overall, this review of customized modelling approaches for SCP within food companies and of research on APS implementation as an enabler of SCP is expected to give a useful indication of the current state of literature regarding SCP in the food industry.

4 Research Segmentation and Overview

In this chapter, collected studies are examined based on year of publication, author, and publishing journal. The final list of papers that could be identified through Scopus and Google Scholar comprises 77 peer-reviewed research papers that deal with SCP within the food industry supporting either of the three planning tasks under consideration. In this paper, only a part of the selected papers will be presented as an illustrative example; the full list can be requested from the authors.

4.1 Distribution of Papers over the Years

In total 22 studies can be categorized as belonging to the domain of supply chain network design. 17 papers are associated with mid-term SCP supporting the S&OP process. The majority of the identified literature, comprising 38 research papers, is aimed at enhancing production planning & scheduling. Overall, there was a growing interest in this kind of SCP research till 2015, with a small decline in published research papers in the past five years (see Figure 2).

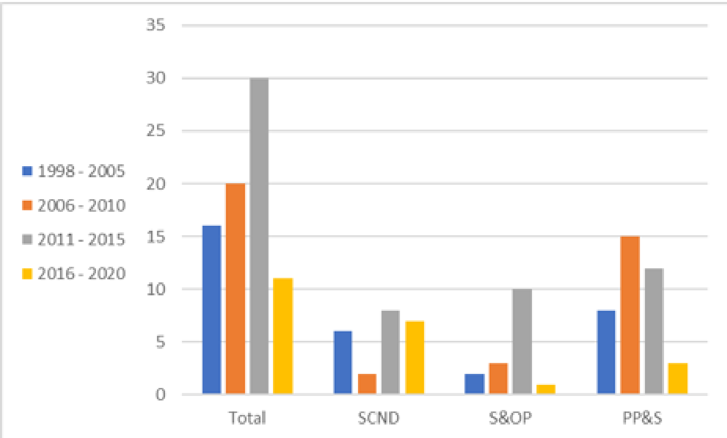


Figure 2: Distribution of papers over time

4.2 Contributions classified by Author

In total 176 scholars have contributed to the 77 selected research papers for this literature review. Akkerman, Bilgen and Grunow are among the top contributing authors to the domain of SCP in the food industry (see Figure 3). While Akkerman can be associated with five papers, Bilgen and Grunow are involved in four studies published in peer-reviewed academic journals.

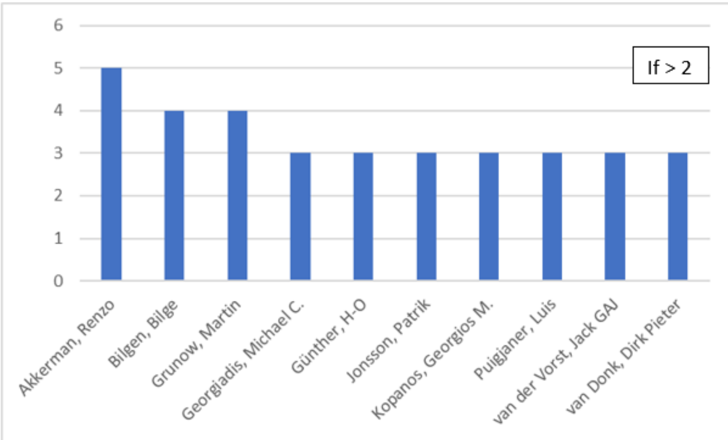


Figure 3: Contributions classified by author

4.3 Contributions classified by Journal

Research papers are selected from 29 different academic journals. Among the various journals, International Journal of Production Research, International Journal of Production Economics and European Journal of Operational Research provided the most contributions in the focused areas of SCP for the food industry (see Figure 4).

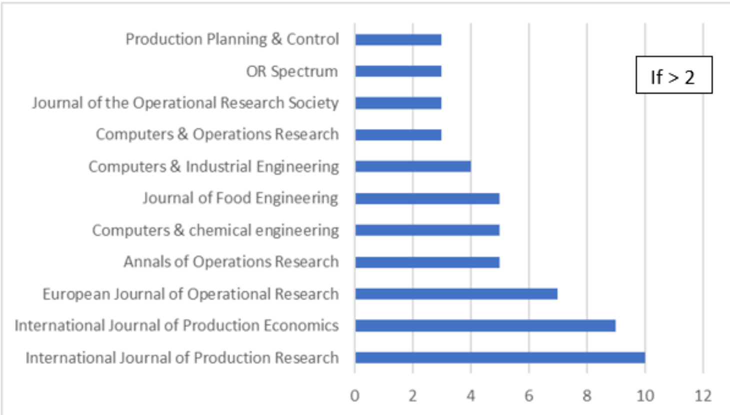


Figure 4: Contributions classified by academic journal

5 Classification based on Problem Context

In this section the individual modelling approaches that can be associated with supply chain network design, S&OP and production planning & scheduling are presented. Characteristics of the targeted food supply chain are depicted to indicate the practical relevance of the selected modelling research. The review further includes an analysis of the literature covering the implementation of APS to support SCP in food companies, as modelling approaches for SCP are normally solved by specialized software modules.

5.1 Supply Chain Network Design

Multiple scholars have studied strategic decisions relating to the supply chain design of specific companies in the food industry (see Table 2). Most of these scholars elaborated models using mixed integer linear programming (MILP) methods to optimize the configuration of the supply chain. Hosseini-Motlagh, Samani and Saadi (2019), for instance, developed a model enabling a reduction of total costs of a supply chain network. The mathematical model is validated by real data of the wheat supply chain network in Iran and integrates choices regarding location and capacities for silos as well as the selection of transportation modes. Furthermore, different models have been formulated to meet strategic investment decisions. Aras and Bilge (2018) developed a model for a company producing snacks in Turkey. Their model supports long-term decisions concerning the location and timing of a new production facility, capacities and the assignment to customers. Likewise, Wouda, et al. (2002) studied the supply chain network of a company operating in the Hungarian dairy industry. Their model is supposed to ascertain the most efficient network design after the acquisition of multiple companies in that industry. Musavi and Bozorgi-Amiri (2017) proposed a hub scheduling model for perishable food supply chains. Their approach ensures that the quality requirements of customers are met while overall transportation costs and carbon emissions of vehicles are reduced. According to these authors, the model can be applied to various kinds of perishable products such as fruit, vegetables or dairy products. Similarly, Mohammed and Wang (2017) investigated a three-echelon meat supply chain and presented a model that involves multiple objectives. The model aims to minimize transportation costs, the number of vehicles needed as well as delivery time, while the optimal number of farms and abattoirs is identified. Further methods have been developed by scholars to optimize material flow within a supply chain network. The model formulated by Khalili-Damghani, Tavana and Amirkhan (2014) considers a multi-objective supply chain under uncertain conditions and is validated by a case study of a seafood producer in Iran. Reiner and Trcka (2004) suggest a product specific supply chain design model. They emphasize that supply chains need to be analysed and configured depending on the demand situation of a certain product. Their model is applied and verified in a case study of a pasta manufacturer. Several authors formulated approaches to include environmentally conscious thinking in their multi-objective models for strategic decision making. Colicchia, et al. (2016), for example, developed a framework to balance their economic and ecological impact, such as the carbon footprint of a company's distribution network. Their model could be verified based on a case study of a chocolate producer in Italy.

Table 2: Example models for supply chain network design

Paper	Product	Country	Method
Hosseini-Motlagh, Samani and Saadi (2019)	Wheat	Iran	Stochastic programming
Aras and Bilge (2018)	Snacks	Turkey	MILP
Musavi and Bozorgi-Amiri (2017)	Perishable food	-	MILP
Mohammed and Wang (2017)	Meat	UK	Multi-objective robust possibilistic programming
Colicchia, et al. (2016)	Chocolate	Italy	MILP
Khalili-Damghani, Tavana and Amirkhan (2014)	Seafood	Iran	MILP
Reiner and Trcka (2004)	Pasta	-	Simulation
Wouda, et al. (2002)	Dairy	Hungary	MILP

5.2 Sales & Operations Planning

Academics have also developed modelling approaches for sales & operations planning in the food industry (see Table 3). In their research Nemati, Madhoshi and Ghadikolaei (2017) compared fully integrated, partially integrated, and a traditional decoupled S&OP approach. The different methods were defined by multi-integer programming models. A case study in the dairy industry revealed a superior performance of the fully integrated S&OP approach over the other two models. The model by Liu and Nagurney (2012) helps managers to maximize profits while considering the interplay of different decision-makers in a competitive supply chain network. Thus, an equilibrium pattern can be calculated including inventories, prices of products and transactions.

Two basic approaches for demand forecasting are time-series-analysis and causal models. Time-series-analysis methods are solely based on past demand assuming patterns of demand over time. The most frequently used methods are the simple moving average and the exponential smoothing method. Causal models assume that demand is influenced by several known factors like weather or temperature (Stadtler and Kilger, 2002). Various researchers compared different forecasting methods at companies within the food industry. Barbosa, Christo and Costa (2015) applied three different exponential smoothing methods (simple exponential smoothing method, Holt's method & Holt-Winters method) to a company producing pasta and sausages in Brazil. Based on the MAPE (mean absolute percentage error) their study indicates that the Holt-Winters method is most effective in forecasting products with trend and seasonality patterns.

Supply network planning represents another essential step within the sales & operations process that can be supported by APS. Multiple models have been formulated to address uncertainties on the supply-side of the supply chain. Rong, Akkerman and Grunow (2011) developed a multi-objective method that can be applied for production and distribution planning. Their approach considers economic factors and explicitly models the quality of food products based on the temperature of products during storage and distribution. Thereby, food waste within the distribution network can be reduced. The model is validated in a case study of a supply chain for bell peppers. Likewise, Ahumada and Villalobos (2011) proposed a model for tactical production and distribution planning for a fresh produce grower in Mexico. The main objective of the model is to maximize revenues. Perishability of products is taken into account by a loss function and by limiting the storage time. Higgins, Beashel and Harrison (2006) formulated a tool to establish an annual schedule for the production and shipping of sugar in Australia. The complexity of the sugar supply chain in Australia stems from the multitude of sugar brands that are produced in different mills and from ships that need to be assigned to the ports while complying with storage constraints of the individual ports. The authors argue that production and shipping costs could be significantly reduced based on the proposed model. Takey and Mesquita (2006) studied production and inventory processes with high seasonal demand of a Brazilian ice cream manufacturer. The modelling approach that they developed defines monthly production plans and work-force requirements. The aggregate plans can be transferred into short-term production plans. Further improvements in demand forecasting leading to inventory reductions are advocated by the authors. Furthermore, Ioannou (2005) reports on a reorganization project in which the distribution network of a Greek sugar producer could be optimized. Newly developed transportation models resulted in essential savings for the company. The method by Sel, et al. (2015) supports integrated tactical and operational decision-making for production planning and scheduling. A heuristic is proposed to decompose mid-term planning into short-term scheduling of yoghurt production. Their approach is validated by illustrative case studies.

Table 3: Example models for S&OP/demand planning/supply network planning

Paper	Product	Country	Method
Nemati, Madhoshi and Ghadikolaei (2017)	Dairy	Iran	MIP
Sel, et al. (2015)	Yoghurt	-	MILP & heuristic
Liu and Nagurney (2012)	Perishable food	-	Algorithm
Ahumada and Villalobos (2011)	Bell peppers & vine ripe tomatoes	Mexico	MILP
Rong, Akkerman and Grunow (2011)	Bell peppers	-	MILP

Paper	Product	Country	Method
Higgins, Beashel and Harrison (2006)	Sugar	Australia	MILP & heuristics
Takey and Mesquita (2006)	Ice cream	Brazil	LP
Ioannou (2005)	Sugar	Greece	LP

5.3 Production Planning & Scheduling

Several modelling approaches have also been developed for production planning & scheduling of food products (see Table 4). Doganis and Sarimveis (2008), for instance, formulated a method to optimize yoghurt production. The approach ensures efficient use of resources and captures the increased complexity of an enlarged product portfolio. Thus, multiple variables such as fat content of products, processing times, diverse due dates and sequence-dependent setup times are considered. Similarly, Bilgen and Dogan (2015) created a MILP model targeted towards multistage production in the dairy industry. The proposed method determines the optimal timing and quantity of intermediates and final products to be produced over a specific time period. A further approach covering uncertainty of milk supply has been developed by Guan and Philpott (2011) to support the production planning of a dairy company in New Zealand. Lütke Entrup, et al. (2005) integrated shelf life in their models for weekly planning of yoghurt production. The approach by Wari and Zhu (2016) addresses the multi-week production scheduling of ice-cream. The model can be used to optimise makespan and includes several constraints such as clean-up sessions and weekend breaks. A method by Kilic, et al. (2013) is formulated to solve the blending problem of a flour manufacturer. The tool helps to determine the optimal blending of intermediates to minimise operational costs. Amorim, Günther and Almada-Lobo (2012) elaborated an approach for integrated production and distribution planning considering freshness of perishable products besides economic objectives. It is shown that the integrated method contributes to significant savings compared to the decoupled approach, although savings compared to the traditional method decrease the higher the freshness standards. Wauters, et al. (2012) developed a specialized scheduler that can be integrated in a manufacturing execution system. The proposed approach enables food processing companies to schedule different production orders at the same time. The routing of production orders within a plant layout is optimised. Thereby, the makespan and the quality of the overall production process is enhanced considering the variety of products.

Table 4: Example models for production planning & scheduling

Paper	Product	Country	Method
Wari and Zhu (2016)	Ice-cream	-	MILP
Bilgen and Dogan (2015)	Dairy	-	MILP
Kilic, et al. (2013)	Flour	-	MILP
Amorim, Günther and Almada-Lobo (2012)	Perisha-ble food	-	MIP & MINLP
Wauters, et al. (2012)	-	-	Algorithm
Guan and Philpott (2011)	Dairy	New Zea-land	Stochastic quad-ratic model & algo-rithm
Doganis and Sarimveis (2008)	Yoghurt	Greece	MILP
Lütke Entrup, et al. (2005)	Yoghurt	-	MILP

5.4 Implementation of Advanced Planning Systems

The literature mentioned above covers multiple mathematical models that have been developed targeted towards certain planning problems in different food supply chains. Typically, such models are integrated into APS to enhance supply chain efficiency. Despite the complexity of food supply chains and the related significant potential benefits from implementing advanced planning solutions, literature on the implementation of APS is sparse (see Table 5).

A few studies have investigated the utilization of planning software in food companies. Vlckova and Patak (2011) examined the demand planning practices of four companies including a food company. Their study revealed that demand planning in the food company was performed via excel spreadsheets. According to the authors, effective demand planning involves collaboration across different departments. It is argued that this could be only achieved by utilizing integrated information systems. Likewise, Jonsson and Ivert (2015) found through a survey among Swedish manufacturing companies, including 30 responses from the food industry, that only a small amount of companies were using sophisticated methods for master production scheduling. They found a positive effect on supply chain performance from the application of planning software for master production scheduling. It is argued that advanced methods would lead to more feasible plans.

There are also a few case studies documenting the implementation of APS modules in specific companies. Zago and Mesquita (2015) conducted a case study at a Brazilian dairy company to assess benefits and risks of the implementation of S&OP software. The study confirms greater planning accuracy providing enhanced control over inventory levels, reduced transportation costs and the opportunity for scenario analysis as the main benefits of the software. Top management support and system integration are mentioned as major challenges in the implementation project. In other research by Brown, et al. (2001), the authors describe the application of a planning software by the Kellogg Company to support short-term as well as mid-term decisions. The system is used for weekly production and distribution schedules and monthly decisions on the production capacity of the different plants. According to the authors, production, inventory and distribution costs could be strongly reduced by the implemented system. Rudberg and Thulin (2009) conducted a further case study in the agriculture industry. It highlights that efficiency along the supply chain can be significantly increased by the use of a master planning module. Higher throughput at lower cost and an improved service level combined with lower inventory were observed as major benefits of the software. Further case studies of APS implementation with more complex supply chain structures are recommended by the authors. Jonsson, Kjellsdotter and Rudberg (2007) conducted explorative case studies of three companies using APS software, including two companies from the food industry. One of them, a producer of vegetable oils and fats, implemented a software module for supply chain network design after a merger to analyse the utilization of two production sites and the impact on logistics costs, based on different scenarios. The other company from the grocery industry introduced a new tool for centralised mid-term supply chain master planning. Both cases reveal enhanced collaboration across different functions and increased commitment to the developed plans as major benefits of APS implementation. A further study examined three companies, among them a food and a brewery company, implementing software for tactical production planning. Three different types of problems that occur during implementation projects could be identified, namely process-, system- and plan-related problems. Process-related problems are associated with difficulties to achieve progress within the project. System-related problems refer to not using the full potential of the software module. The generation of unrealistic plans by the software is considered as a plan-related problem. Various propositions regarding the causes of such problems are provided by the authors (Ivert and Jonsson, 2011).

Table 5: Research papers on APS implementation in the food industry

Paper	Method	Objective
Jonsson and Ivert (2015)	Survey among Swedish manufacturing companies from different industries (including food & beverage)	Determine the impact of different master production scheduling methods on company performance
Zago and Mesquita (2015)	Case study of a dairy company	Examine the benefits of using an APS module for S&OP and determine success factors for the implementation of an APS module

Paper	Method	Objective
Ivert and Jonsson (2011)	Three case studies of manufacturing companies (including a food and a brewery company)	Investigate problems encountered in the different phases of implementation projects of software tools to support tactical production planning
Vlckova and Patak (2011)	Interviews with managers from four companies (including one company from the food industry)	Investigate demand planning practices and the use of software to support demand planning
Rudberg and Thulin (2009)	Case study of a company from the farming & food industry	Examine how master planning can be enabled by an APS module
Jonsson, Kjellsdotter and Rudberg (2007)	Three case studies (including two cases from the food industry)	Examine the use and perceived impact of the application of APS modules for strategic network planning and master production scheduling
Brown, et al. (2001)	Case study of a company producing cereals and convenience food	Examine the effects of using a software supporting tactical and operational SCP

6 Discussion

This literature review has shown that multiple mathematical models of operations research have been developed and customized to complex planning problems within food supply chains. Academics have formulated diverse modelling approaches to support decisions relating to supply chain network design, S&OP and production planning & scheduling, taking account of the specifics in different food sectors around the world. The methods are intended to help supply chain managers to deal with conflicting objectives, a multitude of decision alternatives and uncertainty. Furthermore, a growing number of models have been developed for integrated planning across decision levels (Omar and Teo, 2007; Amorim, Günther and Almada-Lobo, 2012). The applicability of mathematical models is emphasized by scholars. This corresponds to the call by various academics to conduct more practical relevant research (Graves, 2009; Toffel, 2016). While most methods are validated by real data, the implementation in practice of a large part of modelling approaches remains vague.

By applying dedicated software tools, the models can be applied within a reduced planning time. APS ensure increased flexibility in case of deviations from original plans and capture interdependencies of planning decisions (Stadtler and Kilger, 2002). The present review has revealed that empirical investigations regarding the implementation of such software are limited to a few case studies. This is unlike research on other IT software aimed at supply chain efficiency, such as ERP systems (Hong and Kim, 2002; Momoh, Roy and Shehab, 2010). Apart from that, the implementation of ERP systems is also different from APS implementation (Wiers, 2002). Existing research predominantly reports on the benefits of APS (e.g. lower inventory levels) (Zago and Mesquita, 2015). Those papers examining whether APS modules have actually been implemented observe either no utilization or less advanced methods of SCP (Vlckova and Patak, 2011; Jonsson and Ivert, 2015). Moreover, the few case studies on APS implementation are rather focused on tactical SCP. Only two research papers could be identified that deal with the implementation of software tools for either short-term or long-term SCP. Likewise, research does not consider the effects of integrated planning by using multiple APS modules.

This literature review has revealed the great effort that has been committed by researchers in the domain of operations research to capture the complexity of food supply chains. This is reflected by the multitude of customized modelling approaches that have been developed to support SCP. Such complex models mostly require specific software (such as APS) to be solved. Research on the implementation of SCP enabled by specific software tools is rare, however. Therefore, further research needs to be done to explore SCP practices of food companies in practice and to evaluate how supply chains can be effectively supported by APS modules. This corresponds to the propositions of Fisher (2007), who encouraged academics to conduct more empirical research within the domain of operations management. It is argued that, based on empirical observations, hypotheses could be developed and validated to give practical advice for enhanced operations. Likewise, future studies on SCP may empirically investigate the implementation of information technology to support different planning tasks. Considering the complexity of food supply chains comprising fluctuating demand, growing product variety and food characteristics such as limited shelf-life that pose enormous challenges to supply chain managers, research on APS implementation could improve decision-making in food companies and thereby increase its practical relevance, as requested by Toffel (2016).

7 Concluding Remarks

The inherent complexity of food supply chains, including the perishability of products, requires effective decision-support for managers. APS constitute the essential means to enhance operational efficiency along the supply chain. Moreover, sophisticated SCP contributes to ecological benefits, such as reduced carbon emissions and food waste. Multiple models for SCP have been conceptualized for different planning tasks, while studies on the implementation of the proposed methods, and in particular of APS, are rare. Therefore, more research needs to be conducted on APS to empower companies to capitalise on the digitalization of their supply chain.

This literature review is limited to two databases. Consequently, this paper may not cover all of the modelling research targeted to support food companies in the areas of supply chain design, S&OP and production planning & scheduling. Moreover, the categorization of mathematical models into different areas of SCP can be challenging, as transitions between planning tasks in terms of planning horizon and objectives are fluid. Nonetheless, it can be expected that this did not significantly affect the objective of this paper to create an accurate picture of the literature on SCP in the food industry and its practical relevance.

Future research needs to pursue a more empirical approach to the implementation of APS in support of different planning tasks. Based on that approach, new insights could be obtained. Firstly, preconditions for food companies to effectively implement APS modules could be determined. Software tools may require certain data or interfaces to other systems. Secondly, requirements to specific APS modules to better suit the needs of the food industry could be determined. A survey among managers in the food industry could provide new insights regarding the perspective of companies on the benefit of software tools for SCP. Thirdly, an investigation of the relationship between supply chain complexity and the impact on supply chain performance by APS modules provides further interesting research opportunities. Thus, the benefit of certain functions of software tools for SCP may be related to the shelf-life of food products or the amount of stock keeping units that need to be coordinated in a supply chain. Thereby, the understanding of SCP and of an effective use of APS can be continuously strengthened in order to facilitate supply chain management and ultimately enhance the efficiency of food supply chains.

References

Ahumada, O. and Villalobos, J. R., 2009. Application of planning models in the agri-food supply chain: A review. European Journal of Operational Research, 196(1), pp. 1–20.

Ahumada, O. and Villalobos, J. R., 2011. A tactical model for planning the production and distribution of fresh produce. Annals of Operations Research, 190(1), pp. 339–358.

Akkerman, R., Farahani, P. and Grunow, M., 2010. Quality, safety and sustainability in food distribution: a review of quantitative operations management approaches and challenges. Or Spectrum, 32(4), pp. 863–904.

Amorim, P., Günther, H.-O. and Almada-Lobo, B., 2012. Multi-objective integrated production and distribution planning of perishable products. International Journal of Production Economics, 138(1), pp. 89–101.

Aras, N. and Bilge, Ü., 2018. Robust supply chain network design with multi-products for a company in the food sector. Applied Mathematical Modelling, 60, pp. 526–539.

Barbosa, N. d. P., Christo, E. d. S. and Costa, K. A., 2015. Demand forecasting for production planning in a food company. ARPN Journal of Engineering and Applied Sciences, 10(16), pp. 7137–7141.

Bilgen, B. and Dogan, K., 2015. Multistage production planning in the dairy industry: a mixed-integer programming approach. Industrial & Engineering Chemistry Research, 54(46), pp. 11709–11719.

Bilgen, B. and Günther, H.-O., 2010. Integrated production and distribution planning in the fast moving consumer goods industry: a block planning application. Or Spectrum, 32(4), pp. 927–955.

Brown, G., Keegan, J., Vigus, B. and Wood, K., 2001. The Kellogg company optimizes production, inventory, and distribution. Interfaces, 31(6), pp. 1–15.

Colicchia, C., Creazza, A., Dallari, F. and Melacini, M., 2016. Eco-efficient supply chain networks: development of a design framework and application to a real case study. Production Planning & Control, 27(3), pp. 157–168.

Doganis, P. and Sarimveis, H., 2008. Optimal production scheduling for the dairy industry. Annals of Operations Research, 159(1), pp. 315–331.

Fisher, M., 2007. Strengthening the empirical base of operations management. Manufacturing & Service Operations Management, 9(4), pp. 368–382.

Graves, S. C., 2009. A Letter from the Editor. Manufacturing & Service Operations Management, 11(1), pp. 1–3.

Guan, Z. and Philpott, A. B., 2011. A multistage stochastic programming model for the New Zealand dairy industry. International Journal of Production Economics, 134(2), pp. 289–299.

Higgins, A., Beashel, G. and Harrison, A., 2006. Scheduling of brand production and shipping within a sugar supply chain. Journal of the Operational Research Society, 57(5), pp. 490–498.

Hong, K.-K. and Kim, Y.-G., 2002. The critical success factors for ERP implementation: an organizational fit perspective. Information & Management, 40(1), pp. 25–40.

Hosseini-Motlagh, S.-M., Samani, M. R. G. and Saadi, F. A., 2019. Strategic optimization of wheat supply chain network under uncertainty: a real case study. Operational Research, pp. 1–41.

Ioannou, G., 2005. Streamlining the supply chain of the Hellenic sugar industry. Journal of Food Engineering, 70(3), pp. 323–332.

Ivert, L. K., Dukovska-Popovska, I., Kaipia, R., Fredriksson, A., Dreyer, H. C., Johansson, M. I., Chabada, L., Damgaard, C. M. and Tuomikangas, N., 2015. Sales and operations planning: responding to the needs of industrial food producers. Production Planning & Control, 26(4), pp. 280–295.

Ivert, L. K. and Jonsson, P., 2011. Problems in the onward and upward phase of APS system implementation: Why do they occur? International Journal of Physical Distribution & Logistics Management, 41(4), pp. 343–363.

Jonsson, P. and Holmström, J., 2016. Future of supply chain planning: closing the gaps between practice and promise. International Journal of Physical Distribution & Logistics Management, 46(1), pp. 62–81.

Jonsson, P. and Ivert, L. K., 2015. Improving performance with sophisticated master production scheduling. International Journal of Production Economics, 168, pp. 118–130.

Jonsson, P., Kjellsdotter, L. and Rudberg, M., 2007. Applying advanced planning systems for supply chain planning: three case studies. International Journal of Physical Distribution & Logistics Management, 37(10), pp. 816–834.

Khalili-Damghani, K., Tavana, M. and Amirkhan, M., 2014. A fuzzy bi-objective mixed-integer programming method for solving supply chain network design problems under ambiguous and vague conditions. The International Journal of Advanced Manufacturing Technology, 73(9-12), pp. 1567–1595.

Kilic, O. A., Akkerman, R., van Donk, D. P. and Grunow, M., 2013. Intermediate product selection and blending in the food processing industry. International Journal of Production Research, 51(1), pp. 26–42.

Liu, Z. and Nagurney, A., 2012. Multiperiod competitive supply chain networks with inventorying and a transportation network equilibrium reformulation. Optimization and Engineering, 13(3), pp. 471–503.

Lütke Entrup, M., 2005. Advanced planning in fresh food industries: integrating shelf life into production planning. Physica, Heidelberg.

Lütke Entrup, M., Günther, H.-O., van Beek, P., Grunow, M. and Seiler, T., 2005. Mixed-Integer Linear Programming approaches to shelf-life-integrated planning and scheduling in yoghurt production. International Journal of Production Research, 43(23), pp. 5071–5100.

Mayring, P., 2003. Qualitative Inhaltsanalyse-Grundlagen und Techniken [Qualitative content analysis-basics and methods].

Mohammed, A. and Wang, Q., 2017. Developing a meat supply chain network design using a multi-objective possibilistic programming approach. British Food Journal.

Momoh, A., Roy, R. and Shehab, E., 2010. Challenges in enterprise resource planning implementation: State-of-the-art. Business Process Management Journal.

Musavi, M. and Bozorgi-Amiri, A., 2017. A multi-objective sustainable hub location-scheduling problem for perishable food supply chain. Computers & Industrial Engineering, 113, pp. 766–778.

Nemati, Y., Madhoshi, M. and Ghadikolaei, A. S., 2017. The effect of Sales and Operations Planning (S&OP) on supply chain's total performance: A case study in an Iranian dairy company. Computers & chemical engineering, 104, pp. 323–338.

Neumann, K., Schwindt, C. and Trautmann, N., 2002. Advanced production scheduling for batch plants in process industries. Or Spectrum, 24(3), pp. 251–279.

Omar, M. K. and Teo, S. C., 2007. Hierarchical production planning and scheduling in a multi-product, batch process environment. International Journal of Production Research, 45(5), pp. 1029–1047.

Patak, M. and Vlckova, V., 2012. Demand planning specifics in food industry enterprises. Business and Management, 7, pp. 1168–1175.

Reiner, G. and Trcka, M., 2004. Customized supply chain design: Problems and alternatives for a production company in the food industry. A simulation based analysis. International Journal of Production Economics, 89(2), pp. 217–229.

Rong, A., Akkerman, R. and Grunow, M., 2011. An optimization approach for managing fresh food quality throughout the supply chain. International Journal of Production Economics, 131(1), pp. 421–429.

Rudberg, M. and Thulin, J., 2009. Centralised supply chain master planning employing advanced planning systems. Production Planning & Control, 20(2), pp. 158–167.

Sel, C., Bilgen, B., Bloemhof-Ruwaard, J. M. and van der Vorst, Jack GAJ, 2015. Multi-bucket optimization for integrated planning and scheduling in the perishable dairy supply chain. Computers & chemical engineering, 77, pp. 59–73.

Stadtler, H. and Kilger, C., 2002. Supply chain management and advanced planning: Springer.

Takey, F. M. and Mesquita, M. A., 2006. Aggregate Planning for a Large Food Manufacturer with High Seasonal Demand. Brazilian Journal of Operations & Production Management, 3(1), pp. 5–20.

Toffel, M. W., 2016. Enhancing the practical relevance of research. Production and Operations Management, 25(9), pp. 1493–1505.

Trienekens, J. H., Wognum, P. M., Beulens, A. J. M. and van der Vorst, Jack GAJ, 2012. Transparency in complex dynamic food supply chains. Advanced Engineering Informatics, 26(1), pp. 55–65.

Vlckova, V. and Patak, M., 2011. Barriers of demand planning implementation. Economics & Management, 1(16), pp. 1000–1005.

Wari, E. and Zhu, W., 2016. Multi-week MILP scheduling for an ice cream processing facility. Computers & chemical engineering, 94, pp. 141–156.

Wauters, T., Verbeeck, K., Verstraete, P., Berghe, G. V. and Causmaecker, P. de, 2012. Real-world production scheduling for the food industry: An integrated approach. Engineering Applications of Artificial Intelligence, 25(2), pp. 222–228.

Wiers, V. C. S., 2002. A case study on the integration of APS and ERP in a steel processing plant. Production Planning & Control, 13(6), pp. 552–560.

Wouda, F. H. E., van Beek, P., van der Vorst, Jack GAJ and Tacke, H., 2002. An application of mixed-integer linear programming models on the redesign of the supply network of Nutricia Dairy & Drinks Group in Hungary. Or Spectrum, 24(4), pp. 449–465.

Zago, C. F. and Mesquita, M. A. de, 2015. ADVANCED PLANNING SYSTEMS (APS) FOR SUPPLY CHAIN PLANNING: A CASE STUDY IN DAIRY INDUSTRY. Brazilian Journal of Operations & Production Management, 12(2), pp. 280–297.

Evaluation of Data Quality in Dimensioning Capacity

Lea Vliegen [1], Nikolas Ulrich Moroff [1], and Katharina Riehl [1]

1 – Fraunhofer Institute for Material Flow and Logistics IML

Purpose: This paper aims to give an overview of the current state of research on measuring data quality. The identified methods will be applied to the task of dimensioning capacities (e.g. warehouse capacities) in the field of supply chain design (SCD) to further increase trust in decision support and to make full use of the potential of analytics.
Methodology: The data requirements for SCD decisions are identified through the combination of findings of a research project and additional literature research. Moreover, an overview on measuring data quality will be given according to a literature study. Based on the required data, the applicability of methods to measure data quality will be analyzed and an application concept developed.
Findings: The quality of decisions can only be as good as the quality of the data they are based on. The article provides an overview of methods for evaluating datasets and develops an approach for measuring and evaluating data quality for the specific case of capacities in the SCD process.
Originality: The adaption of approaches of measuring data quality to the problem of dimensioning capacities in SCD ensures an adequate evaluation of whether the data fulfills the required quality for the planning tasks.

First received: 13. Mar 2020 Revised: 16. Jun 2020 Accepted: 12. Aug 2020

1 Motivation

Supply chains of companies have changed significantly in the last decades due to the advancing globalization. Company networks become more and more complex in order to serve the growing and changing market requirements. This makes the planning of supply networks, capacities, and inventories increasingly complex.

The services and products offered by the companies have become largely interchangeable, therefore there is an increased focus on flexible customer service, speed and adherence to delivery dates at the lowest possible prices (Wassermann, 2013). This development can be favored by shortened product life cycles, fluctuating customer behavior and increasingly complex data structures in the supply chain (SC). As a result, the entire logistics SC, production capacities and shipping processes must react immediately to market fluctuations, when these cannot be planned in advance using forecasting methods (Erben and Romeike, 2003).

To improve the quality of planning despite challenging environmental influences, methods from the field of data analytics are increasingly used. Especially the areas of forecast demand, production, promotion, pricing and delivery can be optimized with the help of new methods to thus meet the growing requirements of the market (Dash, et al., 2019).

Nevertheless, the basis for the use of data driven methods is a valid database of adequate quality. For this reason, a strong focus is placed on the preprocessing of the data base before the modeling of the data driven approach can be started (Gudivada, Apon and Ding, 2017).

To keep the data preparation effort as low as possible, the data quality has to be measured in advance and assessed for the specific case of application. Due to the increased complexity in SCs, data is gathered at various points in the SC in more detail. The availability of large amounts of data offers potential for the planning process of SCs as well as in operation and for optimizations. In a study from Statista on big data analytics and its SC outcomes for companies it was indicated that 41% of the considered companies had faster and more efficient reaction times and 36% had an improvement of efficiency in their SC exceeding 10% (Statista, 2014). The availability of data is an opportunity and a challenge at the same time for SCs. New approaches and methods have to be adapted and developed to make use of their potential and make data-backed decisions (Waller and Fawcett, 2013). This potential is most promising on a strategic level when the SCs are designed, since the basic structure is set up with its strategic partners, locations, and capacities. The dimensioning of capacities of areas like a warehouse or in production are crucial for the operation of a SCs. If these decisions are based on data with a poor data quality, adjustments demand enormous efforts.

In the research project E^2-Design the focus is to design a toolbox for companies enabling them to include energy efficiency as an additional parameter in the strategic and tactical planning of SC networks. Thereby, energy efficiency extends the currently mainly used target parameters of the magic triangle: Time, costs, and quality/performance. One research question being addressed is dimensioning warehouse and production capacities under ecological aspects. Within the project it became clear that the optimization

depended to a high degree on the data quality, thus a concept was developed to determine data quality for the specific application of capacity dimensioning.
This paper presenting the developed concept is structured into four sections. First, the basics of capacity dimensioning and data quality are introduced. This is followed by the results of the literature search on the topic of methods for measuring data quality. In order to select a method, the specific requirements of dimensioning capacities were evaluated in this paper using a pair comparison and assigned to individual quality dimensions. Based on the resulting requirement profile a new concept was developed to determine the data quality in the best possible way, by connecting existing methods to fulfill the specific requirements of the use case. In the following chapter the SCD task model is described and the use case will be illustrated with a focus on dimensioning capacities to better understand the challenges of the research project.

2 Description of Use Case - Capacity dimensioning

Due to globalization supply networks become more widespread leading to longer lead times. This increases the importance of an efficient SC, making it a decisive competitive factor and therefore, more emphasis is placed on the design on the SC. A SC is characterized as a network of suppliers, production, warehouses, and distribution that transforms an input such as raw materials into finished goods, which are delivered to the customer supplies (Santoso, et al., 2005; Ketchen and Hult, 2007). In the SCD process the basis and long-time structure of the SC are planned and determined. The design process can be structured into planning levels and different tasks (Baghalian, Rezapour and Farahani, 2013; Fattahi, et al., 2015). Based on a literature study by Parlings, Cirullies and Klingebiel (2013) vital tasks for the SCD process were identified, classified, and structured into a reference model. The model is structured hierarchically into three levels: superordinate SCD tasks, SC structure design and SC process design (see Figure 1).

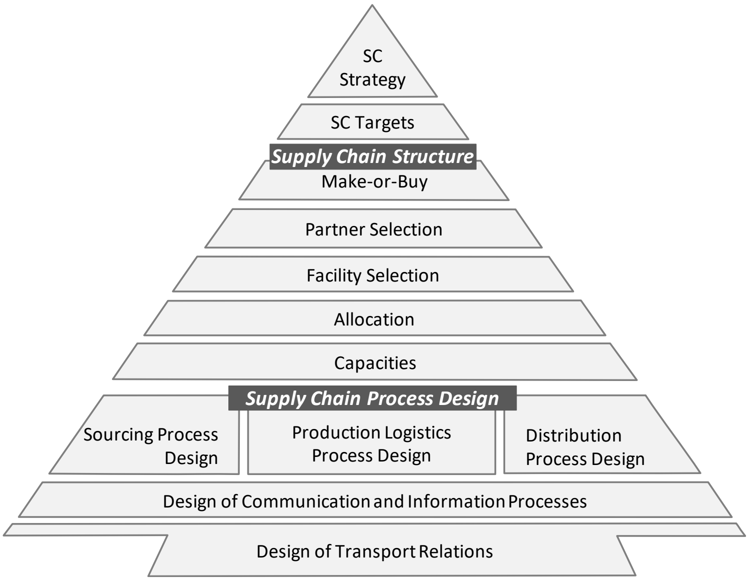


Figure 1: SCD task model (Parlings, Cirullies and Klingebiel, 2013)

In the superordinate tasks the most extensive choices for the SC are made (deciding on the SC strategy and targets). They must be aligned with the overall company strategies and goals. In the SC structure design the decisions for make-or-buy must be done as well as the selection of strategic partners and facilities. Additionally, the allocation of products to locations for production and warehousing and dimensioning of their capacities is a crucial parameter for efficient processes. Especially in manufacturing the capacities are a key driver for capital costs. Higher capacities allow economies of scale, but when already produced quantities cannot be sold due to a lack in demand, utilization is low, and costs increase (Hsu and Li, 2009). In the SC process design the strategic decisions for the sourcing, production and distribution are synchronized with the communication process and transport relations. Within the three planning levels there is no hierarchy of tasks, as they are highly correlated. For the network to function holistically, integrated choices must be made on all levels (Parlings, Cirullies and Klingebiel, 2013). A holistic approach enables fast reactions when adjustments of goals and strategies are necessary to comply with political or legislative changes. With alignments such as designing a SC more energy efficient, but still cost effective, new models and planning tools are being developed (Schreiber, 2019). Simulation is a useful tool to allow SC planners at strategic level to try out different priorities and see the impact before implementation. However, in distributing capacities for e.g. warehouses the dependencies must be clarified. One of the main challenges is to find the appropriate level of abstraction for the use case so that data from the operational level can be used effectively on the strategic level. This occurs especially with dimensioning capacities. The use case is from a company trading raw and processed materials and delivering the service to bring them customized to their client. The materials provided vary greatly in shape, dimension and weight. In all three characteristics restrictions may apply leading to a different need of warehousing and later different processing steps. Due to the variety of products there are around 200 product subgroups, which have different volume parameters. This increases the challenge of selecting ideal warehouse systems.

The dimensions, shape and product subgroup are the basis for the planning process and input for the dimensioning. Therefore, as they are part of the article master data, they have to be correct. Otherwise wrong areas of storage types are defined, and the allocated products cannot be distributed accordingly in the warehouse. Not to mention the fact that the necessary equipment for processing might not be available at the dedicated location. The whole network is planned with locations all over Germany with different warehouse systems including the capacities, transport between locations and also specialized locations. The dimensioning of warehouse and production capacities for each cluster is crucial. To further understand the challenges of the SCD task of dimensioning capacities the process is outlined in the next section and the importance of data quality is further detailed in this use case.

2.1 SCD Task: Dimensioning Capacities

In the group of tasks defining the SC structure the location of production sites and the allocation of raw materials and products to these locations are decided together with dimensioning capacities in warehousing and production. These strategic decisions influence the SC long-term and adjustments are likely to be cost intensive. Network design is often only considered as a definition of the locations however the allocation of the variety of products to the sites and decisions on capacities and technology at each site are more complex (Fleischmann and Koberstein, 2015).

Capacity is defined as the maximum performance of a system. In the case of warehouse and production capacities it is the number of products and components stored or produced in one time period (Minner, 2018). Production and storage capacity planning are closely linked due to their interaction (Friemann, 2015). Capacity planning is typically on a long to medium term basis and is part of the corporate infrastructure planning. The decision between a few large and several small capacity adjustments is significantly influenced by economies of scale of dimensioning costs on the one hand and idle costs of unused capacity on the other hand. The strategic definition of a proactive (lead) strategy must be distinguished from a reactive (lag) strategy in the case of changing demands (Slack and Lewis, 2017). The planning of production capacities in cross-company SCs is particularly difficult if legally independent players cooperate with each other only temporarily (Werner, 2017). A lack of information exchange and communication within the SC makes capacity dimensioning for production and warehousing difficult (Baumgärtel, 2008). For example, even slight fluctuations in demand at upstream stages of the value chain can lead to large increases in demand. A small change triggers an ever-increasing change in final requirements in a downward direction, so that an inventory build-up occurs within the SC (Werner, 2017). A high number of different factors influence the level of capacity (see Figure 2).

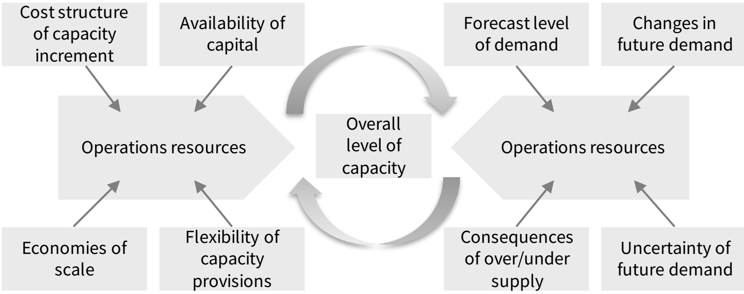


Figure 2: Influencing factors for overall level of capacity (Slack and Lewis, 2017)

Due to the high uncertainty in the long-term data (e.g. in the demand of future products in specific markets, investment volumes, labor costs or exchange rates) flexibility and robustness of the SC have to be considered to reduce risks (Fleischmann and Koberstein, 2015). These factors are linked closely to variables on the tactical and sometimes operational planning levels. This poses the challenge of selecting appropriate levels of abstraction (Friemann, 2015).

On a strategic level one main input for dimensioning capacities is the demand forecast based on potential markets to be served in the future often on an aggregated, annual basis (Friemann, 2015). On this basis, the capacity configuration is carried out along with the decisions on the total capacity required and it is distribution (Slack and Lewis, 2017).

In the research project several challenges occurred in practical experience concerning the data. One obstacle is that process knowledge is in people's minds in different locations and not digitally available and editable. To gather the required data, templates have to be developed so that all locations provide the data in the same structured way. Then the applicability of the template has to be approved by one business division, before it can be distributed to other divisions and locations. This process is time- and labor-consuming, especially if questions occur.

Another challenge is the wide portfolio of different products with diverse requirements. Additionally, planned products for the future should be considered. This means that either more flexible warehousing solutions have to be found or different systems have to be designed to accommodate all needs. Furthermore, for each product the master data must be filled in correctly in a quantified and understandable way. This includes a clear identifier per product and the dimensions as well as all applicable restrictions with units. Preferably only relevant data for dimensioning capacities is included in the dataset.

Before starting the planning process the dataset has to be complete with an adequate quality for dimensioning capacities. To avoid the repetition of planning due to lacking data quality during the planning process, it should be checked beforehand whether the data quality requirements are fulfilled. Therefore, a systematic approach is needed for the use case of capacity dimensioning. To determine the required level of data quality, the theoretical background of data quality will be outlined in the next chapter. Additionally, an overview of existing methods for measuring data quality will be given.

3 Foundations in Data Quality

The aim of this chapter is to define data quality and to present and compare suitable methods for measuring data quality in the context of SCM. The high data density in the SCM area leads to a high potential in the areas of operational efficiency, customer experience and new product development. This means that a high level of data quality and the measurement of data quality provides a decisive competitive advantage in various fields of activity (Addo-Tenkorang and Helo, 2016).

In order to measure the quality of a dataset, the term data quality must be defined and delimited in order to create a common basis. For this reason, the following section presents established definitions of data quality and introduces a list of existing assessment procedures.

3.1 Definition of Data Quality

An essential prerequisite for the use of innovative methods is high-performance data management since data is understood as the basic framework of digital development. Only through further processing and preparation does the data become information, which can be integrated into planning processes (Oppenheim, Stenson and Wilson, 2003).

An effective data management can be characterized by three essential aspects:

1. Control of data volumes
2. Decentralized data processing
3. Definition of data standards

In a survey, data managers from various industries were asked about the greatest challenges in the field of data management. The results show that data quality is regarded as one of the greatest challenges (Österle and Otto, 2014). In order to make an appropriate assessment of data quality, the particular application must be taken into account (Jayawardene, Sadiq and Indulska, 2015). Basically, two concepts can be distinguished in the characterization of data quality: Information technology focus and user-related focus.

The approach of Information Technology Assessment of data quality focuses on the assessment of the data definition, the quality of the dataset content and the data presentation. These three modules form the basic framework for the definition of information technology data quality and were further detailed by English (1998). The detailing of the three quality modules are displayed in Figure 3. The first module focuses on the framework conditions of the data collection. Only data that has been sufficiently specified can be used to measure quality. The second module concentrates on the correctness of the content in terms of unambiguity and completeness. The last module deals with the availability of data. Parameters for this part are e.g. the time of availability and compliance with the format.

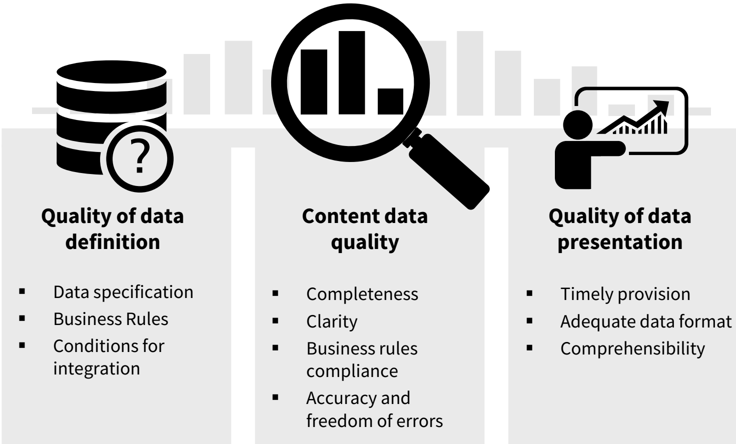


Figure 3: Information Technology Assessment of data quality (English, 1998)

In contrast to the information technology focus, data can also be evaluated on a user-related basis. Here, the focus is on the properties of the dataset and surrounding data models (e.g. definitions and frameworks) are not further considered. Based on the work of Wang and Strong (1996), Sidi, et al. (2012) defined four main components for the evaluation of user-related data quality with the help of an extensive literature research: Timeliness, Accuracy, Completeness and Consistency. These main components have been further detailed in numerous models, resulting in many subcategories.

Especially well known is the model by Rohweder, et al. (2018) which is divided into four quality categories based on 15 dimensions. The key difference between their model to Wang and Strong (1996) is that they do not consider security as a central quality dimension. Instead, they require security as a necessary basis for measuring data quality. In addition to the base model of Wang and Strong (1996), they introduce the usability (ease of manipulation) dimension. These fifteen quality dimensions can be assigned to four criteria: system-supported, inherent, presentation-related, and purpose-dependent. The following Figure 4 presents the model after Rohweder et al. (2018) (based on Wang and Strong (1996)) in detail with the four quality criteria and their focus for determining data quality.

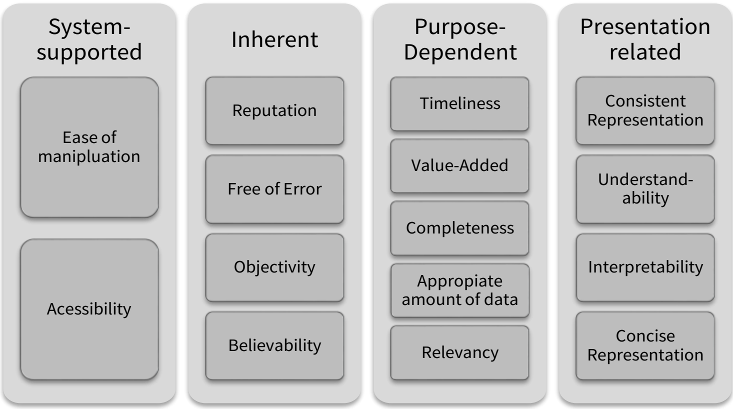


Figure 4: Data quality dimension connected to their quality criteria (Rohweder, et al., 2018)

The previous section provided an overview of possible dimensions of data quality. It becomes clear that due to different perspectives it is not possible to give a general definition of data quality independent of the specific use case. For this reason, the following section presents existing methods for measuring data quality and examines their applicability to the specific use case of capacity dimensioning.

3.2 Methods for Measuring Data Quality

The literature offers a great variety of methods to measure and evaluate data quality. Since the focus of this paper is the application of data quality to the problem of dimensioning capacities in SCD, this paper does not give a complete overview about all existing methods for measuring data quality. Our research is based on the findings of Batini, et al. (2009), who compared many methods for measuring data quality and developed their own. In this paper, Batini, et al. (2009)'s overview is extended with more methods and metrics for measuring data quality. In our research we focused on the quality dimensions that were considered in each method and examined to what extent metrics were used or developed to determine quality. Based on the results, it can be said that there are very general methods for determining data quality that can be adapted to a wide range of applications. Many of them do not contain any metrics and consequently are always a subjective classification. Those methods often aim to improve data quality, rather than exactly measuring the quality. On the other hand, there are procedures that objectively evaluate a single quality dimension in great detail using metrics, but do not consider the context of the use case.

Table shows selected results from the literature review which are connected to the presented use case capacity dimensioning: Name of the methodology and reference, abbreviation and main characteristics. In addition to the main characteristics the included quality dimensions and metrics are important criteria, illustrated in Table 2.

Table 1: Selected methods and main characteristics

Methodology & Reference	Abbre-via-tion	Main characteristics
Total Data Qual-ity Management Wang (1998)	TDQM	- Systematic application of Total Quality Manage-ment with for phases: Definition, Measurement, Analysis, Improvement - Continuous improvement of data quality in op-erational processes within information systems
Data Warehouse Quality Jeusfeld, Quix and Jarkeet (1998)	DWQ	- Measurement of quality objectives and design options in data warehousing - Perspectives: Conceptual, Logical and Physical - Classification of quality goals according to dif-ferent stakeholder groups - Quality meta model provides notation for for-mulating quality goals, queries, and measure-ments
Total Infor-mation Quality Manage-ment English (1998)	TIQM	- Processes and techniques for evaluating, opti-mizing, and controlling the quality of data and in-formation through continuous quality manage-ment - Phases: Assessment, Improvement; Improve-ment Management and Monitoring

Methodology & Reference	Abbre-via-tion	Main characteristics
A methodol-ogy for infor-mation qual-ity assessment Lee, et al. (2002)	AIMQ	- Information quality measurement based on sub-jective assessment of quality (carried out by: Sur-veys and benchmarks) - Components: Product-Service-Performance-Model, quality of data products, Benchmark-Gap-Analysis/Role-Gap-Analysis
Data Quality As-sessment Pipino, Lee and Wang (2002)	DQA	- Developing general definition of data quality metrics (subjective and objective) - Comparing the results of the assessments, iden-tifying discrepancies and taking necessary ac-tions for improvement
Comprehensive methodology for Data Qual-ity management Batini and Scan-napieco (2006)	CDQ	- Combination of data- and process-driven strate-gies for data and information quality optimiza-tion - Selection of optimal quality improvement pro-cess that maximizes benefits for set budget - Phases: State reconstruction, Assessment, Choice of the optimal improvement process

Methodology & Reference	Abbre-via-tion	Main characteristics
Control Charts Jones-Farmer, Ezell and Hazen (2014)	CC	- Control charts for monitoring data quality in aircraft maintenance - Multiple measures of the intrinsic dimensions of data quality
Data Quality Management in Data Warehouse Systems Hinrichs (2002)	DQDWS	- Metrics for selected data quality dimensions to evaluate quality of data stock - Procedure for quantification of data quality aims for objectifiable, target-oriented evaluation - Enables largely automated measurement
Metrics and measurement methods for Data Quality Rohweder, et al. (2018)	MMDQ	- Metrics for dimensions: Completeness, Accuracy, Consistency, and Timeliness - Focus on the requirement of cardinality of metrics
Metrics for Data Quality Assessment	MDQA	- Metrics for dimensions: Completeness, Accuracy, Consistency, and Timeliness

Methodology & Reference	Abbre-via-tion	Main characteristics
Blake and Man-giameli (2011)		
Measuring Data Believability Prat and Madnick (2008)	MDB	- Metric for believability measured by trustworthi-ness, reasonableness, and temporality - Provenance-based
Health Data Qua lity Indicator van Deursen, Ko ster and Petković (2008)	HDQI	- Metric for reputation in healthcare - Considers reputation of information provider and metadata
EigenTrust Algo-rithm Kamvar, Schlos-ser and Garcia-Molina (2003)	ETA	- Metric for reputation in peer-to-peer file-sharing network with unique global trust value for each peer

Table 2: Dimensions and metrics of methods

Abbreviation	Dimensions	Metrics
TDQM	Accuracy, Objectivity, Believability, Reputation, Access, Security, Relevancy, Value-Added, Timeliness, Completeness, Amount of data, Interpretability, Ease of understanding, Concise representation, Consistent representation	-
DWQ	Can be set as objectives	-
TIQM	Inherent dimensions: Consistency, Completeness, Accuracy, Precision,	-
TIQM	Nonduplication, Equivalence of redundant data, Concurrency of redundant data Pragmatic dimensions: Accessibility, Timeliness, Contextual clarity, Derivation integrity, Usability, Rightness, Cost	

Abbre-viation	Dimensions	Metrics
AIMQ	Free-of-error, Appropriate amount of data, Concise representation, Relevancy, Completeness, Understandability, Consistent representation, Interpretability, Objectivity, Timeliness, Believability, Security, Accessibility, Ease of operation, Reputation	-
DQA	Accessibility, Appropriate amount of Data, Believability, Completeness, Concise Representation, Consistent Representation, Ease of Manipulation, Free-of-error, Interpretability, Objectivity, Relevancy, Reputation, Security, Timeliness, Understandability, Value-Added	Suggested percentage ratio
CDQ	Schema: Correctness with respect to the model, Correctness with respect to Requirements, Completeness, Pertinence, Readability, Normaliza-	Accuracy, Completeness, Currency, Timeliness, Volatility, Consistency

Abbreviation	Dimensions	Metrics
	tion - Data: Syntactic/Semantic Accuracy, Semantic Accuracy, Completeness, Consistency, Currency, Timeliness, Volatility, Completability, Reputation, Accessibility, Cost	
CC	Accuracy, Timeliness, Consistency, Completeness	Accuracy, Completeness, Consistency
DQDWS	Accuracy, Objectivity, Believability, Reputation, Relevancy, Value-Added, Timeliness, Completeness, Amount of Data, Interpretability, Ease of Understanding, Concise Representation, Consistent Representation, Accessibility, Access Security	Accuracy, Consistency, Completeness, Amount of Data, Relevancy, Timeliness, Interpretability, Ease of Understanding, Consistent Representation
MMDQ	Ease of Manipulation, Accessibility, Reputation, Free of Error, Objectivity, Believability, Timeliness, Value-Added, Completeness. Appropriate	Completeness, Free of error, Concise Representation, Timeliness

Abbre-viation	Dimensions	Metrics
	amount of data, Relevancy, Consistent Representation, Understandability, Interpretability, Concise Representation	
MDQA	Accuracy, Completeness, Consistency, Timeliness	Accuracy, Completeness, Consistency, Timeliness
MDB	Believability	Believability
HDQI	Reputation	Reputation
ETA	Reputation	Reputation

Due to the wide range of different methods, the optimal determination of data quality must always be based on the specific application. To connect the data quality requirements from dimensioning capacities to the methods for measuring data quality, the requirements will be selected in form of statements with assigned quality dimensions and later matched to the data quality measurement methods from this chapter. Based on the prioritization of the quality dimensions, an own method will be developed for the use case of capacity dimensioning on the base of existing methods.

4 Concept of Measuring Data Quality in Dimensioning Capacities

The requirements for data quality in the use case of dimensioning capacities from chapter 2 are summarized as statements in Table. Since the measurement of data quality and the weighting of the individual quality dimensions is strongly dependent on the case of application, the requirements of the use case are compiled to select a suitable procedure. The statements were collected within the research project to detail the requirements for determining data quality. Each statement is assigned the relevant data quality dimensions and clustered in one of the groups: Master data (MD), context (C) and framework (F).

Table 3: Statements of data quality requirements for dimensioning capacities

Statement	Dimension	Cluster
Digital form	Accessibility, Ease of manipulation	F
All locations have structured data in same way	Consistent representation, Interpretability, Objectivity	F
Centrally available dataset	Accessibility	F
Editable data format	Ease of manipulation	F

Statement	Dimension	Cluster
Content relevant datasets only	Appropriate amount of data, Relevancy	F
Compressed, complete dataset	Appropriate amount of data, Completeness	F
Master data of products must be maintained/ filled	Completeness, Timeliness	MD
Correct master data/ reliable data source	Believability, free of error, Reputation	MD
Consistency of master data (target/ actual)	Believability, Reputation	MD
Levels of aggregation of products (product key)	Completeness, Appropriate amount of data	C
All products from location must be listed	Appropriate amount of data, Completeness, Relevancy	C

Statement	Dimension	Cluster
Unique identifier for each product (e.g. material number)	Appropriate amount of data, Concise representation, Interpretability	C
Future products are included	Appropriate amount of data, Completeness	C
Current time horizon	Timeliness	C
Units are clearly defined	Concise representation	C
Restrictions for relation product - warehouse/handling/machine	Appropriate amount of data, Concise representation	C
No interpretation for attributes (e.g. material)	Interpretability, Understandability	C
Quantifiable dataset	Objectivity, Value added	C

For a structured comparison of these subjective statements there are two popular methods: Single stimulus and pairwise comparison method. In recent literature it was shown that the pairwise comparison method leads to more accurate and reliable results (Mantiuk, Tomaszewska and Mantiuk, 2012). In this method every object (criteria, alternatives, etc.) is compared to all other objects on a scale from -2 to+2 (-2 meaning row is much less important than column, -1 row is less important than column, 0 both are equally important, 1 row is more important than column and 2 row is much more important than column) (Abdi and Williams, 2010; Zhang, et al., 2017). A decision per pair makes the choice easier than handling all choices simultaneously. After ranking each pair, the results can be displayed in a matrix, sum totals can be formed per row, the characteristics are weighed and ranks can be assigned in the proposed order. Especially where direct measurements are impractical the pairwise comparison method is of great value. The statements with the assigned dimensions are weighted, ranked and displayed by quality dimension in Table 4. The sum of the weighted points does not necessarily have to be zero, because the statements examined were assigned to different numbers of quality criteria.

Table 4: Ranked quality dimensions for dimensioning capacities

Rank	Weighted points	Quality dimension
1	27	Free of error
2	13	Concise representation
3	12	Believability, Reputation
4	4	Timeliness
5	3	Completeness

Rank	Weighted points	Quality dimension
6	0	Interpretability
7	-1	Ease of manipulation, Appropriate amount of data
8	-2	Value added
9	-7	Relevancy
10	-8	Understandability
11	-10,5	Objectivity
12	-12,5	Accessibility
13	-19	Consistent representation

This shows the five most relevant data quality dimensions for capacity planning: Free of error, concise representation, believability, reputation and timeliness. Applying the pairwise comparison also to the clusters, gives additional insights (see Table 5).

Table 5: Ranked clusters for dimensioning capacities

Cluster	Weighted points
Master data	11,33

Cluster	Weighted points
Context	2,11
Framework	-8,83

This leads to the conclusion that for dimensioning capacities in the SCD process clear and correct master data is more relevant than the context and the least relevant, the framework.

To identify a suitable method for dimension capacities in SCD the findings from this chapter are applied to the methods of assessing data quality, concerning the five key dimensions as well as the clusters: Master data and context.

4.1 Framework for Measuring Data Quality in Dimensioning Capacities

In the overview from Batini, et al. (2009) and in the additional literature research the main findings were qualitative methods and approaches with a focus on specialized metrics. Also a few hybrid methods containing both aspects were found. The five most significant dimensions for the presented use case are: Free of error (Fe), Concise representation (Cr), Believability (B), Reputation (R) and Timeliness (T). Since these are only partially included in the methods an overview of the approaches containing metrics is given in Table .

Table 6: Methods with metrics for top five quality dimensions of use case

Method	Fe	Cr	B	R	T
CDQ	X	X			X
CC	X	X			
DQDWS	X	X			X
MMDQ	X	X			X
MDQA	X	X			X
MDB			X		
HDQI				X	
ETA				X	

Four methods contain metrics for the dimensions free of error, concise representation and timeliness, but believability and reputation are not included. Hinrichs (2002) includes these three metrics and additionally most other metrics as stated in

Table (further metrics: Consistency, completeness, amount of data, relevancy, interpretability and consistent representation). For better comparison of the individual formulas, the metrics are normalized to the interval 0-1. Adapted metrics are presented to measure the dimensions on different levels: Attribute value level, tuple level, database level and relation level (Hinrichs, 2002).

After selecting the metrics from Hinrichs (2002) only three out of the five dimensions are provided. Therefore, the selection must be supplemented for the missing dimensions believability and reputation. These dimensions often tend to be estimated subjectively, but metrics can be found. These are presented in the following.
For the dimension believability the metric of Prat and Madnick (2008) is applicable. In this method trustworthiness, reasonableness and temporality are identified as the three components of believability. The values for each component are calculated regarding their data provenance (Prat and Madnick, 2008).
For the dimension reputation the metric proposed by van Deursen, Koster and Petković (2008) is fitting the requirements best. The method was developed for the application in the healthcare sector as a reputation-based health data quality indicator. This is especially relevant when patients provide their own information to health care providers and the quality cannot be guaranteed. The method was developed to address this problem and considers the reputation of the information provider and of the metadata provided by measurement systems (van Deursen, Koster and Petković, 2008).
Metrics have been identified for the five key dimensions. This addresses the challenge portrayed in Table with the most important cluster master data. Additionally, the second most important cluster, the context, should also be considered in this method. To meet this challenge a more general measurement method for data quality must be identified, in which the metrics can be embedded. The best combination of existing methods depends on the use case and the focus of the important dimensions. For this use the

applicable general method called Data Warehouse Quality Method from Jeusfeld, Quix and Jarkeet (1998) seems appropriate to apply. All data quality dimensions can be considered, as the first phase of the methodology is that the relevant objectives in the form of quality dimensions are set. The method briefly described in Table is a general approach for measuring data quality. The core of the method is assessing heterogeneous information from different sources to be able to integrate the information uniformly into a data warehouse. One step is to set objectives according to stakeholder groups that can also be quality dimensions. A quality meta model provides notation for formulating quality goals, queries, and measurements (Jeusfeld, Quix and Jarkeet, 1998; Batini, et al., 2009).
To combine the requirements from the use case dimensioning capacities and from the quality dimensions to cluster them into one solution, a two-stage method was developed (see Figure 5). For the general data quality assessment, the method is strongly inspired by the Data Warehouse Quality Method from Jeusfeld, Quix and Jarkeet (1998). First, the context for the assessment of data quality is defined. To formulate the quality goal, the purpose of the project and the different stakeholders must be considered. A focus has to be set for at least the five key quality dimensions in the use case: Free of error, Concise representation, Believability, Reputation and Timeliness. In order to measure the quality goal a quality query is needed against which the goal is calculated by the measuring agent. This value is saved as the expected value, which marks the starting point of the allowed range of values. The next step is the quality metric, the formula used for measuring the quality dimensions set as goals. In this use case the metrics needed for the five key quality dimensions are from Hinrichs (2002), Prat and Madnick (2008) and van Deursen, Koster and Petković (2008). When the

metrics are calculated a time stamp will be saved along with the actual measurement. The result from the measurement provides a value, which by itself has no meaning, but it can be evaluated with the quality query to check if the value is permitted or not, which is the quality domain. The quality domain will be reviewed in continuous intervals.
With the five key quality dimensions and master data and context considered a method for measuring data quality for dimensioning capacities was developed in this paper.

Data Warehouse Quality Method (DWQ)

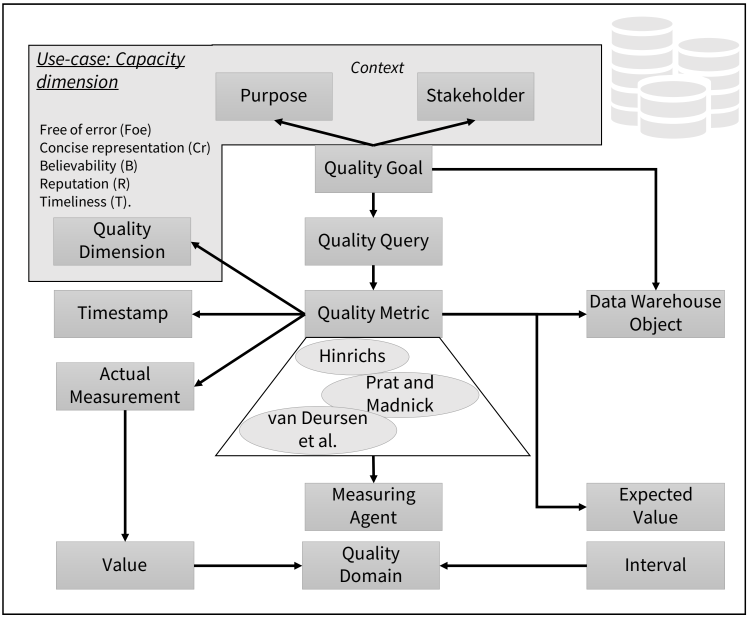


Figure 5: Two step methodology

5 Conclusion

This paper describes the use case of designing SC networks regarding integrating operative indicators in strategic planning. The research project's challenges occurred in the SCD task of dimensioning capacities with the quality of the available data for strategic planning. The challenge to measure data quality in the use case of dimensioning capacities was addressed in this paper. First the SCD tasks were outlined to further understand the context. Then the specific case of application was described and the occurred challenges with data quality. After exploring the theoretical foundation of data quality and methods for measuring and metrics were displayed it became clear, that the methods can be divided into two groups. On one side there are general methods that are defining guidelines, mostly with a focus on improving data quality, which tend to be subjective. On the other side there are specified methods and metrics that mostly focus on one dimension and consider a maximum of nine metrics. To measure the five most important dimensions from the use case along with the clusters of master data and the context, a new two-stepped methodology to assess data quality was developed. The integration of the general method and needed metrics to specifically meet the requirements of the use case provides a benefit for future planning.

In the next step the developed two step method must be validated with a use case to be able to evaluate its applicability. After that it can be assessed if the model can be applied to a wider spectrum of use cases by changing the key metrics. Additionally, it is advisable to collect metrics for the dimensions that are currently not considered in the developed method.

Future research is needed to adapt the metrics to the respective use cases and to develop an evaluation scale for classifying data quality in terms of the benefits that can be derived from the data (cost-benefit estimation).

Financial Disclosure

The results of this paper are based on the research project E^2-Design, funded by the German Federal Ministry for Economic Affairs and Energy (FKZ 03ET1558A).

References

Abdi, H. and Williams, L. J., 2010. Newman-Keuls test and Tukey test. Encyclopedia of Research Design. Thousand Oaks, CA: Sage, pp. 1–11.

Addo-Tenkorang, R. and Helo, P. T., 2016. Big data applications in operations/supply-chain management: A literature review. Computers & Industrial Engineering, 101, pp. 528–543.

Baghalian, A., Rezapour, S. and Farahani, R. Z., 2013. Robust supply chain network design with service level against disruptions and demand uncertainties: A real-life case. European Journal of Operational Research, 227(1), pp. 199–215.

Batini, C., Cappiello, C., Francalanci, C. and Maurino, A., 2009. Methodologies for data quality assessment and improvement. ACM computing surveys (CSUR), 41(3), pp. 1–52.

Batini, C. and Scannapieca, M., 2006. Data Quality: Concepts, Methodologies and Techniques. [e-book]. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg. <http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10145282>.

Baumgärtel, H., 2008. TSCP-Ein taktisches Supply Chain Planungsmodell für Kollaboratives Planen. Informations-und Kommunikationssysteme in Supply Chain Management, Logistik und Transport, DSOR Beiträge zur Wirtschaftsinformatik, 5, pp. 21–38.

Blake, R. and Mangiameli, P., 2011. The effects and interactions of data quality and problem complexity on classification. Journal of Data and Information Quality (JDIQ), 2(2), pp. 1–28.

Dash, R., McMurtrey, M., Rebman, C. and Kar, U. K., 2019. Application of Artificial Intelligence in Automation of Supply Chain Management. Journal of Strategic Innovation and Sustainability, 14(3).

English, L., 1998. Data quality: Meeting customer needs. Pitney Bowes white paper.

Erben, R. F. and Romeike, F., 2003. Komplexität als Ursache steigender Risiken in Industrie und Handel. In: 2003. Erfolgsfaktor Risiko-Management: Springer, pp. 43–63.

Fattahi, M., Mahootchi, M., Govindan, K. and Husseini, S. M. M., 2015. Dynamic supply chain network design with capacity planning and multi-period pricing. Transportation Research Part E: Logistics and Transportation Review, 81, pp. 169–202.

Fleischmann, B. and Koberstein, A., 2015. Strategic network design. In: 2015. Supply chain management and advanced planning: Springer, pp. 107–123.

Friemann, F., 2015. Strategische Lagerkapazitätsplanung: Ein Konzept zur stärkeren Integration in den strategischen Supply Chain Planungsprozess am Beispiel der pharmazeutischen Industrie. ETH Zurich.

Gudivada, V., Apon, A. and Ding, J., 2017. Data quality considerations for big data and machine learning: Going beyond data cleaning and transformations. International Journal on Advances in Software, 10(1), pp. 1–20.

Hinrichs, H., 2002. Datenqualitätsmanagement in data warehouse-systemen. Universität Oldenburg.

Hsu, C.-I. and Li, H.-C., 2009. An integrated plant capacity and production planning model for high-tech manufacturing firms with economies of scale. International Journal of Production Economics, 118(2), pp. 486–500.

Jayawardene, V., Sadiq, S. and Indulska, M., 2015. An analysis of data quality dimensions.

Jeusfeld, M. A., Quix, C. and Jarke, M., 1998. Design and analysis of quality information for data warehouses. In: Springer. International Conference on Conceptual Modeling, pp. 349–362.

Jones-Farmer, L. A., Ezell, J. D. and Hazen, B. T., 2014. Applying control chart methods to enhance data quality. Technometrics, 56(1), pp. 29–41.

Kamvar, S. D., Schlosser, M. T. and Garcia-Molina, H., 2003. The eigentrust algorithm for reputation management in p2p networks. In: Proceedings of the 12th international conference on World Wide Web, pp. 640–651.

Ketchen Jr, D. J. and Hult, G. T. M., 2007. Bridging organization theory and supply chain management: The case of best value supply chains. Journal of Operations Management, 25(2), pp. 573–580.

Lee, Y. W., Strong, D. M., Kahn, B. K. and Wang, R. Y., 2002. AIMQ: a methodology for information quality assessment. Information & management, 40(2), pp. 133–146.

Lewis, M. and Slack, N., 2017. Operations strategy. 5th ed.: Pearson Education.

Mantiuk, R. K., Tomaszewska, A. and Mantiuk, R., 2012. Comparison of four subjective methods for image quality assessment. In: Wiley Online Library. Computer graphics forum, pp. 2478–2491.

Minner, S. (2018): Kapazitätsdimensionierung von Produktionssystemen. In: Corsten: Handbuch Produktions- und Logistikmanagement in Wertschöpfungsnetzwerken.

Oppenheim, C., Stenson, J. and Wilson, R. M. S., 2003. Studies on information as an asset I: definitions. Journal of Information Science, 29(3), pp. 159–166.

Österle, H. and Otto, B., 2014. Das datenzentrierte Unternehmen: Eine Business-Engineering-Perspektive. In: 2014. Enterprise-Integration: Springer, pp. 91–105.

Parlings, M., Cirullies, J. and Klingebiel, K., 2013. A literature-based state of the art review on the identification and classification of supply chain design tasks.

Pipino, L. L., Lee, Y. W. and Wang, R. Y., 2002. Data quality assessment. Communications of the ACM, 45(4), pp. 211–218.

Prat, N. and Madnick, S., 2008. Measuring data believability: A provenance approach. In: IEEE. Proceedings of the 41st Annual Hawaii International Conference on System Sciences (HICSS 2008), p. 393–393.

Rohweder, J. P., Kasten, G., Malzahn, D., Piro, A. and Schmid, J., 2018. Informationsqualität-Definitionen, Dimensionen und Begriffe. In: 2018. Daten-und Informationsqualität: Springer, pp. 23–43.

Santoso, T., Ahmed, S., Goetschalckx, M. and Shapiro, A., 2005. A stochastic programming approach for supply chain network design under uncertainty. European Journal of Operational Research, 167(1), pp. 96–115.

Schreiber, L., 2019. Optimization and simulation for sustainable supply chain design. In: Berlin: epubli GmbH. Digital Transformation in Maritime and City Logistics: Smart Solutions for Logistics. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 28, pp. 271–298.

Sidi, F., Panahy, P. H. S., Affendey, L. S., Jabar, M. A., Ibrahim, H. and Mustapha, A., 2012. Data quality: A survey of data quality dimensions. In: IEEE. 2012 International Conference on Information Retrieval & Knowledge Management, pp. 300–304.

Statista, 2014. Supply Chain results using big data analytics. [online] Available at: <https://www.statista.com/statistics/491211/supply-chain-results-using-big-data-analytics/> [Accessed 18 May 2020].

van Deursen, T., Koster, P. and Petković, M., 2008. Hedaquin: A reputation-based health data quality indicator. Electronic Notes in Theoretical Computer Science, 197(2), pp. 159–167.

Waller, M. A. and Fawcett, S. E., 2013. Data science, predictive analytics, and big data: a revolution that will transform supply chain design and management. Journal of Business Logistics, 34(2), pp. 77–84.

Wang, R. Y., 1998. A product perspective on total data quality management. Communications of the ACM, 41(2), pp. 58–65.

Wassermann, O., 2013. Das intelligente Unternehmen: Mit der Wassermann Supply Chain Idee den globalen Wettbewerb gewinnen: Springer-Verlag.

Werner, H., 2017. Supply Chain Management: Grundlagen, Strategien, Instrumente und Controlling. 6th ed.: Springer.

Zhang, Z., Zhau, J., Liu, N., Gu, X. and Zhang, Y., 2017. An improved pairwise comparison scaling method for subjective image quality assessment. In: IEEE. 2017 IEEE International Symposium on Broadband Multimedia Systems and Broadcasting (BMSB), pp. 1–6.

A Systematic Classification of Database Solutions for Data Mining to Support Tasks in Supply Chains

Joachim Hunker [1], Anne Antonia Scheidler [1], and Markus Rabe [1]

1 – TU Dortmund Fachgebiet IT in Produktion und Logistik

Purpose: Our research shows that considering well suited NoSQL databases is beneficial for logistics tasks. For answering tasks we rely on the widespread methods of Data Mining. We stress that using relational databases as basis for Data Mining tools cannot cope with the growing amount of data and that using NoSQL databases can be an important step to address these issues.
Methodology: This paper discusses Data Mining in the context of Supply Chain Management tasks in logistics and its requirements on databases. The paper demonstrates that using NoSQL databases as basis for Data Mining process models in logistics is a very promising approach. The research is based on a case study, whose core element is the analysis of different well established studies.
Findings: The paper presents results which show that Data Mining tools widely support NoSQL databases through available interfaces. Findings are presented in a comparison table which considers dimensions such as Data Mining tools and supported NoSQL databases. To show practical feasibility, a Data Mining tool is used on data of a Supply Chain stored in a NoSQL database.
Originality: The novelty of this paper emerges from addressing issues that have so far been insufficiently analyzed in the scientific discussion. The modular structure of the addressed research method ensures scientific traceability. Breaking down tasks and their requirements on databases in the field of Data Mining is a first step towards meeting trends like Big Data and their challenges.

First received: 12. Mar 2020 Revised: 21. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

Logistics is one of the most important economic disciplines in Germany. Companies work together and, based on the requirements like globalization and just-in-time processes, form global networks, called Supply Chains. Trends that are summarized by buzz words like "Logistics 4.0" and "Big Data" have a major impact on Supply Chains (Borgi et al. 2017). The addition "4.0" stresses the importance of digital change in the sense of a fourth industrial revolution (Bousonville 2017). One of the consequences of these trends is the exponential growth of highly connected data, e.g., where forecasts predict a rise in worldwide data volume from 25 up to 163 zettabyte in the year 2025 (Reinsel et al. 2018). Therefore, executing tasks in Supply Chains is getting more complex. As an example for the complexity, a Supply Chain Management is confronted with multiple logistics tasks, e.g., real-time monitoring of deliveries throughout whole Supply Chains. Based on the fact that Supply Chains have emergent and coherent effects, the need to assist in answering logistics tasks as decision support for Supply Chain Management is necessary (Teniwut and Hasyim 2020). One of the frequently used methods in logistics is Knowledge Discovery in Databases, with Data Mining as its core process (Rahman et al. 2011). The prerequisite for running a successful Data Mining is a valid and preprocessed data basis. Since the 1970s, relational databases are dominant in the worldwide market (Garcia-Molina et al. 2009). Based on the addressed current requirements and trends, relational databases have difficulties in adapting to and processing of highly connected high volume data (Hecht and Jablonski 2011, Li and Manoharan 2013). These developments are resulting in the rise of different concepts such as non-relational (NoSQL) databases. Surveys and forecasts show that logistics companies focus on hardware and Business Intelligence Analytics, but pay little to no attention towards NoSQL databases (Kelly 2015).

Our research closes the addressed gap and shows that NoSQL databases are well supported by existing Data Mining tools. We will highlight that focusing on well suited databases will be a big benefit for logistics tasks. For solving the logistics tasks, we rely on the widespread methods of Data Mining. For example, we will emphasize that graph databases are a native way to store data, e.g. for routing in Supply Chains, and can be an important step towards real-time decision support in Supply Chain Management.

The paper is structured as follows: Section 2 introduces the theoretical background necessary for this paper. In Section 3 we discuss our research, highlighting interfaces of Data Mining tools in regards to NoSQL databases against the background of logistical tasks and present results while Section 4 discusses our findings. The paper closes with a brief summary and an outlook in Section 5.

2 Theoretical Background

In the following sections the theoretical background necessary for this paper is discussed. First, we introduce the Supply Chain as the problem domain and highlight exemplary tasks. In the light of our problem domain, we discuss different types of data storages, relational databases, and NoSQL databases. Since we rely on the well-established method of Knowledge Discovery in Databases, the process of Data Mining is briefly discussed. At the end of this section, common database interfaces are presented.

2.1 Tasks in Supply Chains

Trends such as globalization and digitalization have a major impact on Supply Chains. Actually, Supply Chains are not chains as the term indicates, but networks of different linked organizations that work together, with different processes and activities that produce a value for customers (Lambert 2014, Christopher 2016). Due to these trends, Supply Chains are nowadays very complex global networks (Serdarasan 2013). Mastering the complexity in a Supply Chain is a problem for Supply Chain Management. It is responsible for the cross-company design of the planning, control, and monitoring of the processes within a Supply Chain. The attempt to master the complexity results, for example, in various logistical tasks with which the Supply Chain Management is confronted and the answers to which are a central task within the framework of a suitable decision support. In this context, Supply Chain Management is confronted with a multitude of different logistics tasks. Typical tasks can be differentiated along the flows of a Supply Chain, e.g., material flow or information flow, e.g., the choice of the most appropriate means of transport or the real-time monitoring of on-time delivery. A typical way to categorize tasks is to use the five top level categories (Plan, Source, Make, Deliver, Return) of the Supply Chain Operations Reference Model (SCOR), an established model for the standardization of processes within a Supply Chain, which has been used in previous work of the authors (Gürez 2015, Scheidler 2017). For example, an exemplary task for the category "Plan" is determining the future customer requirements, or for the category "Deliver" a typical task is finding the right and most efficient means of transport for a delivery. One of the typical characteristics of such tasks is the challenge of finding correlations, which are especially relevant for Supply Chain Management (Harland 1996).

The key factor to support the decision making process for tasks in Supply Chain Management is knowledge. Following the definition given by North and Maier (2018), knowledge is based on information that is combined with more information in a certain context to answer questions like "how", whereas information is based on data that are interpreted and answer questions like "who", "where", and "when". The reader is kindly referred to Rowley (2007) for a deeper analysis of the terms data, information, and knowledge.

Generating knowledge from a data set is a challenge. One of the consequences of today's trends for Supply Chains is the emergence of large, strongly interrelated data volumes, which have to be stored in a persistent and suitable way.

2.2 From Relational to NoSQL Databases

To support tasks in Supply Chain Management adequately and since methods to discover knowledge work on data, an appropriate way of persistent data storage in Supply Chains is necessary. Nowadays, databases are typically used in, e.g., decision support systems. Simply put, a database is a collection of related data and, together with a database management system (a collection of software programs), forms a database system (Elmasri and Navathe 2011, Connolly and Begg 2015). Since the work by Edgar F. Codd in the early 1970s (Codd 1970), databases based on the relational datamodel have become the worldwide de facto standard and a default in systems for decision support today. Prominent examples are Oracle, MySQL, MariaDB, Microsoft SQL Server and IBM DB2 (Solid IT 2020). However, focusing only on relational databases leads to serious drawbacks regarding the modeling of data, e.g., the transformation of graphs into tables or the handling of datasets that fit the Big Data paradigm (Hecht and Jablonski 2011). Such datasets are characterized by at least 3V, volume, variety, and velocity and have been supplemented by experts with two additional Vs, value and veracity, to emphasize the financial value and the varying quality of data (Meier and Kaufmann 2019). To tackle the mentioned problems, a different type of databases has gained attention in recent research (Moniruzzaman and Hossain 2013, Jose and Abraham 2017). These databases are summarized under the term NoSQL, which stands for "not only SQL", to highlight that these databases do not rely on the Structured Query Language (SQL), the dominating, standardized database language to query and manipulate data stored in relational databases (Batra 2018). The term NoSQL was coined by Carlo Strozzi in 1998 while introducing a relational database without the need for SQL (Strozzi 2017). It should be noted that the term NoSQL is in fact misleading as it describes a non-property of such, even relational, databases and should be specified by non-relational. The authors of this paper decided to use the term NoSQL since it has been established in both theory and practice.

Organizing data in a non-relational way is not a new idea per se and has existed even before the relational database has been invented, e.g., in the form of hierarchical databases. A precise, uniform definition for NoSQL databases cannot be identified in the scientific discourse. In this paper, the authors understand NoSQL databases as characterized by Meier and Kaufmann (2019). The authors state that data in NoSQL databases are not stored in relational tables and the database language is not SQL. Besides multiple different database types like object-oriented or XML-databases and a multitude of special-use databases, four core types of NoSQL databases can be distinguished (Edlich et al. 2011):

Key-Value Stores (e.g., Couchbase) store data by using an identifier (the key) and associate a value of any kind and complexity (hashes, strings, lists, sets, XML, etc.) to a key. Searches, for example, can be conducted by querying the keys, but not against values.

Column-Family (or Wide Column) Stores (e.g., Cassandra, HBase) store data in tables, but handle the data in columns (more precise: column-families) rather than in rows. Keys are applied here to any number of Key-Value-Pairs, which can itself be extended by a Key-Value-Pair and form a Column-Family.

Document databases (e.g., MongoDB) handle data similar to Key-Value Stores, but store the data in documents that follow a standard exchange format like the Javascript Option Notation, which enforces the data which are stored in the documents to be at least semi-structured.

Graph Databases (e.g., Neo4j) are databases that store the data in the form of a tree or a graph using nodes and edges, e.g., a labeled property graph.

Within a property graph, nodes and edges can be labeled with properties. Manipulation of the data is done via graph transformation or using the properties of a graph, e.g., traversing. One of the typical database languages is Cypher, which is used for labeled property graphs.

The advantage of this type of databases is that they can handle large volumes of unstructured and highly connected data (Big Data). Graph databases, for example, can handle highly networked data very well due to their graph structure. Both, relational and NoSQL databases, have their strengths. The concept to use different databases in parallel for different situations to make use of their advantages is called Polyglot Persistence (Sadalage and Fowler 2013). The authors stress that the nature of the data that are stored in a database and how to work with the data must be understood first and that using only relational databases per default as the single type of database will lead to disadvantages, e.g., in performance.

The data stored within a database serve as an input for knowledge discovery techniques.

2.3 Knowledge Discovery in Databases

Extracting knowledge from databases and making it available to logistical processes is a value-adding task. Through the targeted analysis of data sets, valuable knowledge can be gained for different business areas. Such knowledge can secure a competitive advantage in the long run. One method of extracting knowledge from large data sets is Knowledge Discovery in Databases (KDD). KDD is a non-trivial (Fayyad et al. 1996), iterative, and interactive process (Wrobel et al. 1996).

KDD consists of different phases, ranging from the pre-processing of data to the actual application of procedures and data preparation for monitoring purposes. The actual application of methods is the central step and is known as Data Mining. This central step is so important that nowadays the terms KDD and Data Mining are often used synonymously and many authors do not make a distinction in content (Adriaans and Zantinge 1996). This also becomes clear in the task definition of Data Mining, which Runkler (2010) states with "Extracting knowledge from data". In his process model, Fayyad et al. (1996) envisage not only Data Mining but also a selection as the selection and export of analysis data, preprocessing as the cleansing and correction of missing or incorrect data, transformation as the transformation of data into a suitable target format for analysis purposes and evaluation respectively interpretation as the evaluation of the results. Figure 1 shows the process model presented by Fayyad et al. (1996).

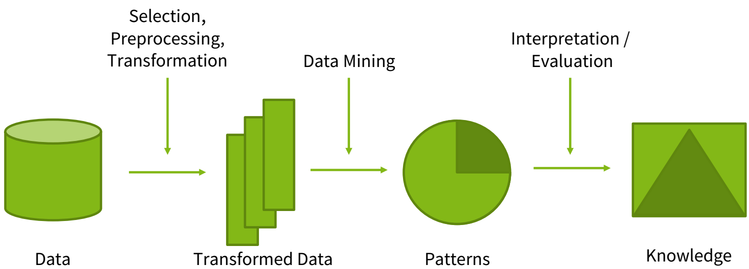


Figure 1: Knowledge Discovery in Databases (according to Fayyad et al. 1996)

Fields of application of Data Mining are complex. In logistics, there are a multitude of questions that can be supported and answered by Data Min-

ing. These include, for example, questions about future customer requirements, distribution centers, or delivery optimization. Depending on the questions, different Data Mining methods are used. As there are usually several Data Mining methods that can be used to solve tasks and often it is not clear which method is best suited, many tools support a wide range of Data Mining methods. This includes in particular various possibilities for preprocessing of data and preparation of Data Mining results. Only by means of a corresponding pre-implemented multitude of methods the company has the possibility to apply different methods and validate results in an acceptable time. In logistics, Data Mining procedures are often embedded in business applications. These include logistic assistance systems or decision support systems. Marakas (2003) and Turban and Volonio (2011) define them as systems that are under the control of one or more decision makers and support the decision-making process by using defined tools. The tools used pursue the goal of structuring decision-making situations and ultimately improving the effectiveness of logistical decision-making processes (Turban and Volonino 2011).
There are many tools available for the application of Data Mining methods, which have different functionalities. For example, the tools have different interfaces to support data import and, in many cases, enable direct application to different database systems.

2.4 Database Interfaces

Data Mining tools heavily rely on data, and the integration of a suitable database is, therefore, a key element. Since in many cases data stored in databases cannot be accessed from external tools directly (unless support is directly integrated in the tool), a middleware can be used to bridge the gap between the server, where the database is running, and the client, where the software is executed (Elmasri and Navathe 2011). This middleware will also support independence from the specific database tool. The common approach of most interfaces is to offer a programming application interface that can be used to convert requests from an external application software such as Data Mining tools into standardized SQL commands, e.g., to extract data (Elmasri and Navathe 2011). This approach has the big benefit that there is no need to know the specifics and specialties of a used database. Both the database and the software must support the interface.

There is a plethora of existing programming interfaces that can be used to establish such a link. Prominent examples of programming interfaces are Open Database Connectivity (ODBC), Java Database Connectivity (JDBC), Object Linking and Embedding (OLE-DB), and ActiveX Data Objects (ADO). ODBC and JDBC are predominant and will, therefore, be discussed briefly in the following:

ODBC is a common, standardized interface when working with relational databases and was developed by Microsoft and the SQL Access Group. It uses standardized SQL to communicate with such databases (Garcia-Molina et al. 2009). ODBC offers a wide range of functions through a library for external applications to connect to an ODBC-capable database and execute SQL statements, e.g., to retrieve data (Li 2009b). It is independent of the programming language and used as a basis for multiple adaptations, e.g., SQL/CLI. Although intended for relational databases, some NoSQL databases also support ODBC (Li 2009b).

JDBC is part of the Standard Application Programming Interface of the JAVA programming language and enables applications written in JAVA to access databases via build in packages (Elmasri and Navathe 2011). It follows the same approach and style as ODBC, but makes heavy use of the object orientation of JAVA. Although oriented towards relational databases (Li 2009a), some NoSQL databases offer JDBC programming interfaces.

Even more flexibility is provided by the use of so-called bridges, which translate from ODBC to JDBC or vice versa.

3 Database Solutions for Data Mining in Supply Chains

In the following section, we present our research that is based on a preliminary study conducted at our department IT in Production and Logistics (Rellensmann 2019). First, we conducted a structured analysis based on several well-established studies to select Data Mining tools. Second, we examined the selected tools regarding database and interface support. Third, we identified the databases supported by the tools and created a matrix based on the findings of the research carried out. The results of the matrix are in the final step exemplary matched to a corresponding task in Supply Chain Management.

3.1 Selection and Analysis of Data Mining Tools

As described in Section 2.3, Data Mining is the core phase of KDD. To perform Data Mining on a given data set, a specialized tool is used. For this research, we conducted a structured analysis based on three well established studies.

First, we used Gartners "Magic Quadrant for Data Science and Machine-Learning Platforms" from 2020, which covers the results from the study carried out in 2019 (Krensky et al. 2020). The analysis of the study resulted in 16 vendors respectively tools. The 16 identified tools are: Altair Knowledge Studio, Alteryx, Anaconda, Databricks, Dataiku, DataRobot, Domino, Google, H20.ai, IBM SPSS Modeler, KNIME, MathWorks MATLAB, Microsoft Analysis Service, RapidMiner, SAS, and TIBCO Software Statistica. In addition to the study carried out by Gartner, we analyzed the results of "Einsatz und Nutzenpotentiale von Data Mining in Produktionsunternehmen" from

Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA (Weskamp et al. 2014). Supplementary to the already mentioned 16 tools by Gartner, the analysis of the study resulted in additional tools, which we included in our research. The tools are Oracle Data Mining, Statsoft Statistica, and SAP BI. As a third study we analyzed "Data Mining Software 2009" carried out by Dill (2009), which reduced the market of tools to a cross-section consisting of twelve programs and subjected it to a functional and benchmark comparison. The examination of this cross-section resulted in the following tools in addition to some programs already mentioned: Weka of University of Waikato, KXEN Analytic Framework, Viscovery SOMine, prudsys Discoverer, prudsys Basket Analyzer, and Bissantz Delta Master.

This results in a total of 25 tools, which were examined in the first step whether they still exists or whether it has been, e.g., bought by a competitor in the meantime. This resulted in four tools which were cut out:

KXEN Analytic Framework was bought by SAP and the features of the KXEN tool have been integrated into the applications offered by SAP.

prudsys Discoverer and prudsys Basket Analyzer have been discontinued and removed from the vendors portfolio.

Statsoft Statistica is distributed by Tibco Software under the same name since 2017 after been acquired by Dell.

In addition, the selected tools where examined with regards to external database support and if not, were cut out. This resulted in leaving out two Data Mining tools:

Google is offering a cloud-only based storage concept. On a side note, most of the tools are still in beta mode.

SAP BI has been integrated into a Data Warehouse Portfolio called SAP BW / 4HANA. It uses an SAP-integrated relational database (SAP HANA).
This reduces the number of Data Mining tools to 19, which will be further examined for database and interface support. It should be noted at this point that some tools offer specialized interfaces or import functions, e.g., for certain rare file formats. This will not be discussed further, since in the context of this paper the connection to databases is in the foreground.
The different tools are examined for database support on the basis of the accompanying documentation, website appearances and descriptions in the literature. Although possible through community support, we cut out self-programmed solutions and programming snippets and look for out-of-the-box-support via programming interfaces or directly implemented tool support as discussed in Section 2.4. In addition, we focus on relational and NoSQL databases as per our definitions given in Section 2.2 and will cut out a multitude of hybrid database systems and data warehouses, that inherit features both of the relational and NoSQL-world (e.g., NewSQL-databases). Some of the Data Mining tools did not mention a supported database directly. However, if they supported one of the interfaces mentioned in Section 2.4, they were included in the results, accordingly.
In the following, we present the analysis results of three selected tools that are representative for the investigation of all Data Mining tools.

3.1.1 Alteryx

Alteryx offers a wide range of supported data sources in an available documentation (Alteryx 2020). In most cases, ODBC is used to establish a connection to a relational database. In some cases, e.g., Microsoft Access, Alteryx is able to read the database files directly. Furthermore, the tool enables a proprietary solution by integrating external interfaces directly (Alteryx Tool). The summary of the analysis is presented in Table 2. Supported interfaces are documented in brackets for every database.

Table 1: Relational and NoSQL Data Sources Supported by Alteryx

Database Type	Database
Relational	Amazon Aurora (ODBC), Amazon Redshift (ODBC), Amazon S3 (Alteryx Tool), Exasol (ODBC), HP Vertica (ODBC), IBM DB2 (ODBC, OLE-DB), Microsoft Access (database files directly), Microsoft Azure Data Lake Store (Alteryx Tool), Microsoft Azure SQL Database (ODBC, OLE-DB), MySQL (ODBC), Oracle (ODBC, OLE-DB), Pivotal Greenplum (ODBC), PostgreSQL (ODBC), SAP HANA (ODBC)
NoSQL	Apache Cassandra (ODBC), MongoDB (Alteryx Tool)

3.1.2 RapidMiner

The Data Mining tool RapidMiner enables the integration of databases via the JDBC interface (see Section 2.4) as stated in the official documentation (RapidMiner 2020). In addition, it offers built-in interfaces that can be used directly by using RapidMiner. The vendor's documentation lists directly supported databases, but emphasizes that all databases which support JDBC are supported and that ODBC is supported via a built-in bridge from JDBC to ODBC. NoSQL databases are supported by implemented connectors that can be used to establish a connection. The results of the analysis are presented in Table 3, which also documents the supported interfaces in brackets.

Table 2: Relational and NoSQL Data Sources Supported by RapidMiner

Database Type	Database
Relational	MySQL (JDBC), PostgreSQL (JDBC), HSQLDB (JDBC), Ingres, Microsoft Access, Microsoft SQL Server, Oracle
NoSQL	Apache Cassandra (RapidMiner Connector), MongoDB (RapidMiner Connector)

3.1.3 MathWorks MATLAB

MATLAB is a tool for data analytics and offers different so-called toolboxes to adapt the tool to certain applications. It offers a software feature called Database Toolbox, which supports the connection to different relational and NoSQL databases via ODBC and JDBC interfaces (see Section 2.4). Listed are the tools officially supported by MATLAB as described in the documentation (MATLAB 2020), although the vendor states that more databases can be possibly connected using the supported interfaces. The results of the analysis are presented in Table 4.

Table 3: Relational and NoSQL Data Sources Supported by MATLAB

Database Type	Database
Relational	Microsoft Access (ODBC), Microsoft SQL Server (ODBC, JDBC), Oracle (ODBC, JDBC), MySQL (ODBC, JDBC), PostgreSQL (ODBC, JDBC), SQLite (ODBC)
NoSQL	Apache Cassandra (MATLAB Toolbox), MongoDB (MATLAB Toolbox), Neo4j (MATLAB Toolbox)

3.2 Data Mining Tools and Database Support

The studies in Section 3.1 yielded 44 supported databases. These have already been divided into two broad categories, relational and NoSQL databases (see Section 3.1). In order to further specify the results, the NoSQL databases were divided into the four core categories as discussed in Section 2.2. In order to reduce the amount of results and to make the presentation in the table clear, prominent examples were selected based on their frequency of support. Here it should be mentioned that the results show a snapshot at a certain point in time of the study. It is possible that the support for a database will be added or terminated in the future by a vendor. The results have been divided into two tables, Table 4 and Table 5, for a better overview. First, results for supported databases by Data Mining tools are presented in Table 4. If one combination is marked by an 'X', the database is officially supported by the tool, otherwise, it is marked by a hyphen. We selected five relational databases (IBM DB2, Maria DB, Microsoft SQL, MySQL and Oracle) and five NoSQL databases (Cassandra and HBase (Wide Column), Couchbase (Key-Value), MongoDB (Document) and Neo4j (Graph)), representing all four core types (see Section 2.2).

Table 4: Supported databases by Data Mining tools

Data Mining Tool / Database	IBM DB2	Maria DB	Microsoft	MySQL	Oracle	HBase	Couchbase	MongoDB	Cassandra	Neo4j
Altair	X	X	X	X	X	X	X	X	X	-
Alteryx	X	X	X	X	X	-	-	X	X	-
Anaconda	-	X	X	X	X	X	X	X	X	X
Bissantz	X	X	X	X	X	X	X	X	X	-
Databricks	X	X	X	X	X	X	X	X	X	X
Dataiku	X	X	X	X	X	X	X	X	X	X
Datarobot	X	X	X	X	X	-	-	-	-	-
Domino	X	X	X	X	X	X	X	X	X	X
H2O.ai	-	X	-	X	-	-	-	-	-	-
IBM SPSS	X	-	X	X	X	-	-	-	-	-
KNIME	X	X	X	X	X	X	X	-	X	X
MATLAB	X	X	X	X	X	X	X	X	X	X
Microsoft	X	X	X	X	X	X	X	X	X	-
Oracle	-	-	-	-	X	-	-	-	-	-
RapidMiner	X	X	X	X	X	X	X	X	X	-
SAS Miner	X	X	X	X	X	X	X	X	X	-
SOMine	X	X	X	X	X	X	X	X	X	-
Tibco	X	X	X	X	X	X	X	X	X	-
Weka	X	X	X	X	X	X	X	X	X	X

To complete the results obtained, Table 5 shows the database interfaces, which have been discussed briefly in Section 2.4, supported by the Data Mining tools. If a tool supports an interface, the combination is marked by an 'X', otherwise by a hyphen. As mentioned above, we list database and interface support, accordingly. One blur is that a database support may be listed, but an interface is used for connection. Nevertheless, we highlight supported interfaces because it is well possible to use this interface to extend the databases that are officially supported.

Table 5: Database interfaces supported by Data Mining Tools

Data Mining Tool / Interface	ODBC	JDBC	OLE-DB	ADO.net
Altair	X	-	-	-
Alteryx	X	-	-	-
Anaconda	-	-	-	-
Byssantz	X	-	X	-
Databricks	-	X	-	-
Dataiku	-	X	-	-
Datarobot	-	X	-	-
Domino	-	-	-	-
H2O.ai	-	X	-	-
IBM SPSS	-	-	-	-
KNIME	-	X	-	-
MATLAB	X	X	-	-
Microsoft	X	-	X	-
Oracle	-	-	-	-
RapidMiner	-	X	-	-

Data Mining Tool / Interface	ODBC	JDBC	OLE-DB	ADO.net
SAS Miner	X	-	-	-
SOMine	X	-	X	-
Tibco	X	-	X	X
Weka	-	X	-	-

3.3 Data Mining and Databases for Tasks in Supply Chain Management - First Experiments

The combination of Data Mining tools and NoSQL databases to answer tasks of Supply Chain Management seems to be beneficial, especially taking into account the developments discussed in Section 2.1 and Section 2.2. For this research and to highlight the practical use on the basis of an application case, we used MathWorks MATLAB (see Section 3.1.3) as the Data Mining tool. As the database we relied on the widespread Neo4j, which is a popular graph database implementing a property graph model (see Section 2.2). Neo4j uses a database language called Cypher instead of SQL to retrieve and manipulate data stored in the database. MATLAB officially supports Neo4j as a Database (see Table 4). We established a connection successfully using the implemented MATLAB Toolbox (see Section 3.1.3).
To use a graph database seems promising, since Supply Chains are networks and are of emergent, coherent nature (see Section 2.1). Supply Chain data are high in volume and heavily interconnected. To use a graph to map a Supply Chain is, from a storage technology point of view, the native form of storing Supply Chain data persistent. The authors state that it is clear that a graph database, e.g., is the appropriate storage solution for tracking

down correlations of interest to Supply Chain Management (see Section 2.1 and Section 2.3).

Figure 2 shows a small excerpt of the anonymized data stored in the database. The dataset consists of multi-level Supply Chain data, filtered to one product, which have been imported into the Neo4j database. Each node as well as every edge contains a plethora of properties, e.g., name or site location (in latitude and longitude).

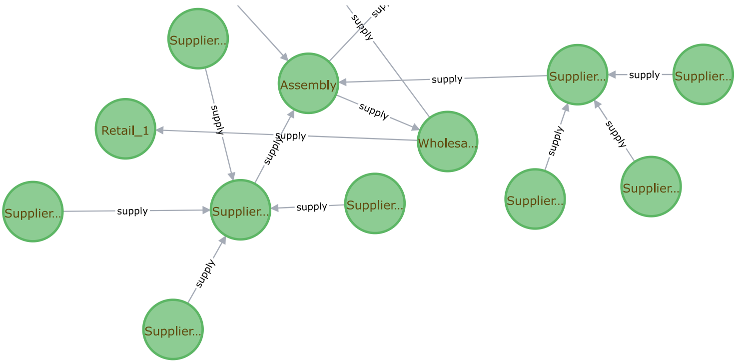
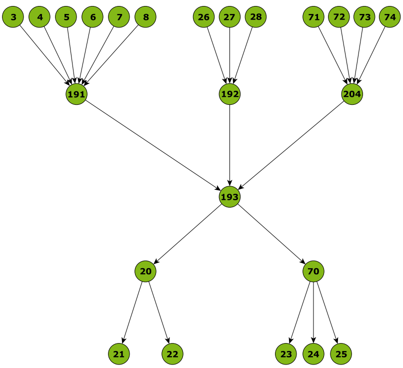


Figure 2: Excerpt of a Supply Chain Scenario in Neo4j

We conducted several tests with MATLAB to check for a correct and working database connection. MATLAB creates a Neo4j object which enables working with the graph directly. Second, we performed small experiments on the graph data, e.g., to track optimized routing or to find interesting patterns in the graph using, e.g., a segmentation algorithm (see Section 2.1 and Section 2.3). For example, exploring the whole structure of the Supply Chain and finding shortest paths can be done by graph traversing and using established algorithms like breadth-first graph search, directly on the data. Apart from this, e.g., to measure the importance of a node in the Supply Chain (centrality), Googles PageRank algorithm can be used, which makes use of the in- and outbound edges of a Node. Figure 3 shows the results generated by MATLAB of the application of PageRank directly onto the graph and a graph visualization.



Name	NodeLabels	NodeData	PageRank
{'191'}	{'Supplier_FirstTier'}	{1×1 struct}	0.088331
{'3' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'4' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'5' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'6' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'7' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'8' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'21' }	{'Retailer'}	{1×1 struct}	0.054531
{'20' }	{'Wholesaler'}	{1×1 struct}	0.094105
{'22' }	{'Retailer'}	{1×1 struct}	0.054531
{'192'}	{'Supplier_FirstTier' }	{1×1 struct}	0.051413
{'26' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'27' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'28' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'23' }	{'Retailer'}	{1×1 struct}	0.041186
{'70' }	{'Wholesaler'}	{1×1 struct}	0.094105
{'24' }	{'Retailer'}	{1×1 struct}	0.041186
{'25' }	{'Retailer'}	{1×1 struct}	0.041186
{'204'}	{'Supplier_FirstTier'}	{1×1 struct}	0.063719
{'71' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'72' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'73' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'74' }	{'Supplier_SecondTier'}	{1×1 struct}	0.014495
{'193'}	{'Assembly'}	{1×1 struct}	0.18727

Figure 3: MATLAB Results for the Centrality of Nodes in the Graph of a Supply Chain

4 Findings

In Table 4 and Table 5 of Section 3.2, we present, in a constructive selection of our results, databases and database interfaces supported by Data Mining tools. Overall, it can be seen across all Data Mining tools that databases can be connected very well. Although relational databases are dominating in practice and research over the last decades, our research shows that NoSQL databases are supported on a good level compared to their counterpart. For every highlighted Data Mining tool in Section 3.1.1, Section 3.1.2 and Section 3.1.3, the support for NoSQL databases can be identified. If we take into account further concepts like Cloud Object stores or Data Warehouses, relational databases are almost evenly well supported. The chart in Figure 4 summarizes the overall results and validates our initial intention. Also, it is visible from the research results of Section 3.2 that interfaces like ODBC and JDBC, although intended for relational databases using SQL (see Section 2.4), are used by NoSQL databases as well by adapting the interface to their own database language, e.g., translating SQL to Cypher when using the graph database Neo4j. Our small experiment in Section 3.3 showed good results on the basic possibility to use a NoSQL database as a basis for Data Mining and, therefore, generating knowledge to answer logistics questions (see Section 2.1). Furthermore, it was possible to use the advantages of the graph database, e.g., through directly applying graph techniques on the data without the need to transfer the Supply Chain as a graph into tables and back into a graph in the Data Mining tool, through a direct visualization of the results of Data Mining or, regarding data, the advanced storage of highly interconnected data.

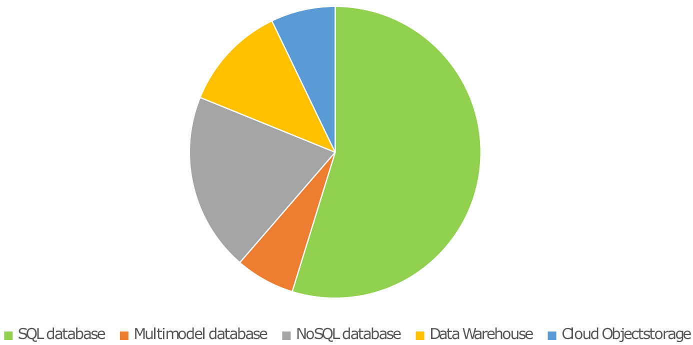


Figure 4: Data storage supported by Data Mining tools

As described in Section 2.3, the KDD phases for data preparation, selection, preprocessing, and transformation are essential for valid input data and running successful Data Mining (see Figure 1). Every phase of data preparation contains complex and time-consuming intermediate steps (see Section 2.3). Our experiments show promising results by using a suitable database to gain knowledge for answering tasks of Supply Chain Management (see Section 2.1) in light of data that fit into the Big Data paradigm (see Section 2.2). It is possible, in a specific Data Mining project, to reduce process steps in the data preparation phases and, therefore, increase overall performance and data quality in Data Mining.

5 Conclusion and Outlook

This paper discusses the possibilities of connecting databases and Data Mining tools for decision support in Supply Chains. To this end, relevant principles and resulting challenges, especially towards Big Data, were discussed. The identified subject areas were subsequently linked together. In a step-by-step modular analysis based on three established studies, relevant Data Mining tools were identified and examined for their interfaces and possibilities for connecting databases. On this basis, the possible databases were described and paired with the Data Mining tools. The results were presented in a comprehensive table using typical database representatives for every type. The associated subject-specific considerations regarding tasks in Supply Chain Management (see Section 2.1) were then discussed using a small logistics example. The example showed that the use of NoSQL databases in combination with Data Mining is worthwhile and in view of Supply Chain data which fit the Big Data paradigm an important component for the future.

The research field of Polyglot Persistence (see Section 2.2) in combination with Data Mining (see Section 2.3) is of central importance for further research, since the research presented in this paper assumes that one database is substituted by another, in our case a relational database by a graph database. At this point, there could be more beneficial opportunities to answer logistical tasks from Supply Chain Management, since the different types of databases could contribute their strengths regarding particular tasks and their specific requirements on data.

References

Adriaans, P. and Zantinge, D., 1996. *Data Mining*. Boston: Addison Wesley Professional.

Alteryx Inc., 2020. *Data Sources: Supported Data Sources and File Formats* [online]. Available at: <https://help.alteryx.com/current/designer/data-sources?tocpath=Data%20Sources%7CSupported%20Data%20Sources%7C_____0> [Accessed 19 May 2020].

Batra, R., 2018. *SQL Primer*. Berkeley, CA: Apress.

Borgi, T., Zoghlami, N., and Abed, M., 2017. Big Data for Transport and Logistics: A Review. In: *2017 International Conference on Advanced Systems and Electric Technologies (IC_ASET)*: IEEE, pp. 44–49.

Bousonville, T., 2017. *Logistik 4.0: Die digitale Transformation der Wertschöpfungskette*. Wiesbaden: Springer Fachmedien.

Christopher, M., 2016. *Logistics & Supply Chain Managem*ent. Harlow, England, New York: Pearson Education.

Codd, E.F., 1970. A Relational Model of Data for Large Shared Data Banks. *Communications of the ACM*, 13 (6), pp. 377–387.

Connolly, T.M. and Begg, C.E., 2015. *Database Systems: A Practical Approach to Design, Implementation, and Management*. 6th ed. Boston, Mass.: Pearson.

Dill, M., 2009. *Data Mining Software 2009: Funktionsvergleich und Benchmarkstudie*.

Edlich, S., Friedland, A., Hampe, J., Brauer, B., and Brückner, M., 2011. *NoSQL: Einstieg in die Welt nichtrelationaler Web 2.0 Datenbanken*. 2nd ed. München: Hanser.

Elmasri, R. and Navathe, S., 2011. *Fundamentals of Database Systems*. 6th ed. Boston: Addison-Wesley.

Fayyad, U.M., Piatetsky-Shapiro, G., and Smyth, P., 1996. From Data Mining to Knowledge Discovery in Databases. *AI Magazine*, 17 (3), pp. 37–54.

Garcia-Molina, H., Ullman, J.D., and Widom, J., 2009. *Database Systems: The Complete Book*. 2nd ed. Upper Saddle River, NJ: Pearson/Prentice Hall.

Gürez, E., 2015. Zuordnung von Data Mining-Methoden zu problemspezifischen Fragestellungen von Supply Chain Management-Aufgaben. Bachelor Thesis. Technical University Dortmund, Faculty Mechanical Engineering, Department ITPL.

Harland, C.M., 1996. Supply Chain Management: Relationships, Chains and Networks. *British Journal of Management*, 7 (s1), pp. 63–80.

Hecht, R. and Jablonski, S., 2011. NoSQL Evaluation: A Use Case Oriented Survey. In: *2011 International Conference on Cloud and Service Computing: IEEE*, pp. 336–341.

Jose, B. and Abraham, S., 2017. Exploring the Merits of NoSQL: A Study Based on MongoDB. In: 2017 International Conference on Networks & Advances in Computational Technologies (NetACT): IEEE, pp. 266–271.

Kelly, J., 2015. *Big Data Vendor Revenue and Market Forecast, 2011-2026* [online]. Available at: <https://wikibon.com/big-data-vendor-revenue-and-market-forecast-2011-2026/> [Accessed 6 May 2020].

Krensky, P., den Hamer, P., Brethenoux, E., Hare, J., Idoine, C., Linden, A., Sicular, S., and Choudhary, F., 2020. *Magic Quadrant for Data Science and Machine Learning Platforms* [online]. Available at: <https://www.gartner.com/doc/reprints?id=1-1YCTPMUL&ct=200213&st=sb&utm_medium=Website+> [Accessed 24 May 2020].

Lambert, D.M., 2014. *Supply Chain Management: Processes, Partnerships, Performance*. 4th ed. Ponte Vedra Beach, Florida: Supply Chain Management Institute.

Li, C., 2009a. Java Database Connectivity. In: *L. Liu and M.T. Özsu, eds. Encyclopedia of Database Systems*. Boston, MA: Springer US, pp. 1577–1578.

Li, C., 2009b. Open Database Connectivity. In: *L. Liu and M.T. Özsu, eds. Encyclopedia of Database Systems*. Boston, MA: Springer US, pp. 1977–1978.

Li, Y. and Manoharan, S., 2013. A Performance Comparison of SQL and NoSQL Databases. In: *2013 IEEE Pacific Rim Conference on Communications, Computers and Signal Processing (PACRIM)*: IEEE, pp. 15–19.

Marakas, G.M., 2003. *Decision Support Systems in the 21st Century*. 2nd ed. Upper Saddle River, NJ: Prentice Hall.

MathWorks, 2020. *Database Toolbox* [online]. Available at: <https://de.mathworks.com/help/database/index.html> [Accessed 19 May 2020].

Meier, A. and Kaufmann, M., 2019. *SQL & NoSQL Databases*. Wiesbaden: Springer Fachmedien.

Moniruzzaman, A.B.M. and Hossain, S.A., 2013. NoSQL Database: New Era of Databases for Big data Analytics - Classification, Characteristics and Comparison. *International Journal of Database Theory and Application*, 6 (4), pp. 1–11.

North, K. and Maier, R., 2018. Wissen 4.0 – Wissensmanagement im digitalen Wandel. *HMD Praxis der Wirtschaftsinformatik*, 55 (4), pp. 665–681.

Rahman, F.A., Desa, M.I., and Wibowo, A., 2011. A Review of KDD-Data Mining Framework and Its Application in Logistics and Transportation. In: *Y. Cho, S. Kawata, and F. Ko, eds. 2011 7th International Conference on Networked Computing and Advanced Information Management (NCM)*. Piscataway: IEEE, pp. 175–180.

RapidMiner Inc., 2020. *Database Connectors* [online]. Available at: <https://docs.rapidminer.com/latest/studio/connect/database/> [Accessed 19 May 2020].

Reinsel, D., Gantz, J., and Rydning, J., 2018. The Digitization of the World – From Edge to Core.

Rellensmann, T., 2019. Data Mining-Werkzeuge und ihre Schnittstellen zu Datenbankmanagementsystemen. Project Thesis. Technical University Dortmund, Faculty Mechanical Engineering, Department ITPL.

Rowley, J., 2007. The Wisdom Hierarchy: Representations of the DIKW Hierarchy. *Journal of Information Science*, 33 (2), pp. 163–180.

Runkler, T.A., 2010. *Data Mining: Methoden und Algorithmen intelligenter Datenanalyse*. Wiesbaden: Vieweg+Teubner.

Sadalage, P.J. and Fowler, M., 2013. *NoSQL Distilled: A Brief Guide to the Emerging World of Polyglot Persistence*. Upper Saddle River, NJ: Addison-Wesley/Pearson.

Scheidler, A.A., 2017. *Methode zur Erschließung von Wissen aus Datenmustern in Supply-Chain-Datenbanken*. Göttingen: Cuvillier.

Serdarasan, S., 2013. A Review of Supply Chain Complexity Drivers. *Computers & Industrial Engineering*, 66 (3), pp. 533–540.

solid IT GmbH, 2020. *DBMS Popularität pro Datenbankmodell: Vollständiger Trend, beginnend mit Jänner 2013* [online]. Available at: <https://db-engines.com/en/ranking_categories> [Accessed 5 Feb 2020].

Strozzi, C., 2017. *NoSQL: A Relational Database Management System* [online]. Available at: <http://www.strozzi.it/cgi-bin/CSA/tw7/I/en_US/NoSQL/Home%20Page> [Accessed 4 May 2020].

Teniwut, W.A. and Hasyim, C.L., 2020. Decision Support System in Supply Chain: A Systematic Literature Review. *Uncertain Supply Chain Management*, pp. 131–148.

Turban, E. and Volonino, L., 2011. *Information Technology for Management: Improving Strategic and Operational Performance*. 8th ed. Hoboken, N.J.: John Wiley.

Weskamp, M., Tamas, A., Wochinger, T., and Schatz, A., 2014. *Einsatz und Nutzenpotenziale von Data Mining in Produktionsunternehmen*. Stuttgart: Fraunhofer-Institut für Produktionstechnik und Automatisierung IPA.

Wrobel, S., et al., 1996. User Interactivity in Very Large Scale Data Mining. In: *W. Dilger, et al., eds. Beiträge zum 9. Fachgruppentreffen Maschinelles Lernen der GI Fachgruppe 1.1.3. Chemnitz: Technische Universität Chemnitz-Zwickau*, pp. 125–130.

A first step towards automated image-based container inspections

Steffen Klöver [1], Lutz Kretschmann [1], and Carlos Jahn [2]

1 – Fraunhofer Center for Maritime Logistics and Services CML

2 – Hamburg University of Technology – Institute für Maritime Logistik

Purpose: The visual inspection of freight containers at depots is an essential part of the maintenance and repair process, which ensures that containers are in a suitable condition for loading and safe transport. Currently this process is done manually, which has certain disadvantages and insufficient availability of skilled inspectors can cause delays and poor predictability.
Methodology: This paper addresses the question whether instead computer vision algorithms can be used to automate damage recognition based on digital images. The main idea is to apply state-of-the-art deep learning methods for object recognition on a large dataset of annotated images captured during the inspection process in order to train a computer vision model and evaluate its performance.
Findings: The focus is on a first use case where an algorithm is trained to predict the view of a container shown on a given picture. Results show robust performance for this task.
Originality: The originality of this work arises from the fact that computer vision for damage recognition has not been attempted on a similar dataset of images captured in the context of freight container inspections.

First received: 11. Mar 2020 Revised: 19. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

The availability of empty cargo containers in an appropriate condition is a prerequisite for consignors to load cargo and shipping companies to move containers to their destination subsequently (Olivo, 2005). In order to ensure sufficient availability of empty containers and thus meet regional demand, shipping companies go to great length. Imbalanced trades require repositioning and temporary storage of empty containers in regional depots (Schlingmeier, 2016). Besides storage these empty container depots also carry out essential inspection, maintenance and repair tasks, which ensure that containers are in a suitable condition for loading and safe transport (Port of Hamburg Magazine, 2020).

Upon arrival at a depot, empty containers are subject to a visual inspection process at the gate. The main objective of this process is to separate intact containers, which can go directly into the storage area, from damaged units, which require maintenance and repair. Where a damage is detected the process will further determine different attributes that characterize the condition (including damage type, extent and location). This information is used to arrange appropriate maintenance and repair measures subsequently and also support commercial transactions with the container owner (customer). Thus, the visual inspection of freight containers at depots is an essential first step of the overall maintenance and repair process. Comparable visual inspection processes can also be found at other container terminals, which primarily fulfill transshipment and handling functions within the supply chain.

Today, inspection processes are carried out by experienced staff, which identify damages visually, document them by taking pictures und provide repair proposals. This process set up has several disadvantages. First of all, damage assessments are subjective and can differ between inspectors based on, amongst others, their individual experience. Further, highly skilled inspectors are in high demand making them expensive respectively limiting their availability. Lastly, inspection of containers upon arrival, identifying individual damages and documenting them manually by taking pictures and entering damage characteristics, e.g. in a handheld device, is both error prone and time-consuming.

With significant advances in the field of computer vision over the recent years, automating visual inspection tasks across industries and applications has become principally feasible (Brownlee, 2019). Today deep learning dominates most computer vision applications and provides state-of-the-art performance (Russakovsky, et al., 2015 and Chollet, 2017). This paper is dedicated to applying computer vision algorithms in the context of visual container inspections with the goal to overcome the previously mentioned disadvantages of the current process. It introduces a computer vision model, which uses deep learning methods, to automate the inspection process. Based on a large dataset of images taken during freight container inspections, a deep learning computer vision model is trained and evaluated in its performance.

In order to confirm the applicability of computer vision for an automation of container inspections the overall research process consist of several steps that need to be investigated. Individual steps include identifying containers with / without damages and classifying these by damage type as well as establishing damage location on the container and specifying the affected container component. Within this overall context, this paper focusses on predicting the view of a container (e.g. top, front, or side view) shown on a given image, which is required to identify and classify a damage as well as establishing its location on the container. Future work will focus on computer vision models, which address other tasks in order to complete further steps of the overall research process. Results presented here, in terms of metrics like accuracy and precision, will also serve as a benchmark for assessing the performance of computer vision models for all individual parts of an automated image-based inspection of freight container condition.

The remainder of this paper is structured as follows. Section 2 gives an overview of the inspection process at empty container depots today and describes which subtask this paper focusses on by describing the results of automating the subtask through a deep learning computer vision model. Subsequently Section 3 introduces current deep learning methods used in the context of computer vision and gives a brief overview of related work. The use cases “predict the container view” is covered in Section 4 with individual subsections describing the data used for model training, the chosen model architecture as well as achieved results. Concluding remarks and possibilities for future research are given in Section 5.

2 Container Inspection Process

At the empty container depot arriving containers are subject to a visual inspection to ensure structural integrity and fitness for safe transport. Reliable identification, evaluation and subsequent repair of any damage to the container is a crucial aspect to comply with the Convention for Safe Containers (CSC, 1972). In this context, the industry has reached an agreement to comply with several generally accepted standards:

- Criteria for assessing damage (UCIRC, RCIRC and IICL6)
- CEDEX coding for damage documentation

The CEDEX coding was developed as "1985-87 ISO TC104" and first published in 1989 as ISO 9897 (ISO 9897). CEDEX is used worldwide as a standard way to document damages to freight containers. It consists of four elements to indicate

- "Location" of a damage (4 digits)
- "Component" affected by a damage (3 digits)
- "Damage" type present (2 digits)
- "Repair" measure suggested (2 digits)

Below, Table 1 gives an exemplary CEDEX code and a decoded description of the affected location and component, the present damage and the associated suggested repair measure.

In practice today, the process of damage identification is characterized by a sequence of manual activities, which are merely supported by digital means. In this context, a mix of paper-based documentation steps and the use of hand-held devices result in a high risk of errors and process steps are time-consuming. On some depots the process is at least partially digitalized. Here an inspector assesses the container's condition and documents his findings on a hand-held mobile device supplemented by taking pictures of the container in its entirety and the a closeup of the respective damage. The process requires several standardized pictures to be taken, which cover the outer container walls from different angles as well as the inside (see Figure 3). In case a damage is detected, it is further documented by a close-up detail picture. The data structure used to document information collected during the inspection process follows the CEDEX code. Figure 1 shows an illustration of the inspection process.

Table 1: Example of CEDEX code and decoded description

	CEDEX example	Description
Location	DH4N	D → Door end (rear) H → Higher portion (upper) 4 → Right-hand side corner post N → element not used in this case
Component	CFG	Fittings located at the corners of containers providing means of supporting, stacking, handling, and securing the container
Damage Type	CU	Component is damaged by being cut
Repair	RP	Remove and replace the complete cross-sectional profile of a component over its entire length and width

The current inspection process - as described before – and subsequent maintenance and repair processes set the framework for an automation of container inspections by using computer vision models, as covered in this paper. Accordingly, automation of the entire visual inspection process or individual parts would require the same output as today to be compatible with the current processes on the depot. This leads to the main research question: is it possible to build a deep learning model that is capable to distinguish damaged from undamaged containers based on a given image and further, in case a damage is identified, determine (or rather predict) the individual CEDEX elements for this damage.

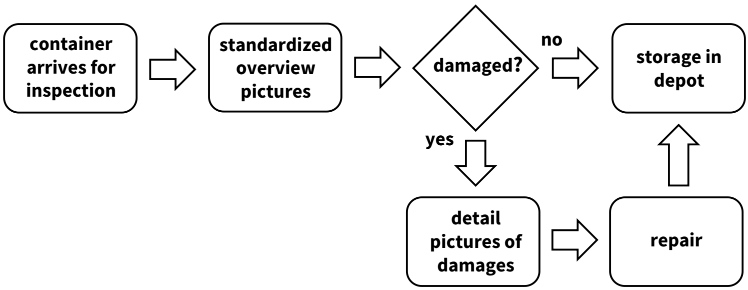


Figure 1: Container inspection process

Due to the different nature of individual sub-problems, a combination of models will most likely be required to meet the overall requirements. Separate models would be dedicated to solve different subtasks. In that sense one model might distinguish damaged containers from intact units while other models are used to predict damage location, damaged component, damage type as well as the appropriate repair measure. Within the overall scope of the described principal research question, this paper addresses a first subtask: automatically predicting the first of four characters that constitute the CEDEX element "damage location". This character specifies the respective face of the container with eight main distinctions. Thus, based on an image taken by an inspector during the inspection process on the terminal, the model has to predict which view of a container is shown.

3 Deep Learning for Computer Vision

Artificial intelligence and in particular machine learning have seen a significant increase in use over the past few years. Machine learning comprises a number of different algorithms that have been developed to learn correlations through pattern recognition in data sets and use these correlations to make predictions for new, previously unknown data (Nelli, 2018). Today, most successful applications of machine learning are from the sub-field of supervised learning. Here a large number of labeled examples (combination of input data and desired output) are processed automatically in order to learn statistic correlations that characterize the relation between input and output. Subsequently, these relationships can be used in the sense of decision rules when predicting the corresponding output for a given input (Müller and Guido, 2017). More recently, deep learning has emerged as a new subfield in machine learning, with performance of deep learning models significantly exceeding the performance of classical machine learning algorithms in various supervised learning problems. Facilitated by ever-increasing computing power and data volumes, deep learning has thus enabled remarkable breakthroughs in applications that process e.g. image, text or sound data (Le Cun and Bengio 1995, Goodfellow, et al., 2016 and Le Cun, et al., 2015).

Computer vision is a subfield of artificial intelligence concerned with the automated extraction of information from visual image data. From inferring the depth of a scene in stereo vision to deducing the presence of an object in recognition, computer vision is a multidisciplinary field with various approaches to address different kind of problems (Prince, 2012). Today

it is powering applications like image search, robot navigation, face detection, autonomous driving and many more (Szeliski, 2010). Achieving the performance of human perceptual vision has been a challenge for decades (Prince, 2012). Through the complexity of visual data, objects can appear in any pose and are often partially occluded by other objects. Recognizing different objects in images requires the extraction of visual features which provide a semantic and robust representation. Due to diversity in appearance, illumination condition and backgrounds it is difficult to manually design feature descriptors like SIFT (Lowe, 2004) and HOG (Dalal and Triggs, 2005) – examples of pre-deep learning computer vision methods - to perfectly describe all kinds of objects (Zhao, 2018). Recognizing objects in images can be treated as a pattern recognition problem, where new images are interpreted based on prior images in which the context is known. This process can be divided into two parts. In learning, the relationship between image and content is modeled. In inference, this relationship is exploited to predict the content of new images (Prince, 2012).
Computer vision methods for image analysis in principal represent a suitable solution for automated detection of damaged containers – the field of investigation in this paper. Under this approach a deep learning model is trained to predict the correct classification of e.g. damage type or damage location in each case based on a dataset of labelled examples - a combination of digital image and the corresponding label. The learned relationship is then used to predict the correct label for a new image taken at a container depot. This way automating the inspection process through computer vision can be framed as an object recognition task. Recognizing objects in

images requires the extraction of features that provide a semantic and robust representation. For image recognition problems of this kind, convolutional neural networks have proven a superior performance compared to “traditional” computer vision methods in terms of error rates (Krizhevsky, et al, 2012). Convolutional neural networks, a special type of deep artificial neural network, are based on a hierarchical multi-stage structure, capable of learning multilevel representations from pixel to high-level sematic features. Compared with traditional “shallow” machine learning, this deeper architecture provides an increased expressive capability (Zhao, 2018). Convolutional neural networks have demonstrated superior performance on a variety of object recognition tasks, like image classification and object detection (Russakovsky, et al., 2015). An important contribution towards the performance of latest generation models has come from the ImageNet Large Scale Visual Recognition Challenge. This annual computer vision competition for both object detection and image classification tasks had a large impact on the evolution of computer vision during the 2010s with the achieved success primarily driven by very large and deep architectures of convolutional neural networks in combination with the computing power provided by graphical processing unit hardware (Brownlee, 2019). As a consequence of this development deep neural networks nowadays perform better than or on par with humans on image classification tasks, especially if good quality image data is available (e.g. limited distortion, noise, blur) (Dodge and Karam, 2017).

The application of computer vision methods has been the subject of scientific publications in several different fields up to this day. A selection of research comparable to this paper regarding the methodology and use cases is discussed hereafter. Jaccard, et al. (2016) apply computer vision methods in the context of X-ray cargo inspections. These inspections take place at border crossings to interdict trade in illicit or security related goods such as contraband, drugs or weapons. In view of rising cargo volumes, increasing regulations and the need for more efficient handling processes at land borders and in ports, automation of parts of the inspection workflow is proposed as a suitable solution. If implemented successfully it could reduce processing times and enable expert operators to focus only on high-risk containers and suspicious images. The authors propose a framework for automated cargo inspection consisting of several modules and use a large dataset of X-ray cargo images for training and evaluation. Besides classical machine learning methods, such as a random forest algorithm used in a car detection module, the setup also includes state-of-the-art deep learning approaches. In particular the authors evaluated convolutional neural network architectures with different depth (number of layers), down-sampling of pixels (to make training computationally tractable), and 3X3 filters trained on 12,000 images from a negative class (no threat) and 12,000 positive class images with a synthetic threat build into the picture. Compared to other computer vision methods the authors where able to demonstrate significantly better detection performance with the suggested deep learning set up, achieving a false positive rate of 0.80% for a detection rate of 90%.

Another recent example can be found in the work done by Patil, et al. (2017) who employed deep learning methods for car damage classification on a relatively small dataset of manually annotated images from the internet. The images show damaged and undamaged sections of cars, enclosing components from a variety of different angles and distances partly similar to container inspection photos. In a multiclass classification with eight classes, including seven damage types and one class for no damage, best results were obtained using state-of-the-art convolutional neural networks pre-trained on the ImageNet dataset as a feature extractor and a fully connected network with softmax activation function as a classifier. With 88.24% accuracy ResNet (He, 2015) performed best. Building an ensemble classifier on top of multiple different pre-trained classifiers was able to boost accuracy slightly up to 89.53%. The work also demonstrates the ability of this approach to localize damage instances at the pixel level. This is achieved by cropping a region of size 100 x 100 around pixels, resize it to 224 x 224 pixels and predicting the class probabilities. Pixels with class probabilities above a threshold can be highlighted respectively.

Other scholars including e.g. Maeda, et al. (2018) and Shihavuddin, et al. (2019) and Perez, et al. (2019) have previously applied state-of-the-art deep learning technologies in different engineering domains in order to recognize structural damage from images, which is somewhat comparable to the use case covered in this paper. Maeda, et al. (2018) focus on damage detection on road surfaces using image data and deep neural networks. They collected and prepared a large road damage dataset and successfully trained a convolutional neural networks model to predict eight different damage types with high accuracy. Another engineering application can be found in Shihavuddin, et al. (2019) who work on detecting surface damages on wind turbine blades. A deep learning-based automated damage detection system for analysis of drone inspection images is proposed with a particular emphasis how advanced data augmentation can increase precision for small training sets. Lastly, Perez, et al. (2019) focus on the use case of automatic detection of building defects from visual images. With an increasing interest in quick and effective means to survey the condition of buildings, developing ways to accomplish this task by computer vision models is presented as a promising alternative. The authors propose a suitable model for their use case based on a pre-trained convolutional neural network classifier and achieve robust results for the task of detecting and localizing building defects.

4 Use Case "Predicting Container View"

Automatic image recognition and evaluation has the potential to increase the efficiency of processes in seaports and terminals. For this reason, terminal operators have been using OCR (Optical Character Recognition) systems for many years to automatically identify incoming truck’s license plates as well as container numbers. (HHLA n.d.) In comparison, automatic detection of damaged containers by computer vision methods goes beyond state of the art.

In this section a computer vision module is introduced, which predicts the first character of the CEDEX damage location code based on a given image. The problem is framed as a multi-class classification problem and state of the art deep learning computer vision models are implemented and evaluated. The reviewed literature demonstrated that supervised learning approaches utilizing convolutional neural networks show state-of-the-art performance in image-based damage classification even on small datasets. Since there is a large number of annotated images available for the use case of this paper pursuing this approach should provide promising results. In the chosen approach a convolutional neural network is trained based the first character of the CEDEX damage location code provided by the inspector's annotation. Besides showing the general feasibility of the selected approach, a main focus was on investigating the impact of image resolution on model performance and thus to get an estimate of how much information loss through compression is still tolerable. This is of particular importance in the considered context as the available data base consists of high-resolution images. However, training a deep learning computer vision

model will require a certain reduction of image size in order to be computable on today's hardware in an adequate time.
The remainder of this section will firstly introduce the used data set of container images and then describe the implemented deep learning architecture. Lastly results of training the model with different image resolutions and with/without fine-tuning is presented.

4.1 Data

The image data available to this research was taken on an empty container depot over the period of 01-2017 to 03-2020. Individual images were captured as part of the inspection process by experienced staff using a mobile handheld device. Overall the dataset contains 568,120 standard type images of containers taken during inspection or at the depot gate. Each image is provided with a label, identifying the respective container view shown on the picture. Overall the following eight classes are distinguished:

- Front view
- Left view
- Door/rear view
- Right view
- Underside view
- Bottom/floor view
- Insight view
- Roof/top view

Five exemplary pictures for each class are shown in Figure 3. These pictures also provide a first impression of possible challenges to a correct automatic

classification by a deep learning model, e.g. due to different perspectives and lighting conditions.
The distribution of class labels in the used data set shows a certain imbalance, which can be another challenge for class prediction with high accuracy. The class door/rear is the majority class representing more than 20% of all images while the label "bottom/floor" is the minority class with less than 5% of all images (see Figure 2). The distributions of class labels found in the overall data set was preserved in all splits used for model training and evaluation (training, validation and evaluation data sets).

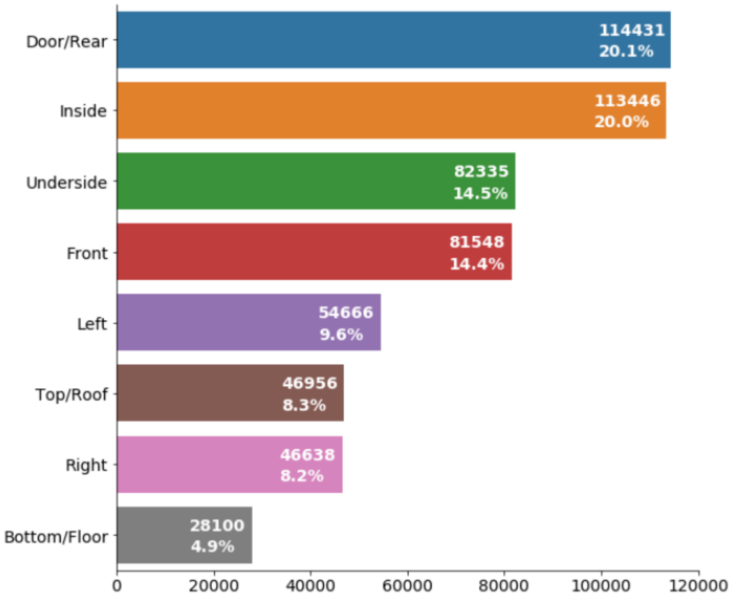


Figure 2: Distribution of class labels in the overall data set

The resolution of the images in the data set varies between 1024 x 768 pixels and 768 x 1024 pixels in height and width. The distributions of image resolution found in the overall data set was also preserved in all splits used for model training and evaluation. Independent of original size (1024x769 or 768 x 1024), images were compressed obtaining equally spaced dimensions in height and width. Further, as part of data pre-processing, pixels were scaled from an initial 0-255 RGB value per color channel to a value between -1 and 1 sample-wise (not averaged over batches).

In the classification experiments 70 % of images in the dataset were used for training and 10 % for validation during training. The remaining 20 % were used to evaluate and compare the performance of trained models.

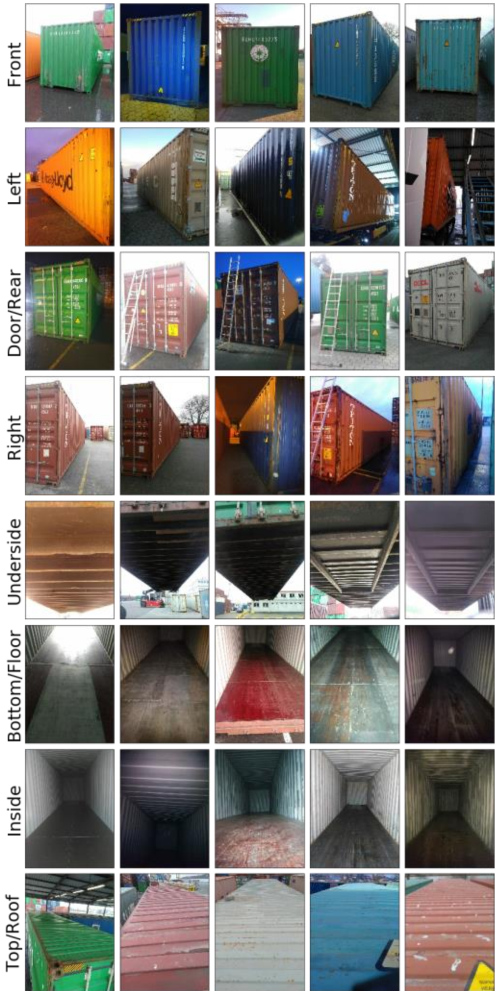


Figure 3: Examples of pictures from the data base representing all classes considered in the use case. Source: HCCR, 2020

4.2 Architecture

The deep learning computer vision architecture used to train a model for the use case “prediction container view” contains of an input layer followed by two main elements, the feature extractor and the classifier.

For the feature extractor the MobileNetV2 architecture (Sandler, 2019) was adopted with weights pre-trained on the ImageNet (Russakovsky, 2015). MobileNetV2 provides a very simple architecture that is specifically tailored for mobile and resource constrained environments by significantly decreasing the number of operations and memory needed while retaining the same accuracy. These properties would principally allow an integration of the computer vision module into mobile devices, which is used during the container inspection process instead of computing on a remote server.

For the classifier a common set up was used, which consists of a fully connected and an output layer. These receive the flattened output of the feature extractor and further match this one-dimensional representation with eight classes in the output layer.

A number of different experiments were considered. First of all, a main focus of this research was on investigating the impact of image resolution on model performance. Accordingly, a high, medium and low resolution set up with pictures resized to 224x224, 112x112, and 56x56 was considered (in effect halving input dims twice). Beyond that distinct experiments were carried out without respectively with fine-tuning the model. The latter included an optimization of the feature extractor weights. Training in all cases started with randomly initialized weights in the classifier (dense / fully connected network with softmax activation layer).

4.3 Results

The performance of the considered classification task “predicting container view” were evaluated by using the metrics accuracy, precision, recall and F1-Score. After each epoch accuracy was measured on the validation set. Training was carried out until performance in terms of accuracy declined on the validation set. At that point all metrics were calculated on the test set.

For each class c_i the number of correctly identified images (True Positives tp_i), and the number of images that were either incorrectly classified as class c_i (False Positives fp_i) or incorrectly assigned to another class (False Negatives fn_i), can be counted individually. The overall Accuracy (1) is defined as the total number of correctly identified image labels across all categories (True Positives tp_i) divided by the total number of images in each class n_i.

$$\text{Accuracy} = \frac{\sum_{\mathrm{i}}^{\mathrm{c}} \mathrm{tp_i}}{\sum_{\mathrm{i}}^{\mathrm{c}} \mathrm{n_i}} \quad (1)$$

Additionally, precision (2), recall (3) and the F1-Score (4) measures were calculated for each class individually and then averaged into a single value (unweighted mean). Calculating the average like this, called macro-averaging, better accounts for class imbalances, since the scores are more influenced by the performance on minority classes (Yang, 1999)

$$\text{Precision} = \frac{1}{\mathrm{C}} \sum_{i}^{\mathrm{C}} \frac{\mathrm{tp_i}}{\mathrm{tp_i} + \mathrm{fp_i}} \quad (2)$$

$$\text{Recall} = \frac{1}{\mathrm{C}} \sum_{i}^{\mathrm{C}} \frac{\mathrm{tp_i}}{\mathrm{tp_i} + \mathrm{fn_i}} \quad (3)$$

$$\text{F1-Score} = \frac{1}{\mathrm{C}} \sum_{i}^{\mathrm{C}} 2 \frac{\mathrm{Precision_i}\ \mathrm{Recall_i}}{\mathrm{Precision_i} + \mathrm{Recall_i}} \quad (4)$$

Table 2 shows the performance of the model on the test dataset for different image resolutions and with/without fine-tuning. Evaluation metrics show that the model performs much worse without fine-tuning layers of the feature extractor. Tracking metrics during training also revealed that the model is not able to generalize well, showing strong overfitting independent of image resolution. The best model accuracy is 0.9753 for 224 pixels for height and width with fine tuning, although the model did not perform much worse using only 112 pixels.

Table 2: Performance of deep learning architectures for predicting the container view

Resolution	Fine-tuning	Accuracy	Precision	Recall	F1-Score
56x56	No	0.7234	0.7411	0.6377	0.6413
112x112	No	0.8145	0.8574	0.7634	0.7828
224x224	No	0.7533	0.9086	0.6366	0.6263
56x56	Yes	0.9404	0.9277	0.9271	0.9252
112x112	Yes	0.9682	0.9594	0.9604	0.9597
224x224	Yes	0.9753	0.9691	0.9674	0.9681

Figure 4 contains the confusion matrix of evaluating the architecture with 224x224 pixels and fine-tuning of the model. A first finding is that class-wise predictions show False-Positives in almost all classes. A possible explanation to this surprising result is wrongly labeled images. Non the less, this aspect warrants a deeper analysis in subsequent research and in particular should the computer vision model be implemented in practice in order to avoid problematic misclassification. Beyond that, there is a number of classes where comparatively many misclassifications occur. This mainly involves:

- Left view misclassified as Front and Right view
- Right view misclassified as Left view
- Front view misclassified as Left view
- Inside view misclassified as Bottom/Floor view
- Bottom/Floor view misclassified as Inside view
- Door/Rear view misclassified as Right view

A visual check of a sample of misclassifications images lead to the following possible explanations. A right / left misclassification can occur if the door or frontside is not visible on the image and thus there is no way of telling if the right or left container side is shown. With respect to distinguishing bottom/floor view from inside view the angle from which a photo is taken is decisive. However, there is no clear separation between this angle in photos of the container floor respectively the container insight. Accordingly, photos with an angle in this gray area are prone for misclassification. A similar effect occurs for a distinction between door/rear and right respectively front and left. One some side views the front/rear is visible but not on all. The same is true for some front/rear views where part of the side is visible on some but not on all. This results in a transition area which is difficult to discriminate for the model.

The applied method shows promising results for inferring the face or view of container which can be used as first step in predicting the location of damages. The results also demonstrate that there are transition areas between the considered categories which can lead to misclassifications. This is a challenging problem which will likely to be intensified in predicting the location of damages in a more fine-grained manner.
On the basis of the results obtained, a number of interesting findings give rise to possible research in the future. First of all, a closer look at classifications errors is warranted. In particular a number of possible causal factors could be investigated:

- Impact of lighting conditions which could result in vanishing boundaries between containers and background.
- Impact of images showing damaged / undamaged containers, which could result in e.g. pictures taken from different angles
- Impact of resolution (1024 x 768 or 768 x 1024) which could lead to different distortions of the object (container) in images

Another promising area of further investigations concerns the use of image augmentation. This includes, amongst other, artificially varying lighting conditions or a padding of images to create original images with a size of 1024 x 1024 by adding a black padding for example.

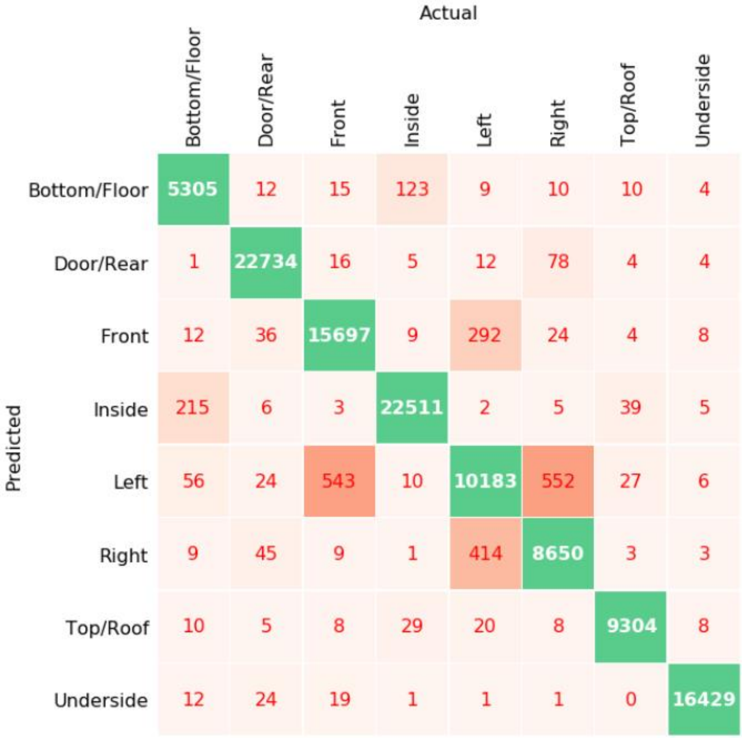


Figure 4: Confusion matrix of deep learning architecture (224x224 pixels with fine tuning)

5 Conclusion

The inspection of containers for damages is an essential part of the maintenance and repair process. Since insufficient availability of skilled inspectors can cause delays and result in poor predictability, automation promises the potential for optimization. Automatically recognizing damages through computer vision would speed up the process and enable inspectors to focus their attention on damages that are likely to be anomalous or not sufficiently visible at the surface.

This paper has demonstrated that state-of-the-art deep convolutional neural networks are capable to predict the correct container view shown in an image captured during the inspection process. This corresponds to a first subproblem of predicting damages according to the CEDEX coding for damage documentation and thus automating the overall inspection of containers for damages. Once further research steps are completed it will be interesting to look for other possible fields of application for the achieved results.

Despite achieving a first step in automatizing container damage inspections, it is clear that much remains to be done. Subsequent research will focus on computer vision models that automatically predict the remaining CEDEX code elements. Accordingly, next steps will involve image-based differentiating between damaged and intact containers, the determination of the exact type of damage as well as the affected component of the container. Moreover, since there are various container types with specific damages occurring more or less often, predicting the correct classification for rare cases will be a particular challenge that needs to be addressed.

Acknowledgements

The authors acknowledge the financial support by the Federal Ministry of Transport and Digital Infrastructure of Germany in the framework of the project COOKIE (project number 19H19006B).

References

Brownlee, J., 2019. Deep Learning for Computer Vision - Image Classification, Object Detection and Face Recognition in Python

Chollet, F., 2017. Deep Learning with Python, Manning Publications Co.

CSC, 1972. The International Convention for Safe Containers

Dalal, N., Triggs, B., 2005. Histograms of Oriented Gradients for Human Detection

Dodge, Samuel and Karam, Lina 2017. A Study and Comparison of Human and Deep Learning Recognition Performance Under Visual Distortions. 26th International Conference on Computer Communications and Networks, ICCCN

European Environment Agency (EEA), 2014. Annual European Union greenhouse gas inventory 1990-2012 and inventory report 2014. [online] European Environment Agency (EEA). Available at: <http://www.eea.europa.eu/publications/european-union-greenhouse-gas-inventory-2014/greenhouse-gas-inventory-2014-full.pdf> [Accessed 18 June 2014].

Flint, D.J., Larsson, E., Gammelgaard, B. and Mentzer, J.T., 2005. Logistics Innovation: A customer value-oriented social process. Journal of business logistics, 26(1), pp.113–147.

Goodfellow, I., Bengio, Y., and Courville, A., 2016. Deep Learning, MIT Press, url http://www.deeplearningbook.org

He, K., Zhang, X., Ren, S., Sun, J., 2015. Deep Residual Learning for Image Recognition

HHLA n.d. Geschichte des HHLA CT Burchardkai. Online: https://hhla.de/de/container/burchardkai-ctb/geschichte-ctb.html. Last accessed 29.05.2020

IICL 6 Inspection Criteria (IICL6) Sixth Edition (IICL-6) - Institute of International Container Lessors

ISO 9897 :1997 Freight containers — Container equipment data exchange (CEDEX)

Jaccard, N., Rogers, T.W., Morton, E.J., Griffin, L.D., 2016. Tackling the X-ray cargo inspection challenge using machine learning. In: Ashok, A and Neifeld, MA and Gehm, ME, (eds.) Anomaly Detection and Imaging with X-Rays (ADIX), 98470N (May 12, 2016); doi:10.1117/12.2222765. (pp. 98470N). Society of Photo-Optical Instrumentation Engineers (SPIE): Bellingham, Washington, USA.

Krizhevsky, A., Sutskever, I., and Hinton, G. E., 2012. Imagenet classifcation with deep convolutional neural networks. Adv. in Neural Information Processing Syst. 25.

Le Cun, Y., Bengio, Y., 1995. Convolutional networks for images, speech, and time series, in The Handbook of Brain Theory and Neural Networks, M. A. Arbib, Ed. Cambridge, MA: MIT Press

Le Cun, Y., Bengio, Y. & Hinton, G., 2015. Deep learning. Nature 521, 436–444 (2015). https://doi.org/10.1038/nature14539

Lowe, D.G., 2004. Distinctive Image Features from Scale-Invariant Keypoints

Maeda, H., Sekimoto, Y., Seto, T., Kashiyama, T., Omata, H., 2018. Road Damage Detection Using Deep Neural Networks with Images Captured Through a Smartphone, Computer Aided Civil and Infrastructure Engineering

Müller C.A., Guido, S. 2017. Introduction to Machine Learning with Python. O'Reilly Beijing Boston Farnham

Nelli, F., 2018. Python Data Analytics. Apress Media, California

Olivio, A., Zuddas, P., Di Francesco, M., Manca, A., 2005. An Operational Model for Empty Container Management

Perez, H., Tah, J.H.M., Mosavi, A., 2019. Deep Learning for Detecting Building Defects Using Convolutional Neural Networks. Sensors 2019, 19, 3556.

Prince, S., 2012. Computer Vision: Models, Learning and Inference. Cambridge University

Port of Hamburg Magazine, 2020. A Cookie for Containers, Port of Hamburg Magzine, Page 14

Plowman, E.G., 1964. Lectures on elements of business logistics. Stanford University, Graduate School of Business.

Refrigerated Container Inspection and Repair Criteria (RCIRC) 3rd Edition 2005. Institute of International Container Lessors

Russakovsky, O., Deng, J., Su, H., Krause, J., Satheesh, S., Ma, S., Huang, Z., Karpathy, A., Khosla, A., Bernstein, M., Berg, A. C., Frei-Frei, L., 2015. ImageNet Large Scale Visual Recognition Challenge

Sandler, M., Howard, A., Zhu, M., Zhmoginov, A., Chen, L., 2019. MobileNetV2 Inverted Residuals and Linear Bottlenecks

Schlingmeier, J., 2016. Koorperation in der martimen Leercontainerlogistik, Fraunhofer Verlag

Shihavuddin, A.S.M., Chen, X., Fedorov, V., Christensen, A.N., Riis, N.A.B., Branner, K., Dahl, A.B., Paulsen, R.R., 2019. Wind Turbine Surface Damage Detection by Deep Learning Aided Drone Inspection Analysis. Energies 2019, 12(4), 676

Szeliski, R., 2010. Computer Vision: Algorithms and Applications, Springer Verlag

Unified Container Inspection & Repair Criteria (UCIRC), Revision 2, 2000. International Chamber of Shipping

Yang, Y., Lui, X., 1999. A re-examination of text categorization methods

Zhao, Z., Zheng, P., Xu, S., Wu, X., 2018. Object Detection with Deep Learning: A Review

IV.
Advanced Manufacturing, Industry 4.0 and Block-chain

First received: 12. Mar 2020 Revised: 21. Jun 2020 Accepted: 12. Aug 2020

Impacts of a Smart Factory on Procurement Logistics

Bennet Zander [1], Kerstin Lange [1], and Hans-Dietrich Haasis [2]

1 – Jade University of Applied Science

2 – University of Bremen

Purpose: In order to keep up with the automation Smart Factories will bring into the market, procurement logistics has to be redesigned to ensure self-organizing production. The purpose of this paper is to examine the future changes of the procurement processes as well as the further role of logistics service providers in the procurement network with references to the building industry.
Methodology: Using an in-depth literature analysis focusing on the needs of a Smart Factory and the state of art of its procurement logistics current gaps are identified. Subsequently, a modified concept for the delivery of the inbound materials is developed.
Findings: The outcome shows, that the traditional truck delivery of the needed goods to a Smart Factory fails to deal with the in-house processes. Solutions have to be generated which provide packaging-free transport to move the already unpacked materials to the production lines more quickly. Furthermore, efficiency gains are identified, which can be generated through the newly adapted procurement logistics concept.
Originality: To-date, Smart Factory research has predominantly focused on internal production processes, without taking the externally required procurement logistics processes into closer consideration. However, significant changes due to wireless communication technologies can be expected in the ordering, transportation, unloading and storage of goods.

First received: 12. Mar 2020 Revised: 21. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

Driven by the age of Industry 4.0, production companies increase their research in developing a Smart Factory concept to create an autonomous production and logistics environment in which manufacturing systems, tools and vehicles communicate with each other independently (Ruile, 2019). Following, production forecast, resource planning, production control and performance analysis can be carried out through cyber-physical systems (Büchi, Cugno, Castagnoli, 2020; Botthof, Hartmann, 2017). In addition to manufacturing, the manual warehouse, goods receipt and goods issue processes are also to be automated (Wang et al., 2016; Achillas et al., 2019).

However, as these processes are predominantly integrated into the procurement, production and distribution logistics of external third-party logistics providers (3PL), they also have to deal with the requirements of implementing an integrated digital supply chain (Ileri, Bülow, Jansen, 2019). Accordingly, the perspective role of 3PLs in Smart Factories needs to be analyzed. Will they still be necessary in future concepts or could they be replaced by cyber-physical systems, and, if they are still needed, which areas of responsibility they could take on? This research aims to address these gaps.

The focus of this paper is on examining the future changes on procurement logistics processes for the supply of a Smart Factory, as significant changes can also be expected in the ordering, transportation, unloading and storage of goods. In addition, architecture and interface solutions in the collaborative work between the supply chain parties are identified. In this context, the analysis partially refers to the building industry in order to get a more specific reference framework besides the theoretical background.

The paper is structured as follows: After a brief description of the purpose in chapter 1, the applied research methodology is explained in chapter 2. In chapter 3 the terms Logistics 4.0 and Smart Factory Logistics are distinguished and future changes on procurement logistics are defined. Subsequently, chapter 4 provides a modified concept for the delivery of inbound materials to illustrate advantages and efficiency gains, which can be generated through the newly acquired information. The paper concludes with a summary and an outlook in chapter 5.

2 Research Methodology

An in-depth literature analysis according to Baker (2000, pp. 219-247) was performed to identify the state of art of the logistical needs of a Smart Factory regarding procurement logistics. The literature review was conducted using IEEE Xplore, EBSCOhost and Google Scholar in April 2020 focusing on German and English literature from 2014 onwards. The following variety of key words was used:

- (<Smart Factory> OR <Intelligente Fabrik> OR <Intelligent Manufacturing>) AND
- (<Procurement logistics> OR <Inbound logistics> OR <Beschaffungslogistik>)

The key words were first applied to the title, then to the abstract and finally to the text. Publications only addressing production processes based on Industry 4.0 were disregarded for the sake of this paper's limitation to procurement logistics. Furthermore, the found journals were selected with regard to the VHB-JOURQUAL 3 ranking. However, this was only for a prioritized selection of the articles listed with a JQ3-rating A-B. Articles from journals that are not mentioned in one of the ratings were not excluded in principle. The search resulted in 310 papers, which support the scientific knowledge progress and thus represent the final relevant database for the analysis and concept development (see figure 1).

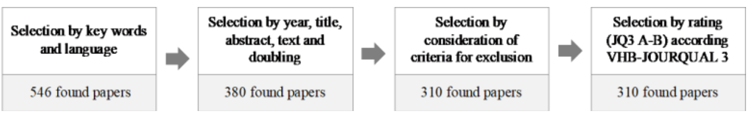


Figure 1: Literature selection sequences

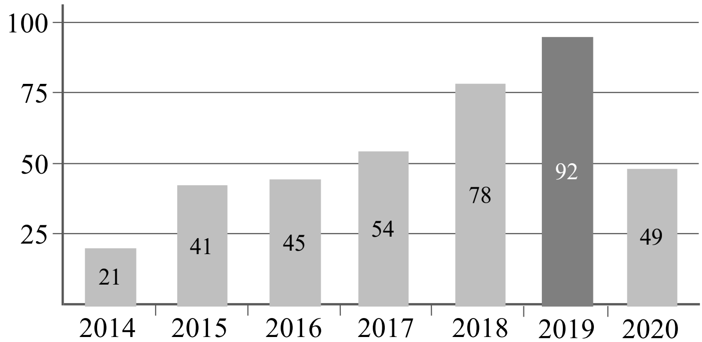


Figure 2: Number of publications since 2014

In the course of the second selection process step, the number of publications per year was also identified (see figure 2). The steady increase shows that the examined topic seems to gain popularity and is explored more deeply the further the 4th Industrial Revolution progresses. Another increase is expected this year since half of all previous year's publications were promulgated in the first four months of 2020.

The final 310 identified publications were then evaluated by using a qualitative data analysis according to Flick (2014) to perform text mining and a content analysis. The analysis used the following two fields in particular:

Field 1: (<Definition> OR <Summary> OR <Concept>)

Field 2: (<Logistics Service Providers> OR <3PL> OR <Outsourcing>)

Applying field 1, the procurement logistics requirements of a Smart Factory were determined in order to define its properties. Building on this and with further consideration of field 2, it was possible to analyze the perspective roles and responsibilities of 3PLs in a Smart Factory and was intended to identify whether they are still necessary.

3 Smart Factory Logistics

3.1 Definition of Terms

The 4th Industrial Revolution includes changing production and logistics processes, management strategies as well as business models. Industry 4.0 has created new opportunities that must be managed and governed to positively impact both business and society (Büchi, Cugno, Castagnoli, 2020). Essentially, Industry 4.0 means the transformation process of a factory into a "Smart Factory", in which its products, workstations and transport vehicles communicate with each other directly and in real time via the internet (Obermeier, 2019). To ensure this, an environment is created in which both manufacturing and logistics systems as cyber-physical systems organize themselves largely without human intervention (Yao et al., 2017). In this vision, the production process is controlled by the products itself. Accordingly, the product carries its production information in a machine-readable form, e.g. on an RFID-chip (Liukkonen, Tsai, 2015). The product knows its physical quality and production status and can thus use this data to manage its way through the factory and individual production steps itself (Kiefer et al., 2018).

In order to characterize a Smart Factory, special reference values are required. These can be distinguished in application, objectives and tasks (Schack, 2007). In this paper, the construction industry is chosen as the area of application for the further procedure, as it is currently undergoing a major change due to the influences of Industry 4.0 (Oesterreich, Teuteberg, 2016). With the help of newly developed technologies, it will be possible in the future to autonomously produce entire renovation packages for houses in Smart Construction Factories. The manufactured products are facade and roof elements which include typical design elements of houses like windows and doors, which can be additionally supplemented with solar panels or heating and ventilation systems. The objective of a Smart Construction Factory is the standardized, cost-effective and faster production of renovation packages for residential properties compared to conventional construction methods (Vestin, Säfsten, Löfving, 2018). The term task refers to the production itself. In this connection, production planning must consider how all incoming goods, warehousing, production and outgoing goods processes can be controlled automatically by cyber-physical systems (Yao et al., 2017).

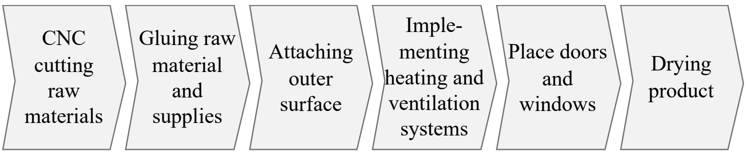


Figure 3: Production steps of a Smart Construction Factory

Figure 3 shows the automated production steps for the facade panel manufacture. In the beginning, the insulation material, e.g. expanded polystyrene (EPS), is cut according to the dimensions of the house with its integrated holes for doors, windows, heating and ventilation systems. This is followed by the gluing process to fabricate a well-insulated panel. Afterwards, the outer surface, e.g. timber, gypsum plaster or bricks, are attached to the wall, before the heating and ventilation systems can be implemented. In the last step, doors and windows are integrated into the facades, so that a finished element is produced, which finally has to dry and then can be attached to the building shell (Landscheidt, Kans, Winroth, 2017).

Among the digitalization of production systems and manufacturing processes, it is also significant to fundamentally adapt internal and external logistical service processes to a Smart Factory. In this context, two types of logistics, "Logistics 4.0" and "Smart Factory Logistics", have to be distinguished, as their reference areas differ (see figure 4).

Logistics 4.0 describes the effects of Industry 4.0 and current megatrends on the logistics industry and supply chain management. In a broader sense, this means the support and shaping of Industry 4.0 through the cross-company and cross-sectional function of logistics (Schneider, Hanke, 2020). It is a key approach to the efficient organization of physical and information logistics and a prerequisite for exploiting the potential of digital technologies here (Zsifkovits, Woschank, 2019). The most important technologies include RFID, Artificial Intelligence, automated guided vehicles (AGV), Big Data and Internet of Things (ten Hompel, Kerner, 2015; Haddud, Khare, 2018).

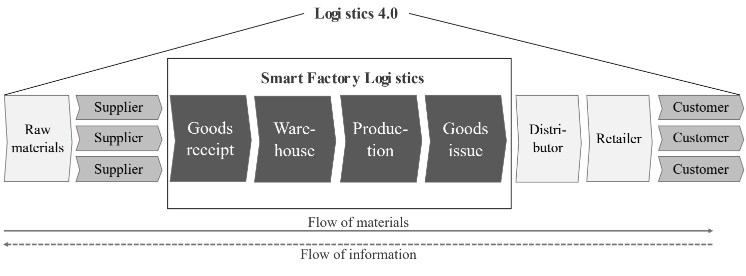


Figure 4: Smart Factory Logistics as part of Logistics 4.0

In Logistics 4.0, members of various vertical value chains integrate themselves into a horizontal value network. As a result, the efficiency (e.g. through automation, response time and error reduction) and effectiveness (e.g. through production individuality) of material and information flows in the supply chain can be increased sustainably (Wehberg, 2018; Steven, Klünder, Reder, 2019). However, this logistical network is exposed to environments characterized by increased volatility and unpredictability. Thus, the need for robustness, flexibility and resilience must become the focus of attention for future logistics system designs. Besides, the aggregation and processing of the gathered data is an important aspect of Logistics 4.0 (Kirch, Poenicke, Richter, 2016).

Smart Factory Logistics, as a combination of Smart Factory and Logistics 4.0, has its origin in organizing the internal transport and information processes of a production factory. It embodies a multi-agent system in supply chain management, since it implements the modern vision of autonomous agents and software objects (Wang et al., 2016). The agents are able to react to events, analyze situations, make decisions and communicate with other agents, which increases the productivity and efficiency of the factory (Cimini et al., 2019; Fiedler, Sackmann, Haasis, 2019). However, even if there are various publications using the term Smart Factory Logistics, no broadly accepted definition is mentioned in science so far. The already considered aspects in literature are now discussed in order to establish an own definition subsequently.

As stated above, products, workstations and transport vehicles of a Smart Factory are linked to each other and independently decide on the correct order of production steps according to available capacities. Their physical logistics processes can be divided into goods receipt, warehouse, production and goods issue (see figure 4) since the general production flow does not differ from a conventional factory (Barreto, Amarala, Pereira, 2017). Within the framework of Smart Factory Logistics, it is crucial that these areas are digitally connected using Logistics 4.0 technologies (Mehami, Nawi, Zhong, 2018; Efthymiou, Ponis, 2019). From an operational point of view, transport vehicles have to supply the production stations with the needed materials at the right time and in the right sequence and also ensure immediate transportation after the production steps. Manufacturing stops can be avoided, which should make the production more efficient (Pei et al., 2017).

In regard to the given description above, an own definition for Smart Factory Logistics is proposed: "Smart Factory Logistics describes the logistics organization of the transport and information processes in a Smart Factory using Logistics 4.0 technologies to enable decentralized control." Thus, efficient Smart Factory Logistics can only work if Logistics 4.0 has been integrated along the logistics supply chain (see figure 4). After the term has now been defined, the impacts on the processes of today's procurement logistics will be analyzed in the further course of the paper. The next chapter deals with the changes, which have to be made in the delivery and unloading of goods, in order to allow autonomy of the in-house processes of the Smart Factory.

3.2 Future Changes on Procurement Logistics

Procurement logistics comprises the connection between the supplier's distribution logistics and the manufacturer's production logistics system.

Its objects are raw materials, supplies and merchandises that have to be made available to the manufacturer as needed. Correspondingly, it is the function of procurement to provide, maintain and develop delivery capacities (Pfohl, 2018; Fleischmann, 2018). Due to digitization of the information flows along the logistics supply chain as part of the Smart Factory development, procurement logistics has to be restructured.

The literature analysis showed that the required changes can be classified into two groups. On the one hand, it is important to consider the ordering processes by the Smart Factory. On the other hand, it is necessary to identify how the physical delivery and unloading of goods by the suppliers will be regulated in future. In order to better illustrate this, the next section is again related to the building industry.

The material ordering of a Smart Construction Factory could be done automatically by ERP-systems (Glas, Kleemann, 2016) or cloud-based Kanban systems (Shahin et al., 2020) according to the pull-principle (Waibel et al., 2017). Depending on the building type of the house, the order is either placed as soon as the minimum quantity has been reached in the warehouse or as part of an individual order after receiving the product order from the customer. Raw materials, e.g. EPS, and supplies, e.g. glue, mounting plugs or fiberglass mats, are rather ordered by the stock replenishment system, whereas individual large orders of merchandise materials with a higher value and importance, e.g. ventilation systems or solar panels, could be placed by separate orders through the product, e.g. the facade or roof panel, itself (Roy, 2017). The product independently searches for the best possible supplier by checking his available stocks and own free production capacities using IoT based Kanban methods. Afterwards, it places an order and informs him about the required materials, delivery times and sequences (Büchi, Cugno, Castagnoli, 2020).

These processes demonstrate the importance of complete data transparency and accessibility along the horizontal and vertical value chain. Production capacities are timed by the Smart Construction Factory in a way that it is almost impossible to build up own intermediate storage stocks (Roth, 2019). The merchandise materials required for production should be delivered directly to the production line to avoid storage costs and simplify internal processes (Wagner, Herrmann, Thiede, 2017).

The suppliers have to ensure that the required materials are provided in the way they were ordered in terms of quantity, quality, time and location. For a high degree of user-friendliness and to ensure controllability in real-time by the Smart Construction Factory, the process must be as transparent as possible (Bogaschewsky, 2019). After the order has been sent to the supplier, he starts to compile the required materials. In this process, it is crucial that the goods are clearly identifiable so that they can directly be assigned to the built facade or roof panel. A possible option could be the use of RFID-chips (Lu et al., 2017). Furthermore, loading equipment and packaging materials also play an important role, as the in-house processes of Smart Factories in general do not envisage the unpacking of incoming materials in order to keep the processes simple and fast. Accordingly, suppliers should organize the transport with minimized packaging and load securing (Jodin, Landschützer, 2017).

Basis of the self-controlling delivery process is the stabilization of the delivery flow using calculated flexible timetables and GPS tracking. Truck tracking should already start during the loading at the supplier's site. Time deviations from the schedule are no longer processed by employees but are recognized and corrected by systems in real-time automatically (Prasad, Babu, 2016). When a truck approaches the Smart Construction Factory, the estimated time of arrival is compared to the calculated time. If a delay is recognized the assigned time window is released and made available to another truck in approach. In this way, the unloading system capacities can be used more efficiently. When the truck reaches the factory, the system should already have sent the delivery note to the incoming goods department. Thus, the truck receives a direct entry permit for the first unloading point and does not need to register at the registration office (Roth, 2019).

Another significant change is expected in the physical unloading of incoming goods at the Smart Construction Factory. Although this will still be realized mainly by loading ramps, no people are involved in the new unloading process (Seder et al., 2019; Mohamed, Al-Jaroodi, Lazarova-Molnar, 2019). Generally, Smart Factories are based on a self-unloading function of the truck by the use of integrated rollers in the loading area (Jodin, Landschützer, 2017; Pfohl, Wolff, Kern, 2020). In contrast to classical unloading no employees of the incoming goods department unload the truck with established systems, e.g. forklifts, and drive into the truck themselves. The used rollers are connected to the floor of the goods receipt as a kind of conveyor belt. As a result, unloading only takes a few minutes. Afterwards, the goods can be separated and checked (Pagnon, 2017). Optionally, there are further autonomous unloading techniques with picking robots or forklifts (Brigant et al., 2018; Custodio, Machado, 2019; Doliotis et al., 2016). An automated unloading process is merely possible if the suppliers are informed in advance about the unloading techniques and adjust the truck loading accordingly. Especially in construction, the materials differ greatly in size, volume and weight, which leads to different unloading techniques for the respective categories.

Furthermore, as the incoming goods are already equipped with an RFID-chip on arrival to be in contact with the product and transport vehicle in the factory during the truck transport, the immediate carriage to the production line can start after unloading (Zakoldaev et al., 2019; Jurenka, Cagáňová, Horňáková, 2018). If production capacities are not available at this time, a corresponding automatic intermediate storage is effected.

4 Concept Development

Winkler/Allmayer (2014, pp. 415-435) state that "accurately planned and designed interorganisational interfaces raise the effectiveness and efficiency of organisations, whereas problems at the interorganisational interface disrupt the value-added processes within supply chain partnerships." Since the internal goods receipt and goods issue processes of an ordinary factory mostly interact with the procurement or distribution network of external 3PLs, their network is linked to suppliers and customers via the service providers. This, in turn, means for the Smart Factory that a Logistics 4.0 concept for the entire supply chain can only be realized if Smart Factory Logistics works accordingly (Fürstenberg, Kirsch, 2017). It is therefore important to analyze the future role of 3PLs in the logistics organization of a Smart Factory.

The area of collaborative work in Smart Factories has not yet been examined in detail in science and hence created a research gap. Only 35 of the identified 310 papers in the literature analysis mentioned the terms of field 2 in their processing. As they do not provide specific solutions, a modified collaborated concept to avoid interorganisational problems is developed in the further part of the paper.

The procurement objective of a Smart Factory is to have all internal goods receipt and transportation processes controlled by cyber-physical systems and to completely dispense with the influence of humans in operation. In future, they should take over only control and programming functions (Spöttl, 2016). As mentioned in the third chapter, unloading is done by automatic systems which belong to the manufacturer. This implies that the 3PL and their up to now offered services will no longer be needed in the visionary goods receipt and warehouse concept of a Smart Factory. However, the question is which new areas of responsibility for 3PLs might occur. In the end, even a Smart Factory or Smart Construction Factory could be dependent on an upstream external logistics center in which the unpacking, sorting and storage processes can be pre-handled for the production. If the suppliers cannot realize the needed implementation of RFID-chips and supply with already unpacked materials because it complicates their own processes, the Smart Factory has to do it itself. But, this again fails due to the complexity issues and lean principle of Smart Factories, in which unpacking and storage processes are not intended. In this case, 3PLs could operate a supply center in the immediate vicinity of the factory where they take over all outsourced processes, e.g. RFID-chip attachment, unpacking and separation, quality check, storage and just-in-sequence (JIS) pre-sorting, which cannot directly be realized by the suppliers or Smart Factory. When materials are now ordered by the product the 3PL can deliver them in the desired quantity, sequence and condition without packaging material. The corresponding visualized overview for the procurement logistics concept of a Smart Factory including 3PLs is seen in figure 5.

The figure provides an overview of the physical flow of goods along the procurement process as well as the systemic order process in opposite flow of direction. The systemic order process shows which systems communicate with each other using which communication technologies. Initially, the information is given to the supplier via pull orders by the 3PL, as they also have a precise overview of the production status in the factory at all times. As soon as the materials are unloaded in the logistics center and RFID-chips are added, they take over the communication. Now the materials are stored until they are released by the intelligent product to be delivered JIS to the Smart Factory. As already described, the later truck unloading can now be handled without packaging materials through cyber-physical systems and the materials can thus be assigned to the production lines by AGVs without intermediate storage (see figure 5).

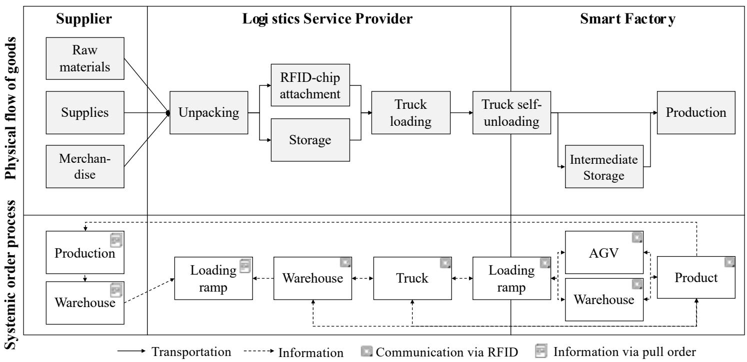


Figure 5: Procurement Logistics concept of a Smart Factory

Nonetheless, it would be ideal for the logistics supply chain of the Smart Factory to have all ordered and already unpacked materials delivered JIS directly by the suppliers. This would allow the manufacturer more control of suppliers and the delivered materials and shorter communication times due to no intermediate stage. In this scenario, only one transport to the Smart Factory is executed (see figure 6). However, this seems admittedly unrealistic after considering the concept development above. Thus, logistics centers will probably be operated by 3PLs in the future to take over the final supply. In this scenario, a second stage of transport is included and the supplier communication is handled both through the Smart Factory and 3PL (see figure 7). The transports to the customers remain the same in both scenarios, as they can be managed without another logistics center. At this stage of research, it is not possible to draw a general conclusion about which scenario should be chosen and put into practice. Scenario 1 offers direct interactions with the suppliers, whereas in scenario 2 physical processes can be outsourced to the 3PL. However, if the communication process runs smoothly, it can be assumed that scenario 2 could appear more realistic in the long term view as other outsourcing benefits, e.g. less appropriated surplus or better scalability, can be achieved as well.

The following two overviews show the possible scenarios of the procurement network from the manufacturers as well as 3PLs perception.

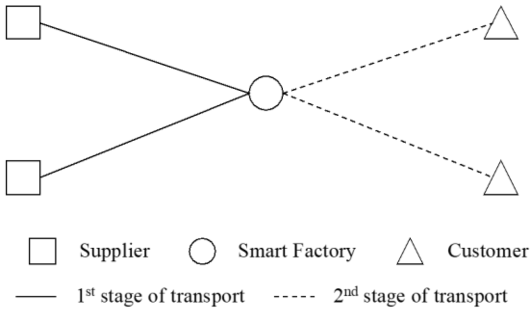


Figure 6: Procurement Network - Manufacturers perception

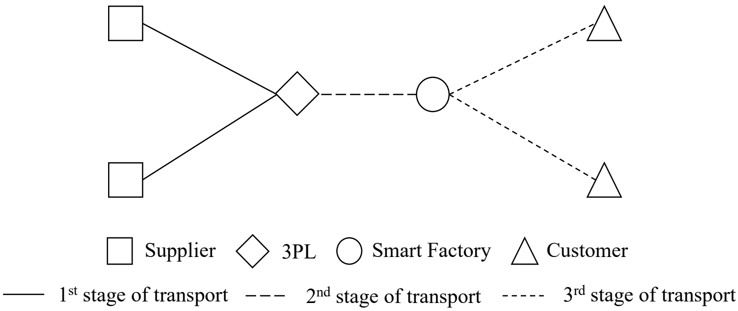


Figure 7: Procurement Network - 3PLs perception

5 Conclusion

The paper presented a literature analysis of future impacts on procurement logistics through the flexibility and automation Smart Factories will bring into the market with references to the building industry. Furthermore, it was able to develop a concept regarding the role and responsibilities 3PLs could have in its logistics organization. Although they will no longer perform directly in the factory, their new role could be in operating a logistics center in the vicinity of the Smart Factory to enable its guaranteed autonomy. By integrating 3PLs, the manufacturers are able to keep their in-house processes as lean and efficient as possible and only focus on their automated production. Thus, the procurement processes unpacking, quality check, separation, storage and pre-sorting are outsourced to the greatest possible extend, but can still be controlled by the product itself.

Interface problems could arise if manufacturers induce their suppliers to directly deliver materials without packaging as well as load securing and equip them with RFID-chips in advance. This would hardly be possible due to complexity problems in handling and transportation. In addition, if a Smart Factory was planned without outsourced processes, the manufactures would have to do the unpacking themselves and would therefore also need own employees. This could then lead to a miss of the Smart Factory Logistics goal of complete autonomy.

However, research on this topic is still in its infancy. The restriction of the investigation represents the not promulgated scientific or practical research about the future roles and responsibilities of 3PLs, which means that no specific comparison to similar publications could have been made. This would have made the concept even more detailed. More conceptual and empirical work is needed to better understand the impacts of Smart Factories and Industry 4.0 on procurement logistics in detail. Nevertheless, future research in this field is probably continuing to grow in the coming years as the actual realization of Smart Factories approaches (see figure 2). This could also close the current research limitation because both science and practice have to be aware of the role and responsibilities of 3PLs when planning logistical processes for or inside a Smart Factory. With these considerations in mind, this work is an initial exploration of the research field and further observations have to be taken.

Acknowledgments

The described object of research was carried out as part of the Interreg project "INDU-ZERO: Industrialization of house renovations towards energy-neutral". The aim of the project is the development of a Smart Factory blueprint for the production of standard renovation packages at an industrial scale helping homes in the North Sea Region to become energy neutral and future-proof. The realization of this project is supported and co-financed by the European Regional Development Fund.

References

Achillas, C., Bochtis, D., Aidonis, D. & Folinas, D., 2018. Green Supply Chain Management. New York: Routledge Verlag.

Baker, M., 2000. Writing a Literature Review. The Marketing Review, 1(2), pp. 219-247.

Barreto, L., Amarala, A., Pereira, T., 2017. Industry 4.0 implications in logistics: an overview. Manufacturing Engineering Society International Conference 2017, Vigo, Spain, Procedia Manufacturing, 13, pp. 1245–1252.

Bogaschewsky, R., 2019. Digitalisierung in Einkauf und Supply Chain Management. In: Obermeier, R. Handbuch Industrie 4.0 und Digitale Transformation, Passau: Springer Gabler, pp. 139-164.

Botthof, A. & Hartmann, E., 2015. Zukunft der Arbeit in Industrie 4.0. Berlin: Springer Vieweg.

Brigant, P., Horňáková, N., Jurík, L., Cagáňová, D., Chovanová, H., Jemala, M., 2018. Implementation of smart solutions in the inhouse logistics. 3rd EAI International Conference on Management of Manufacturing Systems.

Büchi, G., Cugno, M. & Castagnoli, R., 2020. Smart Factory performance and Industry 4.0. Technological Forecasting & Social Change, 150, pp. 1-10.

Cimini C., Pezzotta G., Pinto R., Cavalieri S., 2019. Industry 4.0 Technologies Impacts in the Manufacturing and Supply Chain Landscape: An Overview. In: Borangiu T., Trentesaux D., Thomas A., Cavalieri S., Service Orientation in Holonic and Multi-Agent Manufacturing. SOHOMA 2018, Studies in Computational Intelligence, 803, Springer, pp. 109-120.

Custodio, L., Machado, R., 2019. Flexible automated warehouse: a literature review and an innovative framework. The International Journal of Advanced Manufacturing Technology, 106, pp. 533–558.

Doliotis, P., McMurrough, C., Criswell, A., Middleton, M., Rajan, S., 2016. A 3D perception-based robotic manipulation system for automated truck. IEEE International Conference on Automation Science and Engineering (CASE), Fort Worth, TX, pp. 262-267.

Efthymiou, O., Ponis, S., 2019. Current Status of Industry 4.0 in Material Handling Automation and In-house Logistics. International Journal of Industrial and Manufacturing Engineering, 13(10), pp. 1370-1374.

Fiedler, A., Sackmann, D., Haasis, H.-D., 2019. A Literature Review on the State of the Art of Multi-agent Systems in Supply Chain Management. In: Bierwirth C., Kirschstein T., Sackmann D., Logistics Management. Lecture Notes in Logistics, Springer, pp. 62-74.

Fleischmann, B., 2018. Begriffliche Grundlagen der Logistik. In: Tempelmeier, H. Begriff der Logistik, logistische Systeme und Prozesse. Köln: Springer Vieweg, pp. 1-16.

Flick, U., 2014. The SAGE hadbook of qualitative data analysis. London: SAGE.

Fürstenberg, K., Kirsch, C., 2017. Intelligente Sensorik als Grundbaustein für cyber-physische Systeme in der Logistik. In: Vogel-Heuser, B., Bauernhansl, T. & ten Hompel, M.: Handbuch Industrie 4.0 Bd. 3., 2. ed., Berlin: Springer Gabler, pp. 271-297.

Glas, A., Kleemann, F., 2016. The Impact of Industry 4.0 on Procurement and Supply Management: A Conceptual and Qualitative Analysis. International Journal of Business and Management Invention, 5(6), pp. 55-66.

Haddud, A., & Khare, A., 2018. The Impact of Digitizing Supply Chains on Lean Operations. In: Khare, A., Kessler, D., Wirsam, J. Marktorientiertes Produkt- und Produktionsmanagement in digitalen Umwelten, Wiesbaden: Springer Fachmedien, pp. 27-46.

Ileri, B., Bülow, M., & Jansen, P., 2019. AGCO Smart Logistics – Transformation der dezentralen Inbound Supply Chain zu einer zentralen 4PL-gesteuerten Inbound Supply Chain. In: Hartel, D. Projektmanagement in Logistik und Supply Chain Management, 2. ed., Stuttgart: Springer Fachmedien, pp. 253-269.

Jodin, D., Landschützer, C., 2017. Smart Logistics: Intelligente Logistik für flexible Fabriken. In: Winkler, H., Berger, U., Mieke, C., Schenk, M. Flexibilisierung der Fabrik im Kontext von Industrie 4.0, Band 6, Berlin: Copyright Logos, pp. 133-168.

Jurenka, R., Cagáňová, D., Horňáková, N., 2018. The Smart Logistics. In: Cagáňová D., Horňáková N. (eds) Mobility Internet of Things 2018. Mobility IoT 2018. EAI/Springer Innovations in Communication and Computing. Springer, Cham, pp. 277-292.

Kiefer, L., Kiefer, Voita, P., Richter, C., Reinhart, G., 2018. Attribute-based identification processes for autonomous manufacturing systems – an approach for the integration in factory planning methods. 12th CIRP Conference on Intelligent Computation in Manufacturing Engineering, Gulf of Naples, Italy: Springer, pp. 204-209.

Kirch, M., Poenicke, O., Richter, K., 2016. RFID in Logistics and Production – Applications, Research and Visions for Smart Logistics Zones. 16th Conference on Reliability and Statistics in Transportation and Communication, Riga, Latvia: Procedia Engineering, 178, pp. 526–533.

Landscheidt, S., Kans, M., Winroth, M., 2017. Differences on automation practices in wooden single-family houses manufacturing: Four case studies. In: Zbiec, M., Orlowski, K. 23rd International Wood Machining Seminar Proceedings, pp. 350-359.

Liukkonen, M., Tsai, T.-N., 2015. Toward decentralized intelligence in manufacturing: recent trends in automatic identification of things. International Journal of Advanced Manufacturing Technology, 87, London: Springer, pp. 2509–2531.

Lu, S., Xu, C., Zhong, R., Wang, L., 2017. A RFID-enabled positioning system in automated guided vehicle for smart factories. Journal of Manufacturing Systems, 44(1), pp. 179-190.

Mehami, J., Nawi, M., Zhong, R., 2018. Smart automated guided vehicles for manufacturing in the context of Industry 4.0. 46th SME North American Manufacturing Research Conference, Texas: Procedia Manufacturing, 26, pp. 1077-1086.

Mohamed, N., Al-Jaroodi, J., Lazarova-Molnar, S., 2019. Leveraging the Capabilities of Industry 4.0 for Improving Energy Efficiency in Smart Factories. IEEE Access, 7, pp. 18008-18020.

Obermeier, R., 2019. Industrie 4.0 und Digitale Transformation als unternehmerische Gestaltungsaufgabe. In: Obermeier, R. Handbuch Industrie 4.0 und Digitale Transformation, Passau: Springer Gabler, pp. 3-46.

Oesterreich, T., Teuteberg, F., 2016. Chancen und Risiken der Digitalisierung in der Bauindustrie im Kontext von Industrie 4.0 – Situationsanalyse und Zieldefinition im Zuge einer Technikfolgenabschätzung. In: Mayr, H., Pinzger, M. Informatik 2016, pp. 1429-1443.

Pagnon, W., 2017. The 4th Industrial Revolution – A Smart Factory Implementation Guide. International Journal of Advanced Robotics and Automation (IJARA), 2(2), pp. 1-5.

Pei, F., Tong, Y., He, F., Li, D., 2017. Research on Design of the Smart Factory for Forging Enterprise in the Industry 4.0 Environment. Mechanika, 23(1), pp. 146-152.

Pfohl, H.-C., Wolff, P., Kern, J., 2020. Transshipment hub automation in China's courier/express/parcel sector. In: Elbert, R., Friedrich, C., Boltze, M., Pfohl, H.-C. Urban Freight Transportation Systems, WCTRS, pp. 163-180.

Pfohl, H.-C., 2018. Logistiksysteme. 9th ed., Darmstadt: Springer Vieweg.

Prasad, N., Babu, P., 2016. IoT in Logistics- Smart Product Tracking Solution. International Journal of Latest Trends in Engineering and Technology, 7(2), pp. 144-149.

Roth, L., 2019. Die Logistik wird smart - Audi führt den selbststeuernden Anlieferprozess im Werk Ingolstadt ein. In: Göpfert, I. Logistik der Zukunft - Logistics for the Future, 8th ed., Wiesbaden: Springer Gabler, pp. 349-365.

Roy, D., 2017. Industrie 4.0 – Gestaltung cyber-physischer Logistiksysteme zur Unterstützung des Logistikmanagements in der Smart Factory. Berlin: Universitätsverlag der TU Berlin.

Ruile, H., 2019. Vom Internet der Dinge zum Geschäftsmodell. In: Göpfert, I. Logistik der Zukunft - Logistics for the Future, 8th ed., Wiesbaden: Springer Gabler, pp. 139-156.

Schack, R., 2017. Methodik zur bewertungsorientierten Skalierung der Digitalen Fabrik. In: Forschungsberichte IWB, Munich: Herbert Utz Verlag.

Schneider, J., Hanke, T., 2020. Logistik 4.0 – Grundvoraussetzungen für zukunftsfähige Geschäftsmodelle in der Logistik. In: Tewes, S., Niestroj, B., Tewes, C. Geschäftsmodelle in die Zukunft denken. Essen: Springer Gabler, pp. 165-175.

Seder, M., Petrović, L., Peršić, J., Popović, G., Petković, T., Šelek, A., Bićanić, B., Cvišić, I., Josić, D., Marković, I., Petrović, I., Muhammad, A., 2019. Open Platform Based Mobile Robot Control for Automation in Manufacturing Logistics. IFAC PapersOnLine, 52(22), pp. 95-100.

Shahin, M., Chen, F., Bouzary, H., Krishnaiyer, K., 2020. Integration of Lean practices and Industry 4.0 technologies: smart manufacturing for next-generation enterprises. The International Journal of Advanced Manufacturing Technology, 107, pp. 2927–2936.

Spöttl, G., 2016. Skilled Workers: Are They the Losers of “Industry 4.0”?. In: Schlick C. et al. (eds) Advances in Ergonomic Design of Systems, Products and Processes, Berlin: Springer, pp. 73-87.

Steven, M., Klünder, T., Reder, L., 2019. Industrie-4.0-Readiness von Supply-Chain-Netzwerken. In Obermaier, R. Handbuch Industrie 4.0 und Digitale Transformation, Bochum: Springer Gabler, pp. 247-267.

ten Hompel, M., & Kerner, S., 2015. Logistik 4.0 - Die Vision vom Internet der Dinge. Informatik Spektrum, 38(3), pp. 176-182.

Vestin, A., Säfsten, K., Löfving, M., 2018. On the way to a smart factory for single-family wooden house builders in Sweden. Procedia Manufacturing, 25, pp. 459-470.

Wagner, T., Herrmann, C., Thiede, S., 2017. Industry 4.0 impacts on lean production systems. The 50th CIRP Conference on Manufacturing Systems, Procedia CIRP, 63, pp. 125-131.

Waibel, M., Steenkamp, L., Moloko, N., Oosthuizen, G., 2017. Investigating the effects of Smart Production Systems on sustainability elements. 14th Global Conference on Sustainable Manufacturing, Procedia Manufacturing, 8, pp. 731–737.

Wang, S., Wan, J., Zhang, D., Li, D. & Zhang, C., 2016. Towards Smart Factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination. Computer Networks, 101, pp. 588-600.

Wehberg, G., 2018. Logistik 4.0 – die sechs Säulen der Logistik in der Zukunft. In: Göpfert, I. Logistik der Zukunft - Logistics for the Future. 8th ed., Wiesbaden: Springer Gabler, pp. 367-395.

Winkler, H., Allmayer, S. 2014. Supply chain interface problems affecting productivity. International Journal of Logistics Systems and Management, 18(4), pp. 415-435.

Yao, X., Zhou, J., Lin, Y., Li, Y., Yu, H., Liu, Y., 2017. Smart manufacturing based on cyber-physical systems and beyond. Journal of Intelligent Manufacturing, 30(8), pp. 2805-2817.

Zakoldaev, D., Gurjanov, A., Shukalov, A., Zharinov, I., 2019. Classification of Cyber and Physical Systems of Industry 4.0. IOP Conf. Series: Materials Science and Engineering, 582.

Zsifkovits, H., Woschank, M., 2019. Smart Logistics – Technologiekonzepte und Potentiale. BHM Berg- und Hüttenmännische Monatshefte, 164, pp. 42-45.

Framing Supply Chain Visibility Through a Multi-Field Approach

Lucie Lechaptois [1]

1 – CRET-LOG (Centre de recherche sur le Transport et la LOGistique), Aix-Marseille University

Purpose: Supply chain management (SCM) literature places great importance on supply chain visibility (SCV) and companies are looking to improve it. While better SCV offers benefits to supply chain (SC) actors, SCV is not clearly defined and little is said about how to achieve it. Our aim is to identify its existing meanings, facilitating/hindering factors and to elaborate on the concept.

Methodology: To grasp this complex notion, situated at the interface of several fields, we conducted a literature review on the visibility concept using a multi-field approach. This conceptual work was complemented by an exploratory empirical study in an industrial company. Using a "life stories" methodology, we gathered respondents' experiences of visibility issues in the field to enrich the proposed framework.

Findings: Visibility is recognized as a strategic challenge for supply chains, but is also used in other fields. Its complexity and the richness of capabilities it creates is discussed in several disciplines. Field experiences highlight visibility issues in the context of a supply chain: it concerns different needs, objects and organizational levels. These inputs helped to build the SCV conceptual framework.

Originality: The originality of this research is that it provides a multidisciplinary perspective to complement the knowledge of SCV in SCM literature. Using the "life story" research strategy, concept characteristics enrich and give meaning to the proposed SCV framework. The resulting integrative SCV framework is helpful to better understand the academic concept and its managerial relevance.

First received: 12. Mar 2020 Revised: 21. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

Supply chain visibility (SCV) is a widely used concept in supply chain management (SCM) (Francis, 2008) and although many people have tried to define it, there is still no consensus on its definition. Perhaps more important than looking for the SCV definition, it is necessary to understand what SCV means, why it is so important to improve SCV and how to improve it (Busse et al., 2017). In this paper, we propose to develop an SCV framework by combining an SCV literature review, a multidisciplinary overview of the visibility concept and an empirical study gathering field experiences about visibility needs in SCM. The first section of this paper presents the literature review on the SCV concept. The methodology section then explains how the multidisciplinary overview and the empirical study were conducted. We also provide a figure to explain how the SCV framework is built. The third section presents the findings from the multidisciplinary overview and the empirical study. In the last section, we discuss their contributions in relation to the SCV literature and propose an SCV framework combining the three approaches.

2 About SCV literature

Companies are looking to develop their SCV and, from an academic point of view, the SCV concept is gaining importance in the SCM literature. The technological context of the 2000s, with the development of the Internet and information and communication technologies, has led many actors to seek greater visibility (Roussat et al., 2018). Furthermore, the increasing complexity of supply chains tends to impede the visibility of flows, activities, processes, resources and makes it more difficult to manage them (Christopher, 2005). The outsourcing of activities in supply chains requires more coordination between companies (Handfield and Nichols, 2002). However, the lack of visibility negatively impacts collaboration and coordination between actors (Simatupang and Sridharan, 2002) because “the supply chain is bounded by a fuzzy horizon” (Carter et al., 2015). In this context, SCV has become a highly studied concept in the SCM literature and a major concern for companies (Enslow, 2006).

Companies are suffering from a lack of visibility both inside and outside the supply chain (Fabbe-Costes and Lemaire, 2004) and are looking to improve it. In an annual report on the supply chain industry, Deloitte (2018) characterized the SCV concept as being highly strategic. Based on a systematic literature review, Roussat et al. (2018, p.8) propose the following definition of SCV: "Supply chain visibility (SCV) may be defined as the capacity to see the state of resources and the functioning of activities in the supply chain. SCV allows actors to access or share information relating to a given area or section of the supply chain, using systems and technology, in order to improve the management and/or strategic positioning of the supply chain." Thus, SCV is also closely related to traceability because tracking/tracing technologies help to enhance visibility (Goel, 2010). In addition to the importance of having access to data through technologies and information systems, SCV emphasizes the benefits of real-time visibility. Real-time visibility can improve companies' responsiveness and potentially impact their agility and strategic alignment (Dubey et al., 2018) and hence help SCs to become more resilient (Azevedo et al., 2013). SCV is therefore a capacity that can play a role in the dynamics of SCs and be an antecedent of many benefits.

SCV is considered strategic for many reasons (Caridi et al., 2010). By improving SCV, companies make their supply chains more competitive (Caridi et al., 2014). SCV can improve operational efficiency, operational performance and process planning. Through its impact on collaboration and relations with partners in the chain, SCV contributes to developing competitive advantages. It brings many benefits to the various actors in the network, and therefore has a positive impact along the entire supply chain as well. A global view of the SC (Roussat et al., 2018) makes it possible to ensure the quality of processes, products and services and thus improve SC performance. All these benefits are made possible through information sharing and improved transparency between the actors in the chain. SCV is gained through the information extracted from the traceability system. Finally, in order to benefit from this visibility, it is necessary to develop a "distinctive visibility" (Baratt and Oke, 2007) to create value for all SC actors.

However, there is so far no consensus on how to define SCV. It is a subject of interest, but remains an extremely complex concept at the interface of different research areas, including logistics, information systems and operational research (Roussat et al., 2018). It is even more difficult to define SCV given that it is often associated with the notions of traceability, information sharing and transparency (Evrard-Samuel and Ruel, 2016). Even though there are many articles that seek to define the concept, it is characterized as under-defined and ambiguous (Roussat et al., 2018) and researchers tell us little about how to improve it (Busse et al., 2017).

The aim of this paper is not to propose a new definition of SCV, but to build a framework to better understand its importance in SCM. The SCM literature leads us to the following three research questions:

- RQ1: Why is it important to have visibility?
- RQ2: What do we want to have visibility of?
- RQ3: What factors, conditions and / or tools could facilitate or hinder visibility?

To extend the study of SCV and to understand it by taking a broader and deeper approach, beyond the boundaries of the SCM literature, we have focused our study on the notion of visibility itself. Therefore, in addition to the above SCM approach to SCV, we conducted a multidisciplinary overview of the visibility concept to produce a robust conceptual framework. We also carried out an exploratory study in an industrial company in order to enrich these theoretical perspectives with an empirical study. To develop an SCV framework, we combined these three approaches: the SCM literature, the multidisciplinary overview and the analysis of the field study. Figure 1 below summarizes the overall logic used to build the framework.

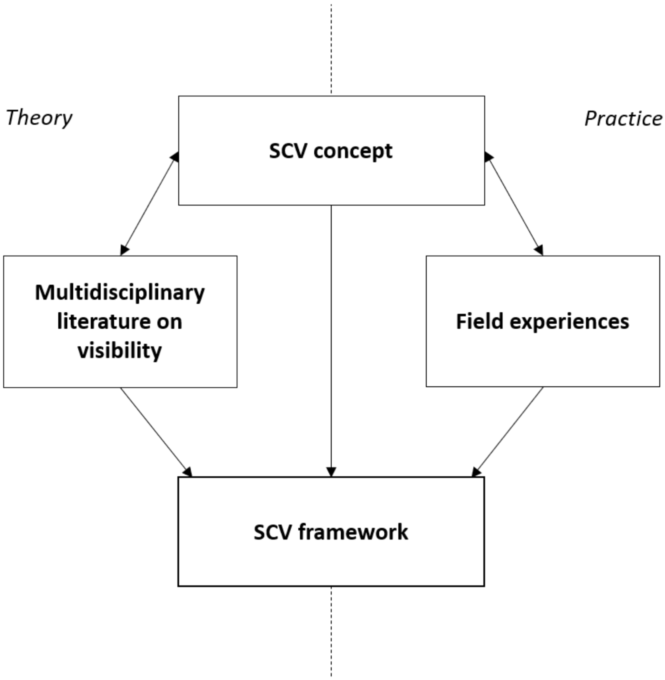


Figure 1: Building the SCV framework

Table 1 is the starting point for building the SCV framework. Drawing on the SCM literature, it provides a definition of SCV and summarizes existing answers to our research questions.

Table 1: SCV concept

Definition and RQs	SCM approach	References
Definition of SCV	"Supply chain visibility (SCV) may be defined as the capacity to see the state of resources and the functioning of activities in the supply chain. SCV allows actors to access or share information relating to a given area or section of the supply chain, using systems and technology, in order to improve the management and/or strategic positioning of the supply chain. Actors' level of visibility thus depends on the magnitude and quality of information sharing."	Roussat et al., 2018 (p.8)
RQ1 Why do we need SC visibility?	Improve SC performance by ensuring the quality of processes, products and services Improve process planning, operational performance / efficiency Develop competitive advantages Improve the responsiveness, agility and resilience of companies and SCs	Caridi et al., 2014 Christopher, 2005 Dubey et al., 2018 Azevedo et al., 2013

Definition and RQs	SCM approach	References
RQ2 See what?	Flows, activities, processes, resources	Christopher, 2005
RQ3 Facilitating factors	Information sharing (including strategic information), transparency, traceability system	Evrard-Samuel and Ruel, 2016 Goel, 2010
RQ3 Hindering factors	Supply chain complexity, reluctance to share information, opportunism, protection of business models based on information asymmetry	Simatupang and Sridharan, 2002 Christopher, 2005

The following section explains how the multidisciplinary overview and the empirical study were carried out. It also clarifies how we combined these perspectives to build the SCV framework that we then present in the discussion section.

3 Methodology

In order to build the SCV framework, in addition to the existing SCM literature, we used two complementary methods: a multidisciplinary overview of the concept of visibility and an exploratory empirical study in an industrial company.

3.1 Multidisciplinary overview of visibility

Regarded as under-defined and ambiguous (Roussat et al., 2018), the SCV concept is complex and is situated at the interface of different research areas. We have therefore chosen to improve our understanding by studying the notion of visibility through disciplines other than SCM. This methodology is inspired by Yao and Fabbe-Costes (2018), who studied Supply Network Resilience. Their literature review was based on SCM and other sciences in order to better understand the studied concept.

In this paper, the multidisciplinary overview combines several perspectives from disciplines that deal with the notion of visibility. We selected three broad areas from among the sections proposed by the French Centre National des Universités (CNU):

- Humanities and social sciences: philosophy, sociology and history
- Physical sciences: optical physics, astronomy and meteorology
- Multi-field: communication and information science

After identifying the relevant disciplines, we selected papers by leading and recognized authors that deal with the concept of visibility. In conducting this overview, we selected and focused on the ideas we considered most important on the subject matter in the different fields. Our reading of these papers was guided by the search for answers to our three research questions. The results are summarized in Table 2 (see section 4 - findings).

3.2 "Field experiences" research

Using a qualitative life stories methodology, we can explore three topics: social worlds, categories of situation or social trajectories (Bertaux, 2016). Our research looks for categories of situation and focuses on any "lack of visibility situations" as a unit of analysis. The objective is to collect data from key informants facing such situations who have one thing in common (Sanséau, 2005): a lack of visibility.

The field research was done at Renault Group, an automotive company with a worldwide and complex SC that outsources a lot of activities. The company is currently looking to improve its SCV. We were able gather data from key informants at Renault Group, involved in the management of its supply chain and with experience(s) of a lack of visibility.

Data collection was done from March until May 2020. Therefore, most interviews were conducted by telephone owing to the lockdown caused by the Covid-19 health crisis. To build our sample, we conducted purposive sampling, which is a non-probability method frequently used in management research (Thiétart, 2014). Some respondents were selected on the advice of a manager working in the outbound SC department and others were proposed by the first interviewees, i.e. a snowballing method. Not all participants could be interviewed due to planning constraints. Of the eleven respondents, one works for the inbound SC division (in transport/ logistics operations) and ten for the outbound SC division (five in transport/ logistics operations, two in sales operations, two in outbound SC, and one in distribution network engineering). Of the 11 interviews done, 10 were recorded and transcribed. Forty-five field experiences were gathered concerning situations where the informant felt a lack of visibility. Four experiences were collected on average per interview. A short interview guide was used, consisting of an introduction to the study and three questions:

1. Have you had one or more experiences linked to a lack of visibility?
2. In which areas did you want to have visibility?
3. Why and for what purpose?

The analysis and understanding of situations are subject to interpretation since respondents have their own particular history and affiliations. Two types of analysis were conducted to answer the three research questions: a thematic analysis in order to highlight the variety of situations and a comparative analysis to study commonalities that characterize the lack of visibility situations. The results are summarized in Table 3 (see section 4 - findings).

4 Findings

4.1 Multidisciplinary overview of visibility concept

4.1.1 Humanities and Social sciences

In this sub-section, we combine philosophy, sociology and history to contribute to the conceptualization of visibility.

A study of the notion of visibility cannot be done without considering the work of Maurice Merleau-Ponty. In his work *The Visible and the Invisible* (English edition, 1968), the notions of the visible and the invisible are concomitant. He explains that the experience of the visible is not just the thing we see. There is something beyond the visible that gives shape to it: the invisible. Visibility is therefore what gives access to the invisible, to the basis of the visible. In *Discipline and Punish* (English edition, 1977), Michel Foucault also uses the notion of visibility. He talks about the relations between power and visibility. Using the concept of the panopticon developed by Jeremy Bentham, he develops the idea that visibility can be harnessed to exercise control in modern societies. However, Foucault's model has been criticized as it completely overlooks the role of the communication media (Thompson, 2005). This role must be taken into account since media modify interactions and thus offer new forms of visibility to individuals. It is no longer about the means of surveillance, but new tools to communicate using media to exercise a form of power. These new forms of communication allow a few people to be visible to many, whereas the panopticon model makes many individuals visible to a few. Axel Honneth (2001) also uses the notion of visibility and develops recognition theory. He considers that there is no possible recognition of an individual without visibility. This notion therefore refers to a practical relationship in which recognition implies that attention is paid to that individual. Those who do not have the means to be recognized and need recognition are called the invisible ones (Rosanvallon, 2014).

Although they are distinct, these approaches allow us to argue that we seek visibility of that which is not visible. Essential to the understanding of the notion of visibility, the contributions of these authors have defined visibility as an entire social dimension (Brighenti, 2007). In *Visibility in Social Theory and Social Research* (2010), Brighenti explains that the concept of visibility helps to differentiate the visible from the invisible and characterizes it with three attributes:

1. Relational, since visibility determines relationships between individuals, because they can only be recognized if they are visible (Honneth, 2001), and to the use of visibility as a means to create a form of power (Foucault, English edition 1968; Thompson, 2005).
2. Strategic, since visibility is manipulated by subjects in order to obtain social effects. We can refer to the "constructed dimension of reality" by using the traces left by history (Tardy, 2007) and also to the way visibility is used by individuals (Thompson, 2005).
3. Evental, since the social effects of visibility are ambivalent: “it can confer power, but it can also take it away” (Brighenti, 2010).

4.1.2 Physical sciences

Optical physics, astronomy and meteorology also mobilize the notion of visibility. In the hard sciences it is characterized as an ability to observe phenomena or objects.

Visibility is very important for human beings because they are endowed, naturally, with the ability to see: vision is certainly the dominant sensory modality in humans according to Jean Bullier (Encyclopaedia Universalis consulted on 20 February 2020). When an individual's eye receives light reflected by an object, he/she sees this object. Light, the eye, but also optical instruments such as glasses give humans the ability to see and identify an object in their field of vision (Hubel, 1988). However, this ability can also be hindered by darkness, an opaque body, distance or even by our eyes, when they do not have or only partially have this ability "to see" (Galifret, 1990). Beyond our sense capacity based on vision, human beings have sought to see even further. The science of observation and astronomy aims to understand the origin, evolution and physical and chemical properties of the stars. Many are studied: the sun, the stars, the inner and outer solar system, the Milky Way, the planets, the Big Bang, the Universe and the galaxies. With the help of specific optical instruments such as telescopes and satellites, this discipline finally seeks to obtain a projection, an image of these extremely distant objects (Maurel, 2002). Although it can be slowed down by the agitation of the atmospheric air, visibility in astronomy affects our ability to observe the stars in the universe (Parisot et al., 2003). It is precisely these atmospheric air disturbances that interest meteorologists. When they are observed, they lead to the construction of hypotheses with the aim of anticipating and predicting phenomena that occur in the atmosphere. These predictions remain uncertain, but can nevertheless help many sectors of activity, such as maritime or air transport (Babari, 2012). In this discipline, visibility has been defined as "the distance up to which an observer located near the ground or the sea can see and identify an object in a given direction in the atmosphere" (Météo France). Visibility allows viewers to observe and study one or more phenomena occurring in the atmosphere up to a certain distance and in a given direction. This ability is sometimes impeded by obstacles such as weather conditions or the size of oceans and deserts, i.e. the distance at which the phenomenon occurs.

4.1.3 Multi-field

Other disciplines, such as communication and information science, also use the concept of visibility. Generally, it is approached through issues related to information systems within organizations.

Visibility is provided by the information system (IS): making information visible entails transforming raw and heterogeneous data into visible and comprehensible information, which means "it is a matter of organizing, putting things in order, making them accessible" according to Flichy (2013). In order to provide visibility by sharing data via systems at the intra- and inter-organizational levels, actors need to know the role of the IS they are using and the services it offers in order to use it in a relevant way. This is one of the roles of the organization's IS management: ensure that the organization's actors know the value of the system they are operating (Bohnk, 2010).

Beyond users' knowledge of systems, an optimal transmission of data between the different IS would allow companies to be more flexible (Evgeniou, 2002). Indeed, the transmission of data at the intra- and inter-organizational levels should lead to better collaboration, cooperation and coordination between the different actors of one or more organizations (Said, 2006; Boulay and Isaac, 2007). Nevertheless, this sharing of information requires that the systems be aligned and integrated, according to their functions, but also to the structure of the organizations (Said, 2006). It is precisely thanks to this alignment that visibility is made possible (Flichy, 2013). On the other hand, poor IS construction and architecture or the applications used could lead to poor transmission of information, and therefore to a drop in visibility (Bohnk, 2010). This integration of systems is only possible if the different actors involved communicate about the objectives and issues that drive them. Furthermore, IT systems make the tasks of individuals in the organization visible (Andonova and Vacher, 2013).

Table 2: Synthesis of the multidisciplinary overview of visibility

Definition and RQs	Humanities and Social sciences	Physical sciences	Multi-field
Definition of SCV	Social dimension giving capability to differentiate between the visible and the invisible. Visibility is relational, strategic and evental	Ability to observe objects or phenomena	Transform raw and heterogeneous data into visible information
RQ1	Access to invisibility	To see what is around us	Gain organizational flexibility

Definition and RQs	Humanities and Social sciences	Physical sciences	Multi-field
The need for visibility	Use it to obtain social effects Be visible to gain recognition	Obtain an image of distant objects Anticipate and predict phenomena	Improve collaboration and coordination between actors
RQ2 See what?	Individuals, institutions, social world	Objects and phenomena	Data, information and tasks performed by actors
RQ3 Facilitating factors	Social recognition, communication media	Visual ability (eyes), light, simple and specific optical instruments	Information systems, systems alignment and integration, collaboration
RQ3 Hindering factors	Social position, access to institutions or media	Darkness, opaque body, distance or visual ability	Poor IS architecture and communication on IS value, poor collaboration

Although these elements are not from the SCM literature, they will contribute to building the SCV framework in the discussion section.

4.2 Empirical study

We gathered field experiences from respondents to answer our research questions. The findings are therefore structured in three distinct parts according to the RQs and are summarized in Table 3. If a direct quotation is used, we indicate the experience number it refers to in brackets (e.g. [12]).

Among the 45 field experiences gathered, we found 8 areas in which respondents expressed the need for visibility. Twenty-six experiences mentioned the importance of visibility in order to meet delivery times and/or satisfy end-customers: “Customers are not necessarily satisfied when you can't give them dates” [20]. The idea is to gain visibility in order to satisfy the customer by delivering the product on time. The anticipation of needs and risks is also often addressed: “be able to anticipate our transport capacities” [16], “receive weather bulletins or notification of a worker strike... to be able to anticipate a little bit” [3]. The need to give visibility to all SC actors also arises in interviews: “We are able to explain to the client the reasons for the delays and give them dates” [24]. Costs monitoring and achieving performance targets were also brought up: “The lack of visibility also impacts costs, especially when it comes to speeding up your transport” [44], “I like to anticipate and make sure I'm going to achieve my inventory targets” [16]. Invisibility of some information or actions takes up a lot of working time (“it takes months of email exchanges to find a solution” [41]) and might have an impact on work motivation as well (“The team is losing its motivation although they were actually quite confident” [32]). Lastly, in the case of exceptional situations: “the cars, for example, they come out of the facility to be repaired and that's not tracked" [8], there is a need for visibility in order to keep track of the products.

The need for visibility does not tell us what respondents are seeking to see though. Seven elements were identified in the field experiences:

- 14 discussed the need for visibility of resources: means of transport, storage and transport capabilities, vehicle information in systems or customs documents (e.g. "to know how many cars there are at each of the centers" [29])
- 14 discussed lead times: the delay of a vehicle launch in manufacturing, of the resumption of activities or vehicle release (e.g. "Today it is difficult to give visibility to the sales department on repair times" [28])
- 9 discussed activities: variations in factory output, vehicle modification possibilities or information about projects: ("it is an informational concern because you see a vehicle that's modifiable and it is not" [37])
- 7 discussed planning or planning variances: e.g. overestimation / underestimation of manufacturing forecasts, the delay or cancellation of means of transport, changing performance targets
- Institutions are discussed during the Covid-19 crisis since the company needs to know government decisions, laws and decrees to reorganize its activities
- Phenomena i.e. visibility concerning weather forecasts and events such as storms
- Actors' responsibility

During the interviews, respondents sometimes explained the causes of the lack of visibility. Most often, there is a lack of communication between actors, mainly at the intra-organizational level (e.g. "No one communicates with each other and it's always very complicated to get information" [25]).

Differences in objectives between company departments help to explain this lack. Exceptional situations mean that the actors do not have the desired visibility e.g. in the event of a health crisis or weather hazard, as such events are difficult to predict. When there is no traceability, it is hard to gain visibility: “We asked them to provide traceability of the customs documents. They haven't done it, so we don't have that visibility” [15]. Another hindering factor is short-term decisions taken by the company that lead to trade-offs between performance objectives. Other obstacles to visibility that were touched on include: non- assumption of responsibility, unreliable information in systems and misaligned systems at the intra-organizational level.

Table 3: Answers to the research question from the field experiences

RQs	Items from field experiences	Number of stories citing the item
RQ1 The need for visibility	Meeting delivery times and/or satisfying end-customers	26
	Anticipating needs and risks	21
	Giving visibility: carriers, centers, subsidiaries, dealers, end-customers	9

RQs	Items from field experiences	Number of stories citing the item
	Costs monitoring: avoid additional storage, transport costs, etc.	8
	Saving work time in handling problems	7
	Achieving performance targets (e.g. vehicle invoicing)	6
	Keeping track of resources in exceptional situations	4
	Maintaining work motivation	2
RQ2 See what?	Resources	14
	Lead times	14
	Activities	9
	Planning	7
	Actors' responsibility	1
	Institutions	1

RQs	Items from field experiences		Number of stories citing the item
	Phenomena (e.g. weather forecasts)		1
RQ3 Hindering factors	Lack of communication	Intra-organizational level	12
		Inter-organizational level	3
	Exceptional situations (e.g. health crisis)		10
	Lack of traceability		8
	Short-term decisions leading to trade-offs		6
	Non-assumption of responsibility		2
	Unreliable information in systems		2
	Misaligned systems at the intra-organizational level		1

5 Discussion

In the discussion section, we combine the three perspectives (SCM literature, multidisciplinary overview and field study) and highlight how they complement each other in answering each research question. This discussion ends with an integrative SCV framework.

5.1 Benefits of visibility

Throughout this paper, we have been looking at why we want to have visibility (RQ1). We found commonalities between the three perspectives, but also some differences. Three subjects came up in each approach: we seek visibility in order to be efficient and respond quickly in the face of uncertainty and to predict/monitor situations, processes, activities or objects. We seek performance by developing competitive advantages (Table 1), gaining organizational flexibility (Table 2), improving customer satisfaction, costs monitoring, saving work time, maintaining work motivation and achieving performance targets (Table 3). Being responsive also refers to agility and resilience in the event of out of control situations (Table 1), but also controlling and anticipating phenomena thanks to a projection of distant objects that are not visible (Table 2). It could be to keep track of objects in exceptional situations (Table 3). Visibility is also useful for predicting and monitoring: planning process (Table 1), phenomena (Tables 2 and 3) and needs/ risks (Table 3). Our findings from the multidisciplinary literature (Table 2) introduce a new element: social aspects. We seek visibility in order to act on the relational dimension. This involves improving collaboration and coordination between actors and could confer a form of power as a social effect (Table 2). Sharing information improves visibility for all SC actors (Table 3). Therefore, relational aspects can have an impact on information sharing and transparency, collaboration, alignment between IS, and social recognition. The emergence of a relational dimension is all the more interesting as it also appears in the results of the empirical study in an SC context, but not in the SCM literature.

5.2 What we want to see

Concerning RQ2, two topics appear in the three approaches: the need for visibility of different kinds of resources and activities. We want to see flows, resources (Tables 1 and 3), individuals, data, and information (Table 2). The need for visibility of activities such as processes (Table 1) or tasks performed by actors (Table 2) is also common to all the approaches. The field experiences reveal concerns about events and times such as lead times or planning (Table 3). The field study thus adds the notion of time, which is not addressed is the SCM literature. Deadline visibility would make it possible to transmit information to the different SC actors, and, if it is reliable, to take action on meeting delivery times and on customer satisfaction. Our findings from the multidisciplinary literature also emphasize a social aspect since it includes the need for visibility of institutions and social worlds (Table 2). It highlights the importance of focusing not only on resources or activities, but on entities and groups as well. To this we may add the need to know what their responsibilities are (Table 3). There is one final contribution: we seek visibility of phenomena (Tables 2 and 3). This was not found in the SCM literature, but it appears in the field experiences, in particular concerning external/environmental phenomena that impact SCs. The challenge here is to be able to anticipate needs and risks (Table 3).

5.3 Conditions that facilitate / hinder visibility

We deal with the hindering/ facilitating factors together since they are in fact related and both feed the discussion concerning the third research question (RQ3). Two subjects emerge in each approach. The first is information sharing and transparency (Table 1). The facilitating condition is collaboration (Table 2), since information cannot be shared without it. Nevertheless, there are situations where the lack of collaboration and communication hinders visibility (Tables 2 and 3). The second subject is information systems. Traceability systems help to collect and share information (Table 1). The multidisciplinary literature complements the SCM literature since it discusses information systems, visual and communication tools. It also emphasizes the alignment between systems and tools (Table 2). If the architecture of the different systems/tools is not well constructed, it will become a visibility impediment (Tables 2 and 3). The reliability of the information shared via the tools is also essential to avoid producing false visibility, i.e. false information (Table 3). Furthermore, the complexity of SCs and the outsourcing of activities (Table 1) probably contribute to the difficulty of achieving systems alignment. The field experiences reveal that company decisions and the non-assumption of responsibility may also obstruct visibility (Table 3). These elements are new and not mentioned in the SCM literature. Finally, there is a social contribution from the multidisciplinary overview, as shown in Table 2: the social recognition of individuals as a facilitating condition for visibility. This is also related to the social position of individuals, which could be a hindrance to accessing visibility. Another social contribution is institutions/media access, which may constitute an obstacle to visibility for individuals (Table 2).

Combining the three perspectives, we construct the following SCV framework (Figure 2). After comparing them, no inconsistencies were identified between the three. The model is made up of three parts, formed according to the RQs. The first part is composed of facilitating and hindering factors (in two boxes to preserve what has been found in the literature and in the empirical study). A second part shows what we want visibility of and a third one for the benefits gained from improving SCV. All factors constitute items that affect visibility. By improving visibility, there are potential benefits for SC actors. These benefits will, in turn, act on the facilitating and hindering factors. Although it could influence them, these elements interact with each other. Every positive factor has an opposite that constitutes a hindering factor. Finally, the integrated framework brings together all the responses to the RQs and constitutes an academic synthesis of the SCV concept for future research. The field experiences gathered were useful because they illustrated the multidisciplinary literature more than the SCM literature. This confirms the fragmented nature of the SCM literature and the importance of not focusing solely on the SCV concept in this field of research. Finally, the framework could be a useful tool in a business context in conducting an audit or a diagnosis to identify items that affect SCV positively or negatively, especially since the empirical study has brought up a need to see objects, flows, activities, resources and so on.

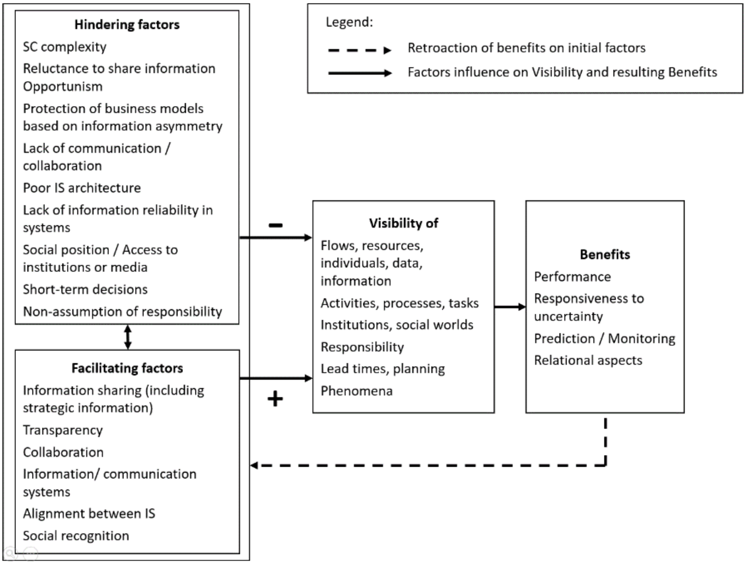


Figure 2: Integrative framework of SCV.

6 Conclusion

In conducting a literature review of SCV, we found that there is not as yet any consensus about how to define SCV. This concept is a subject of interest, but remains extremely complex. Situated at the interface of different research areas (Roussat et al., 2018), it is even more difficult to understand because it is often associated with the notions of traceability, information sharing and transparency (Evrard-Samuel and Ruel, 2016). It is characterized as under-defined and ambiguous (Roussat et al., 2018) and researchers tell us little about how to improve it (Busse et al., 2017).

In this paper, we seek to build a framework of the SCV concept. To extend the study beyond the boundaries of the SCM approach, we studied the notion of visibility in general. A multidisciplinary overview of the concept of visibility was performed and complemented by an exploratory study in an industrial company in order to gather field experiences concerning instances of a lack of visibility. At each step of the research, we sought to answer the following questions: why is it important to have visibility? (RQ1); what do we want to have visibility of? (RQ2); what factors, conditions and/or tools could facilitate or hinder visibility? (RQ3).

Our results brought out new elements that complement the SCM approach. By comparing and combining the SCM literature, the multidisciplinary literature and field experiences, we built a framework of SCV.

Because of the Covid-19 crisis, we could only interview 11 key informants, which is a limitation of our empirical study. We need to continue this research by expanding the base of the empirical study. We would like to broaden and diversify our sample, at the intra and inter-organizational levels. The Covid-19 health crisis will probably raise new needs for SCV and boost company projects to develop SCV. This could be an opportunity for action research with Renault Group.

Acknowledgements

I thank Renault Group for supporting this research and agreeing to make data and persons available for this study, which is part of a larger research project supported financially by ANRT (CIFRE n°2018/1125). I also would like to thank Jean-François Lomellini (Vehicle logistics leader, Supply Chain Department, Alliance Renault–Nissan, Guyancourt, France) for his support and facilitation during this study as well as the managers that agreed to participate in this study. Special thanks to Prof. Nathalie Fabbe-Costes for her support, coaching and advice during the research; and to Andrew Beresford for the copy-editing of this paper.

References

Andonova, Y. and Vacher, B., 2013. Nouvelles formes de visibilité des individus en entreprise : technologie et temporalité. Communication et organisation, (44), pp.5–14.

Azevedo, S.G., Govindan, K., Carvalho, H. and Cruz-Machado, V., 2013. Ecosilient Index to assess the greenness and resilience of the upstream automotive supply chain. Journal of Cleaner Production, 56, pp.131–146.

Babari, R., 2012. Estimation de la visibilité météorologique par caméras routières. Doctoral Thesis. Université Paris-Est. [online] HAL. Available at: <https://tel.archives-ouvertes.fr/tel-00851176/document> [Accessed 15 May 2020].

Barratt, M. and Oke, A., 2007. Antecedents of supply chain visibility in retail supply chains: a resource-based theory perspective. Journal of Operations Management, 25(6), pp.1217–1233.

Bertaux, D., 2016. Le récit de vie. Armand Colin, 4th edition, 128 pages.

Bohnk, S., 2010. Moderniser son système d’information. Eyrolles, Parts II and III, 290 pages.

Boulay, J. and Isaac, H., 2007. Contrôler les réseaux d'entreprises avec les technologies de l'information. Revue française de gestion, 170(1), pp.103–115.

Brighenti, A., 2007. Visibility: A Category for the Social Sciences. Current Sociology, 55(3), pp.323–342.

Brighenti, A., 2010. Visibility in Social Theory and Social Research. Palgrave Macmillan UK, 214 pages.

Bullier, J., 2020. Vision, Neurophysiologie visuelle. [online] Encyclopædia Universalis. Available at: <https://www.universalis.fr/encyclopedie/vision-neurophysiologie-visuelle/> [Accessed 20 February 2020].

Flichy, P., 2013. Rendre visible l'information. Une analyse sociotechnique du traitement des données. Réseaux, 178–179(2), pp.55–89.

Busse, C., Schleper, M.C., Weilenmann, J. and Wagner, S.M., 2017. Extending the supply chain visibility boundary. Utilizing stakeholders for identifying supply chain sustainability risks. International Journal of Physical Distribution & Logistics Management, 47(1), pp.18–40.

Caridi, M., Crippa, L., Perego, A., Sianesi, A., and Tumino, A., 2010. Measuring visibility to improve supply chain performance: a quantitative approach. Benchmarking: An International Journal, 17(4), pp.593–615.

Caridi, M., Moretto, A., Perego, A., and Tumino, A., 2014. The benefits of supply chain visibility: A value assessment model. International Journal of Production Economics, 151, pp.1–19.

Carter, C. R., Rogers, D. S. and Choi, T.Y., 2015. Toward the Theory of the Supply Chain. Journal of Supply Chain Management, 51(2), pp.89–97.

Christopher, M., 2005. Logistics and Supply Chain Management: Creating Value-Adding Networks. Pearson Education, Harlow, 3rd edition, 305 pages.

Deloitte, 2018. Overcoming Barriers to NextGen Supply Chain Innovation, 2018 MHI Annual Industry Report. [online] MHI. Available at: <https://www.mhi.org/publications/report> [Accessed 8 may 2020].

Dubey, R., Altay, N., Gunasekaran, A., Blome, C., Papadopoulos, T. and Childe, S. J., 2018. Supply chain agility, adaptability and alignment: empirical evidence from the Indian auto components industry. International Journal of Operations & Production Management, 38(1), pp.129–148.

Enslow, B., 2006. Global supply chain benchmark report: industry priorities for visibility, B2B collaboration, trade compliance, and risk management. [online] Calaméo. Available at: <https://fr.calameo.com/read/0000469925f3f7c5e934c> [Accessed 19 May 2020].

Evgeniou, T., 2002. Information Integration and Information Strategies for Adaptive Enterprises. European management journal, 20(5), pp.486–494.

Evrard-Samuel K. and Ruel, S., 2016. Visibilité des Supply Chains : Proposition d'un agenda de recherche. Communication at the International Meetings of Research in Logistics (RIRL), 7 to 9 September 2016 at the Swiss Federal Institute of Technology in Lausanne (EPFL). [online] ResearchGate. Available at: <https://www.researchgate.net/publication/308803147_Visibilite_des_Supply_Chains_Proposition_d'un_agenda_de_recherche> [Accessed 10 February 2020].

Fabbe-Costes, N. and Lemaire, C., 2010. L'évolution d'un système de traçabilité totale dans une chaîne logistique : analyse des facteurs d'influence à partir d'une étude longitudinale dans le secteur du fromage pré-emballé. Revue Economie et Sociétés, 32(9-10), pp.1535–1555.

Foucault, M., 1977. Discipline and Punish: The Birth of the Prison. New York, Pantheon Books, 1st edition, 333 pages.

Francis, V., 2008. Supply chain visibility: lost in translation? Supply Chain Management, 13(3), pp.180–184.

Galifret, Y., 1990. Les mécanismes de la vision. Belin, Bibliothèque pour la Science, 186 pages.

Goel, A., 2010. The value of in-transit visibility for supply chains with multiple modes of transport. International Journal of logistics: research and Applications, 13(6), pp.475–492.

Handfield, R.B. and Nichols, E.L., 2002. Supply chain redesign: Transforming supply chains into integrated value systems. Financial Times, Digital Print Ed, 400 pages.

Honneth, A., 2001. Invisibility: On the epistemology of recognition. Aristotelian Society Supplementary Volume, (75), pp.111–126.

Hubel, D., 1988. Eye, Brain, and Vision. New York, Scientific American Library, 240 pages.

Maurel, A., 2002. Optique géométrique. Belin, belin sup sciences, 217 pages.

Merleau-Ponty, M., 1968. The Visible and the Invisible. Northwestern University Press, 1st edition, 282 pages.

Météo-France, 2020. Comprendre. Tout savoir sur la météo, le climat et Météo-France. [online] Météo-France. Available at: http://www.meteofrance.fr/prevoir-le-temps/la-prevision-du-temps/les-etapes-de-prevision/ [Accessed 20 February 2020].

Parisot, J.P., Segonds, P. and Le Boiteux, S., 2003. Cours de physique - Optique. Dunod, Sciences Sup, 368 pages.

Rosanvallon, P., 2014. Le Parlement des invisibles. Paris, Seuil, Raconter la vie, 80 pages.

Roussat C., Lazzeri J. and Fabbe-Costes N., 2018. Vers une conceptualisation de la “supply chain visibility”. Communication at the International Research Meetings on Logistics and Supply Chain Management (RIRL-SCM), AIRL-SCM 22 and 23 May 2018 at the Cité internationale universitaire of Paris. [online] HAL. Available at: <https://hal.archives-ouvertes.fr/hal-01800484> [Accessed 8 May 2020].

Said, S.M., 2006. Le système d’information : système nerveux des supply chains. De l’intégration à la modularisation. Réalités industrielles, pp.47–55.

Sanséau, P.Y, 2005. Les récits de vie comme stratégie d’accès au réel en sciences de gestion : pertinence, positionnement et perspectives d’analyse. Recherches qualitatives, 25(2), pp.33–57

Simatupang, T.M. and Sridharan, R., 2002. The collaborative supply chain. International Journal of Logistics Management, 13(1), pp.15–30.

Tardy, J-N., 2007. Visibilité, invisibilité. Voir, faire voir, dissimuler. Hypothèses, 10(1), pp.15–24.

Thiétart, R.A., 2014. Méthodes de recherche en management. Dunod, 4th edition, 656 pages.

Thompson, J. B., 2005. The New Visibility. Theory, Culture & Society, 22(6), pp.31–51.

Yao, Y. and Fabbe-Costes, N. (2018), Can you measure resilience if you are unable to define it? The analysis of Supply Network Resilience (SNRES). Supply Chain Forum: International Journal, 19(4), pp.255–265.

Realization and Validation of a Collaborative Automated Picking System

Mathias Rieder [1] and Richard Verbeet [1]

1 – Ulm University of Applied Sciences

Purpose: A picking system is presented ensuring order fulfilment and enabling transformation from manual to automated picking using a continuous learning process. It is based on Machine Learning for object detection and realized by a human-robot collaboration to meet requirements for flexibility and adaptability. A demonstrator is implemented to show cooperation and to evaluate the learning process.

Methodology: The collaborative process, system architecture, and an approach for evaluation and workload balancing for order fulfilment and learning of robots during picking have already been introduced. However, a practical application is still missing. A demonstrator is implemented using an agent-based architecture (JADEX) and a physical robot (UR5e) with a camera for object detection and first empirical data are evaluated.

Findings: Single components of the demonstrator are already developed, but a pending task is to implement their interaction to analyze overall system performance. This work focuses on human-robot-interaction (Emergency Call), automated generation of images extended by feedback information, and training of algorithms for object detection. Requirements of human-machine interface, technical evaluation of image recording, and effort of algorithm training are discussed.

Originality: Many approaches for automated picking assume a static range of objects. However, this approach considers a changing range as well as a concept for transformation of manual to automated picking enabled by human-robot cooperation and automated image recording while enabling reliable order fulfilment.

First received: 12. Mar 2020 Revised: 21. Jun 2020 Accepted: 12. Aug 2020

1 Introduction

Picking as a major logistic task is the customer order specific composition of a subset from a total assortment of goods (VDI, 1994). This composition often must be executed by exact number and therefore is often carried out by humans due to the impractical level of standardization of processes and the resulting needed flexibility (Müller, et al., 2019). This flexibility is based on the ability of humans to observe and understand their environment and to recognize and grip objects.
Order picking must often face steadily changing environments imposing high requirements on automated systems' flexibility. Recent developments in the field of Artificial Intelligence have reached a level of maturity to enable flexibility and adaptivity allowing the automation of processes only humans are able to execute so far (Gerke, 2015). But even considering further technical and conceptual progress in automated picking, robots will depend on humans in order picking systems. Therefore, an efficient setup of an operational human-robot picking system needs a reliable human-machine interaction (Azadeh, Koster and Roy, 2017). This kind of interaction must be integrated into planning and control of order picking systems fundamentally. A nearby approach is a cooperative picking environment to help robots to fulfil order picking and to support their ability of adaption. By developing sensor technologies to ensure the safety of humans the conditions for cooperative industrial applications have been created (Müller, et al., 2019). The cooperation of humans and robots is also of major importance in the context of the emergence of Cyber-Physical Systems in Industry 4.0 (Kamarul Bahrin, et al., 2016).

The picking environment must be implemented by an architecture enabling the realization of an adaptive robot system as well as the fulfilment of picking orders. Agent technology has proven to be a reliable approach by transforming heterogenous technical systems into Cyber-Physical Systems to realize integrated connectivity. These systems can also be equipped with local mechanisms for problem solving (Verbeet and Baumgärtel, 2020). (Verbeet, Rieder and Kies, 2019) introduce such an approach.
Contributions of this paper are the following: (1) definition and creation of a data set for training and testing of Convolutional Neural Networks (CNN) for object detection during automated picking, (2) training, evaluation and selection of CNN, (3) realization of a demonstrator consisting of the training environment described by Verbeet et al. (2019) and a virtual picking environment, which is implemented as multiagent-system, as well as (4) an analysis of a picking system by the demonstrator using selected CNN to evaluate the by Verbeet et al. (2019) proposed concept of a feedback loop (Emergency Call) in a cooperative human-robot picking system.
The remainder of this work is organized as follows. The second chapter describes related work about approaches and technical applications of automated picking. In chapter three the concept for a cooperative picking environment is described, which is used to design the demonstrator presented in chapter four to evaluate the resilience of this concept according to order fulfilment and improvement of object detection. Chapter five presents first empirical results describing the data set, training of CNN for object detection as well as first experiments. This paper concludes with a critical discussion and a prospect to future research.

2 Related Work

Many approaches exist to encounter challenges in order picking by automation of processes. In established applications and concepts robots often either transport or grasp goods, but rarely carry out the complete picking task (EHI Retail Institute, 2019).

(Wang, Chen and Wang, 2019) propose a heuristic for local routing of distributed units in a collaborative human-robot picking system. Many approaches focus on partwise automation by automating transportation within intralogistics (Zou, Zhang and Qi, 2019) (Valle and Beasley, 2019) because the tasks of recognizing and gripping objects during picking are too complex to be fulfilled by machines (Jansen, et al., 2018). Kugler and Gehlich (2013) propose a goods-to-person picking system by an agent-based conveyor system supplying human pickers. Salah et al. (2018) describe a human-robot system for apple harvest, in which robots transport apples as autonomous bins.

In contrary to transportation where some degree of standardization can be established by loading devices, gripping an object requires high flexibility (Müller, et al., 2019), because each object or at least each object class must be gripped in its own way (Liu, Huang and Huang, 2019). A common approach is the creation of a known and controlled picking environment. Martinez et al. (2015) propose a system for bin picking and Wahrman et al. (2019) for shelf picking. An industrial application for bin picking is provided by Photoneo (2020).

Only a few solutions exist to fulfill the whole picking task considering movement to shelves, picking objects and delivery to a transfer place. An application in a laboratory environment is provided by Bormann et al. (2019).

Magazino realizes an industrial picking robot capable of travelling to shelves, picking specific objects (cubic objects) and delivering them to a transfer station (Mester and Wahl, 2019). Such systems only provide a limited ability to adapt to changes of the picking environments or the range and look of stored objects concerning reliability of automated object detection (Wahrmann, et al., 2019). Bormann et al. (2019) and Thiel et al. (2018) confirm the need for an adequate amount of training samples in logistics environments to enable a reliable object detection.

One approach to face these dynamics in picking is a human-machine cooperation where robots support human activities and humans may compensate a robot's lack of adaptivity (Lee, Chang and Choe, 2018). Werner et al. (2017) describe the collaboration of humans and robots in a static assembly cell. Rieder and Verbeet (2019) present a process model to realize a cooperative picking system defining an Application-Phase and a Learning-Phase to ensure order fulfillment and continuous improvement of robots' ability for object detection. This model is extended by Verbeet et al. (2019) by an Adjustment-Phase and a Cooperation-Phase as well as by a conceptual picking system. Rieder and Verbeet (2020) show how this picking system can be evaluated using a capacity evaluation. They define an equilibrium between the requirements of order processing, the picking performance of humans and robots and the effort for improving object detection. By linear programming it can be used for strategic evaluation of the automated picking performance of robots, for tactical resource planning, and for operational workload balancing.

3 Cooperative Picking System

The model for a cooperative picking system proposed by Verbeet et al. (2019) contains two basics phases for learning and application. Within a Learning-Phase an algorithm for object detection is created and improved using image data recorded in a controlled environment as well as data from operational picking processes. This phase is decoupled from operational order picking within an Application-Phase where humans and robots work in parallel within a picking environment. A picking robot is supposed to successfully grip and withdraw from a storage location after a successful object detection, e.g. by a combination of images and depth information as discussed by Shao and Hu (2019). In case of an unsuccessful object detection a robot tries to find a solution on its own by predefined options during an Adjustment-Phase, e.g. by moving its camera to a different position. If this is not successful, a Cooperation-Phase is triggered calling a human picker to support the robot (Emergency Call).

As an extension to the original concept this support is organized in three levels. At first the human picker tries to modify the environment to enable the robot to detect the object, e.g. if it is covered or has fallen (Support Level 1). When the robot is still unable to detect the object, the human picker marks the object with a bounding box in an image recorded from current storage location using an interface provided by the robot. This bounding box is used for calculation of a gripping point and the recorded image is saved for retraining (Support Level 2). In case of a not successful calculation the human picker picks the object to fulfill the robot's picking order (Support Level 3). However, due to the assumption picking robots can successfully grip every object they can detect, this last support level is not considered in this paper. The complete process of an Emergency Call is shown in Figure 1.

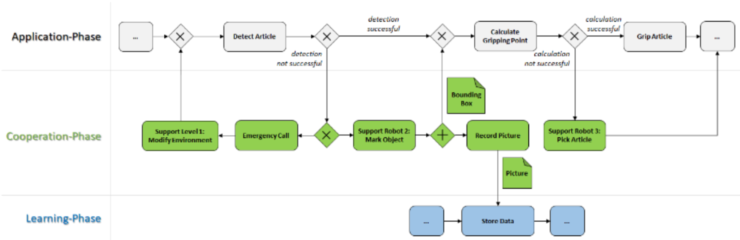


Figure 1: Support Level 1-3 during the process of an Emergency Call

Verbeet et al. (2019) propose the agent-based system architecture shown in Figure 2 to realize the process model. A Warehouse Management System (WMS) is responsible for administration of inventory data and initializing the allocation of picking orders. Human pickers and picking robots cooperatively process assigned orders. Furthermore, a Picture Recording Machine (PRM) is used for image recording in a controlled environment (Rieder and Verbeet, 2019). These images are stored on a data server and are used for training of algorithms for object detection by a computation cluster. Interaction patterns define the sequence of messages between components and embed it into picking processes. Assignment of orders to human pickers and picking robots is of major importance because it enables workload balancing. It is realized by a one-stage auction process arranged according to Contract Net Protocol (FIPA, 2019). The same mechanism is used for the assignment of an Emergency Call.

A picking robot can detect each object with a probability dependent on a trained algorithm for object detection. Rieder and Verbeet (2020) propose an evaluation of the picking system considering system parameters like working time (WT), picking capacity of humans (C_H) and robots (C_R) and a demand forecast (D_F) to define an equilibrium for system performance:

$$C_H \cdot WT - \frac{L_{EC,H,SR}}{WT} + C_R \cdot WT - \frac{L_{EC,R,SR}}{WT} \geq D_F \quad (1)$$

$L_{EC,H,SR}$ and $L_{EC,R,SR}$ describe a time effort due to Emergency Calls for humans and robots considering a probability for object detection (P_{OD}) weighted with a demand for each object.

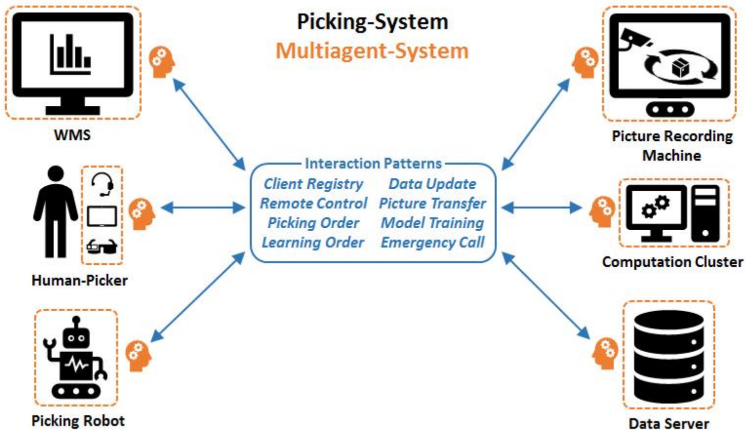


Figure 2: Agent-based architecture of a picking system realizing the process model according to (Verbeet, Rieder and Kies, 2019)

4 Demonstrator

An approach for a cooperative picking system has been developed and a concept how this system can be realized. An architecture has been proposed, its interactions are designed to realize the concept, and its performance in terms of picking and learning can be measured. A next step is the analysis of empirical data to show the resilience of the concept and to improve the mechanisms and processes.

Therefore, a demonstrator is created to illustrate the general functionality of the approach. It is implemented in two stages, which initially are supposed to work independently of one another: training environment and picking system. The training environment enables the recording of images and the training of a neural network for object detection. The picking system is an agent-based demonstrator in which the trained algorithms are used to evaluate the performance of object recognition and the effect of Emergency Calls.

4.1 Training Environment

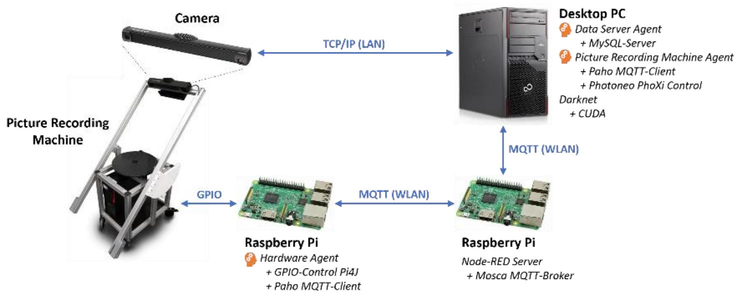


Figure 3: System architecture of the training environment

The system architecture to realize the interaction patterns "Picture Transfer", "Model Training" und "Data Update" is shown in Figure 3. For programming agents, the framework JADEX (Braubach, Pokahr and Lamersdorf, 2011) is used realizing agents following BDI concept (Bratman, 1987) basing on the FIPA compliant (FIPA, 2019) framework JADE (Braubach, Lamersdorf and Pokahr, 2003).

Image recording is done by PRM (Rieder and Verbeet, 2019). Its motors are controlled by a Hardware Agent implemented on a Raspberry Pi using GPIO to trigger motor drivers. Connection to an agent on a desktop PC is established by a Mosca MQTT broker (Noren and Müller, 2020). This allows control of PRM by the services "moveRocker" and "moveTurntable" using FIPA conform XML messages. Paho is used as MQTT client (Eclipse, 2020). The Photoneo 3D Scanner is connected to the desktop PC via LAN. Image recording of objects is coordinated by a Picture Recording Machine Agent using Photoneo software PhoXi Control and controlling object positioning by services of PRM. A graphical user interface is provided to interact with this agent to control image recording. Recorded images are saved locally and referred to in a MySQL database managed by a Data Server Agent offering necessary services to select or change data.

The images must be annotated before used for training. The software Yolo Mark (Bochkovskiy, 2020b) is used for annotation displaying images and object classes. A user marks the objects with a bounding box after choosing the appropriate object class. Selected class as well as coordinates of the bounding box are saved to a text file.

A Convolutional Neuronal Network (CNN) is used for object detection within the demonstrator. It is being trained with recorded and annotated images by the framework Darknet (Redmon, 2016). This training bases on a neural network that was pretrained using MS COCO data set (Lin, et al., 2014) to reduce training duration (He, Girshick and Dollár, 2018). This network is trained using Darknet and CUDA support (NVIDIA Corporation, 2020) by a special adaption of YOLO algorithm version 3 (Redmon and Farhadi, 2018) for Windows (Bochkovskiy, 2020a). Windows 10 (64-Bit) is used as operating system running on a commercial desktop PC equipped with 32GB RAM and NVIDIA GeForce GTX 745. The trained CNN is saved locally and is referenced in the database.

Complete automation is not realized yet, i.e. recording, annotation and training must be controlled manually. Automated placement of an object on PRM is not possible and reliable automation of image annotation within such a well controllable recording environment must be evaluated. Annotation must be done highly accurate to ensure training success in follow up processes.

4.2 Picking System

The structure of a warehouse's picking zone and the agent types creating the multiagent-system to realize the interaction patterns "Picking Order" und "Emergency Call" are shown in Figure 4. Again, agents are implemented by JADEX. Their communication is realized by a framework specific service-oriented architecture (SoA) based on service interfaces. Physical processes are simulated by an idle function within the agents.

Human and Robot Picker Agents do not have a physical representation yet, i.e. it is a completely virtual realization of the picking system. However, the agents can be understood as digital twins of the components with their capabilities and can be extended by hardware interaction in a subsequent step. Using a SoA makes the interaction pattern "Client Registry" not necessary, appropriate mechanisms for registry, discovery and invocation are provided by the JADEX framework. Furthermore, there is no need for "Remote Control" as there is no hardware. To simplify data evaluation an additional Monitor Agent is implemented. The interaction pattern "Learning Order" is not realized at this stage of work.

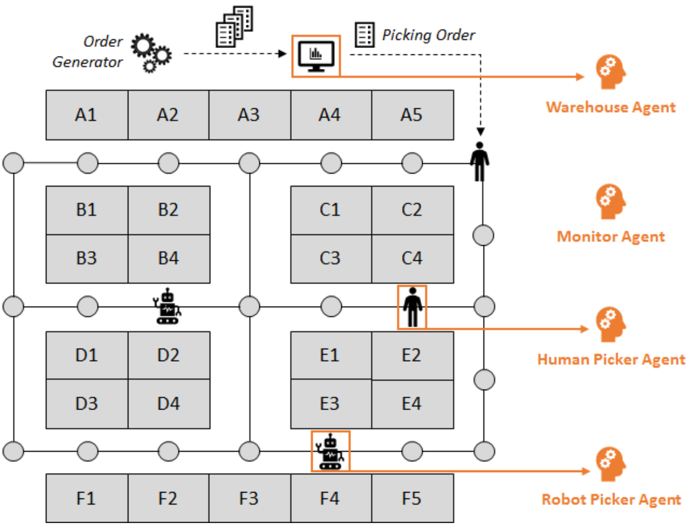


Figure 4: Warehouse structure and agent types of the virtual demonstrator

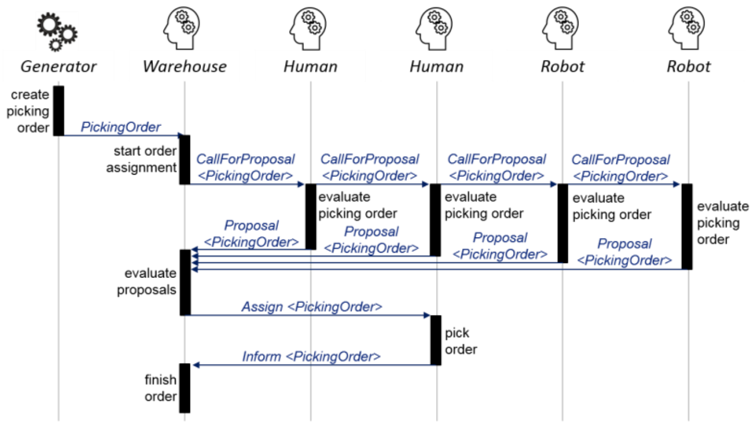


Figure 5: Auction for assignment of a picking order

Picking orders are generated by an order generator within a Warehouse Agent and are distributed to human pickers and picking robots using the auctioning process shown in Figure 5. For simplicity, picking orders consist of one order line containing a single object with quantity one. During this one stage auction a call for proposal is sent to all human pickers and picking robots requesting their current workload as well as their estimation to execute the transmitted picking order. The Warehouse Agent selects the picker with the lowest response value and assigns the order (Verbeet, Rieder and Kies, 2019).

Prerecorded images are used to simulate operational object detection within the demonstrator. These images are not included in the data set the CNN is trained with and are not used for follow up retraining. For each object detection an image is randomly chosen and is handed over to the CNN. Each agent contains a list of assigned picking orders which are processed one after another in sequence of assignment. To fulfill a picking order, an agent moves through the picking zone on shortest path to the waypoint assigned to the storage location of a corresponding object. After reaching this storage location Human Picker Agents start gripping instantly while a Robot Picker Agent starts an object detection using Darknet. A successful object detection is followed by gripping the object and completing the order. If the prediction accuracy is below the certain threshold of 95% a Robot Picker Agent tries to achieve sufficient accuracy by recording and testing a new image of the current shelf with a maximum of two attempts (Adjustment-Phase).

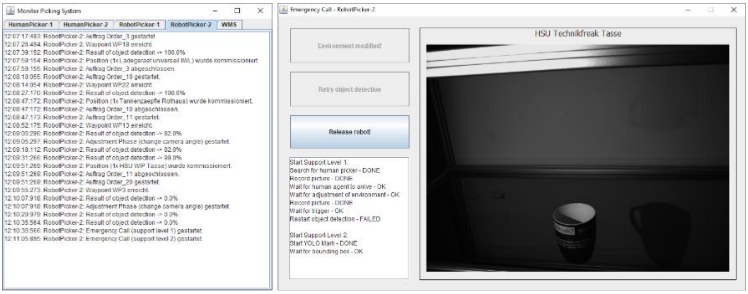


Figure 6: Monitor Agent showing processing of a picking order by a Robot Picker Agent (left) and the GUI of an Emergency Call (right)

In case of still failing, an Emergency Call is triggered calling a nearby Human Picker Agent. This agent interrupts its current activity and moves to the Robot Picker Agent's position (waypoint) which enables interaction by a GUI. Therefore, an Emergency Call is handled by the user modelling the support levels "Modify Environment" and "Mark Object" proposed in chapter three. The modification of the environment is simulated by loading another image followed by an object detection. If the predicted accuracy is below the threshold Yolo Mark is started enabling the user to mark the searched object. After finishing marking the robot can be released to grip the object and complete the picking order. Figure 6 shows a Robot Picker Agent's status updates during order processing (left) and the GUI for an Emergency Call (right).

5 Empirical Data

This chapter introduces the data set of images used for training of the neural network, the network itself and empirical results of object detection. Furthermore, neural networks in different training stages are evaluated by the demonstrator to estimate their impact on the overall picking system.

5.1 Data Set

A data set containing the following 12 objects of different materials is generated to be used by the demonstrator: a bucket, 4 different ceramic cups, a glass, 2 different plastic cups, a key, a charger, a plastic bottle, and a glass bottle. These objects are supposed to represent an object set in a realistic logistics environment with partially similar shape. Images of this data set are grouped into the three categories "PRM-Data" (images created by PRM), "EC-Data" (images based on Emergency Calls), and "D-Data" (images to simulate object detection). These images are recorded using a Photoneo PhoXi 3D Scanner M and are saved as black and white PNG files with 2064 x 1544 pixels.

PRM-Data − Using PRM images are recorded for each object using 18°-steps for object rotation (turntable) and 10°-steps for camera angle (rocker) resulting in 200 images for each object. The images are taken as texture images without additional lighting. They are saved to the data base extended

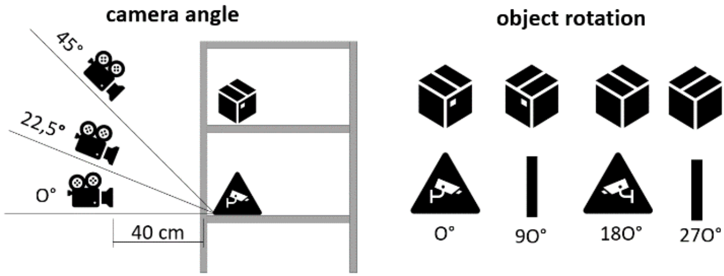


Figure 7: Setup for camera and objects for image recording of EC- and D-

by object information (ID, name, group, …) and the recording setup (camera angle, object rotation, …). Each image is annotated by YOLO Mark. PRM needs about 21 minutes to record a set of 200 images of one object and manual annotation of these images takes about 15 minutes.

EC-Data − These images are recorded from a demonstrating rack in a logistics laboratory using the same camera model mounted at PRM to simulate an operational shelf of a warehouse. Each object is recorded in 90°-steps for object rotation and with camera angles at 0°, 22.5° and 45° resulting in 12 images of each object. The specifications for camera angle and object rotation are approximations and are not adjusted exactly for image recording to simulate a realistic logistics environment in which objects are normally not stored to a specific view. The recording setup is shown in Figure 7.

Table 1: Data set categories and recording specifications

Data set	*Camera angel*	*Object rotation*	*No. of images*
PRM-Data	*Range: 0°-90°* *Step: 10°*	*Range: 0°-342°* *Step: 18°*	*2400*
EC-Data	*Range: 0°-45°* *Step: 22.5°*	*Range: 0°-270°* *Step: 90°*	*144*
D-Data	*22.5°*	*Range: 0°-330°* *Step: 30°*	*144*

D-Data – These images are recorded with the same setup as EC-Data but at a fix camera angle of 22.5°. This seems to be the most realistic angle of view considering shelfs of racks. Objects are rotated in 30°-steps leading to 12 images of each object. Similarity to EC-Data is desired. Table 1 gives an overview of applied camera angles and object rotations as well as the number of resulting images of the data sets. Figure 8 shows exemplary images from the different data sets for one object class.

Figure 8: Object "ceramic cup 2" in PRM-Data with different camera angles and 90°-step rotation (top), EC- and D-Data recorded with camera angle of 22,5° and 90°-step rotation (middle, bottom)

5.2 Training and Testing of Neural Network

This section describes training, testing, and evaluation of the neural network. During testing an image is given to a CNN. It analyzes the image by means of the 12 trained object classes resulting in several detections each with a probability of object detection greater than 25%. Figure 9 shows the different steps of training and testing as well as used data sets and resulting neural networks.

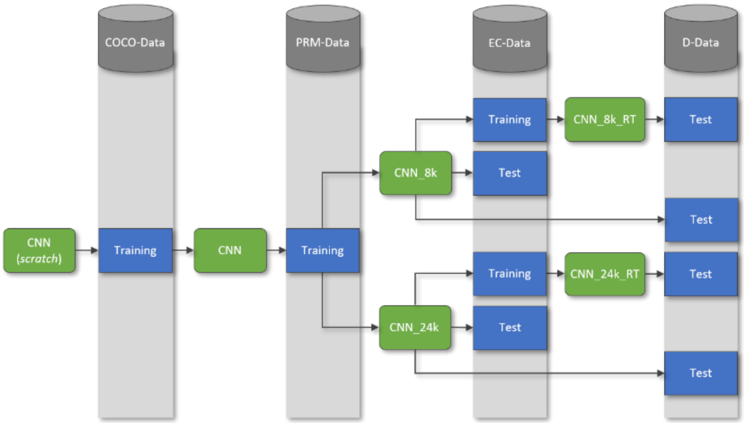


Figure 9: Training and testing of neural networks

Predictions of a neural network for an image are classified into True Positives (TP) (correct prediction: correct object class and location), False Positives (FP) (false prediction: false object or incorrect located) and False Negatives (no prediction but image contains searched object). A TP is a correct result leading to a successful pick whereas FP can provoke errors during operations, e.g. by damaging an object or by picking a wrong object. FN give a hint that a specific object is not trained in a satisfying manner and for further data must be collected by Emergency Calls.

5.2.1 Training with PRM Data

The initial training of the CNN with PRM-Data (2400 images) lasts for about 14.5 days. For this training, the data set is randomly divided into 75% training and 25% validation images. It is evaluated and steered by an average loss being calculated after an iteration each using a random subset of 64 images. Bochkovskiy (2020a) recommends the number of iterations to be calculated by 2000 times the number of object classes within the data set, i.e. training with PRM-Data terminates after 24000th iteration. Training with PRM data starts with an average loss greater than 1400, decreasing exponentially, and reaching an average loss of 1 at about 500 and 0.5 at about 1000 iterations. It gets steady at about 5000 iterations with an average loss of 0.05 and stops with 0.014 after 24000 iterations.

Table 2: Detections of CNN trained with PRM-Data (1k to 24k) tested against EC-Data

Camera angle	*Number of tests*	*Detections = 0 (negative)*		*Detections > 0 (positive)*		*TP*		*FP*	
0°	*1152*	*511*	*44.4%*	*641*	*55.6%*	320	36.0%	570	64.0%
22.5°	*1152*	*240*	*20.8%*	*912*	*79.2%*	682	58.6%	481	41.4%
45°	*1152*	*289*	*25.1%*	*863*	*74.9%*	612	57.9%	445	42.1%

A CNN is saved after each 1000th training iteration and is tested against EC-Data. The number of detections can be greater than the actual number of images as there can be more than one prediction for an image. However, only one prediction can be correct because an image of EC-Data contains only one object. The results of the analysis are shown in Table 2 and reveals the CNN work best on images recorded from a camera position of 22.5° showing higher rates of TP than angles of 0° and 45°. Furthermore, the rate of FN is almost the same. This accompanies a camera angle of 22.5° to be used in operational processes enabling an unblocked view on a stored object in a shelf. The steeper this angle the less insight into the shelf.

To evaluate which stage of training should be used for object detection the CNN after each 1000th iteration is tested against EC-Data at 22.5°. The results are shown in Figure 10. After 8000 iterations the gap between TP and FP implies a reliable object detection. Because the levels of TP and FP are also better than after 24000 iterations, in addition to the recommended CNN after 24000 iterations (CNN_24k) the training stage after 8.000 iteration is also considered during the following evaluation (CNN_8k).

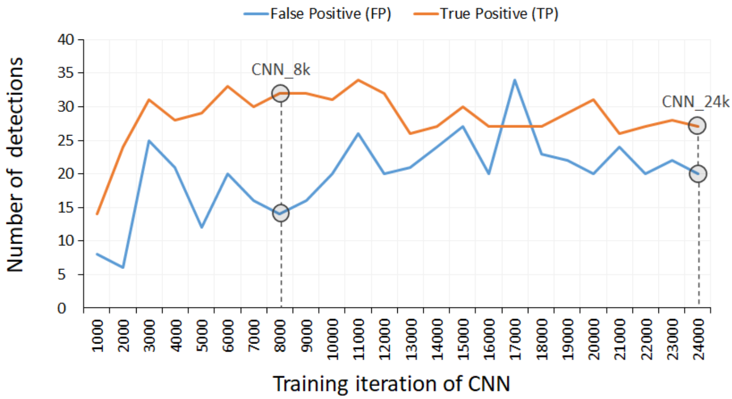


Figure 10: Test of training stages against EC-Data at a camera angle of 22.5° (48 images)

5.2.2 Retaining with EC Data

CNN_8k and CNN_24k are retrained with EC-Data to evaluate the impact of training an existing network with a few operational images initially trained with laboratory data. Retraining starts with an average loss value smaller than 0.7 resulting from the initial training with PRM-Data. During retraining about 70 iterations are calculated per hour which is a similar performance as during initial training with PRM-Data. After 200 iterations the number of TP increases and the number of FP declines significantly.

Table 3: Test of CNN 8k, 24k, 8k_RT, and 24k_RT against D-Data

	CNN_8k		*CNN_8k_RT*		*CNN_24k*		*CNN_24k_RT*	
True Positive	*98*	*52.4%*	*138*	*92.0%*	*78*	*46.7%*	*137*	*89.5%*
False Positive	*73*	*39.0%*	*10*	*6.7%*	*75*	*44.9%*	*14*	*9.2%*
False Negative	*16*	*8.6%*	*2*	*1.3%*	*14*	*8.4%*	*2*	*1.3%*
∑	*187*	*100%*	*150*	*100%*	*167*	*100%*	*153*	*100%*

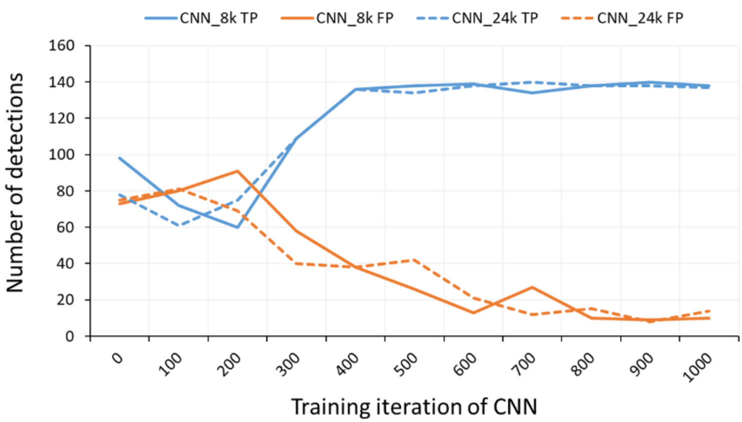


Figure 11: Test of CNN 8k, 24k, 8k_RT, and 24k_RT against D-Data

Because this trend converges at about 400 iterations only the first 1000 iterations are considered. The retraining for 1000 iterations lasts 14.3 hours for CNN_8k and 15.3 hours for CNN_24k. The resulting CNN "CNN_8k_RT" and "CNN_24k_RT" (RT = retrained) are each tested against D-Data. The results are shown in Figure 11. After 1000 iterations of retraining CNN_8k_RT and CNN_24_RT show similar behaviour. In Table 3 the results from testing all selected CNN against D-Data is shown. Comparing CNN_8k and CNN_24k reveals CNN_8k performing better by reaching a higher number of TP.

5.2.3 Evaluation of object classes

Further analysis evaluates single object classes. P_{OD} is computed by calculating an average probability for a true positive object detection for each object class. Some objects already show a P_{OD} greater than 90% after testing CNN_8k and CNN_24k against D-Data, but some do not get even one single positive detection (0%). By using CNN_8k_RT and CNN_24k_RT a great improvement can be reached for all classes except ceramic cup 3. The results for all objects classes are shown in Table 4.

Table 4: P_{OD} for all object classes resulting from testing against D-data

Object class	*CNN_8k*	*CNN_8k_RT*	*CNN_24k*	*CNN_24k_RT*
bucket	*23,5%*	*99,8%*	*6,1%*	*100,0%*
ceramic cup 1	*19,3%*	*97,3%*	*0%*	*99,7%*
ceramic cup 2	*0%*	*83,3%*	*0%*	*91,5%*
ceramic cup 3	*90,8%*	*70,8%*	*86,9%*	*60,1%*
ceramic cup 4	*87,2%*	*100,0%*	*89,3%*	*91,7%*
glass	*54,4%*	*99,9%*	*22,1%*	*99,9%*
plastic cup 1	*65,8%*	*99,7%*	*29,7%*	*100,0%*
plastic cup 2	*30,6%*	*99,8%*	*11,8%*	*100,0%*
key	*0%*	*86,4%*	*31,3%*	*93,4%*
charger	*73,3%*	*91,2%*	*80,9%*	*91,6%*
plastic bottle	*76,9%*	*99,4%*	*48,6%*	*99,0%*
glass bottle	*92,8%*	*100,0%*	*91,0%*	*99,8%*

Analyzing FP data reveals occurring misdetections between certain objects. Figure 12 shows a group of objects having a very similar appearance causing 9 of 12 misdetections of CNN_8k_RT and 9 of 14 for CNN_24k_RT. The images are taken from D-Data with an object rotation of 60° and 180°. The object "ceramic cup 1" has a slightly different form and a darker surface, therefore it is not affected by misdetections. These images show the challenge to distinguish between these object classes.

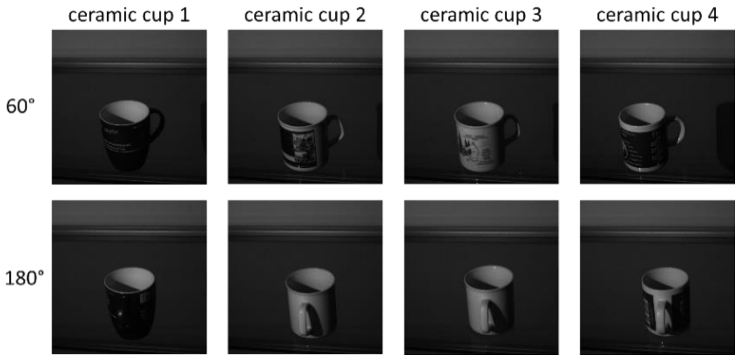


Figure 12: Similarity of ceramic cups with 60° and 180° (images enlarged)

5.3 System Evaluation

All 12 objects of the data set are assigned randomly to a shelf within the picking zone described in section 4.2 to evaluate the efficiency of the trained CNN. 720 predefined picking orders are generated by the order generator containing each one order line with a single object with quantity one uniformly distributed over all objects as a forecast for one hour. Picking orders of real systems may contain more than one order line but this configuration simplifies parameter setting and evaluation. However, multi order line orders can be interpreted as a sequence of several single order line orders. Orders are fulfilled by two human pickers and two picking robots using CNN_24K for object detection.

At first this scenario is evaluated by the capacity planning according to Rieder and Verbeet (2020) shown in chapter three. The calculation of $L_{EC,R}$ is extended by a duration for object detection t_4 during Adjustment-Phase. Used parameters and formulas are shown in Figure 13. The optimization (CPLEX OPL Studio 12.8.0.0) considers picking capacity, expected object detection performance by CNN_24k and the time effort caused by Emergency Calls. It shows that fulfilment of all picking orders of the forecast is possible. Capacities are almost used completely with C_H= 552 and C_R= 182.

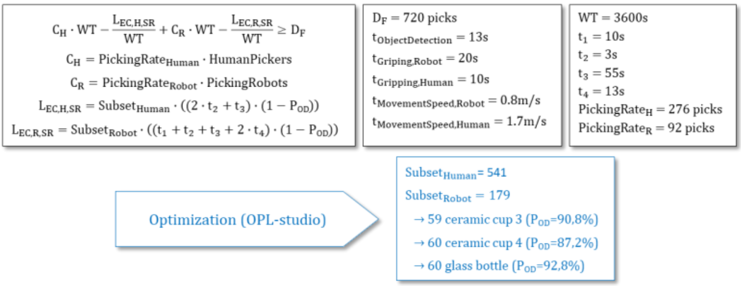


Figure 13: Formulas and parameters for system evaluation

As $Subset_{Robot}$ contains only objects with a high P_{OD} dynamic order assignment during simulation will not result in complete order fulfillment within one hour. System performance is evaluated by measuring the degree of order fulfilment as well as current workload of human pickers and picking robots.

The progress of order fulfilment during simulation is shown in Figure 14. Confirming expectations released orders cannot be fulfilled completely within one hour due to 55 triggered Emergency Calls leading to an order backlog of 176 orders. Using CNN_24k_RT in a second run almost every order can be completed successfully while only a single Emergency Call is triggered. The backlog of 7 orders after one hour results from the delay between order release and order processing.

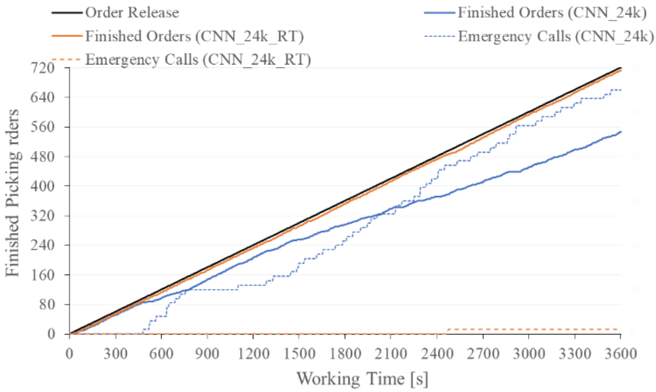


Figure 14: Results of simulation using CNN_24k and CNN_24_RT

6 Discussion

Contributions of this paper are the definition and creation of a data set containing data for training and testing CNN for object detection, the training and evaluation of these CNN to enable picking, and the implementation of an agent-based demonstrator to create empirical data to evaluate the concept of a feedback loop within a cooperative human-robot picking system. 12 objects of different material are selected to evaluate the cooperative picking system representing objects of a realistic picking zone with partially similar objects. For an initial training 2400 images are recorded, for retraining and testing each 144. Because no additional lighting is used during recording it results in quite dark images showing barely recognizable objects. The intention is to create realistic images showing the impact of a small data set during initialization of an automated system. Even if the number is quite small and some images are bad illuminated object detection provides good results. Images are saved as black and white data not containing as much information as RGB data, but the used 3D-scanner only provides texture information in a black and white mode. Furthermore, each image contains a single object to simplify image recording and evaluation. The operational images the trained CNN are tested against are recorded with a camera angle of 22.5°. Nevertheless, images recorded by PRM between 0° and 90° are also useful because the effective angle of operational object detection may match these angles due to positioning of the object, e.g. images from above (0°) become relevant if the object is on side. The presented results encourage to pursue the presented approach. Evaluating industrial applications might need to extend data set with images containing more objects from different classes as well as fallen or damaged objects enabling development of error handling strategies for misclassification during object detection.

The authors of this work support the thesis images from a laboratory environment can be used to train a CNN for object detection in real picking environments. It is shown a well performing CNN can be trained with only a few iterations and a small data set. However, during training each interim stage must be analyzed to select the best performing CNN while ensuring the ability to adapt to new objects by retraining, which is a necessary ability in logistics environments with a dynamic object range. Furthermore, only a few images from a close to reality setting is necessary to adapt a CNN by retraining with laboratory generated images to significantly improve performance. This training approach seems reliable for logistics applications and should be evaluated by further research to confirm the promising results for object detection. The handling of false positive predictions provided by a CNN must also be considered in further developments by implementation another double check mechanism to avoid false friend picking.

Simulation of the picking system by the virtual demonstrator using the trained CNN reveals weaknesses within the basic mechanisms of order release and order assignment. A predictive capacity utilization is prevented by the evenly distributed order release. Therefore, performance of order picking is limited by released orders, which means a later drop in performance due to Emergency Calls is difficult or even impossible to make up for. This effect can be observed particularly during CNN_24k simulation. The previous calculation of a possible order distribution by optimization does not adequately consider system dynamics since the subsets are defined pure in sorts using objects with a high P_{OD}. With additional time constraints the resilience of the subsets could be increased. An evenly distribution of picking orders between pickers by the auction mechanism is prevented by triggered Emergency Calls. The reason is the immediate distribution using a local order list within each agent. This leads to the effect human pickers are running out of picking orders while picking robots still must process several picking orders at the end of working time during simulation. Therefore, agents should either be given the option to take over picking orders from other agents or the local order lists must be restricted to ensure a balanced distribution. An alternative approach is a mechanism for a preselected order assignment described by Verbeet et al. (2019) to control order distribution considering critical objects with a low P_{OD}.

7 Conclusion

Automation of transport, object detection and gripping within picking processes are major challenges for robots. One approach is a cooperative human-robot picking system to ensure a fallback for order fulfillment and to support robots in a dynamic learning process by a feedback loop (Emergency Call). An agent-based demonstrator should examine the resilience of this approach. The proposed system is divided into an environment for controlled image recording and training of a Convolutional Neural Network (CNN) for object detection as well as a picking environment for order fulfillment and operational image recording. Currently the picking environment is implemented virtually as multiagent-system, but a connection to physical components is possible and planned. A data set consisting of laboratory images (PRM-Data) and operative images (EC-Data) for the training of the CNN is created. The CNN is trained with this data set, is tested against additional operational data (D-Data), and is evaluated by a simulation using the virtual picking environment. The results show that even with a few images gathered by a feedback loop and low training effort good results can be achieved in automated object detection. For an industrial application, however, further development is necessary.

The evaluation of trained CNN shows the challenge to find a best fitting configuration and training stage considering all objects. This problem may increase in a real setup considering thousands of objects. One possible approach is the training of many specialized CNN with a single object or a group of similar objects. Because the system knows which objects are stored at which shelf a specific CNN can be chosen for object detection. The results gained from these special CNN can also be marshaled and evaluated by an additional mechanism to provide an even more reliable object detection. Thereby, the effort for initial training and retraining may be reduced while retaining the ability to adapt to a changing object range. The demonstrator is planned to be extended by a physical picking station realized by a UR5E robotic manipulator embedded into the multiagent-system, i.e. a new agent type will be implemented as digital representation to control the robot. Recording of images using PRM cannot be automated, but the training environment and the demonstrator can be linked to automate retraining of CNN. Both systems are already realized as multiagent-systems. During writing this paper version 4 of YOLO was published (Bochkovskiy, Wang and Liao, 2020). Assuming this new version improves performance of object detection the demonstrator should be updated and tested.

Acknowledgments

This work is part of the project “ZAFH Intralogistik”, funded by the European Regional Development Fund and the Ministry of Science, Research and Arts of Baden Württemberg, Germany (F.No. 32-7545.24-17/3/1).

References

Azadeh, K., Koster, M. B. M. de and Roy, D., 2017. Robotized Warehouse Systems: Developments and Research Opportunities. SSRN Electronic Journal. http://dx.doi.org/10.2139/ssrn.2977779.

Bochkovskiy, A., 2020a. darknet: Yolo-v4 and Yolo-v3/v2 for Windows and Linux. [online] Available at: <https://github.com/AlexeyAB/darknet>.

Bochkovskiy, A., 2020b. Yolo_mark: Windows & Linux GUI for marking bounded boxes of objects in images for training Yolo v3 and v2. [online] Available at: <https://github.com/AlexeyAB/Yolo_mark>.

Bochkovskiy, A., Wang, C.-Y. and Liao, H.-Y. M., 2020. YOLOv4: Optimal Speed and Accuracy of Object Detection. <http://arxiv.org/pdf/2004.10934v1>.

Bormann, R., Brito, B. F. de, Lindermayr, J., Omainska, M. and Patel, M., 2019. Towards Automated Order Picking Robots for Warehouses and Retail. In: D. Tzovaras, D. Giakoumis, M. Vincze, and A. Argyros, eds. 2019. Computer Vision Systems. Cham: Springer International Publishing, pp. 185–198.

Bratman, M., 1987. Intention, plans, and practical reason. Cambridge: Harvard University Press.

Braubach, L., Lamersdorf, W. and Pokahr, A., 2003. Implementing a BDI-Infrastructure for JADE Agents. EXP, (3), pp. 76–85.

Braubach, L., Pokahr, A. and Lamersdorf, W. Jadex: A short overview. In: Net. Object-Days, pp. 195–207.

Eclipse, 2020. MQTT Client Paho. [online] Available at: <https://www.eclipse.org/paho/> [Accessed 20 May 2020].

EHI Retail Institute, 2019. Robotics4Retail – Automatisierung und Robotisierung in Handelsprozessen. <https://www.robotics4retail.de/fileadmin/Robotics/EHI_Poster_Landkarte_Robo-tics4Retail_2019.pdf> [Accessed 19 November 2019].

FIPA, 2019. FIPA. [online] Available at: <http://www.fipa.org/index.html> [Accessed 5 June 2019].

Gerke, W., 2015. Technische Assistenzsysteme: Vom Industrieroboter zum Roboterassistenten. [e-book]. Berlin: De Gruyter Oldenbourg. <http://tib-hannover.eblib.com/patron/FullRecord.aspx?p=1563389>.

He, K., Girshick, R. and Dollár, P., 2018. Rethinking ImageNet Pre-training. <http://arxiv.org/pdf/1811.08883v1>.

Jansen, P., Broadhead, S., Rodrigues, R., Wright, D., Brey, P., Fox, A., Wang, N., King, O., Chatila, R. and Romano, V., 2018. State-of-the-art Review: WP4 AI & Robotics. <https://www.sienna-project.eu/digitalAssets/787/c_787382-l_1-k_sienna-d4.1-state-of-the-art-review--final-v.04-.pdf> [Accessed 19 May 2020].

Kamarul Bahrin, M. A., Othman, M. F., Nor Azli, N. H. and Talib, M. F., 2016. INDUSTRY 4.0: A REVIEW ON INDUSTRIAL AUTOMATION AND ROBOTIC. Jurnal Teknologi, [e-journal] 78(6-13), pp. 137–143. http://dx.doi.org/10.11113/jt.v78.9285.

Kugler, W. and Gehlich, D., 2013. Einsatz von Agentensystemen in der Intralogistik. In: P. Göhner, ed. 2013. Agentensysteme in der Automatisierungstechnik. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 113–128.

Lee, J. A., Chang, Y. S. and Choe, Y. H., 2018. Assessment and Comparison of Human-Robot Co-work Order Picking Systems Focused on Ergonomic Factors. In: P. Arezes, ed. 2018. Advances in Safety Management and Human Factors. Cham: Springer International Publishing, pp. 516–523.

Lin, T.-Y., Maire, M., Belongie, S., Bourdev, L., Girshick, R., Hays, J., Perona, P., Ramanan, D., Zitnick, C. L. and Dollár, P., 2014. Microsoft COCO: Common Objects in Context. <http://arxiv.org/pdf/1405.0312v3>.

Liu, Y.-R., Huang, M.-B. and Huang, H.-P., 2019 - 2019. Automated Grasp Planning and Path Planning for a Robot Hand-Arm System. In: 2019 IEEE/SICE International Symposium on System Integration (SII). 2019 IEEE/SICE International Symposium on System Integration (SII). Paris, France, 14.01.2019 - 16.01.2019: IEEE, pp. 92–97.

Martinez, C., Boca, R., Zhang, B., Chen, H. and Nidamarthi, S., 2015 - 2015. Automated bin picking system for randomly located industrial parts. In: 2015 IEEE International Conference on Technologies for Practical Robot Applications (TePRA). 2015 IEEE International Conference on Technologies for Practical robot Applications (TePRA). Woburn, MA, USA, 11.05.2015 - 12.05.2015: IEEE, pp. 1–6.

Mester, J. and Wahl, F., 2019. Robotik in der Intralogistik - Ein Projekt der Unternehmen Fiege und Magazino. In: I. Göpfert, ed. 2019. Logistik der Zukunft - Logistics for the Future. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 199–211.

Müller, R., Franke, J., Henrich, D., Kuhlenkötter, B., Raatz, A. and Verl, A., 2019. Handbuch Mensch-Roboter-Kollaboration. München: Hanser.

Noren, A. and Müller, P., 2020. MQTT Broker Mosca. [online] Available at: <https://crycode.de/homepi-mqtt-broker-mosca> [Accessed 20 May 2020].

NVIDIA Corporation, 2020. CUDA-Zone: TRAIN MODELS FASTER. [online] Available at: <https://developer.nvidia.com/cuda-zone>.

Photoneo, 2020. Bin Picking Studio: "Alles in einem" Toolbox für Roboterintegratoren. [online]. Bratislava. Available at: <https://www.photoneo.com/de/bin-picking-studio-alles-in-einem-toolbox-fuer-roboterintegratoren/>.

Redmon, J., 2016. Darknet: Open Source Neural Networks in C. [online] Available at: <http://pjreddie.com/darknet/>.

Redmon, J. and Farhadi, A., 2018. YOLOv3: An Incremental Improvement. <http://arxiv.org/pdf/1804.02767v1>.

Rieder, M. and Verbeet, R., 2019. Robot-human-learning for robotic picking processes.

Rieder, M. and Verbeet, R., 2020. Evaluation and Control of a Collaborative Automated Picking System. In: 2020. Smart and Sustainable Supply Chain and Logistics – Trends, Challenges, Methods and Best Practices.

Salah, K., Chen, X., Neshatian, K. and Pretty, C., 2018 - 2018. A hybrid control multi-agent cooperative system for autonomous bin transport during apple harvest. In: 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA). 2018 13th IEEE Conference on Industrial Electronics and Applications (ICIEA). Wuhan, 31.05.2018 - 02.06.2018: IEEE, pp. 644–649.

Shao, Q. and Hu, J., 2019. Combining RGB and Points to Predict Grasping Region for Robotic Bin-Picking. <http://arxiv.org/pdf/1904.07394v2>.

Thiel, M., Hinckeldeyn, J. and Kreutzfeldt, J., 2018. Deep-Learning-Verfahren zur 3D-Objekterkennung in der Logistik.

Valle, C. A. and Beasley, J. E., 2019. Order allocation, rack allocation and rack sequencing for pickers in a mobile rack environment. <http://arxiv.org/pdf/1903.06702v4>.

VDI, 1994. 3590. Kommissioniersysteme. Berlin: Beuth Verlag. <https://www.vdi.de/richtlinien/details/vdi-3590-blatt-1-kommissioniersysteme-grundlagen-1> [Accessed 19 May 2020].

Verbeet, R. and Baumgärtel, H., 2020. Implementierung von autonomen I4.0-Systemen mit BDI-Agenten. In: M. ten Hompel, B. Vogel-Heuser, and T. Bauernhansl, eds. 2020. Handbuch Industrie 4.0. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 1–36.

Verbeet, R., Rieder, M. and Kies, M., 2019. Realization of a Cooperative Human-Robot-Picking by a Learning Multi-Robot-System Using BDI-Agents. SSRN Electronic Journal. http://dx.doi.org/10.2139/ssrn.3502934.

Wahrmann, D., Hildebrandt, A.-C., Schuetz, C., Wittmann, R. and Rixen, D., 2019. An Autonomous and Flexible Robotic Framework for Logistics Applications. Journal of Intelligent & Robotic Systems, [e-journal] 93(3-4), pp. 419–431. http://dx.doi.org/10.1007/s10846-017-0746-8.

Wang, H., Chen, W. and Wang, J., 2019. Heterogeneous Multi-agent Routing Strategy for Robot-and-Picker-to-Good Order Fulfillment System. In: M. Strand, R. Dillmann, E. Menegatti, and S. Ghidoni, eds. 2019. Intelligent Autonomous Systems 15. Cham: Springer International Publishing, pp. 237–249.

Werner, T., Riedelbauch, D. and Henrich, D., 2017. Design and Evaluation of a Multi-Agent Software Architecture for Risk-Minimized Path Planning in Human-Robot Workcells. In: T. Schüppstuhl, J. Franke, and K. Tracht, eds. 2017. Tagungsband des 2. Kongresses Montage Handhabung Industrieroboter. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 103–112.

Zou, Y., Zhang, D. and Qi, M., 2019. Order Picking System Optimization Based on Picker-Robot Collaboration. In: Unknown. Proceedings of the 2019 5th International Conference on Industrial and Business Engineering - ICIBE 2019. the 2019 5th International Conference. Hong Kong, Hong Kong, 27.09.2019 - 29.09.2019. New York, New York, USA: ACM Press, pp. 1–6.

Enhancing B2B supply chain traceability using smart contracts and IoT

Mohamed Ahmed [1], Chantal Taconet [2], Mohamed Ould [3], Sophie Chabridon [2], and Amel Bouzeghoub [2]

1 – ALIS – Institut Polytechnique de Paris

2 – Institut Polytechnique de Paris

3 – ALIS

Purpose: The management of B2B supply chains that involve many stakeholders requires traceability processes. Those processes need to be secured. Furthermore, quality traceability data has to be transparently shared among the stakeholders. In order to improve the traceability process, we propose to enhance blockchain based traceability architectures with the capability to detect and record well-qualified incidents.

Methodology: To achieve this goal, we propose a generic smart contract for B2B traceability data management, including transport constraints such as temperature, delay and allowing automatic incident detection and recording. We propose an architecture where data are collected by connected objects and verified and qualified before being sent to the smart contract. This proposition has been validated with medical equipment transport use cases.

Findings: As results, the proposed generic template contract can be used in various traceability use cases, well qualified incidents are transparently shared among stakeholders, and secured, qualified and verified traceability data can be used in case of claims or litigation and can facilitate also the automation of invoicing process.

Originality: The originality of this work arises from the automated B2B traceability management system based on qualified IoT data, contractual milestones and process coded in a generic smart contract, and also from the fact that traceability related data and incidents are verified and qualified in order to increase the integrated data quality.

First received: 11. Mar 2020 Revised: 2. Jun 2020 Accepted: 12 Aug 2020

1 Introduction

The collection and management of traceability data and the agreement on its management rules are today major challenges for the B2B supply chain. According to Van Dorp (2002), ISO defines the traceability as: "the ability to trace the history, application or location of an entity by means of recorded identification". Consequently, the traceability requires to store and share securely the data and the process related to an entity among all its stakeholders.

The supply chain with all its stakeholders was among the firsts use cases of the blockchain technology outside the cryptocurrency’s domain, as this technology responds to the issues of securing data sharing between stakeholders. The usage of the blockchain in the supply chain helps to meet key supply chain management objectives such as cost, quality, speed, dependability, risk reduction, sustainability and flexibility as stated by Kshetri (2018).

The emergence of the blockchain has facilitated the development of smart contracts. According to Szabo (1997), smart contract designates the hard coding of all contract clauses in a hardware or software in order to be executed automatically in a secured and distributed environment. In the end of 2013, Ethereum comes with an integrated framework for smart contract development Buterin (2014). Since, it has become a standard in blockchain implementations to integrate the support of smart contracts.

Traceability solutions are proposed in many articles using the blockchain. However, many of these proposals stop at the first level of use of the blockchain, using it just as a storage medium, and thus, they do not take advantage from the automation possibilities offered by smart contracts to implement distributed, secure and reliable process of contractual milestones and incidents management.

Additionally, many solutions of the state of the art propose to use premissionless blockchains in a private network (as in Lin et al. (2019), Westerkamp et al. (2018) and Hasan et al. (2019)), but these blockchains are not adapted to the B2B supply chain context. All stakeholders are well identified in the B2B supply chain and there is a certain level of trust established by contracts between them. The needs, in this specific context, are more to share securely and reliably data and processing rules among those stakeholders and manage different access levels to the shared data and process.

The combination of the IoT with blockchain traceability-based systems provides those systems with auto collected and real time field data. In the state of the art, some works propose to set up blockchains at the level of the IoT network as in Hinckeldeyn & Jochen (2018), but the blockchain with its resources needs is not adapted to the IoT network level which is resource limited. Some other works propose to integrate in the blockchain raw data captured and transmitted by the various connected objects of the supply chain without any IoT data qualification process as in Hasan et al. (2019). Those above cited two propositions are not adequate, and there is a need to provide the blockchain traceability-based systems with only relevant IoT data without outlier or redundant data.

Automation possibilities of smart contracts and the IoT auto data collection capabilities open new opportunities for enhancing the traceability with secured, transparent, reliable and shared rules and data. The traceability enhancing brings questions about incidents management. The incidents are elements of the daily life in the supply chain and the lack of secured and transparent process for their management affects seriously the data quality of traceability systems.

The contributions of this work to enhance B2B supply chain traceability are the proposition of a generic smart contract to handle contractual milestones, IoT data, incidents creation and qualification rules. The genericity of the proposed smart contract means that it can be deployed across the majority of B2B supply chain contexts without needs for new development efforts. We propose also to use IoT data qualification servers to automatically qualify the IoT data, collected from connected objects or provided by the traceability process stakeholders, before its integration in the smart contract, in order to reduce the amount of data to be stored in the underlying blockchain. A stakeholder's confirmation process is also proposed in the smart contract for some elements such as incidents to confirm the stakeholder's involvement in those elements and their agreement on their related data.

The rest of the paper is organized as follows: in Section 2 we study the works related to supply chain traceability using smart contracts and IoT. In Section 3 we present the architecture of the proposed B2B supply chain traceability solution. Section 4 presents an evaluation of the proposed solution. Finally, we conclude in Section 5 and present some future works.

2 Related works

The usage of smart contract combined with IoT in the supply chain is a recent research trend, and several solutions have been proposed using those technologies. As state Rejeb et al. (2019), the combination of smart contracts and IoT could enhance the transparency, the confidence, the efficiency and the traceability of the supply chain. In this paper, we focus on the traceability enhancing and we analyze literature concerning the works that use smart contracts to tackle the supply chain traceability problem.

We studied the related works according to five traceability enhancing requirements. Firstly, the usage of the IoT technology (R1) which is essential to accelerate and automate the field data collection and incidents detection. Secondly, the genericity (R2) of the proposed smart contract in term of logic and manipulated entities, such as milestones, transport conditions and incidents. This means that the proposed smart contract could be applied in another supply chain traceability context without needs for further development efforts. Thirdly, the usage of contractual milestones (R3) between stakeholders, which are essentials for B2B traceability. Fourthly, the integration of an IoT data qualification module (R4), which is necessary for submitting into the smart contract only relevant IoT data, and consequently alleviate the underlying blockchain data amount. Finally, the support of traceability incidents management (R5), for example the auto detection and qualification of non-compliance with contractual milestones dates or transport conditions, which are essentials for B2B supply chain traceability systems.

Some of the related works try to resolve the supply chain traceability issues using only smart contracts without IoT as in Lin et al. (2019), Westerkampet al. (2018), Cui et al. (2019), Yong et al. (2020), Salah et al. (2019) and Helo & Hao (2019). Yong et al. (2020) proposed a traceability solution for the vaccine supply chain, allowing to detect vaccine expiration which is an incident related to the vaccine lifecycle management rather than the supply chain process. Chang et al. (2019) tried to reengineer theoretically the tracking process and proposed to introduce control points for B2B scenarios by modifying the data structure without giving more detail on how to do that. The lack of use of IoT affect the automation and the data collection capabilities of those solutions.

Other related works take advantage of the combination of smart contract and IoT to resolve traceability problems as in Bumblauskas et al. (2020). Wen et al. (2019) proposed a privacy compliant traceability solution, but with a limited number of stakeholder roles that does not cover all the possible roles in the supply chain such as the broker role for example. The shipment management system in Hasan et al. (2019) handles only some limited package status and transport conditions that could not cover all different contexts specific needs in terms of status and transport conditions. In the model of architecture for Food Supply Chain (FSC) traceability proposed by Casino et al. (2019), the IoT data are stored only locally and a reference to the locally stored data is used in blockchain, but there is no reference in their work to an IoT data qualification process.

All the aforementioned smart contracts have been developed for some specifics supply chain contexts and are not generic to be used in other contexts. Also, their proposed solution lacks methods to qualify IoT Data before its integration in the smart contract. That impacts the performance because of the huge amount of data generated by the IoT and that need to be stored in the underlying blockchain. The incidents management also is an important part of the traceability process that has not been or not well treated in those related works.

Table 1 summarizes the studied works and how they meet the studied five requirements:

Table 1: Related works comparison

Related work	IoT (R1)	Genericity (R2)	Contractual Milestones (R3)	IoT data Qualification (R4)	Incidents Management (R5)
Lin et al. (2019), Westerkamp et al. (2018), Cui et al. (2019), Yong et al. (2020), Salah et al. (2019) and Helo & Hao (2019)	N/A	N/A	N/A	N/A	N/A
Chang et al. (2019)	N/A	N/A	B2B control points	N/A	N/A

Related work	IoT (R1)	Genericity (R2)	Contractual Milestones (R3)	IoT data Qualification (R4)	Incidents Management (R5)
Casino et al. (2019) and Bumblauskas et al. (2020)	Fulfilled	N/A	N/A	N/A	N/A
Wen et al. (2019)	Fulfilled	Generic smart contract (without transport conditions)	N/A	N/A	N/A
Hasan et al. (2019)	Fulfilled	Smart contract with hard coded shipment status and transport conditions	N/A	N/A	N/A

Related work	IoT (R1)	Genericity (R2)	Contractual Milestones (R3)	IoT data Qualification (R4)	Incidents Management (R5)
This work	Fulfilled	Generic smart contract with generic transport conditions	Contractual milestones management	IoT data qualification process	Incidents auto detection and qualification in the smart contract

3 Architecture of the proposed B2B traceability solution

As depicted in Figure 3, we propose a novel architecture that meet all the requirements defined in the related works section.

The proposed B2B traceability solution is comprised of two main parts: the generic smart contract and the server responsible of IoT data qualification. The smart contract is responsible of the contractual milestones and the incidents detection and management process. The IoT data qualification server is responsible of the qualification of the collected IoT data based on the constraints defined by the smart contract data and the IoT tag specifications.

As a relevant illustrative application, we choose some scenarios from the medical cold chain. These use cases involve generally B2B stakeholders and have specific requirements such as specific temperature transport conditions in case of transport of medical temperature-sensible products. For those reasons, they are relevant use cases for our proposed traceability solution.

In the next subsections, we present the medical cold chain use case and the selected illustrative scenarios, the generic traceability smart contract and the IoT data qualification process.

3.1 Medical cold chain use cases

The medical equipment cold chain is handled by specific transport means. Some of the medical equipments, like perishable medical diagnostic kits used in blood tests, need to be transported under elevated transport conditions with a temperature between a minimum of +2 and a maximum of +8 Celsius degrees. Shipper generally use data loggers to collect the temperature during the transport operation data and those data loggers are returned to the shipper after the end of the transport operation to control if there has been any incident related to the temperature excursion.

Furthermore, the transport conditions and milestones data are made available by carrier through EDI or web services. In existing traceability systems, all those data are collected in a central traceability system and can then be accessed by all stakeholders.

This scenario with current systems presents several challenges that are not handled by most of traditional traceability systems. For example, the incident declaration is delayed due to the post-control of the transport condition respect after the end of the transport operation using the returned data logger. Also, the central traceability system hosted by one of the stakeholders or an external actor, without guaranties on the security and the reliability of data available in this system.

For this work, we present three implemented scenarios that show the genericity of our smart contract and how it handles different types of incidents. Those scenarios involve three main stakeholders: a shipper, a carrier and a consignee. In all these scenarios, connected IoT tags (Figure 2) accompany the shipments and collect automatically in near real time the shipment temperature and position.

The first scenario is about the transport of Cytomegalovirus (CMV) test Kit, used to diagnostic human CMV infections. This test kit needs to be transported under strict temperature condition of [+2°C,+8°C]. In this scenario

we focus on the incidents related to the non-compliance with the temperature transport condition enshrined in the shipment transport conditions.
The second scenario is about the transport of Thyroid Stimulating Hormone (TSH) test Kit, used as a diagnostic test for common condition of thyroid hormone deficiency. In this scenario we focus on incident related to the non-compliance with delivery date concluded for the shipment delivery milestone.
The last scenario is about the transport of Automatic immunohematology analyzer, and in this scenario, we focus on incident related to the damaging of transported material either at origin or during placement in the aircraft.

3.2 The smart contract

The smart contract proposed in this work handles the logic, the traceability rules and the incidents management in a generic way. In order to do that, we used generic entities (See Figure 1) and methods without any reference to a specific B2B traceability context, such as specifics stakeholders, milestones, transport condition or incidents. Therefore, this smart contract could be used in the majority of the B2B supply chain traceability contexts without needs for further modifications of its entities or methods. Additionally, the incidents automatically detected by this smart contract are well organized by their non-compliance origins (transport conditions or milestones) and their stakeholders also are well identified. This organization gives a clear view of those incidents and simplifies their management process.

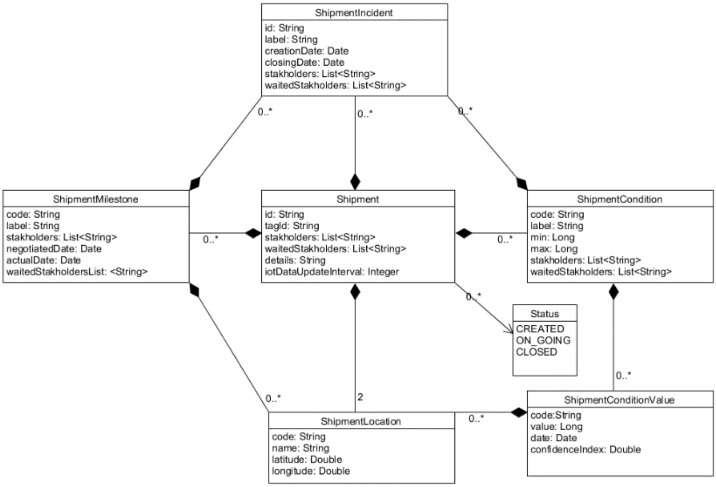


Figure 1: Entity class diagram

The main methods of the proposed smart contracts are *createShipment, updateMilestone, addIoTEvent, createIncident and confirmIncident.*

The *createShipment* method is called by the initiator of the shipment to create a new shipment. It takes as argument a description of the shipment to be created with all its related elements: description, milestones, transport conditions and stakeholders. The method initializes the shipment milestones with empty incidents list, verifies that the initiator organization is not in the waiting for confirmation stakeholders list, if that's the case remove it and initiates the shipment status. It gives as output the created shipment.

The *updateMilestone* is called by the concerned milestone stakeholders to update the milestone actual date and location. It takes as argument the milestone to be updated and gives as output the updated milestone, see Algorithm 1. If necessary, it creates a milestone date compliance incident.

Algorithm 1: Update milestone

Input: An existing shipment id and an existing milestone related to the given shipment
Begin
  if The update requestor company is in the shipment stakeholders list and also in the milestone stakeholders **then**
    Retrieve and update the given milestone actual date and location using the milestone code
    if The milestone actual date is after the milestone negotiated date **then**
      Create a milestone non-compliance incident involving all the milestone stakeholders
    end if
  else
    Throw error: unauthorized update
  end if
End
Output: Updated milestone

The *addIoTEvent* is called by the IoT data qualification server when an IoT event (ShipmentConditionValue) is received and is eligible to be sent to the smart contract. It takes as argument the qualified IoT event and gives as output the updated shipment, see Algorithm 2. It may also generate a transport conditions compliance incident.

Algorithm 2: Add IoT event

Input: An existing shipment id and an IoT event related to an existing transport condition of the given shipment
Begin
  if The update requestor company is in the shipment stakeholders list and also in the transport condition stakeholders **then**
    Retrieve the concerned transport condition using its code and add the event to
    the transport condition events
    if The event value is not compliant with the fixed transport condition ranges **then**
      Create a transport condition non-compliance incident involving all the transport condition stakeholders
    end if
  else
    Throw error: unauthorized update
  end if
End
Output: Updated shipment

The *createIncident* method is called by the shipment stakeholders to *r*eport manually other types of incidents that are not directly related to the milestone's dates or the transport conditions respect. For examples a damaged material incident. It takes as arguments the shipment's id and the incident to be created and gives as output the updated shipment.

The *confirmIncident* method is called by shipment stakeholders to confirm that they are effectively involved in the given incident. It takes as arguments the shipment id and the id of the incident to be confirmed, and gives as output the updated shipment, see Algorithm 3.

Algorithm 3: Confirm incident

Input: An existing shipment id and an existing incident id related to the given shipment
Begin
  if The confirm requestor company is in the shipment stakeholders list and also in the given incident stakeholders **then**
    Retrieve the concerned incident and remove the requestor company from the list
    of the incident waited for confirmation stakeholders
  else
    Throw error: unauthorized update
  end if
End
Output: Updated shipment

As instantiation examples of our generic smart contract, we use the above presented three scenarios. For all those scenarios, the stakeholders will be the shipper, the carrier and the consignee. Those stakeholders agree on the following basic milestones list: Pickup (involving the shipper and the carrier), Departure (carrier), Arrival (carrier) and Delivery (carrier and consignee). The shipper calls the smart contract method *createShipment* to create a shipment.

In the first scenario, we only have a temperature transport condition with a minimum of +2°C and a maximum of +8°C, which results in the following transport condition instance: («TEMP (code)», «Temperature (label)», «2 (min)», «8 (max)», «the shipper and the carrier as temperature transport condition stakeholders»). When an out-temperature range value (10 for example) is received by the smart contract, it creates automatically an incident related to the temperature transport condition with the following information: («incident auto generated id (id)», «Non-compliance with Temperature transport condition [2,8], the received value was 10 (Label)», «the received Temperature date (Creation date)», «the shipper and the carrier as incident stakeholders (the incident stakeholders are the same as the transport condition stakeholders)»).

In the second scenario, we have a delivery date of 12/03/2020 at 13h00 for the shipment delivery milestone, which results in the following milestone instance: («DLV (code)», «Delivery (Label)», «12/03/2020 at 13h00 (negotiated date)», «the carrier and the consignee (delivery milestone stakeholders)»). When the smart contract receives an actual date which is after the negotiated date (12/03/2020 at 16h00 for example), it automatically creates an incident related to the delivery milestone with the following information: («incident auto generated id (id)», «Non-compliance with Delivery milestone negotiated date 12/03/2020 at 13h00, the received actual date was 12/03/2020 at 16h00 (Label)», «The received milestone actual date (Creation date)», «the shipper and the carrier as incident stakeholders (the incident stakeholders are the same as the milestone stakeholders)»).

In the last scenario, the incident related to the damaging of transported material is reported manually. For example, the shipper calls the smart contract method *createIncident* and gives all the incident related information,

for example: (« Damaging of transported material (Label)», «The formal date of the incident (Creation date)», «the carrier as incident stakeholders (the incident stakeholders designated by the shipper)»).
The above presented smart contract, in contrast to the existing smart contracts in the state of the art, is more adapted to the B2B traceability context, with its integrated milestones, IoT data and incident management. The genericity of this smart contract allows its deployment in various B2B traceability context without needs of further development efforts.

3.3 The IoT Data collection and qualification

The architecture of our traceability solution is designed to automatically detect traceability incidents by the smart contract based on the data collected by the IoT. Due to the encryption and the replication of blockchain data, the blockchain is not a good storage support for huge data amount. The data generated by the connected objects is not directly integrated into the smart contract. An IoT data server is used to improve the IoT data quality and send to the smart contract only qualified IoT data, see Figure 2.
We consider the following approaches for enhancing IoT data quality: outlier detection, data cleaning and data deduplication as stated by Karkouch et al. (2016). Other aspects of the IoT data qualification such as interpolation and data integration need to be considered in future work.

In this work, we consider as outlier data, every value that is outside the ranges of the possible values defined by the sensor's specifications. The outlier data are not sent to the smart contract. The data cleaning is performed through the comparison of the format of the received IoT data with the expected data format and the verification of the IoT data date which should be valid and not a future date.

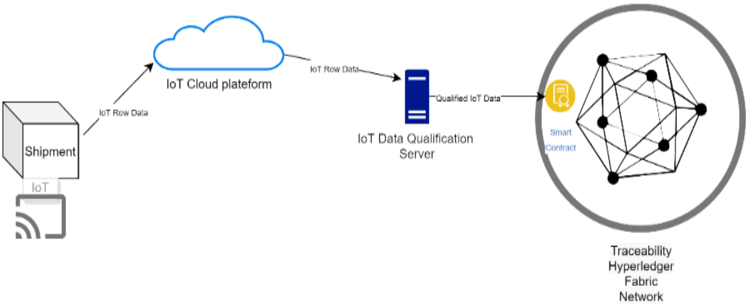


Figure 2: IoT Data qualification process

The IoT data deduplication is performed by an IoT data filter used to reduce the number of IoT events sent to the smart contract. This filter takes as argument the IoT event to qualify, the last received IoT event and the shipment. It gives as output the list of events sent to the smart contract, see Algorithm 4.

Algorithm 4: IoT Data Filter

Input: An existing shipment id or shipment tag number and a new IoT event value
Begin
Retrieve the correspondent transport condition ranges and the shipment IoT data timeout interval
  if The shipment IoT data timeout interval is not elapsed **then**
    if The new IoT event value is in the ranges **AND** the last sent value to the smart contract was outside the ranges **OR** the new IoT event value is outside the ranges
    AND the last sent value to the smart contract was in the ranges **then**
      send the new IoT event value to the smart contract
      send also the previous received value to the smart contract, if it has not been already sent
    end if
  else
    send the new IoT event value to the smart contract
  end if
End
Output: Events sent to the smart contract

---

4 Implementation, Test and Evaluation

In this section we present an implementation of the smart contract proposed in this work. Some performance tests and results are also presented, in order to prove the ability of the proposed architecture to be deployed in real live production scenarios. Finally, we evaluate the proposed architecture based on performance test results.

4.1 Implementation

The proposed smart contract has been implemented using Hyperledger Fabric Java Chaincode. Hyperledger Fabric is a permissioned blockchain implementation designed for enterprise purposes. It presents many advantages in comparison with the other permissioned blockchain implementations, among them : a parametrized consensus protocol, a node architecture based on the notion of organization to establish a trust model more adapted to the enterprise context and the support of Go, Javascript and Java for smart contracts writing.
For the development and the deployment of our smart contract, we have used the following software versions:

Table 2: Test software versions

Software	Version
Hyperledger Fabric Docker Images Tag	1.4.6
Hyperledger Fabric Java Chaincode	1.4.3
Hyperledger Fabric Gateway Java	1.4.1
Docker	19.03.6
Java	1.8.0

For deployment purpose, we implemented a simplified Hyperledger Fabric architecture (Figure 3) with three stakeholders interacting with the blockchain: a shipper, a carrier and a consignee. In this architecture, the IoT data

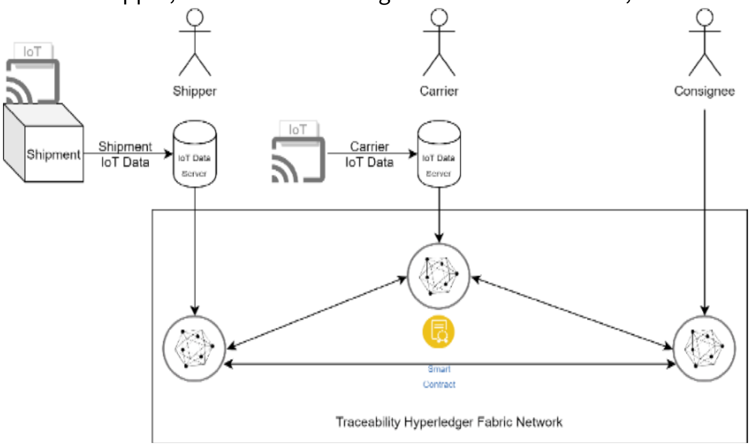


Figure 3: Global architecture of the solution

sent by the shipment IoT tag or by the carrier is qualified in local IoT Data Servers before its integration in the smart contract.
The stakeholders have been created as independent Hyperledger Fabric organizations. Each organization has the following components: Certificate Authority, responsible of the organization user certificates management; Tow peers, with a local CouchDB database for each peer. One of the two peers is designated as the endorser peer, which is responsible of the correct execution of the smart contract on the organization side.
All the endorsers peers are connected to a channel called « my-channel ». The transaction order is handled by one ordering service node, see Figure 4.

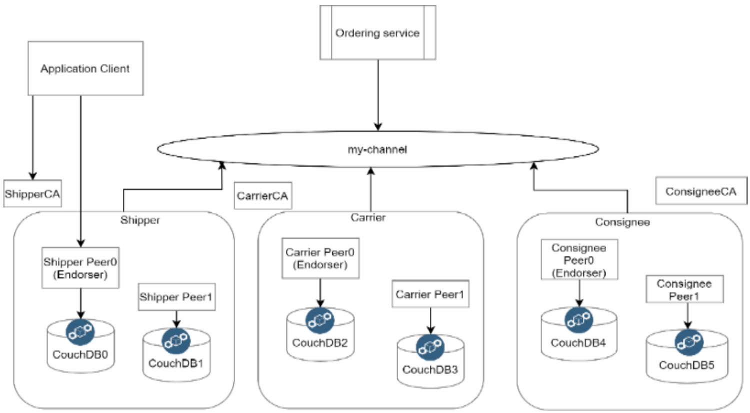


Figure 4: Detailed architecture of the Test Hyperledger Fabric Network

4.2 Test and evaluation

The objective of this subsection is to test the performance of the proposed smart contract and the IoT data qualification module, in order to show that they can be used in a real live traceability system. It's not a subsection about the Hyperledger Fabric performance which has been already treated by Androulaki et al. (2018) and Yuan et al. (2020). For our smart contract POC, the performance tests objective is to prove that the response time of the main smart contract methods is tolerable. In order to evaluate the response time tolerance, we defined a user tolerable response time of maximum 3 seconds, based on the work of Zhou et al. (2016).

Regarding the IoT qualification module, the tests objective is to prove that this module helps to reduce considerably the amount of IoT data to be sent to the smart contract.

For the test purpose, one machine has been used, and all the architecture components have been deployed on this machine using Docker. The test machine has the following characteristics:

Table 3: Test machine characteristics

Characteristic	Details
OS	Ubuntu 18.04.4 desktop amd64
CPU	1 CPU Intel(R) Core™ i7-8565U
RAM	8G
Virtual Disk	50G

We set the Hyperledger Fabric block creation timeout to 1 second and the maximum number of transactions per block to 15. This means that after the reception of a new transaction, the system will trigger the block creation either after a time wait of 1 second or after a total number of 15 new transactions is reached. In this POC, we use the Raft consensus algorithm (Ongaro & Ousterhout (2014)), with a unique ordering service node.

The *createShipment*, *updateMilestone* and *addIoTEvent*, the three main methods of the smart contract have been tested using three batches of shipments. A first batch of 500 shipments, a second batch of 1000 shipments, and a last batch of 2000 shipments. The average response time of the three methods was around 1.4 seconds. It's a good result for the POC regarding the single machine used to deploy all the architecture components. However, further tests are needed to confirm the performance of this architecture in a real distributed environment with network constraints and more stakeholders, since those elements could impact the architecture performance.

The proposed IoT Data Qualification module has also been tested 1000 times using a series of 1000 randomly generated temperature values. The shipment IoT data interval was set to 60 minutes and there was a timeslot of 3 minutes between every two values of the temperature series. Those parameters have been chosen from a specific context of shipment IoT tag that use Sigfox technology to send a message of 3 temperatures values every 10 minutes. This gives around 1000 temperature values received for 2 days of IoT data collection.

As result of those tests, the percentage of retained IoT data to be sent to the smart contract by the IoT data qualification server, depends on the test series values. For normal series with only in-ranges temperatures, and abnormal series with only out-ranges temperatures, this percentage is equal to the IoT values timeslot divided by IoT update interval defined in the shipment, which gives 5% in our test case (3/60). In case of a mixed series, the

percentage of retained IoT data depends on the IoT values timeslot, the IoT update interval defined in the shipment and the number of out-ranges temperatures. For our test case, with a series of around 36% of out-ranges values, the percentage of retained IoT data was around 31%.
The proposed IoT data qualification method allows getting into the smart contract only the pertinent IoT data for the traceability management and reduce considerably the number of IoT events to be stored in the underlying blockchain. However, many other aspects of the data quality have not been covered in this work such as the heterogeneity of sources (for example shipper IoT data vs carrier IoT data) and need to be considered in future work.

5 Conclusion and future work

In this paper, in order to enhance B2B supply chain traceability, we have proposed, implemented and tested a generic smart contract for B2B traceability. This smart contract handles contractual milestones, IoT data and the auto detection and qualification of traceability incidents. We developed also a solution for the qualification of IoT data before its integration in the smart contract.
The architecture proposed in this paper could be enhanced by future work on the data to be stored outside the blockchain (off-chain data), for example by using IPFS technology (Benet (2014)) to share and synchronize off-chain data and to store traceability attachments files, in a distributed architecture. Also, other aspects of the IoT data quality such as the handling of imperfect data, the data integration and interpolation, need to be considered in future work. Additionally, we have proposed some manual confirmation methods in this work. The impacts of those methods on the traceability process automation should be studied versus the trust that those methods add to shipment, milestones and incidents data.
Furthermore, this work has some managerial implication such as the need to subscribe the negotiated milestones in the stakeholder's service contract, the approval of connected objects to be used for data collection, some data manual confirmation process and the management by exception through a clear vision of elements that are non-compliant with the stakeholders concluded service contract.

Finally, the research on the use of smart contracts and the Internet of Things (IoT) suffers from several limitations out of the scoop of this work, among them: the difficulty of deploying blockchain based solutions, the maturity of blockchain technology, and the securing of IoT data collection and processing.

References

Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., Enyeart, D., Ferris, C., Laventman, G., Manevich, Y., Muralidharan, S., Murthy, C., Nguyen, B., Sethi, M., Singh, G., Smith, K., Sorniotti, A., Stathakopoulou, C., Vukolic, M., Cocco, S. W. & Yellick, J. (2018), Hyperledger Fabric: A Distributed Operating System for Permissioned Blockchains, pp. 1–15. arXiv: 1801.10228. URL: http://arxiv.org/abs/1801.10228

Benet, J. (2014), 'IPFS - Content Addressed, Versioned, P2P File System', arXiv e-prints p. arXiv:1407.3561.

Bumblauskas, D., Mann, A., Dugan, B. & Rittmer, J. (2020), 'A blockchain use case in food distribution: Do you know where your food has been?', International Journal of Information Management 52, 102008.
URL: http://www.sciencedirect.com/science/article/pii/S026840121930461X.

Buterin, V. (2014), 'Ethereum: A next-generation smart contract and decentralized application platform'. Accessed: 2020-04-28.
URL: https://github.com/ethereum/wiki/wiki/White-Paper

Casino, F., Kanakaris, V., Dasaklis, T. K., Moschuris, S. & Rachaniotis, N. P. (2019), 'Modeling food supply chain traceability based on blockchain technology', IFAC-PapersOnLine 52(13), 2728 – 2733. 9th IFAC Conference on Manufacturing Modelling, Management and Control MIM 2019.
URL: http://www.sciencedirect.com/science/article/pii/S2405896319316088

Chang, S. E., Chen, Y.-C. & Lu, M.-F. (2019), 'Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process', Technological Forecasting and Social Change 144, 1 – 11. URL: http://www.sciencedirect.com/science/article/pii/S0040162518305547

Cui, P., Dixon, J., Guin, U. & Dimase, D. (2019), 'A blockchain-based framework for supply chain provenance', IEEE Access 7, 157113–157125. Hasan, H., AlHadhrami, E., AlDhaheri, A., Salah, K. & Jayaraman, R. (2019), 'Smart contract-based approach for efficient shipment management', Computers&Industrial Engineering 136, 149 – 159.
URL: http://www.sciencedirect.com/science/article/pii/S0360835219304140

Helo, P. & Hao, Y. (2019), 'Blockchains in operations and supply chains: A model and reference implementation', Computers & Industrial Engineering 136, 242–251. Hinckeldeyn, J. & Jochen, K. (2018), (short paper) developing a smart storage container for a blockchain-based supply chain application, in '2018 Crypto Valley Conference on Blockchain Technology (CVCBT)', pp. 97–100.

Karkouch, A., Mousannif, H., Al Moatassime, H. & Noël, T. (2016), 'Data quality in internet of things: A state-of-the-art survey', Journal of Network and Computer Applications.

Kshetri, N. (2018), '1 blockchain's roles in meeting key supply chain management objectives', International Journal of Information Management 39, 80. URL: http://search.proquest.com/docview/2059164679/

Lin, Q., Wang, H., Pei, X. & Wang, J. (2019), 'Food safety traceability system based on blockchain and epcis', IEEE Access 7, 20698–20707.

Ongaro, D. & Ousterhout, J. (2014), In search of an understandable consensus algorithm, in '2014 USENIX Annual Technical Conference (USENIX ATC 14)', USENIX-Association, Philadelphia, PA, pp. 305–319. URL: https://www.usenix.org/conference/atc14/technicalsessions/presentation/ongaro

Rejeb, A., Keogh, J. & Treiblmaier, H. (2019), 'Leveraging the internet of things and blockchain technology in supply chain management', Future Internet 11, https://www.mdpi.com/1999–5903/11/7/161.

Salah, K., Nizamuddin, N., Jayaraman, R. & Omar, M. (2019), 'Blockchain-based soybean traceability in agricultural supply chain', IEEE Access 7, 73295–73305.

Sigfox technology (n.d.). URL: https://www.sigfox.com/en/what-sigfox/technology

Szabo, N. (1997), 'Formalizing and securing relationships on public networks', First Monday 2(9). URL: https://ojphi.org/ojs/index.php/fm/article/view/548

Van Dorp, K. (2002), 'Tracking and tracing: a structure for development and contemporary practices', Logistics Information Management 15(1), 24–33. URL: https://doi.org/10.1108/09576050210412648

Wen, Q., Gao, Y., Chen, Z. & Wu, D. (2019), A blockchain-based data sharing scheme in the supply chain by iiot, in '2019 IEEE International Conference on Industrial Cyber Physical Systems (ICPS)', pp. 695–700.

Westerkamp, M., Victor, F. & Küpper, A. (2018), Blockchain-based supply chain traceability: Token recipes model manufacturing processes, in '2018 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)', pp. 1595–1602.

Yong, B., Shen, J., Liu, X., Li, F., Chen, H. & Zhou, Q. (2020), 'An intelligent blockchainbased system for safe vaccine supply and supervision', International Journal of Information Management 52.

Yuan, P., Zheng, K., Xiong, X., Zhang, K. & Lei, L. (2020), 'Performance modeling and analysis of a hyperledger-based system using gspn', Computer Communications 153, 117 – 124.
URL: http://www.sciencedirect.com/science/article/pii/S0140366419306474

Zhou, R., Shao, S., Li, W. & Zhou, L. (2016), How to define the user's tolerance of response time in using mobile applications, in '2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)', pp. 281–285.

Semantic service discovery in heterogeneous cyber-physical systems

Andreas Lober [1], Hartwig Baumgärtel [1], and Richard Verbeet [1]

1 – Ulm University of Applied Sciences

Purpose: A primary requirement of Industry 4.0 and realization of Cyber-Physical Systems in production and logistics is the dynamic connection of physical and digital components. Service-oriented Architectures are a well established approach to meet this requirement. However, a service discovery using syntactic descriptions of services limits efficient application of a Service-oriented Architecture concerning the complexity and variability of existing processes.

Methodology: A semantics based mechanism for service discovery can solve this limitation. It uses an ontology management system containing a domain specific ontology and modelling specific Cyber-Physical Systems as individuals. SPARQL Protocol And RDF Query Language (SPARQL) queries searching this ontology with context-related parameters. A use case demonstrates the mechanism by realizing an in-house transport request.

Findings: A syntax based service discovery requires a definition and publishing of unique service names. However, complex Cyber-Physical Systems using multiple parameters during service calls require disproportionate effort to implement and maintain these names. A semantics based service discovery considers various parameters by using a specific ontology calling services by their properties without knowing the service name.

Originality: A semantics based is decoupled from specific service implementations of components in a Cyber-Physical Systems. Therefore, an explicit specification of parameter configurations in service descriptions is not necessary. A Service-oriented Architecture can be implemented in complex systems without extensive adjustments or coordination mechanisms.

First received: 11. Mar 2020 Revised: 2. Jun 2020 Accepted: 12 Aug 2020

1 Introduction

The fourth industrial revolution is currently a widely debated topic in industry, politics, and science. Two essential aspects of Industry 4.0 (I4.0) are horizontal and vertical integration, which means networking of production and logistics systems and their components across technical system hierarchies as well as across company borders. A key problem in linking heterogeneous systems is the control of their interfaces (Baumgärtel and Verbeet, 2020). A common approach to realize this integration are Service-oriented Architectures (SoA), which enable the design of distributed systems and the implementation of dynamic access to capabilities and information of components during runtime by other components by the concept of services. Common SoA are Enterprise Service Bus, OPC UA, and Arrowhead.

In production and logistics systems, most components that must cooperate according to horizontal and vertical integration, are cyber-physical systems (CPS). They consist of physical elements, like machines, tools, robots, and conveyors, as well as of control units that are IT elements, like microcontrollers or Industrial PCs. These IT elements are parts of and connected to IT networks of their companies, e.g. to enable access to service clouds via the Internet. On the IT side, CPS can use technologies like SoA as normal computers. For example, they can offer services to others and use services of different CPS.

In the context of I4.0, CPS in production and logistics are called "I4.0 components" (BMWi, 2017). Services that are offered by I4.0 components are defined as "I4.0 services" in DIN SPEC 16593-1 (DIN, 2018), as they implement capabilities of their I4.0 component (Verbeet and Baumgärtel, 2020).

This connection of the digital and physical world leads to an increased difficulty in describing services, due to the complexity and variety of physical processes capturing by services.

Mechanisms for providing, requesting, and consuming services are a central requirement of a SoA. An essential component to realize these mechanisms is the service discovery, which means a targeted or general search for services based on a service registry and service descriptions (see Section 2). A general problem of syntax based service discovery is the complexity for installing and maintaining them to ensure the interoperability and flexibility required by I4.0. These systems have similar structures but differ in detail and use different syntax. Examples of this diversity are machines, manufacturing technologies, and handling operations, which exceed the variance of pure IT approaches that are used in the web service area. Due to globally networked processes, semiconductor manufacturing is tremendously complex manufacturing methods of all. Despite manufacturing technologies and equipment are similar for all semiconductor plants, this industry comprises a huge variety of designations even for same or similar processing technologies, steps, and equipment (Ehm, et al., 2019; Moder, et al., 2020) An alternative is the semantics based description of services with the help of ontologies. This paper discusses syntax based and semantics based approaches for service discovery and presents a concept for a semantics based using an Ontology Management System (OMS) for service registry and discovery without any syntax based searching mechanism. This concept is illustrated by an in-house transport request of the digital twin of a stored product within a production system whose components are interlinked by a SoA. The paper presents an exemplary ontology for a semantic description of services and a SPARQL query for the implementation of a corresponding discovery. SPARQL stands for "SPARQL Protocol And RDF Query Language" and is a common query language and protocol for semantic data sources.

This paper is organized as follows: Section 2 introduces SoA and clarifies central terms and concepts. Section 3 presents the related work of semantic service discovery. Syntax and semantics based approaches for discovery are analysed in Section 4 illustrated by an in-house transport use case using a semantics based discovery in Section 5. Section 6 discusses the presented approaches and the final section 7 concludes this paper and gives an outlook on future work.

2 Service-oriented Architectures

A SoA is a style of software design modularizing previously monolithic IT systems. It is based on the concept of a service, a mechanism providing access to a capability of a software or hardware system through a predefined

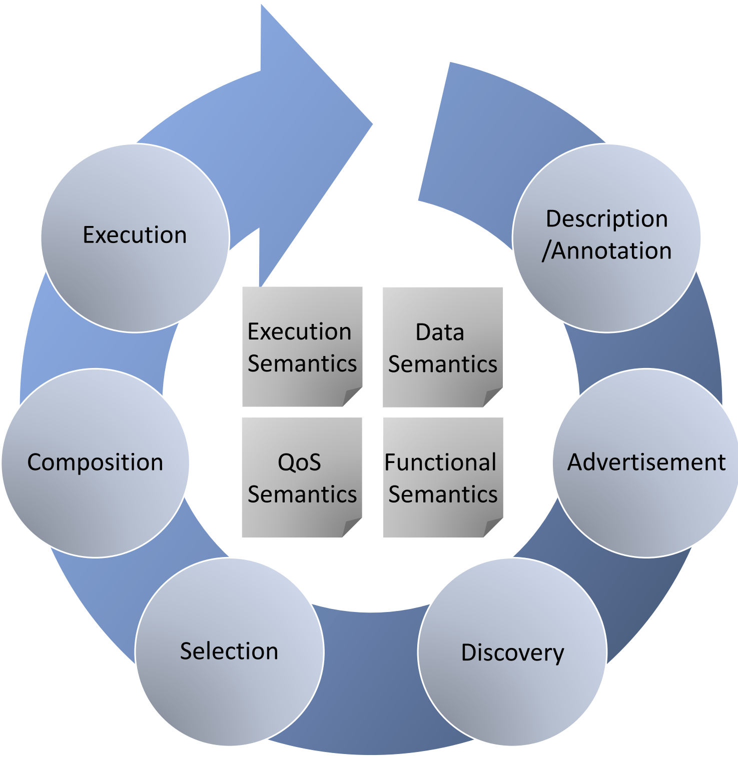


Figure 1: Service lifecycle and semantics, adopted from Cardoso and Sheth (2005)

interface by restrictions and policies defined in a service description (OASIS, 2006). Other systems can consume these services, creating a local or global communication network containing various hosts running software systems providing and consuming services. A service provider is a system offering services and a system using it service consumer. Service discovery is the process of finding services. During this search and selection process, i.e. before establishing a connection (service binding), a potential consumer is called service requester.

SoA base on a technical and conceptual hierarchy that consists of hosts, software systems, services, and methods. Hosts are physical resources like computers or CPS that can execute software systems. SoA software systems are installed and executed on a host and offer one or several services. Services consist of one or more methods. Methods are the basic building blocks that can be called to produce concrete results. Service consumption consists of the call and parametrization of service methods and the receipt of the produced results.

According to the OASIS reference model (OASIS, 2006), a SoA is defined by the following principal concepts: Service Description (definition of information needed to use a service), Visibility (descriptions of technical requirements, constraints, policies, and mechanisms for access or response), Interaction (definition of messages and sequence of their exchange), Real World Effect (actual result of using a service), Execution Context (technical or business conditions for interaction), and Contract and Policy (represents a constraint, condition, or agreement on use or deployment of an entity).

Cardoso and Sheth (2005) present a model for a web process lifecycle using services and semantics (Figure 1). Even if it is designed for web services it

can be used to define a general lifecycle model for services. It contains the stages Description, Advertisement, Discovery, Selection, Composition, and Execution, whereby every stage might profit from using semantics.
Description: A service description contains information about a service to enable other systems to use it. Standardized languages such as Web Service Description Language (WSDL) or Web Application Description Language (WADL) can be used to syntactically describe a service. Textual service description documents contain textual descriptions of the semantics of the services, e.g. data semantics, functional semantics, and Quality of Service (QoS) semantics. If the use of a specific service is planned at the design time of a software system, the developers of this system can download these description documents, read and understand it and program their code accordingly. Machine-readable and processable descriptions of service semantics can be provided by an ontology, e.g. through a Web Ontology Language (OWL) document.
Advertisement: To use a service, potential consumer must know this service or be able to find it by service discovery. Typically, only the service name or the service name added by some key-value pairs expressing characteristic properties of services is used to register services. This information is by far not all information from the service description. Meta services can be used for targeted dissemination, dynamic dissemination can be realized via global platforms or central service registers. Universal Description, Discovery, and Integration (UDDI) and Domain Name Service for Service Discovery (DNS-SD) were approaches for a global service register (Bellwood, 2002).
Discovery: The intention of service discovery is to seek for an appropriate service in a communication network according to requester's requirements and descriptions of provided services (Dong, Hussain and Chang, 2013).

Selection: After discovering services whose descriptions match the requester's requirements, the most suitable service must be selected. Each service can have different quality aspects and authorization policies. Therefore, service selection involves evaluating these aspects for each service leading to a filtered by authorization rating called QoS. The selection can either be based on the information given in the service registry record, or on the whole service description documents. In the latter case, the service description documents must be downloaded, processed ("understood"), and evaluated by the requester.

Composition: Service Composition is the combination of a set of services for achieving a certain purpose by developing customized services by integration and execution of existing services. According to (Liegener, 2012) different service composition types can be distinguished: Orchestration, Choreography, Coordination, and Wiring. These variants differ in their technical implementation of a service call and the place of decision making.

Execution: Execution of a service, which may include physical or digital processes, e.g. a mechanical assembly or a complex calculation procedure. A service provider can also initiate complex interactions with the service consumer by message exchange during execution of a service. Data exchange during use can be performed via application protocols like http, OPC UA binary protocol, CoAP etc.

In a distributed system of CPS, service discovery is particularly important among the phases of the life cycle due to the challenge of evaluating heterogeneous service descriptions. These descriptions can be realized syntax based or semantics based (Zorgati, Djemaa and Amor, 2019). Syntax based descriptions are implemented as a list of predefined attributes, identified by keywords and values, whereby discovery is performed by a matching of these keywords and values to evaluate the QoS. provider and consumer each must know these keywords for a successful service binding, even a slight mismatch prevents a successful discovery. A syntax based can also be realized by matching the service name with the request. Semantics based descriptions are defined by ontologies, which contain classes for resources and services, adopt new resources and services as instances to the appropriate classes, link them by object properties and express their parameters by object or data properties. Services that meet requester's requirements in the ontology can be identified by specific search mechanisms, i.e. a semantics based is realized by a query on an ontology, e.g. by SPARQL.

3 Related Work

Many technologies and concepts appeared the first time by the mapping of software services in the web area. However, they have been adapted for other domains in recent years (Baumgärtel and Verbeet, 2020). DIN SPEC 16593-1 (DIN, 2018) defines a service as a mechanism to enable access to one or more capabilities, which must be provided by an Application Programming Interface (API). Tihomirovs and Grabis (2016) discuss the general approaches SOAP and REST for realizing a SoA and to design services. Providing services based on SOAP means to describe the service interface based on an interface language, such as WSDL (DIN, 2018). REST represents a programming paradigm for distributed systems in the context of web services, to simplify access to these services by using HTTP basic operations instead of adding a new data processing layer on the transmission and communication stack (Fielding, 2000).

In SOAP a service provider publishes this specific description to a service registry. Service consumers can use this service by requesting a instance (Tihomirovs and Grabis, 2016). DIN SPEC 16593-1 (DIN, 2018) describes SOAP-based web services as a technology that uses interface languages to allow a flexible choice of parameter names and its definition of their meaning. REST-based web services are managing self-defining resources and providing these resources which can be identified by a Uniform Resource Identifier (Tihomirovs and Grabis, 2016).

Zorgati, Djemaa and Amor define syntax based discovery as a mechanism using a protocol discovery based on a central service registry (2019). In this registry, each service has a unique identifier. Its properties are described either by its name or by an attached service description (Dong, Hussain and

Chang, 2013). Semantics based discovery relies on semantic web technologies to refer to services by ontologies.

A general example of a syntax based service discovery is based on the DNS mechanism (Klauck and Kirsche, 2013). DNS is still the most common approach for link domain and hostnames in URLs to IP addresses of physical computers. DNS-SD realizes a syntax based discovery (Klauck and Kirsche, 2013). DNS-SD allows services to be published and found by so-called DNS resource records (Cheshire and Krochmal, 2011). Another approach for the syntax based discovery is UDDI. It is motivated by the idea of a standardized directory of services (universal business registry). A business registration based on UDDI supplies three distinct sets of information: White Pages (address, contact, identifier), Yellow Pages (industrial categorizations based on standard taxonomies), and Green Pages (technical information about services). Service consumers are linked to service providers by a public brokerage system (Bellwood, 2002). Dong, Hussain, and Chang (2013) describe mechanisms for syntax based service discovery as hard to realize in an open environment with widely distributed resources. As a major obstacle, they describe the limitations of scalability and technical interoperability of heterogeneous systems in a commercial web environment.

With service description Languages (SDL) like OWL for Services (OWL-S) or Web Services Modeling Ontology (WSMO) web services can be described and made accessible as parts of larger domain ontologies (Dong, Hussain and Chang, 2013). Query languages like SPARQL, (Jacobs, 2010), can process their content (Harris and Seaborne, 2013). The semantics based approaches divide into hybrid and full semantics. Full semantics approaches use SDL to describe the services and apply semantics to discover them. A

hybrid-based approach uses SDL for description or apply semantics for discovery.
Dong, Hussain and Chang classify different technologies and methods of the semantic service discoveries with six categories, e.g. discovery architectures and matching approaches. The main options for discovery architectures are the use of registers and peer-to-peer based approaches. Matching approaches are divided into logic-based, non-logic-based, hybrid, and adaptive ones (Dong, Hussain and Chang 2013).
A similar survey by Zorgati, Djemaa, and Amor (2019) discusses different approaches for syntax and semantics based discovery and compares them according to IoT requirements. It categorizes the syntax based service discoveries that are using a protocol into CoAP-based, MQTT-based, and DNS-based discoveries. Semantics based approaches use description languages to describe services and semantics to find those services. In summary, many approaches use a register or a peer-to-peer mechanism for discovery and using description languages such as WSMO, SAWSDL, OWL-S, or WSDL-S for description.
Lobov et al. (2019) show a concept in which a combination of SoA and agents for service composition and discovery is presented. This approach uses an ontology to describe the capabilities of resources in a production environment and is an example of a hybrid mechanism of service description and discovery. A SPARQL query identifies the next resource for an upcoming production step. In contrast to other approaches, the mechanism searches for a requested production step instead of services. The description of the services is based on WSDL and can be assigned to the syntactic

description languages according to the classification of Zorgati, Djemaa, and Amor (Zorgati, Djemaa and Amor, 2019).

Fujii and Suda describe a framework consisting of three elements: CoSMoS, CoRE, and SeGSeC (2009). CoSMoS defines different resources together with their dependencies on operations. The approach uses an ontology for knowledge representation and applies different discovery technologies (Fujii and Suda, 2009). A semantic wrapper is used to translate a syntax based request into a semantics based.

Fumagalli et al. propose a similar approach using the digital platform eScop to combine embedded systems with an ontology-driven service-based architecture. (2014). The ontology describes a production system to enable service matching. This description is called eScop MSO and represents a type of domain ontology (Fumagalli, et al., 2014). Juan and Yanzhong define an OMS as a software system managing ontologies through their lifecycle containing its built, test, usage, and maintenance (2010). Within the European research project Productive4.0 another approach of an OMS is used. One aim of this project is to implement a digital platform for offering and searching diverse services (Ehm, et al., 2019). The architecture of this platform is described by Sipsas et al. (2020). Content of this platform is the Digital Reference (DR) Ontology, which combines knowledge of a supply network and is modelled by an ontology consisting of several small ontologies from different domains, e.g. production, process, and supply chain. This ontology can be regarded as a domain ontology and services described in OWL-S can be integrated into it.

4 Semantic Service Discovery

For the discovery of these services and their methods, three different approaches exist: syntax based, hybrid, and semantics based. It will be shown how they generally behave when their description is expanded by parameters, whereby a parameter in this context represents specific information of a service to distinguish it from other services, e.g. size or maximum weight. Figure 2 shows variants of different syntax based and semantics based discoveries. They differ in their mechanism for registry and discovery. A third variant combining both concepts using a semantic wrapper is also presented.

In a syntax based approach, parameters are stored in the service description documents and partially are encoded in the registration information of the services, i.e. the name and optional key-value pairs, to describe it as precisely as possible for discovery. Therefore, syntax based search depends on meaningful names of services and parameters that must be known by a requester in advance. In the syntax based variant, a provider registers a service by its name in the registry. When a service is requested, the requester contacts the registry. This request needs the specific name of the service the requester must know before. As a result, the registry responds to a list of all services and their endpoints, which match with the requested service.

The hybrid variant uses an additional semantic wrapper during service discovery (Fujii and Suda, 2009). The registration of a service by a provider is still syntax based using a specific name in the registry. However, a semantic wrapper is placed between the requester and the registry supporting a service request. The requester can query the ontology within the wrapper for services by using SPARQL. This ontology describes the properties (classes) and characteristics (individuals) of services. Each service is assigned with a name, which is stored in a data property of the individual. Therefore, the query process is based on two steps. First, the wrapper determines one or more syntactic names of services by a SPARQL query and uses those names to initiate a classic query at the registry. Now the wrapper submits an address, a name, or reference of the original requester to the registry in terms of "reply to". Thereafter a list with service names is sent to the requester by

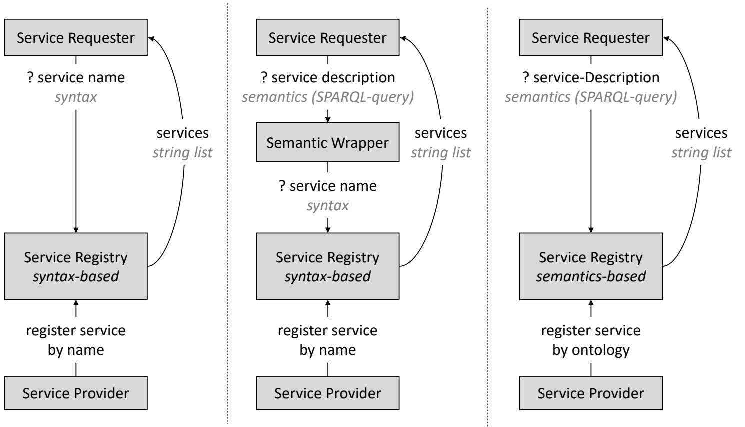


Figure 2: Approaches for Service Discovery: Syntax based (left), Hybrid (middle), Semantics based (right), own illustration

the registry. Registered services at a registry must be mapped into the ontology of the wrapper. This is done by a mapping process connecting the syntactic name of a service with existing classes and individuals of the ontology. Thereby a requester does not need to know the syntactic service name when making a request. It can also reach a service with different syntactic names if they are stored in the ontology.

In the full semantics based variant a wrapper is not necessary since service discovery is carried out exclusively semantically by an OMS, e.g. Apache Jena Fuseki. A provider registers a service at the registry using an ontology based service description. During this registration, a class of services is searched in the T-Box of the ontology describing this service to register it as an individual for this class, whereby any syntactic name can be chosen for the service. The registered service can be linked via relations (object properties) and matching properties (parameters), which both are included in the online hierarchy. A request by a SPARQL query is transferred directly to the registry respectively its ontology. This request finds corresponding services as individuals and results in a list with the names and endpoints of these services, which are stored as properties for the individual. A semantics based enables querying all parameters defining a service more precisely. Due to the specific search for a service using a SPARQL query only services matching requester's requirements will be shown. The requirements are a consistent structure of the ontology and a comprehensible classification of services as individuals in this ontology. Besides that, the semantics based approaches start with the description of the services that are transferred to a registry. These descriptions must be designed so that they can be inserted into an ontology. To achieve this, two main approaches exist:

The first approach requires a small ontology that is created by the manufacturer of a component for its service. Such ontologies can, for example, be expressed in OWL-S. This ontology is sent to the registry for registration.

By ontology merging the new partial ontology introduces all registered services into the already existing domain ontology in the registry (Martin, et al., 2004).

The second approach is that the service manufacturer sends a conventional list of parameters as key-value pairs, in which each element is supplemented by an annotation that refers to a known ontology. In the case of sensors, SOSA/SSN could be such an ontology. In this case, the target system operator would only have to announce in advance that he is working with the ontology. When registering, the key-value pairs and the service endpoints can then be included in the ontology of the registry according to their annotations. Additionally, the second case offers the possibility to be associated with an extension of the WADL file. For this purpose, WADL can use a reference to a grammar in the header, which is the basis of the description. Similarly, an element for one or more ontologies can be included in this header. The annotations are added to each element using additional XML tags or XML attributes. In such a case this would mean for the registry that there is consistency between the WADL file, and the parameters reported to the registry, provided that the parameters for the registry are filtered out of this file.

5 Use Case In-house Transport

The following chapter describes a semantics based discovery for an in-house transport task.

5.1 Scenario

A europallet stores a product which is requested to be transported to a supply location beneath an assembly line. The logistics of the production system contains various alternatives for transportation for carrying out this transport: forklifts, AGVs, and flying drones. They provide their capabilities as services that are registered at a central semantic service registry using an ontology. The product is represented by a digital twin, which takes care of its transport autonomously and can request a transport service. In addition to different technical properties and capabilities the heterogeneity of transport systems is increased by using systems purchased from different manufacturers. The delivery should be made by direct transport, i.e. no combination of different transport systems is considered. Besides restrictions for weight, the transport is also time-critical due to synchronization with assembly processes.

5.2 Syntax based Service Discovery

For realizing the shown use case, a system implements a central syntax based registry and discovery. In this system, components must register their service. Also, they store a description to describe this service and to define parameters as well as their value ranges. These parameters are necessary for the service request. This description must follow a standard format and structure, so that a centralized system can evaluate and take these services into account in discovery. If there is no standard like UDDI or DNS-SD, evaluation mechanisms must be implemented in this system for matching different descriptions. Alternatively, the system can read and interpret different formats and structures.

The Transport system registers the service "TransportService" and sends additional parameters to the registry to be stored in a database to be used for matching with service requests. Information for service registration can be sent in JSON format. Relevant parameters for the use case are Asset, MaxWeight, and MaxSpeed. The service could contain even more, e.g. Provider, NetworkID, and ServiceCall. Figure 3 shows an exemplary JSON description of a forklift service.

```
{
 "Service": "TransportService",
 "Provider": "Forklift 4712",
 "NetworkID": 151.12.5.125:23001,
 "Parameters ":
  {
   "Assets":["SLC", "Europallet", "Container"],
   "MaxWeight": 1500,
   "MaxSpeedValue": 1.5,
   "MaxSpeedUoM": "meter per second",
   "ServiceCall": ["Asset", "Weight", "Start", "Destination"]
  }
}
```

Figure 3: Syntax based description of a forklift service in JSON, own illustration

If a request is made, all descriptions of registered services filtered by the specified parameters. The system reports only services which fulfil the request. In the use case, a load carrier requests a "TransportService" with appropriate parameters for weight and speed. But for filtering for a specific speed, both the requested speed value and the correct unit of measure have to be stated in the query. As a result, the registry returns a list of providers. It can retrieve their services with the information of the service call.

5.3 Transport Ontology

The service ontology for an in-house transport is shown in figure 4, which is an excerpt of an ontology containing all resources and services of the warehouse and production system to illustrate the mentioned use case. It describes the five-class hierarchy moving_service, move asset, resource, data format, and protocol.

In the class moved_asset movable physical and digital handling units as well as humans are listed to describe transported objects. The individuals of respective subclasses can be used to describe a service more precisely by adding additional data properties.

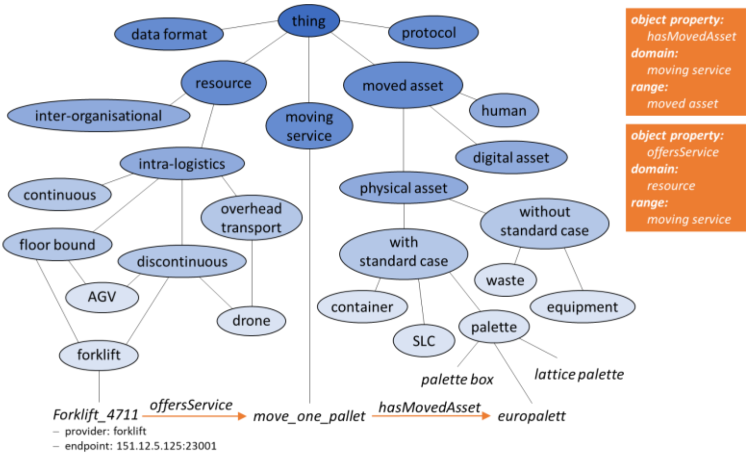


Figure 4: Service ontology for in-house transport, own illustration

In this use case europallet, palette box, and lattice palette are assigned to the palette subgroup as individuals. A specific maximum weight or standardized dimensions can be attached to these individuals via data properties.

The class moving service specifies existing services to transport a moved asset. The Resources are divided into "inter-organizational" and "intra-logistics". A corresponding service provided by forklifts is shown in figure 4 as an example of an in-house transport of pallets. Assets that are intended to use this service must possess the property "accessible for fork". Special application cases can be integrated analogously.

According to the system hierarchy of a SoA, a resource is a physical device representing a host whose integrated control software represents the software system providing a service. The resource forklift is assigned to "move_one_pallet", an individual of the class forklift transport service. This assignment is described by the object property "offersService" and at the same time implemented by a data property of type String containing the endpoint of the service. The endpoint represents information about the host and therefore can implicitly describe the provider. If resources are included, they can be connected to the services they provide via an object property. In figure 4 this is indicated by the class resource.

The properties used to classify services can be viewed as parameters for a request. Since a transport service can be described by various parameters and it becomes difficult to guarantee the completeness of the taxonomy, other parameters instead are created as separate sub-taxonomies in the ontology. The parameters contained in these sub-taxonomies are linked with appropriate services. Therefore, services are linked to the transported objects in the in-house transport use case. The classes moved asset (Range) and moving service (Domain) are linked with each other by the object property "hasMovedAsset". As an instance of the object property has moved asset, the individual move_one_pallet is assigned to the individual europallet of the subclass palette.

The classes protocol (e.g. HTTP) and data format (e.g. JSON, WADL) can be used for further specification of the service realization.

5.4 SPARQL-Query

A service discovery for the discussed in-house transport use case, using the presented ontology, can be realized by a SPARQL query. Figure 5 shows an exemplary query, which the digital twin of the product must process to find a suitable transport service. The SPARQL query contains an upper, mid, and lower area. The upper area names prefixes that contain different data sources. The middle area specifies the displayed information (SELECT) and restrictions for this information (WHERE) defines the lower area. In the SELECT clause all columns are displayed by using "*", that match all restrictions. It is filtered by conditions defined in the WHERE clause. These conditions describe the transport request. The first line returns all services in the system with their associated endpoints. Any transport services of individual resources represented in the ontology are added by the second line. The third line filters the results on all resources that can transport a europallet. The last six lines add filters to remove the services which are not matching the restrictions for weight and transport speed. The lines querying all existing values are first presented in pairs querying all existing values and thereafter filter them by a relational operator. In the in-house transport scenario these restrictions are “speed ≥ 0.8m/s”, “weight ≥ 1500kg”, and "amount of moved asset = 1".

A list of service endpoints and their resources are returned because of this

Data Source

```
PREFIX inlog: <http://www.semanticweb.org/anwender/ontologies/2020/3/untitled-ontology-41#>
```

Display Information

```
SELECT *
```

Restrict Information

```
WHERE  {?moving_service inlog:endpoint ?endpoint.
        ?moving_service inlog:hasMovedAsset inlog:europallet.
        ?moving_service inlog:transportSpeed ?TransportSpeed.
        Filter (?TransportSpeed >= 0.8).
        ?moving_service inlog:amountOfMovedAsset ?MovedAsset.
        Filter (?MovedAsset =1).
        ?resource inlog:offersService ?moving_service.
        ?resource inlog:maxTransportWeight ?maxTransportWeight.
        Filter (?maxTransportWeight >=1500).}
```

Figure 5: SPARQL query as Service Discovery, own illustration

query. Those endpoints are the network address of resources (host) on which the service software is running, added by the port of the service. The

SPARQL query of figure 5 lists move_one_pallet as possible moving service which can be offered by forklift_4712 and AGV_4731. The moving services of Forklift_4711 and drone_4721 does not correspond to the parameters of the SPARQL query.

The shown system was simplified for the presented use case, as it does not elaborate the methods of the services.

6 Discussion

Three types of service description are discussed in this work: (i) description of a service for registration, e.g. a record in DNS-SD with endpoint and key-value pairs expressing some important characteristics of the service,(ii) automatically processable service description, e.g. a WADL document or an OPC UA information model, and (iii) additional documentation of a service in form of a text document, e.g. service descriptions provided by the Service Description, Interface Design Description, and System Design Description in the Arrowhead documentation model (Delsing, 2017). It should be noted that the first kind is not referred to as "service description" by the SoA community, but as "service registration record" or "service advertisement information". However, the nature of this information is to describe a service so that it can used for discovery.

Many RESTful services and APIs rely on syntax based approaches for information for registry and machine processable descriptions. Both human-directed textual descriptions and machine-directed formalized descriptions like WADL documents carry any machine-processable semantics. WADL documents often describe only data formats instead of information semantics, and textual documents use examples for description which need to be understood by humans. Hence, automated service or API discovery and composition are not possible (Verborgh, et al., 2014).

Furthermore, a description used for registration is different from automatically processable descriptions by a WADL document Therefore, the existence of detailed descriptions and PDF documents does not say anything about how a service is registered and how it can be searched for.

A requirement for search of services is knowledge about names and various notations of a service and its characteristics describing keys and values. Without this knowledge a search query can only be based on educated guesses by which, many potential services may be missed, or, in case of very unspecific queries, too much inadequate services are returned. If every key with every value is queried, then the parameters have no restrictive effect on a search and the discovery of the right service might become time consuming. A semantics based mechanism does not need to know conventions of services provided or consumed by other systems regarding syntax of names and parameters with value ranges. Standardized specifications can be replaced by synonyms in the ontology. By using an OMS, a semantics based can handle a high number of combinatorial possibilities. In general, a semantics based discovery performs a parameter specific and thus a demand-oriented request. The query result better meets the query intention, even if exact names of services or parameters are not known.

The use case implementation from Section 5 delivers a proof of concept for the pure semantics based discovery approach. The main components for this approach are i) a semantic service description by an ontology, expressed in a standard ontology serialization format like OWL, ii) a domain ontology to which the description ontology can be linked or merged, iii) an OMS that contains both ontologies and acts as registry component of the SoA, and iv) the use of SPARQL as logic-based matching approach for query answering, that has to be provided as service by the OMS.

Since OMS and SPARQL services are often seen as standard in semantics based environments, it is important to mention them as necessary components for a semantics based discovery approach. Many authors focus in their papers on this subject on semantic descriptions or annotations of services. However, these descriptions can only be effective for service searches if they are managed by an OMS and the OMS is used as a service registration component. Hence, approaches for the implementation of Cyber-physical production and logistics systems (CPPS and CPLS) should use a general architecture as exemplified by the proof of concept.

Furthermore, for practical applications a well established domain ontology should be used. The DR Ontology, developed in the Productive4.0 project, is a promising approach for this. It can and will be extended by subsequent projects, e.g. with general domain descriptions for several industries (Ehm, et al., 2019).

The need for semantics based discovery approaches in CPPS and CPLS results from their inherent distributed, complex, and heterogeneous nature and the requirements on their dynamics. These systems are requested to be able to dynamically react to new situations, e.g. by dynamically reconfigure their processes and operations. This requires the ability to dynamically discover appropriate services and compose them. That is, the SoA realizing the IT part of these systems must be able to realize the "late binding" principle for services in heterogeneous environments with changing components and unknown service names. This contradicts with established software development approaches in the Web Service or RESTful http based service world, where service bindings are most often fixed at design time, or late binding bases on a priori known service names. There, textual, non-machine-readable service descriptions can be used by the software developers to know the names and understand the semantics of the services they want to use.

Even OPC UA does not fully support efficient late binding. Service descriptions as part of information models are automatically accessible and machine-readable due to the OPC UA standard services. However, to analyse the semantics of application services offered by an OPC UA Server requires to browse the information model, find and process the according data and conclude on the semantics. In case of many OPC UA Servers are available in a production or logistics environment, this must be performed for many different servers which makes the discovery, decision and composition inefficient. The reason behind this is, that OPC UA is not designed for highly dynamic systems, but to support efficient commissioning of components in production and logistics systems.

For late binding in the described context, existence of machine-readable and -processable descriptions of service semantics is mandatory. They must be used for service registry and discovery. With this, the information gap between information for registry and service descriptions can be minimized, and late binding can be executed efficiently.

7 Conclusion and future work

The presented work discusses three different type of service discovery: syntax based, hybrid, and semantics based. An in-house transport use case is provided showing the processing of a transport request for a europallet using a semantics based discovery. A limitation of syntax based service descriptions for registration and discovery regarding names, parameters and value ranges is discussed, revealing a requirement of specific knowledge about services in advance.
Also, a proof of concept for a pure semantics based discovery approach is presented, which can be divided in its four-part architecture, consisting of a semantic description, e.g. in OWL, a domain ontology, an OMS and the use of a logic-based matching approach like using a SPARQL query.
In further research, other use cases will be investigated for the applicability of a semantic discovery and composition in CPS. For this purpose, a flexible manufacturing system and an extended in-house transport system will be examined due to their high flexibility and complexity. The objective is to define solutions for open points like, e.g. the creation of a uniform general ontologyor the scalability performance of SPARQL queries, when the number of parameters and size of the ontology increases.

References

Baumgärtel, H. and Verbeet, R., 2020. Service and Agent based System Architectures for Industrie 4.0 Systems. In: B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel, eds. 2020. Handbuch Industrie 4.0. Industrie-4.0-Anwendungsszenarien für die Automatisierung. 3rd ed. Berlin, Heidelberg: Springer-Verlag.

Bellwood, T., 2002. UDDI Version 2.04: API Specification. [online] Available at: <http://www.uddi.org/pubs/ProgrammersAPI-V2.04-Published-20020719.htm> [Accessed 12 May 2020].

BMWi, 2017. Fortschreibung der Anwendungsszenarien der Plattform Industrie 4.0: Fortentwicklung des Referenzmodells für die Industrie 4.0-Komponente SG Modelle und Standards.

Cardoso, J. and Sheth, A., 2005. Introduction to Semantic Web Services and Web Process Composition. In: J. Cardoso, and A. Sheth, eds. 2005. Semantic web services and web process composition. First international workshop, SWSWPC 2004, San Diego, CA, USA, July 6, 2004 ; revised selected papers. Berlin: Springer, pp. 1–13.

Cheshire, S. and Krochmal, M., 2011. DNS-Based Service Discovery. [online] Available at: <https://tools.ietf.org/html/draft-cheshire-dnsext-dns-sd-11> [Accessed 12 May 2020].

Delsing, J., 2017. IoT automation: Arrowhead framework. Boca Raton, FL: CRC Press, Taylor & Francis Group.

DIN, 2018. DIN SPEC 16593-1. DIN SPEC 16593-1:2018-04, RM-SA_- Referenzmodell für Industrie 4.0 Servicearchitekturen_- Teil_1: Grundkonzepte einer interaktionsbasierten Architektur; Text_Englisch. Berlin: Beuth Verlag GmbH.

Dong, H., Hussain, F. K. and Chang, E., 2013. Semantic Web Service matchmakers: state of the art and challenges. Concurrency and Computation: Practice and Experience, [e-journal] 25(7), pp. 961–988. http://dx.doi.org/10.1002/cpe.2886.

Ehm, H., Ramzy, N., Moder, P., Summerer, C., Fetz, S. and Neau, C., 2019. Digital Reference – A Semantic Web for Semiconductor Manufacturing and Supply Chains Containing Semiconductors. In: 2019 Winter Simulation Conference (WSC). 2019 Winter Simulation Conference (WSC). National Harbor, MD, USA, 08.12.2019 - 11.12.2019: IEEE, pp. 2409–2418.

Fielding, R. T., 2000. Representational State Transfer (REST). [online] Available at: <https://www.ics.uci.edu/~fielding/pubs/dissertation/rest_arch_style.htm> [Accessed 12 May 2020].

Fujii, K. and Suda, T., 2009. Semantics-based context-aware dynamic service composition. ACM Transactions on Autonomous and Adaptive Systems, [e-journal] 4(2), pp. 1–31. http://dx.doi.org/10.1145/1516533.1516536.

Fumagalli, L., Pala, S., Garetti, M. and Negri, E., 2014. Ontology-Based Modeling of Manufacturing and Logistics Systems for a New MES Architecture. In: B. Grabot, B. Vallespir, S. Gomes, A. Bouras, and D. Kiritsis, eds. 2014. Advances in Production Management Systems. Innovative and Knowledge-Based Production Management in a Global-Local World. IFIP WG 5.7 International Conference, APMS 2014, Ajaccio, France, September 20-24, 2014, Proceedings, Part I. Berlin, Heidelberg, s.l.: Springer Berlin Heidelberg, pp. 192–200.

Harris, S. and Seaborne, A., 2013. W3C SPARQL 1.1 Query Language. [online] Available at: <https://www.w3.org/TR/sparql11-query/> [Accessed 12 May 2020].

Jacobs, I., 2010. Description of W3C Technology Stack Illustration. [online] Available at: <https://www.w3.org/Consortium/techstack-desc.html> [Accessed 13 May 2020].

Juan, Y. and Yanzhong, D., 2010. A Framework of Ontology Management System. In: E-Business and E-Government (ICEE), 2010 International Conference on. 2010 International Conference on E-Business and E-Government (ICEE). Guangzhou, China, 5/7/2010 - 5/9/2010: IEEE, pp. 1719–1722.

Klauck, R. and Kirsche, M., 2013. Enhanced DNS message compression - Optimizing mDNS/DNS-SD for the use in 6LoWPANs. In: 2013 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops). 2013 IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops 2013). San Diego, CA, 18.03.2013 - 22.03.2013: IEEE, pp. 596–601.

Liegener, B., 2012. Service Composition: Definitions. [online] Available at: <https://www.s-cube-network.eu/km/terms/s/service-composition/index.html> [Accessed 18 February 2020].

Lobov, A., Lopez, F. U., Herrera, V. V., Puttonen, J. and Lastra, J., 2019. Semantic Web Services framework for manufacturing industries. In: 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC). 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC). Bari, Italy: IEEE, pp. 2104–2108.

Martin, D., Burstein, M., Hobbs, J., Nokia, O. L., McDermott, D., McIlraith, S., Narayanan, S., Paolucci, M., Parisa, B., Payne, T., Srinivasan, N. and Sycaram, K., 2004. OWL-S: Semantic Markup for Web Services. [online] Available at: <http://www.w3.org/Submission/OWL-S>.

Moder, P., Ehm, H., Baumgärtel, H. and Ramzy, N., 2020. Semantic Web: Befähiger der Industrie 4.0. In: B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel, eds. 2020. Handbuch Industrie 4.0. Industrie-4.0-Anwendungsszenarien für die Automatisierung. 3rd ed. Berlin, Heidelberg: Springer-Verlag, pp. 1–25.

OASIS, 2006. Reference Model for Service Oriented Architecture 1.0: Committee Specification 1. [online] Available at: <http://www.oasis-open.org/committees/download.php/19679/soa-rm-cs.pdf> [Accessed 18 February 2020].

Sipsas, K., Zalonis, A., Broechler, R., Baumgärtel, H. and Ehm, H., 2020. A platform appliaction for exploiting the Digital Reference Ontology. In: IEEE International Conference on Industrial Cyber-Physical Systems 2020. Tampere, Finland, 10.06.2020 - 12.06.2020: IEEE.

Tihomirovs, J. and Grabis, J., 2016. Comparison of SOAP and REST Based Web Services Using Software Evaluation Metrics. Information Technology and Management Science, [e-journal] 19(1). http://dx.doi.org/10.1515/itms-2016-0017.

Verbeet, R. and Baumgärtel, H., 2020. Implementierung von autonomen Industrie 4.0-Systemen mit BDI-Agenten. In: B. Vogel-Heuser, T. Bauernhansl, and M. ten Hompel, eds. 2020. Handbuch Industrie 4.0. Industrie-4.0-Anwendungsszenarien für die Automatisierung. 3rd ed. Berlin, Heidelberg: Springer-Verlag.

Verborgh, R., Harth, A., Maleshkova, M., Stadtmüller, S., Steiner, T., Taheriyan, M. and and Van de Walle, Rik, 2014. Survey of Semantic Description of REST APIs. In: C. Pautasso, E. Wilde, and R. Alarcon, eds. 2014. REST: advanced research topics and practical applications. New York, NY, Heidelberg, Dordrecht: Springer, p. 70–70.

Zorgati, H., Djemaa, R. B. and Amor, I. A. B., 2019. Service discovery techniques in Internet of Things: a survey. In: 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC). 2019 IEEE International Conference on Systems, Man and Cybernetics (SMC). Bari, Italy: IEEE, pp. 1720–1725.

Identification of socio-technical changes caused by Industry 4.0

Felix Schnasse [1], Jörn Steffen Menzefricke [2], Stefan Gabriel [3], Daniela Hobscheidt [3], Matthias Parlings [1], Arno Kühn [3], and Roman Dumitrescu [3]

1 – Fraunhofer Institute for Material Flow and Logistics IML

2 – Heinz Nixdorf Institute University of Paderborn

3 – Fraunhofer Institute for Mechatronic Systems Design IEM

Purpose: Industry 4.0 provides significant potentials for companies. Despite the promising opportunities, companies, especially SME, are still hesitant to implement new technologies. The main reasons are far-reaching changes with respect to the socio-technical dimensions causing risks that are difficult to assess. This research provides a methodology to identify these socio-technical changes for Industry 4.0 use cases.
Methodology: Based on the three Design Science Research Cycles, a procedure and the corresponding methods for identifying socio-technical changes and risks during the introduction of Industry 4.0 will be designed.
Findings: The developed tool enables the derivation of use-case specific changes and risks in the socio-technical dimensions of human, technology and organization. These interactions have to be considered when introducing Industry 4.0 use cases in order to ensure a promising usage. In addition, the need for further research in the field of socio-technical risk management is identified.
Originality: Classical approaches do not address socio-technical interdependencies during the implementation of Industry 4.0 solutions. To bridge this gap, this methodological approach combines risk management and the concept of socio-technical system design.

First received: 14. Feb 2020 Revised: 15. Jun 2020 Accepted: 07. Jul 2020

1 Introduction

Progressive technological development in the form of information and communication technologies induces fundamental change in a wide range of sectors (Dowling 2016, p. 3). Digital transformation, digitization and Industry 4.0 are the frequently named catchwords by which this change is understood.

Industry 4.0 stands primarily for the digital networking of people, machines and companies through innovative information and communication technologies (Dowling 2016, p. 3). Intelligent networking and automation in particular are characteristic features of the current advancing change. Existing and proven technologies and processes are continuously being expanded or replaced by new ones (Forstner and Duemmler 2014, p. 200; Obermaier 2017, p. 31).

New technologies enable faster communication for companies, especially in the working environment, thereby creating shorter product development cycles and a more efficient use of resources (Forstner and Duemmler 2014, p. 199). Real-time capability, decentralized control and automation in production play a major role in this context and contribute to increased efficiency (Forstner and Duemmler 2014, p. 199; Appelfeller and Feldmann 2018, p. 8). Industry 4.0 also has an impact on interdisciplinary cooperation, for example by facilitating data exchange (Obermaier 2017, p. 293). It therefore stands to reason that companies want to recognise and exploit the opportunities of Industry 4.0 for themselves. New business areas, partners and customers can be acquired and the entrepreneurial competitive position can be improved. (Bitkom Research 2019, p. 9) Due to the rapid development, companies are challenged to identify suitable Industry 4.0 solutions and to implement them to their benefit. However, many companies are currently hesitant to take a comprehensive approach to Industry 4.0 (Staufen AG 2019, p. 9). This affects especially small and medium-sized enterprises. The reasons for this are manifold. For example, the low level of automation and the historically grown expertise of individual employees are often seen as obstacles to the adaptation of previously formulated Industry 4.0 concepts. (Ludwig et al. 2016, p. 73) Thus, Industry 4.0 has an equally impact on the employees, technology and the organization (Kauffeld and Maier 2020, p. 1).

The listed obstacles are reflected in risks which make companies shy away from the introduction of Industry 4.0. In order to be able to define measures to prevent or reduce these "socio-technical" risks, a better understanding about the reasons for the occurrence of these risks is essential. For this purpose, the changes which are associated with Industry 4.0 have to be identified. These are the triggers for the emergence of risks. Identifying the triggers is one of the most important steps in the risk management process (Romeike 2008, p. 39). Previous methods for identifying these socio-technical risks focus on individual instruments which are used separately for each area of expertise (compare e.g. Romeike 2003, p. 157). Moreover, they often do not address the triad of human, technology and organisation equally (Hobscheidt, Kühn and Dumitrescu 2019, p. 2). Against this background, the question is how socio-technical changes and risks can be identified holistically. In order to answer this question, the aim of this paper is to develop a process model that systematically leads companies through the process of identification. This will facilitate the introduction of Industry 4.0.

The following chapter first gives an insight into the basics necessary for the construction of a process model that is suitable with regard to the research question. At the end of each subchapter, requirements for the development will be defined. These requirements are part of the research design which is presented in chapter 3. On this basis, a process model for the derivation of socio-technical changes and risks is designed and applied as an example in chapter 4. The paper concludes with a summary of the results and further steps in the field of socio-technical risk management for the introduction of Industry 4.0.

2 Theoretical background

The aim of this chapter is an explanation of the relevant theoretical principles in the conext of socio-technical risk management and the derivation of requirements for the development of a process model. Due to the large number of different definitions of Industry 4.0, companies do not have an overview of which use cases are suitable for them to introduce (Greschke and Greschke-Begemann 2017, pp. 28-29). In order to build a suitable understanding and define the application framework of the model, the term "Industry 4.0 use case" is explained in more detail in chapter 2.1. Afterwards, chapter 2.2 focuses on the challenges of introducing Industry 4.0 in detail. This substantiates the need for an instrument that supports the introduction process. Chapter 2.3 then discusses the principles of risk management. These are used as the basis for deriving the process model. Finally, the significance of the concept of socio-technical system design is postulated in chapter 2.4.

2.1 Industry 4.0 use case

There are different interpretations of the term "use case" in the context of Industry 4.0 (VDE/DKE 2018, p. 87). One reason for this can be found in the various definitions of Industry 4.0 itself. For example, while some authors focus on the technical aspects, others extend this understanding to the function of Industry 4.0 and its effects on the entire value chain (Obermaier 2017, pp. 7-8; Roth 2016, pp. 5-6).

Against this background, the German Institute for Standardization (2018) differentiates between three interpretations of the term use case, which are compared to each other in Figure 1.

	Use Cases in the context of industry 4.0		
View	Business model logic	Technical system	Concrete project
Exemple(s)	Self-organizing adaptive logistics	Automated guided vehicle system	Introduction of an AGV, Introduction of a digital learning platform to empower employees for the AGV

Figure 1: Different interpretations of Industry 4.0 use cases according to (VDE/DKE 2018, pp. 87–88)

The similarity is that different stakeholders, in particular users and operators, will gain a better understanding of Industry 4.0 through the use cases. In this way, company-specific potentials, needs for action, challenges and solution approaches can be identified. Accordingly, a use case is a practical or research example in the context of Industry 4.0. (VDE/DKE 2018, pp. 87-88; Fay, Gausemeier and ten Hompel 2018, p. 6; Kohl et al. 2019, p. 2) The business model logic maps use cases in the form of scenarios at a high level of abstraction, which act as idea generators. By contrast, use cases in the form of a technical system can be used to derive specific requirements for functionality, architecture and interoperability. On the other hand, the concrete projects provide information about the greatest need for action from a market perspective. In addition to the hardware, supporting processes such as the introduction of a digital learning platform are also included. (VDE/DKE 2018, pp. 87-88) As concrete projects are particularly suitable for the derivation of risks, this perspective will be taken as a basis in the following.

Use cases in the form of concrete projects are recorded in application collections. For example, the platform Industry 4.0 from the Federal Ministry for Economic Affairs and Energy lists over 350 concrete application examples in the so-called Industry 4.0-Map. This enables users and operators to select and adapt the appropriate use cases for their specific needs. (Platform Industry 4.0 2020; Platform Industrie 4.0 2016, pp. 6-7) Application collections form the basis for the identification and characterization of relevant use cases.

Requirement 1: Enabling companies to select suitable Industry 4.0 Use Cases.

In the course of the implementation of these Industry 4.0 Use Cases, a number of challenges arise, which will be explained in more detail subsequently.

2.2 Challenges during the implementation of Industry 4.0

According to a 2019 study by STAUFEN AG, 48 percent of the surveyed companies are already implementing individual Industry 4.0 initiatives. However, only eight percent of the companies manage the step from individual initiatives to comprehensive transformation. This applies in particular to mechanical and plant engineering (Staufen AG 2019, p. 10). This is due to the challenges that companies are facing in course of introducing Industry 4.0. Therefore, prerequisites must be created for Industry 4.0. For example, a suitable infrastructure is required to be able to implement innovative technologies (Forstner and Duemmler 2014, p. 199). However, the implementation of innovative Industry 4.0 solutions does not only have a technological impact on companies. Rather, information and communication

technologies are changing structures, business processes and value chains (Lipsmeier et al. 2019, p. 3; Krause and Pellens 2018, p. 194; Kreutzer, Neugebauer and Pattloch 2017, p. 122). Especially because these changes are not fully visible in advance, it often seems too costly for companies introducing comprehensive technological solutions (Andelfinger and Haenisch 2017, p. 69). These technology-induced changes can give rise to a variety of risks that can hinder successful implementation and subsequent profitable operation (Schuh et al. 2020, pp. 33-34). On the one hand, these changes affect the technical infrastructure. With each new technological solution, the requirements to be ensured, e.g. for IT security and interfaces in the company increase. Many companies are not yet sufficiently equipped to comply with the new security standards (Bitkom Research 2019, p. 12; Andelfinger and Haenisch 2017, p. 100).
On the other hand, there are changes for the employees, who are also significantly involved in the successful introduction of new solutions. New types of human-machine interactions create new ways of working, for which the employees have to be prepared. If new technologies are not used due to a lack of acceptance by the employees, the introduction has failed (Staufen AG 2019, p. 22). This type of changes will be found along the entire value chain. From the initial development by means of novel programs up to production, in which, for example, assistance systems are supposed to support the employees, problems of acceptance may occur (Kauffeld and Maier 2020, p. 1; Obermaier 2017, p. 297).
In addition to the changes in the technological infrastructure and employees, the changes also affect the organisation of the companies. The organisation is not only confronted with the financial risks of new innovations. It

is possible that new technologies require adaptations in existing processes and therefore cannot be easily implemented in existing company structures. As a result, complex restructuring may become necessary in order to use the new technologies to create value (Leyh and Bley 2016, p. 30; Obermaier 2019, p. 356).

The outlined changes represent a breeding ground for risks that could be decisive for the failure of Industry 4.0. An isolated consideration of the technological risks is not sufficient here, since the changes affect the employees and the organization of the company equally (Kauffeld and Maier 2020, p. 1).

Requirement 2: Identification and assessment of potential risks during the implementation of Industry 4.0.

In order to treat risks by developing measures as soon as the risks arise, their causes have to be identified first. Classical approaches of risk management alreadyprovide support in this process. The basic principles of risk management are explained in the following section.

2.3 Foundations of risk management

The term risk management is used to describe "coordinated activities to manage and control an organization with regard to risks" (DIN ISO 31000:2018, p. 7). The risk management norm ISO 31000 defines guidelines for dealing with risks. A risk is defined in the norm as "the effect of uncertainty on targets" (DIN ISO 31000:2018, p. 7). In this context, an effect is understood as a "deviation from the expected" (DIN ISO 31000:2018, p. 7), which can initially be either positive or negative. Whether risks arise depends on certain events that occur with a certain probability. The result of an event is called an effect. Risks can be controlled by taking measures. (DIN ISO 31000:2018, pp. 8-9)

The use of risk management is often described by using the reference process shown in Figure 2. In practice, this process is carried out iteratively. The first step of the reference process is to define the scope of application and the setting. This includes the establishment of risk criteria, which have to be set in relation to the targets. The criteria define the type and scope of risk that is accepted by the organization. The second step is the risk assessment, which includes risk identification, risk analysis and risk evaluation. (DIN ISO 31000:2018, pp. 17-23) First of all, the step of risk identification requires the identification of changes that give rise to the risks. Only when these changes are recorded, risks can be identified holistically. (Ellebracht, Lenz, and Osterhold 2011, pp. 80-81). In the second step of the risk analysis, risks are to be described, for example, by means of the causes and effects, whereby the level of risk can be derived. In the risk evaluation, based on the risk analysis, a comparison to the previously defined risk criteria is done, in order to decide on additional actions, such as options for risk treatment or further analyses. The third step is the risk treatment. This includes the selection of measures to influence the probabilities and effects of risks (DIN ISO 31000:2018, pp. 17-23).

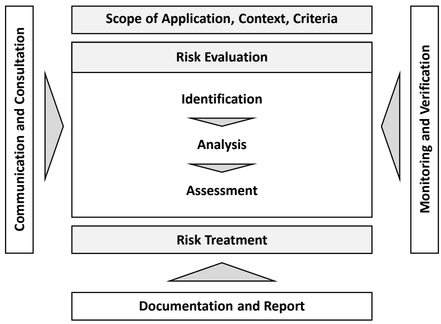


Figure 2: Reference process for risk management according to ISO 31000 (DIN ISO 31000:2018, p. 16)

These three steps are pursued through accompanying activities designed to ensure the success of risk management. Through the regular communication and consultation, opportunities are provided to involve relevant stakeholders and thereby to gather sufficient information, opinions and know-how at each step of the risk management process. The monitoring and verification process ensure the quality and effectiveness of the risk management process. The documentation and reporting aim to communicate the results of the risk management process across the organisation. This is intended to provide information for decision making and to improve risk management activities at the same time (DIN ISO 31000:2018, pp. 17-23).

Building on or extending on the guidelines of this risk management norm, there are numerous other works by various authors, which often focus on a specific risk management issue. Wolke (2008, p. 4) defines a reference process similar to the norm with the four steps risk identification, risk measurement and analysis, risk management and risk controlling. He divides operational risks into external and internal risks, which are divided into personal, process and system risks (Wolke 2008, pp. 201-202). Oehmen (2019, pp. 9-10) sees the ISO 31000 norm as the basis for value-added risk management. This should not be a burden for companies, but should contribute to value creation as a natural part of development. An essential part of this is the adaptation of the risk management process to specific requirements. As an example, a reference process for product development is presented based on the ISO 31000 norm (Oehmen 2016, p. 64).

Hopfener and Bier (2018, pp. 10-11) look at risk management in the context of digitization and see risk management as being moved into a new role in the future due to digitization. According to a survey it is expected that in risk management the advisory function as well as a control function coordinated with the corporate strategy will become increasingly important. This requires a close integration of corporate strategy and risk strategy. To control the corporate targets in a risk-oriented manner, a risk strategy derived from the corporate strategy is required. The knowledge gained from risk management can in turn be used to continuously review and adjust the corporate strategy. In addition to this new role, a change in risk management methods is also expected. An increasing use of standardized processes and quantitative mathematical models (e.g. big data analyses) in risk management is predicted. This allows a more reliable analysis of risks as well as a more transparent provision of information. It also enables risk management to be more closely integrated into strategic issues and to contribute to value creation (Hopfener and Beer 2018, pp. 10-16).

The focus of this paper is primarily on the phase of risk identification, because risks cannot always be identified and assessed due to a lack of information (Gunkel 2010, p. 59). In this context, Romeike (2008, p. 39), for example, describes the gathering of information as the most difficult phase in the entire risk management process, but at the same time it has a key function for the subsequent phases. Therefore, this paper will take a closer look at this important part of the risk management. In addition, a first evaluation of these risks is made.

Requirement 3: Capturing changes in order to understand the background of the emergence of risks by using established structures from the field of risk management.

Through its involvement in strategic issues, especially in the context of Industry 4.0, risk management affects the company as a whole. There are various ways to structure this holistic approach. The socio-technical systems approach is used in many disciplines to structure the technology-induced changes. This will be discussed in the following chapter.

2.4 Socio-technical structuring framework

As already apparent in chapter 2.2, it is not sufficient to consider only technological factors when introducing Industry 4.0 solutions. For example, the use of autonomous guided vehicles in intralogistics requires optimally coordinated collaboration between human and machine, for example by stopping the transport robots when necessary and allowing employees to correct malfunctions. In addition, the use of robots requires an optimization of processes, which in turn requires the experience and knowledge of the employees. The introduction of new technological solutions must

therefore be considered together with the organizational and personnel elements and especially with regard to their interfaces and interactions (Hirsch-Kreinsen et al. 2016, pp. 10-13).
A general connection between the technological, organisational and human elements is described by the concept of the socio-technical system. The socio-technical system is defined as follows by Hirsch-Kreinsen and Weyer (2014, p. 11) in reference to Rice (1963, pp. 181-185):
„A socio-technical system can be understood as a production unit consisting of interdependent technological, organisational and personnel subsystems. Although the technological subsystem limits the design possibilities of the other two subsystems, the latter have independent social and work psychology characteristics, which in turn have an impact on the functioning of the technological subsystem. Moreover, the overall system is always in close interaction with its environmental conditions." (Hirsch-Kreinsen and Weyer 2014, p. 11; Rice 1963, pp. 181-185).
With this definition, Ulich (2013, pp. 4-5) describes the three dimensions of human, technology and organisation in the context of socio-technical system design. These three dimensions always have to be considered in their interdependence and can only be optimised together. Ulich (2011, p. 111) captures as the human dimension the social system with aspects such as task characteristics or personal development. The dimension technology includes the technical system, such as production systems in the manufacturing process. The dimension organisation forms the framework for linking the social and technical systems and can be considered at different levels such as the entire company or other organisational units. (Ulich 2013, pp. 4-7) According to these definitions, a clear classification into the three

dimensions human, technology and organisation is possible. However, there are many different illustrations in the literature that show differences in the assignment of aspects to the respective dimension.

Hobscheidt, Kühn and Dumitrescu (2019, pp. 2-3) have analysed these different aspects of the dimensions of the socio-technical system with regard to the frequency of their mention in each dimension in the current literature and have formed clusters. These are named components. For the dimension technology, the resulting components are automation, IT systems and data management. For the dimension organization the components culture, knowledge and processes and organization were created. In the dimension human the resulting components are collaboration, qualification, cooperation and work task. The three dimensions with their respective components are shown in Figure 3.

The need to take equal account of technological, organizational and human elements in risk management becomes already apparent in Wolke (2008, pp. 201-202). He classifies risks into personal, process and system risks, which corresponds to a similar classification to the three dimensions of human, technology and organization. But a holistic socio-technical consideration of risk management is not yet taking place. To bridge this gap, the procedure model has to combine the field of risk management with the concept of the socio-technical system design.

Requirement 4: Consideration of the dimensions human, technology and organization for a holistic collection of changes and risks.

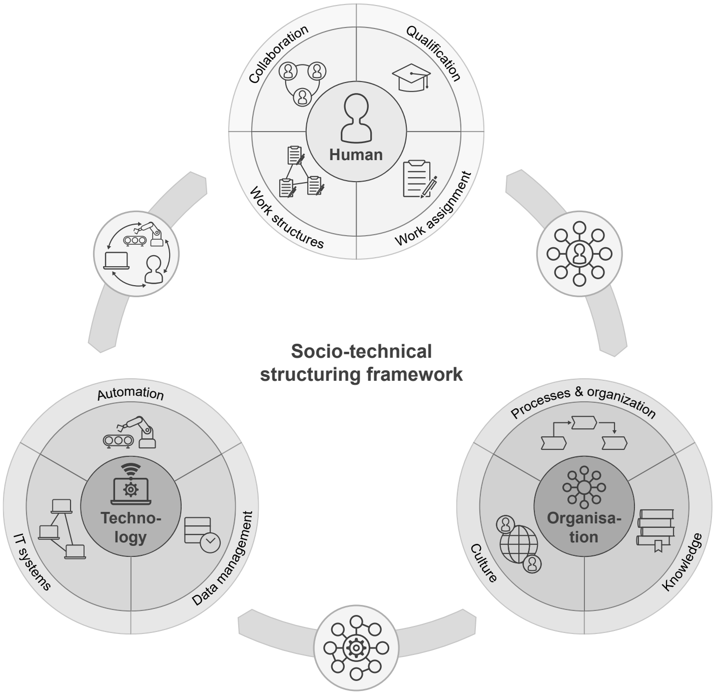


Figure 3: Socio-technical structuring framework (Hobscheidt, Kühn and Dumitrescu 2019, p. 2)

3 Research Design

The approach for the development of a process model is based on the design science research cycles from Figure 4 by Hevner (2007). This method-

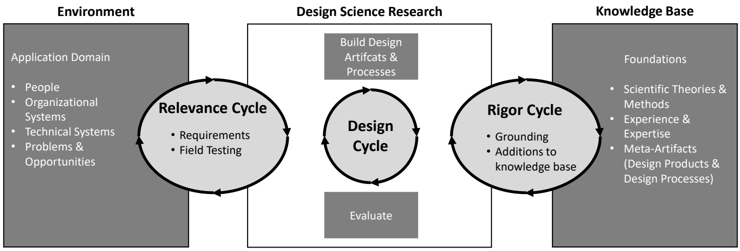


Figure 4: Design Science Research Cycles (Hevner 2007, p. 89)

ology is structured into three inherent research cycles. The relevance cycle bridges the design science activities with the contextual environment of the research project. Whereas the rigor cycle connects the knowledge base of scientific foundations, experience and expertise with the design science activities. The central design cycle uses the information from the rigor cycle and the relevance cycle to iteratively develop new design artifacts and processes. (Hevner 2007, p. 89) In this case, the goal is to develop a process model for the identification of risks, which is based on various methods.

In order to capture the theoretical foundations, the relevant basics for the development of a process model have already been presented in chapter 2. As these fundamentals have a strong practical relevance, requirements were derived which reflect the relevance of a process model for the identification of risks. Thus, in the context of the relevance cycle, not only requirements for the research are provided as input, but also acceptance criteria for the final evaluation of the research results are defined (Hevner 2007, p. 90). In the following, the defined requirements are summarized:

- Requirement 1: Enabling companies to select suitable Industry 4.0 Use Cases.
- Requirement 2: Identification and assessment of potential risks during the implementation of Industry 4.0.
- Requirement 3: Capturing changes in order to understand the background of the emergence of risks by using established structures from the field of risk management.
- Requirement 4: Consideration of the dimensions human, technology and organization for a holistic collection of changes and risks.

In order to fulfill these requirements, a process model was developed within the design cycle. This is presented in chapter 4. To exploit the potential of the developed approach, workshops were performed with four companies in the context of the field tests. Thereby real solutions in the form of use cases were used and evaluated by using the procedure model. 13 company experts took part in these workshops. The companies come from various sectors, with sizes varying from small and medium-sized enterprises to large companies. This resulted in a diversified picture for the identified risks.

4 Methodology for the derivation of use case specific changes

The introduction of Industry 4.0 involves a variety of changes, which in the worst case also entail risks (see section 2.2). These can prevent a successful implementation, especially for SMEs. In order to capture these risks holistically and to be able to derive adequate measures to avoid or reduce them, the changes that trigger the risks have to be identified first. In this context, it is not sufficient to capture only the technological changes. The organization and the human are also affected by the change. Against this background, a sequential process model was developed to identify socio-technical changes and risks during the introduction of Industry 4.0. As explained in chapter 3, the development is based on the design science research approach. The aim was to develop a process model that fulfills the identified requirements. The model is shown in Figure 5. In the following, the individual steps are described in more detail and exemplarily applied to a concrete Industry 4.0 use case of one of the involved companies.

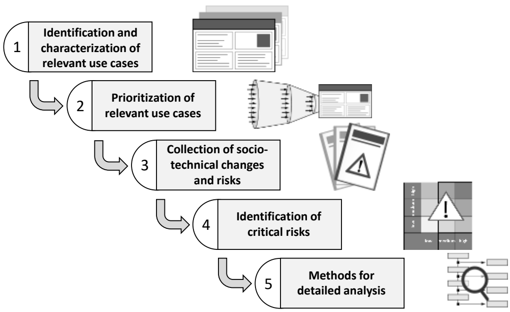


Figure 5: Process model for the identification of socio-technical changes during the introduction of Industry 4.0 use cases

4.1 Identification and characterization of relevant Industry 4.0 use cases

In order to support companies in the selection of Industry 4.0 Use Cases according to requirement 1, a knowledge base of the current possibilities in the context of Industry 4.0 has to be established first. Therefore, the first step of the process model aims at the collection of Industry 4.0 use cases, which offer potentials for the respective company. For this purpose, the range of use cases from the different fields of application has to be shown first, before a concrete selection can be made by internal experts. The application collections described in chapter 2.1 provide a basis for this, visually demonstrating companies the diverse possibilities of Industry 4.0. In addition, the targeted search for scientific publications or the exchange of experience with the surrounding business environment are also helpful sources of information. These external sources are supplemented by internal sources, such as the company's own employees, who can provide helpful impulses through their experiences (Wellensiek et al. 2011, pp. 140-169; Kohl et al. 2019, p. 6).

As the use cases form the basis for deriving socio-technical changes and risks, a uniform understanding is essential. For this purpose, the selected use cases can be characterized by using fact sheets which have the property of presenting essential aspects in a shortened form and thus make information easy to transport. In addition, they are suitable for comparisons among themselves and serve as a basis for discussion (Wellensiek et al. 2011, pp. 138). Against this background and with respect to the following prioritization in chapter 4.2, the profile shown in Figure 6 was designed. In addition to a brief description, the fact sheets contain an assessment of the maturity using three levels based on Bischoff et al. (2015, pp. 25-26) and Schuh et al. (2011, pp. 43-44):

Basic-solution: This includes Industry 4.0 use cases, whose market potential has been greatly exploited. No exclusive knowledge is required for the application and therefore no unique selling point is achieved with this solution. However, its use is still a market standard and the abandonment of this application would have negative competitive consequences. Since the solution is already established, there is no uncertainty about its performance.

Key-solution: This level covers Industry 4.0 solutions with a large economic potential that are already established on the market. However, since they are not available to all competitors, their use can create significant competitive advantages. Since the application is reserved for only a few experts, there is a medium uncertainty with regard to the performance. As the application is reserved for only a few experts, there is a medium uncertainty with regard to performance.

Pacemaker-solution: Pacemaker solutions are expected to have a high economic potential. Since they are still in the development phase, there is a high degree of uncertainty whether the solution will become established in industry.

In addition to the maturity level, those areas of the value chain which are directly affected by the introduction of the use case have to be marked. This, as well as the assessment of the maturity level, provides the first indications for the derivation of desired potentials and challenges, which are then also recorded in the fact sheets. These four elements serve as a basis for the company specific pre-selection of the Industry 4.0 use cases, as they

show first findings about the consequences of the introduction and the associated risks.
In figure 6 the fact sheet of the use case "Data acquisition and analysis in the system for generating smart services" is presented as an example. This has been shortlisted, in addition to the introduction of agile development teams and the introduction of a customer-integrated development team. In essence, this involves the collection of machine data, which is to be used for new services, such as predictive remote maintenance of machines. In order to achieve a consistent understanding of the process model, the next steps are explained by using this use case as an example.

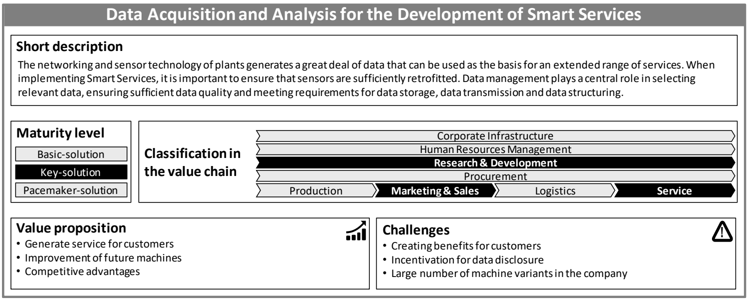


Figure 6: Exemplary fact sheet for the description of an Industry 4.0 use case

4.2 Prioritization of relevant use cases

In order to select a promising use case and to fulfill requirement 1, a ranking of the pre-selected use cases needs to be generated. The use case with the highest priority offers the potentially highest added value for the company. From the field of methods for investment decisions, the instruments of ben-

efit analysis are particularly suitable for this application, since it is uncomplicated in its use and is bound to only a few preconditions (Buses von Colbe, Laßmann and Witte 2015, p. 311). With the benefit analysis, a methodology is selected that focuses primarily on the non-monetary aspects for the multidimensional evaluation of action alternatives (Busse von Colbe, Laßmann and Witte 2015, p. 312; Weber and Schäffer 2014, p. 313). In the literature, different forms of benefit analysis are discussed (Zangemeister 1976, p. 252-255.; Blohm et al. 2012, p. 161-163). This paper distinguishes four steps, based on Busse von Colbe, Laßmann and Witte (2015), which will be transferred to the application framework of this paper in the following.
At the beginning of the benefit analysis, evaluation criteria have to be defined. For this purpose, the five criteria according to Hobscheidt, Kühn and Dumitrescu (2019, p. 5) are used. These were identified as part of the development of risk-optimised implementation paths for Industry 4.0 based on socio-technical patterns:

- High strategy fit: devisional strategy, strengthening of core competence, competitive relevance
- High urgency: competitive pressure, customer pressure, internal preparations
- Low expenditure: personnel expenditure, cost expenditure, project scope
- Low risk: market risk/competitors, acceptance/motivation of employees
- High benefit: economic efficiency, satisfaction of employees/customer, further development of the company

In the second step, the evaluation criteria are related by weighting them according to their relevance for the user. The method of pairwise comparison can be used for this. The following third step consists in determining the partial utility values for each criterion and each use case (Busse von

Colbe, Laßmann and Witte 2015, pp. 315-316). A five-level Likert scale ("0 - does not apply at all" to "4 - fully applies") can be used for the assessment (Blasius 2014, pp. 1051-1062). The partial utility values are then obtained by multiplying the weight factor by the estimate from the Likert scale. In the last step, the individual partial utility values per use case are added together to calculate the total utility value. The highest total utility value represents the use case with the highest potential for the company (Busse von Colbe, Laßmann and Witte 2015, pp. 318-321).

In the selected application example from the research project, the use case from figure 6 was rated highest. An excerpt from the benefit analysis is shown in figure 7.

Evaluation Criteria 4 = Agree completely . . . 0 = Disagree completely	Weighting [%]	Industry 4.0 Use Cases				
		Data Acquisition and Analysis for the Development of Smart Services		Introduction of Agile Development Teams		
		Rating (1-3)	Partial Utility Rating x Weight.	Rating (1-3)	Partial Utility Rating x Weight.	
High Strategy Fit	40,00	3	120,00	2	80,00	
High Urgency	0,00	3	0,00	2	0,00	
Low Effort	10,00	2	20,00	2	20,00	
High Benefit	30,00	3	90,00	1	30,00	
Low Risk	20,00	2	40,00	2	40,00	
Total Utility			**270,00**		**170,00**	

Figure 7: Excerpt from the benefit analysis of a company

4.3 Collection of socio-technical changes and risks

After the selection of Industry 4.0 use cases has been prioritized, the third step involves the identification of the changes accompanying with the introduction and the resulting risks. For this purpose, a canvas was designed based on the Business Model Canvas by Osterwalder and Pigneur (2010) against the background of socio-technical risk management for each of the three dimensions of human, technology and organization. The canvas for the dimension organization is shown exemplarily in figure 8. The canvas shows results that were developed in cooperation with an industrial company. For this reason, the results have been made anonymous and slightly modified. The contents are recorded individually for the three dimensions and for each Industry 4.0 use case. Depending on the components of the socio-technical structuring framework of Hobscheidt, Kühn and Dumitrescu (2019, p. 2) of chapter 2.4, the changes are first identified. These form the basis for the derivation of risks. Thereby, the identified risks could address several dimensions. The components serve as an aid for the derivation of concrete changes and risks. In order to generalize these use case-specific risks, risk categories are finally defined and evaluated hierarchically.

With the help of the presented canvas, changes as well as risks can be derived for each of the socio-technical dimensions, whereby requirements 2, 3 and 4 are fulfilled.

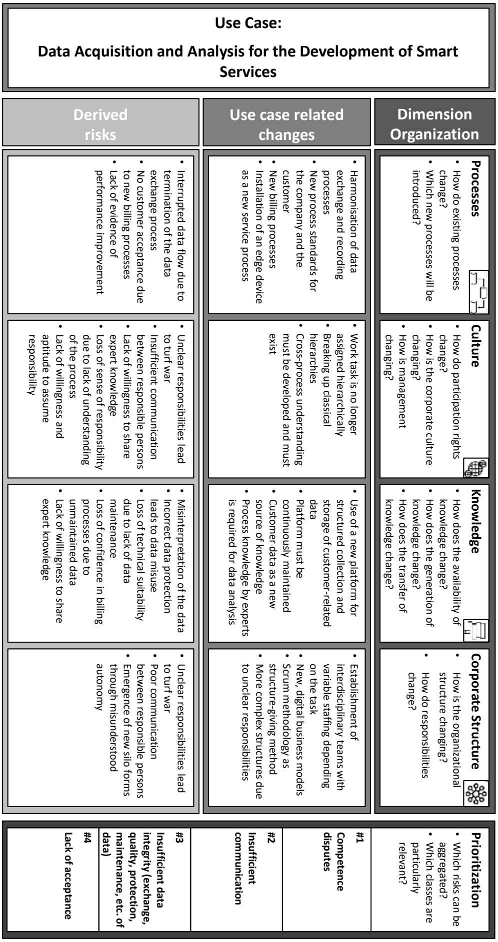


Figure 8: Canvas for the identification of changes and risks in the dimension organization using the example of Smart Services

4.4 Identification of critical risks

As the resources especially of SMEs are often limited (Müller 2016, p. 8), measures cannot be derived for all risks. Therefore, and with regard to requirement 2, which requires an initial assessment of the risks, the fourth step of the process model is to identify the particularly critical risks. For this, following Brauweiler (2018, pp. 8-11), the assessment of the dimensions of probability of occurrence and damage potential per risk is suitable. The assessment is made by company experts. To facilitate the assessment of damage potential, the criteria from chapter 4.2 of Hobscheidt, Kühn and Dumitrescu (2019, p. 5) can be used as a guide. The assessment of the probability of occurrence reveals itself to be much more difficult. In order to get hints for this evaluation as well, the Quick Check Industry 4.0 from the research project INLUMIA can be used (Pierenkemper et al. 2019, p. 31). By determining the actual state of the dimension's technology, business and human, conclusions can be drawn about the potential probability of occurrence of the risks. Thus, for example, the assessment of the company's decision-making structure in "central" or "collective" (Inlumia 2020), can lead to findings about the probability of the risk cause "unclear responsibilities". The assessment of the damage potential and the probability of occurrence in low, medium and high is shown in a risk matrix. The coloring of the individual areas additionally symbolizes the significance of the individual risks. The risk with the highest probability and the highest extent of damage should be examined more closely in the next step.
Figure 9 shows an example of a possible classification of critical risks. Here, as an example, the risks in the component culture of the dimension organization from the application example were evaluated. In this case, the risks "loss of sense of responsibility due to lack of understanding of the process"

and " lack of willingness and aptitude to assume responsibility" must be examined more closely.

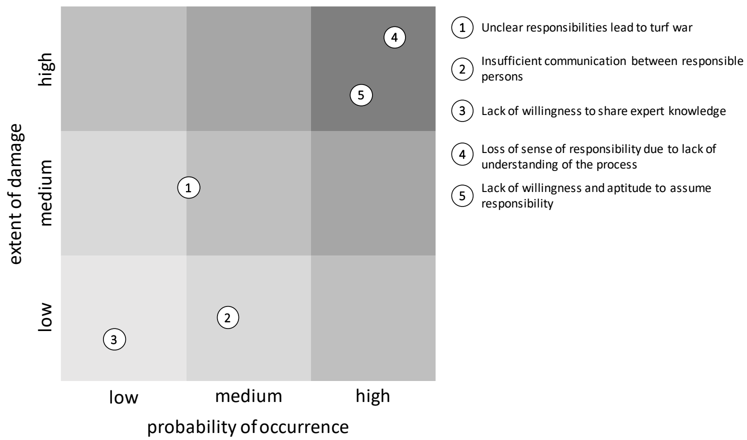


Figure 9: Risk matrix for identifying critical risks according to (Brauweiler 2018, p. 10)

4.5 Methods for detailed analyses

In order to obtain a better understanding of the risks and to fulfill requirement 2, the critical risks identified in chapter 4.4 have to be analysed in more detail. For this purpose, a toolbox has been developed, which explains different methods in the form of fact sheets for each socio-technical dimension. Thereby, in addition to the objective, the usage hints, the advantages and disadvantages as well as the concrete approach of the methodology, an evaluation is also presented. Here, the criteria difficulty factor, level of detail of the results, required employee capacities as well as the time required are roughly rated on a four-level scale. It should be noted that the actual effort can vary depending on the individual application. Nevertheless, the evaluation provides a first indication of the scope of the respective method, which should facilitate the selection.

The in-depth analysis of the critical risks forms the basis for deriving efficient measures to avoid or reduce the risk causes. The selection of a suitable method depends on the components of the dimension of the risks. Figure 10 shows a simplified version of the toolbox. An exemplary method from the dimension human is the stakeholder analysis. With it, for example, target groups can be identified which are particularly affected by a change. These groups are usually those with the highest risk potential.

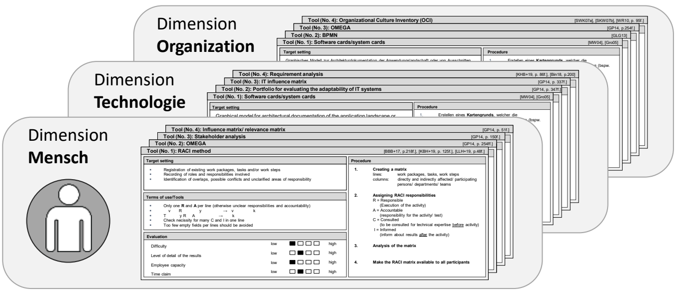


Figure 10: Toolbox for in-depth analysis of the critical risks

5 Conclusion and further research

This paper highlights the various changes during the introduction of Industry 4.0. These represent a breeding ground for risks, which makes particularly SMEs shy away from the implementation of Industry 4.0. The changes that occur during the implementation process relate not only to the technological aspects but also to the human and the organization. Against this background, classical risk management was linked with the sociotechnical systems approach. The focus was on the phase of risk identification. In order to derive suitable measures to avoid or reduce risks, the concrete changes that trigger these risks have to be identified and understood first. This phase of risk identification represents one of the most challenging tasks in the field of risk management. For this reason, a five-step process model was developed, based on the research cycles of design science by Hevner (2007). This process model enables companies to derive socio-technical changes and risks depending on their specific Industry 4.0 use case and the individual company requirements. Methods were developed for the individual stages of the process model, which were validated in practice in cooperation with companies. These methods allow a detailed analysis to understand the manifold reasons for risks.

Based on the identified socio-technical changes and risks, the next step involves the identification of interactions between risks among each other and between different socio-technical dimensions. These interactions also affect the selection of appropriate countermeasures to avoid or reduce risks. In addition, for a selection, risk strategies have to be defined first, which are in line with the corporate strategy.

Financial Disclosure

The results of this paper are based on the research project SORISMA - socio-technical risk management for the introduction of Industry 4.0, funded for three years with around 2.7 million euros by the European Regional Development Fund (ERDF).
The NRW Research College "Design of Flexible Working Environments – Human-centered Use of Cyber-Physical Systems in Industry 4.0" supports doctoral projects from various disciplines, for example to research technology-induced changes within the working environment.

References

Appelfeller, W. and Feldmann, C., 2018. Die digitale Transformation des Unternehmens. Berlin, Heidelberg: Springer Berlin Heidelberg.

Andelfinger, V. P. and Hänisch, T., 2017. Industrie 4.0. Wiesbaden: Springer Fachmedien.

Bischoff, J.; Taphorn, C.; Wolter, D.; Braun, N.; Fellbaum, M.; Goloverov, A.; Ludwig, S.; Hegmanns, T.; Prasse, C.; Henke, M.; ten Hompel, M.; Döbbeler, F.; Fuss, E.; Kirsch, C.; Mättig, B.; Braun, S.; Guth, M.; Kaspers, M. and Scheffler, D., 2015. Erschließen der Potenziale der Anwendung von Industrie 4.0 im Mittelstand. BMWi. Mülheim an der Ruhr: agiplan GmbH.

bitkom research, 2019. Industrie 4.0: Status Quo und Perspektiven, Januar 2019.

Blasius, J., 2014. Skalierungsverfahren. In: Baur, N.; Blasius, J. (Ed.): Handbuch Methoden der empirischen Sozialforschung. Wiesbaden: Springer, S. 1051–1062.

Brauweiler, H., 2018. Risikomanagement in Unternehmen. Zwickau: Springer Gabler, 2. Edition.

Busse von Colbe, W.; Laßmann, G. and Witte, F., 2015. Investitionstheorie und Investitionsrechnung. Berlin, Heidelberg: Springer Berlin Heidelberg, 4. Edition.

DIN Deutsches Institut für Normung e.V., 2018. DIN ISO 31000:2018. Risikomanagement - Leitlinien. Berlin: Beuth Verlag GmbH.

Dowling, M.; Eberspächer, J.; Neuburger, R.; Noll, E. and Zisler, K., 2016. Neue Produkte in der digitalen Welt. München: Münchner Kreis.

Ellebracht H., Lenz G. and Osterhold G, 2011. Systemische Organisations- und Unternehmensberatung. Wiesbaden: Gabler Verlag, 4. Edition.

Fay, A., Gausemeier, J. and Hompel, M. ten, 2018. Einordnung der Beispiele der Industrie 4.0-Landkarte in die Anwendungsszenarien. München: acatech – Deutsche Akademie der Technikwissenschaften.

Forstner, L. and Dümmler, M., 2014. Integrierte Wertschöpfungsnetzwerke – Chancen und Potenziale durch Industrie 4.0. In: e & i Elektrotechnik und Informationstechnik, 131; S. 199–201.

Greschke, P and Greschke-Begemann, G., 2017. Keine Angst vor Industrie 4.0: Digitalisierung als Chance für humane Arbeit. Norderstedt: BoD - Books on Demand.

Gunkel, M. A., 2010. Effiziente Gestaltung des Risikomanagements in deutschen Nicht-Finanzunternehmen. Doctoral thesis. Norderstedt: BoD - Books on Demand.

Hevner, A. R., 2007. A Three Cycle View of Design Science Research. Scandinavian Journal of Information Systems. 19(2), pp. 87-92

Hirsch-Kreinsen, H., ten Hompel, M., Ittermann, P., Niehaus, J., Dregger, J., 2016. Social Manufacturing and Logistics. Begleitforschung AUTONOMIK für Industrie 4.0, Alfons Botthof (Ed.), Berlin: VDI/VDE Innovation + Technik GmbH.

Hirsch-Kreinsen, H. and Weyer, J., 2014. Wandel von Produktionsarbeit – „Industrie 4.0“ - Soziologisches Arbeitspapier Nr. 38/2014. Dortmund.

Hobscheidt, D., Kühn, A. and Dumitrescu, R., 2019. Development of risk-optimized implementation paths for Industry 4.0 based on socio-technial pattern. Procedia CIRP, 2020.

Hopfener, A. and Bier.S., 2018. Risikomanagement im Zeitalter der Digitalisierung: Rolle und Herausforderungen. Risiko Manager, no. 9, pp. 10-16.

INLUMIA, 2020. Quick-Check Industrie 4.0. [online] Available at: <https://www.surveymonkey.de/r/inlumia> [Accessed 15 Mai, 2020]

Jakoby, W., 2012. Projektmanagement für Ingenieure. Ein praxisnahes Lehrbuch für den systematischen Projekterfolg. 2. circ. Wiesbaden: Springer-Vieweg.

Kauffeld, S. and Maier, G. W., 2020. Digitalisierte Arbeitswelt. In: Gruppe. Interaktion. Organisation. Zeitschrift für Angewandte Organisationspsychologie (GIO), 51; S. 1–4.

Kohl, M., Malik, B., Lopitzsch, J. and Fottner, J., 2019. Auswahl- und Priorisierungsmodell für Industrie 4.0-Use Cases in der Logistik. München: Lehrstuhl für Fördertechnik Materialfluss Logistik, Fakultät für Maschinenwesen, Technische Universität München; MAN Truck & Bus SE.

Krause, S. and Pellens, B. (Ed.), 2018. Betriebswirtschaftliche Implikationen der digitalen Transformation. Wiesbaden: Springer Gabler Verlag.

Kreutzer, R. T.; Neugebauer, T. and Pattloch, A., 2017. Digital Business Leadership – Digitale Transformation – Geschäftsmodell-Innovation – Agile Organisation – Change Management. Wiesbaden: Springer Gabler Verlag.

Leyh, C. and Bley, K., 2016. Digitalisierung: Chance oder Risiko für den deutschen Mittelstand? – Eine Studie ausgewählter Unternehmen. In: HMD Praxis der Wirtschaftsinformatik, 53; p. 29–41.

Ludwig, T., Kotthaus, C., Stein, M., Durt, H., Kurz, C., Wenz, J., Doublet, T., Becker, M., Pipek, V. and Wulf, V., 2016. Arbeiten im Mittelstand 4.0 – KMU im Spannungsfeld des digitalen Wandels. In: HMD Praxis der Wirtschaftsinformatik, 53(1), pp. 71–86. Wiesbaden: Springer Fachmedien.

Müller, R., 2016. Forderungsmanagement für KMU nach dem Minimalprinzip. Weil im Schönbuch: HDS-Verlag

Obermaier, R., 2017. Industrie 4.0 als unternehmerische Gestaltungsaufgabe: Strategische und operative Handlungsfelder für Industriebetriebe. In: R. Obermaier, ed. Industrie 4.0 als unternehmerische Gestaltungsaufgabe. Betriebswirtschaftliche, technische und rechtliche Herausforderungen. 2. corrected edition. Wiesbaden: Springer Gabler, pp. 3–34.

Obermaier, R., 2019. Handbuch Industrie 4.0 und Digitale Transformation. Wiesbaden: Springer Fachmedien Wiesbaden.

Oehmen, J., 2016. Risiko- und Chancenmanagement in der Produktentwicklung. In: Lindemann, U.: Handbuch Produktentwicklung. München: Carl Hanser Verlag, pp. 59-98.

Oehmen, J., 2019: Wertschöpfendes Risikomanagement in Technologieunternehmen. Controlling, no. 3, pp. 23-30.

Osterwalder, A. and Pigneur, Y., 2010. Business Model Generation: a Handbook for Visionaries, Game Changers, and Challengers. Wiley.

Pierenkemper, C.; Reinhold, J.; Dumitrescu, R. and Gausemeier, J., 2019. Erfolg versprechende Industrie 4.0-Zielposition. Industrie 4.0 Management, 35 (5), pp. 30-34.

Plattform Industrie 4.0, 2016. Fortschreibung der Anwendungsszenarien der Plattform Industrie 4.0. Bundesministerium für Wirtschaft und Energie (BMWi), ed. München.

Plattform Industrie 4.0, 2020. Anwendungsbeispiele. Deutschland als Vorreiter in der Industrie 4.0. Available at: <https://www.plattform-i40.de/PI40/Navigation/DE/Angebote-Ergebnisse/Industrie-4-0-Landkarte/industrie-4-0-landkarte.html> [Accessed 23 April 2020].

Rice, A., 1963. The enterprise and its environment, London.

Romeike, F., 2003. Der Prozess des strategischen und operativen Risikomanagements. In: F. Romeike and R. B. Frank, ed. Erfolgsfaktor Risikomanagement. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 147-164.

Romeike, F., 2008. Risikomanagement. Wiesbaden: Springer Gabler.

Roth, A., 2016. Industrie 4.0 – Hype oder Revolution? In: A. Roth, ed. Einführung und Umsetzung von Industrie 4.0. Grundlagen, Vorgehensmodell und Use Cases aus der Praxis. Berlin, Heidelberg: Springer Gabler, pp. 1–16.

Schuh, G.; Klappert, S.; Schubert, J. and Nollau, S., 2011. Grundlagen zum Technologie management. In: G. Schuh and S. Klapper, ed. 2011. Technologiemanagement. Heidelberg Dordrecht London New York: Springer.

Schuh, G.; Anderl, R.; Dumitrescu, R.; Krüger, A. and ten Hompel, M., 2020. Der Industrie 4.0 Maturity Index in der betrieblichen Anwendung. Aktuelle Herausforderungen, Fallbeispiele und Entwicklungstrends. acatech-Studienreihe.

Staufen AG and Staufen Digital Neonex GmbH, 2019. STAUFEN. Studie Industrie 4.0 Index 2019.

Ulich, E., 2011. Arbeitspsychologie. vdf Hochschulverlag AG an der ETH Zürich. Zürich, Stuttgart: Schöffer-Poeschel Verlag, 7., new revised and extended edition.

Ulich, E., 2013. Arbeitssysteme als Soziotechnische Systeme – eine Erinnerung. Psychologie des Alltagshandelns, Vol. 6, Iss. 1, pp. 4–12.

VDE/DKE, 2018. Deutsche Normungsroadmap. Industrie 4.0. Version 3. Berlin: DIN e. V.; DKE Deutsche Kommission Elektrotechnik.

Weber, J. and Schäffer, U., 2014. Einführung in das Controlling (14. Aufl.). Stuttgart.

Wellensiek, M.; Schuh, G.; Hacker, P. A. and Saxler, J., 2011. Technologiefrüherkennung. In: Schuh, G. (Ed.): Technologiemanagement. Berlin, Heidelberg: Springer-Verlag Berlin Heidelberg, S. 89–169.

Wolke, T., 2008. Risikomanagement. Berlin, München: Oldenbourg Verlag, 2. Edition.

Zangemeister, C., 1976. Nutzwertanalyse in der Systemtechnik (4. Aufl.). München: Zangemeister & Partner.

Mastering the Supply Chain by a Concept of a Digital Control-Twin

Wilmjakob Herlyn [1] and Hartmut Zadek [1]

1 – Otto-von-Guericke Universität Magdeburg

Purpose: The purpose is to design a new concept for control of the Supply-Chain for the era of industry 4.0 exploiting the huge amount of actual data of material flow objects which are available thru new identification technologies, localization and communication systems and to use appropriate tools for evaluation and analyzing actual data.
Methodology: The approach uses the idea of a Digital-Twin Concept for logistics that bases of three pillars: 1) 'reality': actual status of material flow objects 2) 'repository': digital mapping of material flow objects 3) 'regulation' of material flow. The real and virtual material flow objects are permanently compared, deviations are evaluated and harmonized by using the principle of closed-loop-control.
Originality: The concept is a very new approach to master material flow for final products and required components. For this a 'Big- Picture' of a Digital Control Twin (DCT) System is designed, which is a necessary complement to the engineering oriented Digital-Twin-Concept to run a smart factory.
Findings: The paper shows how the idea of a Digital Twin Concept for engineered products can be transferred into the world of logistics and especially for supply chains. The Digital Control Twin controls, monitors and balances material flow objects according to quantity, location and time and can help to predict and solve problems in advance.

First received: 14. Feb 2020 Revised: 15. Jun 2020 Accepted: 07. Jul 2020

1 Introduction

Digitization is a phenomenon that has accompanied industrial companies for decades, but with the emergence of 'Industry 4.0' digitization reaches a new level through a variety of new technologies, intelligent software tools and cloud-based communication. One of the most important trends is called "Digital Twin" which focusses on the beginning mainly on engineered objects. Meanwhile many international logistics companies are integrating a 'digital supply chain' into their portfolios. New identification technologies, localization and communication systems are creating not only new challenges but also new opportunities for companies in productions and logistics management. The huge amount of permanent available data requires a new concept to master the supply chain, which gets more importance because of increasing product variants and globalization of production and supply chain networks. The existing methods to control supply chains base on ERP-/MRP-concepts which have some weak points: 1. The using 'water-fall model' has no feedback and recursion to a preceding or higher level 2. Order instruction are calculated by the 'gross-net-method' which is hardly useful for Digital Twins 3. Existing ERP-/MRP-Systems use a fixed schema of algorithms that is hardly adjustable for different logistic and operational task and application levels (Stadler 2015, Wiendahl, 2011).

1.1 The Emergence of the Digital Twin Concept

The "Digital Twin Concept" (DTC) was elaborated and introduced by Michael Grieves and John Vickers. Their concept "contains three main parts:

a) physical products in ‘Real Space’ b) virtual or digital products in ‘Virtual Space’ and c) the connections of data and information that ties the virtual and real products together” (Grieves, 2014). The permanent communication between the real and virtual world is the crucial point because in the past the DT was more a 'simple' digital mapping of an object. Their concept referred to engineered objects, which are accordingly described by engineering data as Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM), you can find a literature overview by (Kritzinger, 2018, Johns 2020). But an engineering-oriented DTC is used for design, manufacturing and maintenance of physical objects and cannot directly used for logistics objects and order-oriented processes.

1.2 The Digital Twin Concept for Logistics and Supply Chain

The Digital Twin Concept is hardly treated in standard textbooks of logistics and supply chain or operations management (e.g. Schuh, 2013, Bauernhansl, 2014, Kilger, 2015, Schönsleben, 2016, Klug, 2018, Stevenson, 2018, Heizer, 2020). Scientific papers offer different approaches like data-model-based and driven-concepts (Ivanov 2019, 2020, Chankov, 2016), simulation or stochastic based algorithms (e.g. Timm, 2015, Lorig, 2015, Rodicz, 2017, Uhlemann, 2017, Kunath, 2018). Several papers, whitepapers and recommendations of institutes focus on Cyber-Physical-Objects and autonomous process control as a core part of a smart factory and smart logistics (e.g. Plattform Industrie 4.0, WiGeP, Fraunhofer IML, Luściński, 2018, Farahani, 2020). International logistic companies (e.g. DHL 2018) and leading software houses (e.g. SAP 2019) are developing concepts of DT for better logistic performance and lower cost in supply chains. Their concepts are focused on technical and handling aspects and monitoring of flow objects mainly, they are not order-oriented, and an overall planning and control of MF are not really included.

In this paper we focus on a deterministic and rule-based regulation between the real and virtual logistic world which is a crucial part of a Digital Twin Concept of Grieves/Vickers. For industry 4.0 a holistic concept is needed where real and virtual logistic processes are controlled and harmonized in one IT-System (Zadek, 2020). For this we transfer the idea of Grieves/Vickers into the world of logistics for planning and monitoring of material flow objects (MFO) in a production and material flow (PMF) network. For this we give some terms a name slightly different to make it more understandable for logistic applications. We call the three pillars in short: Reality, Repository and Regulation. We call data that flow from real to virtual world ‘Digital Shadow’ and information that flow from virtual to real world ‘Digital Trigger' (s. fig. 1). This is the basic idea and fundament to design a DCT-Concept for logistic purposes that means to control, monitor, and regulate MFOs in a dynamic logistic and time-driven environment.

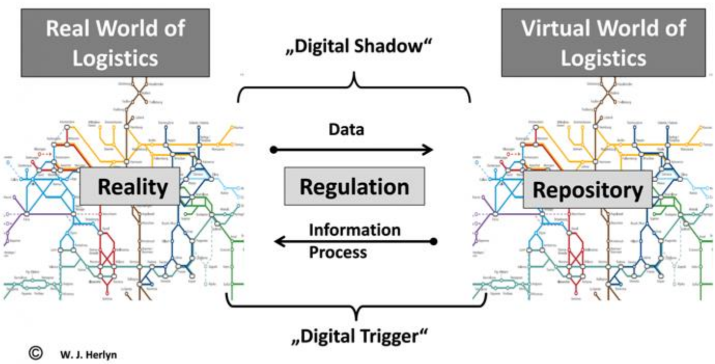


Figure 1: Three Pillars of the Digital Control Twin Concept for Logistics

To make sure: There is a general difference between an engineering and logistic oriented DTC. The target values of physical objects like CAD/CAM-Data are fixed in time and are replicated by instances but in logistics target values like order quantities are changing and must be balanced over time. Therefor a logistic-oriented DTC must treat objects and data with other methods than an engineering-oriented DTC because of the different characteristic of the observed objects, processes, and tasks. The logistic oriented DTC must ensure that the right MFO is available at the right place, at the right time and in the right quantity over a certain time-period.

2 Big Picture for a Digital Control Twin System

For logistic purposes we design a Digital Control Twin (DCT) System which is illustrated by a Big-Picture. The main three pillars are explained in short:
1. Reality: By "Reality" we mean a certain cutout of interested MF-Sections and MF-Objects whose flow should be controlled. If we look at a manufacturer this includes the production and transportation of the end-products and all necessary components (modules, assemblies, individual parts, etc.). A part of reality is all kinds of transporting means like trucks, trains etc. and loading means like bins, container, racks etc. and real routes or railways are a part of logistic reality too.
2. Repository: Under "Repository" digital mapping of MF-Reality in corresponding databases is understood. The "Repository" stores are all kinds of master-data (like Network- and Product-Structure) as well as further control data, which serve for the description of the material flow and for the assignment of all MFOs. Master data are order-independent and includes work calendars, control data for material dispatching etc. On the one hand we have order-dependent 'transaction data', which includes e.g. sales orders and production schedules as well as order for required components.
3. Regulation: "Regulation" means all kinds of planning, monitoring and balancing MF of MFOs including determination of schedules and order calculation. The main task of regulation is to ensure that the right MFO must be available at the right time, in the right quantity and at the right place. For this purpose, the exact order quantities of products and components must be determined for the entire PMF-Network. Target values or placed orders are transmitted to the operation units and called 'digital trigger'. Actual registered values represent the fulfillment of placed orders and are

called 'digital shadows'. The type of data acquisition and recording can be carried out using various tools and identification systems like barcode, RFID etc. Both digital trigger and digital shadows represent the real and virtual logistic world only at a certain moment and are balanced by a certain algorithm of the DCT-System. The DCT-Controller reacts to any situation by means of defined rules and control instructions. All results are stored in a Data-Gravity-Center and can be analyzed by Data-Analytic-Tools and used for predictive 'maintenance' and optimization of logistic procedures or data (s. fig. 2).

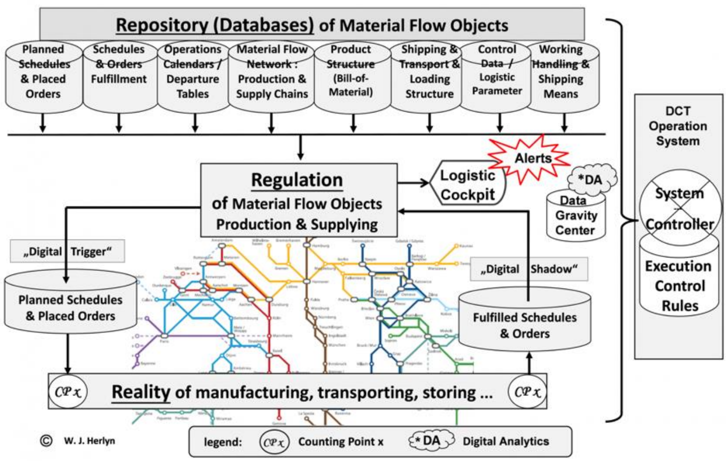


Figure 2: Big Picture of a 'Digital Control Twin' System

2.1 Reality of Material Flow Objects and Data Acquisition

Logistic 'Reality' covers all kinds of manufacturing, transporting, storing, sorting, distributing etc. of all components, e.g. raw material, single parts, assembly groups, modules etc., that are required to produce final products. Reality covers all kinds of logistic means like bins, boxes or trucks, trains or ships which are necessary for fulfill orders and schedules. All logistic activities are performed in a MF-network wherein all kinds of material items have to move like transportation routes, factory grounds, shops and halls, railways, harbors or distribution center, warehouses, stores or buffers.

Digital Shadow: Real material flow items leave a ‘Digital Shadow’ which is registered by special tools, devices, and IT-Technologies. Digital Shadows are all kinds of data which comes directly from the real MFOs. The Digital Shadow should cover at a minimum the quantity, current state, and location of a single or a couple of correct identified items. The data can be acquired in different ways and by different techniques supporting by different technical equipment and features. Data Acquisition (DA) can be entered into an IT-System by hand or scanned from a Bar-Code or a QR-Code or acquired by an active or passive RFID-Chip. In the future bigger components become more and mor 'Cyber-Physical Object’ which can store, process and share data and is identified by an IP-Address. For a DCT-System it does not matter which kind of data acquisition techniques is used, its only that data are available for the DCT-System when they are needed, this is the crucial criteria for the appropriate technique of data acquisition.

DCT-System must be always ‘on-air’ to process the real und virtual data parallel and permanently. This does not mean that the DCT-System must know the values and status of every MFO at every moment and every place.

The calculation of the target values and the comparison with the actual data is carried out for each MFS in a certain defined cycle time (CT), which is aligned to the LT of the real process of the respective MFS. A Digital Shadow is like a snapshot which is taken from time to time and shows the reality only at that time.

The DCT-System itself is 'real-time' oriented and can have a linkage to all other processing IT-concepts depending on the concrete tasks. A characteristic of DCT-System is the capability to use and combine different concepts of data processing and operating systems. This allows us to use data from older IT-Systems that are ‘batch-oriented’, more modern IT-System that are ‘online oriented’ and latest IT-Systems that are ‘cloud-oriented’. The actual data can be processed from different sources, at different times and different locations by different IT-modules which can be a part of another IT-System. The execution of the DCT-System is carried out by a System-Controller, which works by means of control instructions and rules. The control instructions, rules and cycle-times for regulation are stored in a database that is maintained by experts from specific departments.

2.2 Repository - Databases for Mapping the Logistic World

Repository maps all data that are required to plan, control and monitor MFOs which represent the virtual logistic world and stores them in different specific databases:

1. Material-Flow-Network or PMF-Structure 2. Product-Structure (PS) normally known as 'Bill-of-Material' (BoM) 3. Shipping-Structure that includes transport, loading and packaging data 4. Operational or Working Calendars, including departure- and arrival-dates for shipping and starting- and

ending-dates for manufacturing 5. Control Data also known as disposition parameters 6. Capacity Data for describing technical assets, equipment and working means 7. Planned schedules and places orders for all MFOs 8. Fulfilled schedules and orders for all MFOs.
In the following we will explain only the Material Flow Network and Product Structure and Lead-time (LT) and Lot-Size (LS) as the main logistic parameter of Control Data.

2.3 Digital Mapping of Production and Material Flow Structure

In the center of the 'Repository' stands the mapping of the production and material flow (PMF). There are various methods for mapping production and material flow such as flow charts, tables, matrices or graphics. Normally the material items flow from a source only in one direction to a sink, it has built up a linear flow structure, but "today most material flow systems are networks because the process is partly organized in series or parallel" (Arnold D., Furmans K., 2019). The material flow of discrete products is not arbitrary but linear oriented and follows the structure of the production process itself and the supplying network is depending on this. This linear type of network can be observed in industries such as the automotive industry (Herlyn, 2012).
For mapping we use the mathematical theory of an ideal Boolean interval lattice. We assume that the material flow of discrete products can be represented by a linear ordered chain of Boolean intervals which are closed open defined by a left and right boundary and should meet the requirements of an ideal Boolean interval lattice. There are no jumps or overlaps between

the next following intervals, no interval in the chain is missing or lies outside the entire interval whereby each interval is defined as closed-open. The beginning is defined by an 'Entry Point' (EP) which lays inside the interval and the end is defined by another EP which lays outside the interval and must be the beginning of the next-following interval. The complete algebraic definition of intervals and subintervals is omitted here for reasons of space. Detailed information about Boolean Interval Algebras can be found in (Koppelberg, 1998, Herlyn, 2012, 2017).

2.4 Ideal Boolean Intervals and Real Material-Flow-Sections

The described PMF-Structure is at first only a logical structure but not a physical representation of the real logistic world. For this it is necessary to link this logical structure with the physical material flow structure. Each EP of the logical MF-structure must be referenced to an existing Data Acquisition Point (DAP) and only then we get a Counting Point (CP) thereby. By this strictly ordered CPs material flow, e.g. a certain transportation, can be planned and monitored although the concrete transportation carrier can use different routings and loading means. This referencing method has many advantages because structural data is very stable and can be adapted easily to different changes and new conditions in practice. Another advantage is that several DAPs can be referenced to only one logical EP. An example: if there is less space for storing goods in a plant incoming goods are received at different 'goods-receipt-points' in logistics centers outside the plant boundaries. For the logical structure it does not matter whether the physical DAPs are located internally or externally of a plant or company.

And when a DAP has moved from one location to another, only the reference between logical CP and physical DAP is changed but the logical PMF-structure remains the same.

2.5 Mapping of Product Structure as Bills-of-Material (BoM)

PMF-Structure must be supplemented by the Product Structure (PS) in order to incorporate and identify MFOs. The PS describes all required components of a final product and is stored as a 'Bill of Material' (BoM). Product data are required to plan and calculate concrete shipping, manufacturing, stocking, or delivery orders for components. Due to the complexity and configuration of the end products the PS can be stored in different BoMs which use specific methods to map substructures. Without any reference to the PS the defined PMF structure is only a needless and empty framework, PMF and PS together built the backbone of the DCT-System. For each manufacturing interval we need a specific BOM which contains all items that are used in the concerned interval; The Complex-BOM for a is linked to the CP ''FF' (end of final assembly line) and contains all components of car variants (s. fig. 3). Depending on the type of manufacturing process and complexity of products different types of BOMs are used (Schönsleben, 2016).

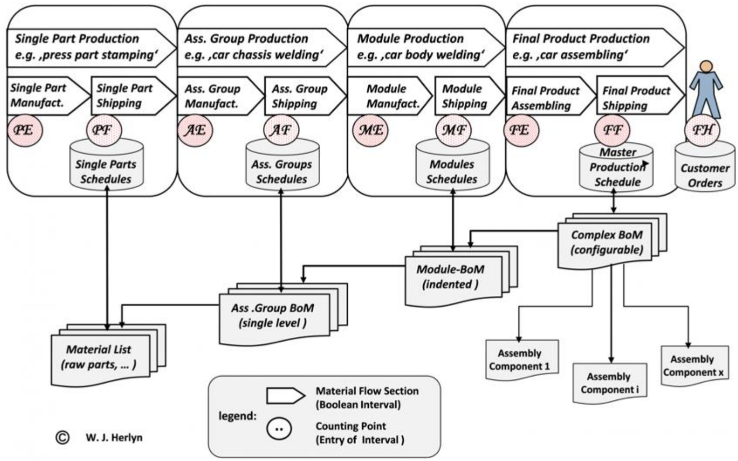


Figure 3: Reference of PMF-Structure and Different Kinds of BoM

We distinguish four typical types of BOMs that are adapted to the type of production for single parts, assembly groups, modules, and final products. Each BoM is linked to the ending CP of the corresponding manufacturing interval which is starting CP of the next-following interval. In the DCT-System there is a strong requirement that each ending CP of a manufacturing section must be referenced by one specific BOM and vice versa each specific BoM must be linked to a certain unique CP.

3 Regulation Methods for the DCT-System

Regulation for the DCT-System means generally all methods, algorithms and tools to plan, calculate, schedule and monitor the flow of MFOs. In a DCT-System we cover under regulation not only planning methods and tools but also simulation and optimization methods and tools. The DCT-System can combine these different tools and methods for planning and scheduling MFOs but here we focus only on planning methods especially for depended components of an end-product.

3.1 Digital Trigger and Material Flow Regulation

Digital Trigger: In our case Digital Triggers are nothing else then placed orders or planned schedules that are calculated by the regulation software. Placed orders and planned schedules are used as target values for process controlling by a 'Closed-Loop-Cycle'. But there is a crucial difference if we compare 'Digital Trigger' of material items with an engineered product: target values of an engineered product are the data of a CAD-System and are replicated by an instance every time (Grieves, 2014). Target values of an MFO are changing in time because the regulation is a dynamic one. Target values for planned schedules and placed orders are calculated permanently referring to changing customer over time and, actual order values are also updated permanently.

In connection with the LT the reaction or response time (RT) of MFO and the cycle-time (CT) for new targets values plays an important role. On the one hand CT depends on the required LT and RT is additively influenced by factors such as batch sizes and departure times. If the CT is (far) below the RT, then the real process cannot keep up with the virtual process so the system will react too quickly which will lead to hectic and incorrect reactions. If the CT is (far) above LT then DCT-System reacts too slowly, which can lead to material shortages and provokes additional avoidable costs.

3.2 DCT-Regulation and Closed-Loop-Control

The **regulation** of MFOs by the DCT-System can be carried out by the principle of 'Closed-Loop-Control'; the 'Digital Trigger' is nothing else than a target value and the 'Digital Shadow' corresponds to the actual value in a closed loop cycle. For each CP, the target values are determined in a certain Cycle Time (CT) and compared with the actual values at this time. The values are compared and by deviations they are harmonized via the DCT-regulation algorithm. As soon as the target values for orders have been calculated they can be compared with the actual order fulfillment. The deviation between the planned target and the registered actual value is evaluated for each MFO according to defined criteria, which are stored in the database for execution and control rules of the System-Controller. If critical deviations are detected certain 'Warnings' or 'Alerts' are issued and visualized via a Logistic-Cockpit. And automatically a certain regulation tools/method is initiated by the DCT-Controller to balance target and actual values. It is obvious that the appropriate method of regulation depends on the type of process. In the following we can show this on one example only (see below).

3.3 Control-Data resp. Logistic Disposition Parameters

Control-data: This database contains all disposition parameters for planning of material flow and for calculation of schedules and orders for all

MFOs. The exact setting of the control data is an important influencing variable for planning and must be carried out very carefully for each MFS and each MFO. Here we focus on lead-time (LT) and in combination with the lot-size (LS) for transportation or manufacturing which are the most important logistic parameter for regulation.

3.4 Lead-time and Planning of Material Flow

3.4.1 Lead-time and the Role for Control of Material Flow

Lead-time, also called ‘flow time’ or 'throughput-time', is a crucial element in a DCT-System is the most important parameter for MRP-/ERP-Systems. Although LT is of central importance it is not possible to go into all aspects which can be read in (Wiendahl, 1997). Here we will concentrate on LT in a supply chain.

“The total time spent by a flow unit within process boundaries is called flow time” (Anupindi et. al, 2012). In an ideal PMF-Network LT is the elapsed process time between two next-following CPs. Every Interval resp. MFS has its own LT which is transferred to all MFOs passing through. Because of the ideality of PMF-Structure we can add the LT of all next-following intervals so the completely LT of an MFO is the sum of all passed intervals. Thus, if a single part is a component of an assembly group which itself is a component of a higher assembly etc. then the total LT of this item is the sum of all passed MFS until the completion of the final product. We use the ‘reverse’ of LT (RLT) for backward-calculation to determine the ‘right time’ for MFOs by ‘shifting’ the MFOs along the CPs of the PMF-Structure. For backward calculation neither the kind of operation (production, transportation or storing) nor the ‘physical length’ of an interval is important, once and only the real elapsed time between two CP’s is the decisive factor. Any kind of MFO is equal "rated" even if the process character or environment is different. If we are interested in the total LT of a specific MFO we add the individual LTs s of all passed PMF sections. By backward-calculation we can determine at which time the concerned MFO should pass the concerned CPs from single part fabrication over installation in an assembly group or module which is mounted into the final product. We can do the same for a complex supplying process with different material flow sections.

3.4.2 An example for using different Lead-times in a delivery process

Lead-time is one of the most important parameters for MRP-/ERP-Systems and for the DCT-System. Since the LT is an attribute of PMF-Structure we must define alternative MFS for means of transport or routes etc. to be able to differentiate the LT for MFOs. In the following example (s. fig. 4) we define for the same delivery task (upper Interval) three alternative delivery concepts (lower Intervals). The upper MFS (Int-D) is defined by a beginning CP 'D' and an ending CP 'GR' (goods receipt) and consist of three ideal embedded sub-intervals (Int-D(1), Int-D(2), Int-D(3)), each of them covers exactly the upper interval, therefore the beginning and ending CPs of them match exactly.

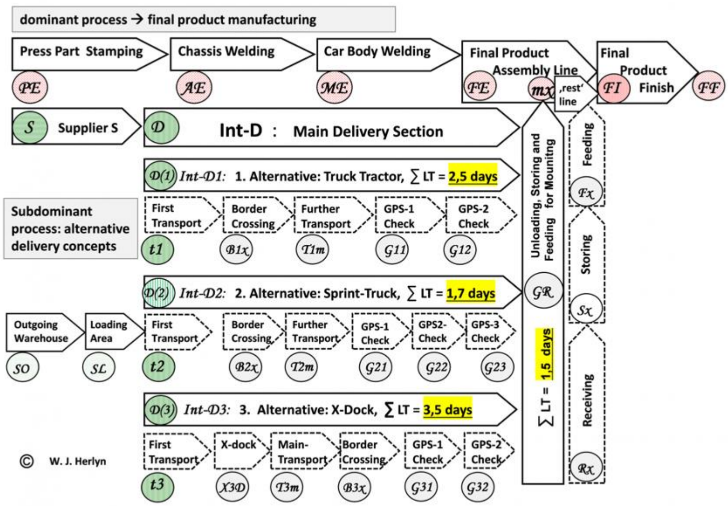


Figure 4: Definition of Alternative Delivery Concepts

Each of these sub-intervals is divided into strictly ordered next-following sub-sub-intervals whereby each represents a certain section in the supply chain and has its own a beginning and an ending CP. But each of these alternative delivery-intervals has its own specific sub-intervals and CPs for discrimination of the delivery process.

1. **Direct Shipping by truck tractor**: By this concept transportation is performed directly from goods loading at the supplier to the unloading at the OEM by a truck-tractor. For this concept, the MFS (Int-D (1)) and CPs are defined: 1. First transport: CP 't1'; 2. Border crossing: CP 'B1x' 3. further

transport: CP 'T1m' 4. GPS-Check: CP 'G11' 5. GPS-Check: CP 'G12' 6. Goods Receipt: CP 'GR'. The complete LT from CP 't1' to CP 'GR' for this concept is about 2.5 days.

2. **Direct-Shipping by sprinter trucks**: In this case the transportation (Int-D (2)) is performed by using a small truck instead of a truck-tractor. By this concept, LT is lower because of less speed-limitation or weekend-bans. By this the shipping lot-size will be lower and the frequency of delivery will be higher so the response time will be lower, and flexibility is higher to react on order changes or actual deviations so this concept can be useful in some critical situation. Although the transportation route could be the same as for truck-tractor, we need a separate MFS to differentiate LT and LS. The complete LT from CP 't2' to CP 'GR' for this concept is about 1.7 days.

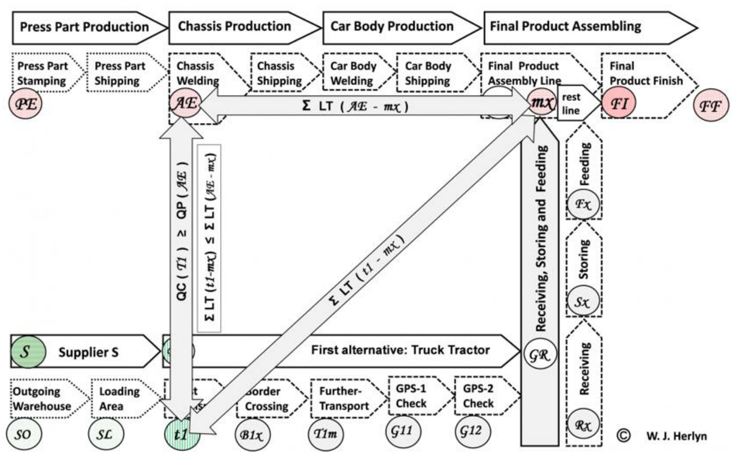
2. **Direct-Shipping by sprinter trucks**: In this case the transportation (Int-D (2)) is performed directly by using a small truck instead of truck-tractor. By this concept, LT is lower because of less speed-limitation or weekend-bans but the shipping lot-size will be lower and logistic cost are higher. The frequency of delivery will be higher so the response time (RP) will be lower, and flexibility is higher to react on order changes or actual deviations so this concept can be useful in some critical situation. The concrete transportation route could be the same as for truck-tractor, but we need a separate MFS because of different LT and LS. The complete LT from CP 't2' to CP 'GR' for this concept is about 1.7 days.

3. **Shipping using a Cross-Dock**: In this case the components are not transported (Int-D (3)) by one freight unit only, but a Cross-Dock is used for trans-loading goods, whether to put together different components in bigger container or to use bigger freight means for cheaper transportation charges. In addition, the X-dock can be used also for safety stocks and for

optimization of shipping and space in freight-carrier (e.g. fully loaded container) which will expand LT in shipping. In this case the overall LT from CP 't3' to CP 'GR' is about 3.5 days.
Hint: Here we ignore the cost aspect and other relevant factors which must be taken in account normally.

3.4.3 The Magic Triangle to Control a Complex Supply Chain

The PMF-Structure itself is only a neutral framework, for control of MFOs we need additional information about the relationship of MFOs inside this framework. Therefor we define a dominant process that represents the production of the final products and several sub-dominant MFS for depended MFOs. This allows us to control and monitor material flow of all depended components at certain CPs (s. fig. 5). Our focus is on the right time, right place, and right quantity of all right MFOs. For this we use the concept of Cumulative Quantities (CQC) to get a completely overview about the planed status and target values of all MFOs in the network (Herlyn, 2014, 2017). We will explain this only for a certain case by an example of car manufacturing. First, we built the Cumulative Curve of the final products (e.g. cars) at the very last CP 'FF' (Final Products Finished) by adding up the single orders which are stored in the MPS along an equidistant timeline. Thereafter we calculate the curves for all preceding CPs of car manufacturing and components by shifting the quantities of final products along the defined CPs using the corresponding LT for the MFS. By this method we can calculate curves for all required components. Each component must have a common CP with the final product, e. g. a takt of assembly line, where the component is mounted into the product which we call therefor a "Mounting



Point" (MP). By this procedure, all Curves relate to the final product curve and can connect with each other. After calculation of curves for all CPs step by step, we get a data grid of quantities for all components and their corresponding PMF-Structure. This data grid can be used for different logistic purposes e.g. to predict if actual shipped quantities of a component is sufficient for a secure supplying of final assembly line. Example: we compare the actual QP of cars at CP 'AE' with QC of components at CP 't1' whereby CP 'AE' can be the Order-Entry-Point, CP 't1' is the loading point of components and CP 'mx' is the 'takt' in the final assembly line of cars.
For comparing CQs of final products and components at a certain time and for certain Counting Points and we formulate a condition: only those CPs

Figure 5: Magic Triangle for Control of Delivery of Depended Components

of the dominant process are chosen where the LT between two preceding CPs is ≥ than the LT of two preceding CPs of the sub-dominant process whereby both processes referring to a common CP, e.g. a certain MP 'mx' in the final assembly line:

$$QP\ (n)\ =\ \sum_{t=1}^{n} P(t)\ ;\quad t =\ 1 \dots x \dots n \tag{1}$$

$$QC\ (n)\ =\ \sum_{t=1}^{n} C(t)\ ;\quad t =\ 1 \dots x \dots n \tag{2}$$

$$LP\ (p)\ =\ \sum_{p=PE}^{FF} LP(p)\ ;\ \ p = PE \dots < AE \dots < mx \dots < FF \tag{3}$$

$$LC\ (c)\ =\ \sum_{c=SO}^{FF} LC(c)\ ;\quad c =\ SO \dots < t1 \dots < mx \dots < FF \tag{4}$$

$$\sum_{p=AE}^{mx} LP(AE : mx) >= \sum_{c=t1}^{mx} LC(t1 : mx) \tag{5}$$

The delivery process is only secure if the quantity of component at the time 'x' QC(x) and the Counting Point CP 't1' is equal or higher than the quantity of products at the time QP(x) and the Counting Point CP 'AE'.

$$QP(x)\ (AE)\ =\ QP(x + LP(AE :\ mx)\quad ;\quad t =\ 1 \dots x \dots n \tag{6}$$

$$QC(x)\ (t1) =\ QP\ (x + LC\ (t1 : mx)\ \ ;\quad t =\ 1 \dots x \dots n \tag{7}$$

$$QC(x)(t1)\ -\ QP(x)(AE)\ \ \geq\ 0\ \ (6);\ \ t = 1 \dots\ x \dots n \tag{8}$$

By this method we can compare actual values for a component at every CP with the target values data for final products to evaluate if a problem can occur or not. We will show this by a concrete example using the above defined delivery alternatives. The overall LT for shipping components by truck tractor is about 5 days and should cover 2400 final products at Friday but only 2340 components are actual shipped by the supplier (s. fig. 6; upper dotted line). The quantity of 2340 components will cover final product assembling only until the end of Thursday. In this case the lower limit of target

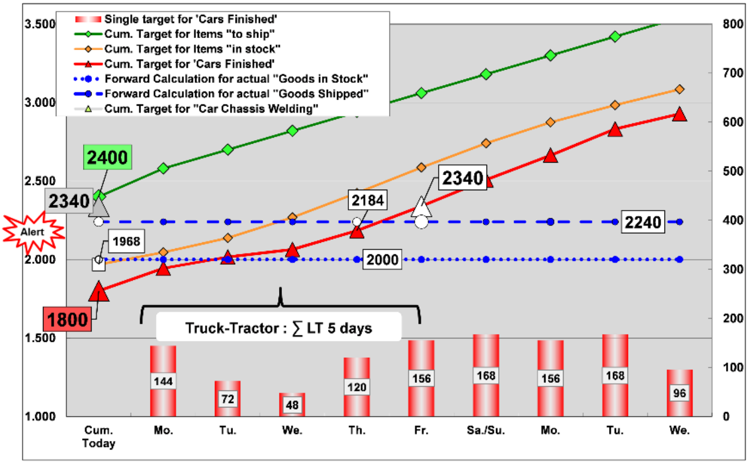


Figure 6: Standard Delivery Process by a Truck Tractor

values has been violated and DCT-Controller must change to another delivery alternative if possible.

In this case the delivery process is changed from truck tractor (alternative 1 with LT = 2,5 days) to 'sprint truck' (alternative 2 with LT = 1,7 days). By this the overall LT of supplying is reduced from 5 to 4,2 days with the result that the range of coverage is now sufficient, because goods will arrive a day earlier and material shortage can be avoided (s. fig. 7).

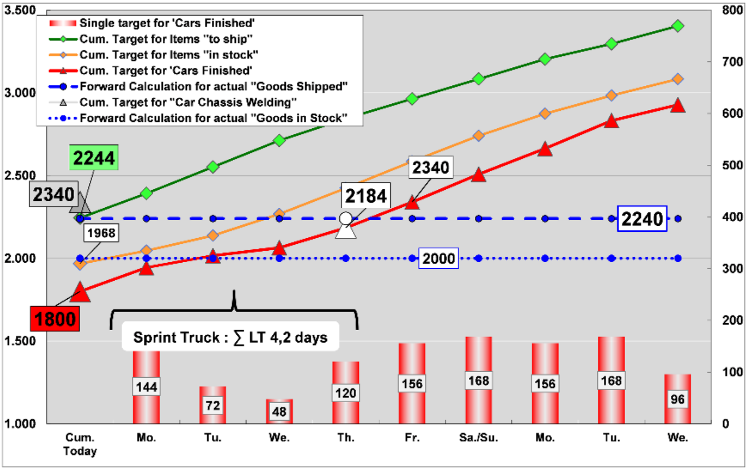


Figure 7: Delivery Process after Change from Truck-Tractor to a Sprint-Truck

The actual values for 'goods in stock' and 'goods received' matches with the values for final products (lower dotted lines) The actual QC of received components at CP 'GR' are in the defined range and the actual QC of components that have passed CP 'Sx' and are stored in the internal stock of the car manufacturer are in the accepted range too.

After this automatic change, an expert can analyze the situation in more depth and can initiate other countermeasures if needed e.g. permanent monitoring of transportation carrier or he can change the safety lead-time for the inhouse stock etc.

3.4.4 Distribution of Lead-time and Material Flow Balancing

In the example above we have calculated an average LT for the MF, but this is normally a stochastic process and therefore the LT is not a fixed value but has a certain distribution. The longer and more public the roads are, the more LT varies; there are also other influences like weather, traffic jams, road works, additional speed limits etc. Therefor we can estimate LT by a normal or a partially skewed distribution curve. Especially important are the minimum and maximum LT, for which we can define a certain sigma value level. The LTs are used for regulation of dominant and subdominant processes. Here we can discuss only some main aspects in general for two extreme scenarios:

1. Scenario: LT of the dominant process of product production gets the Min-LT and LT for the sub-dominant process of components gets the Max-LT, then the QC of components must always still higher than QP for products. If this condition is fulfilled, then stock-inventories of components will go down and safety-stock be consumed soon. Then the delivery process must be run very precisely and without any disturbances otherwise a material shortage will occur. For a safe delivery process, the Min-LT of products must be compared with the Max-LT of the dependent components.

2. Scenario: The dominant process gets the Max-LT and the sub-dominant process gets the Min- LT, then stock inventory of components will grow up so we need more space in the warehouses and also other negative aspects like higher storage and performance cost and more complication in material handling etc.

For this kind of planning we can use the same PMF-Structure, BoMs etc. but we must use other Control-data and chose other MFS etc. to find out critical scenarios and to balance order quantities of dominant and sub-dominant processes. For balancing we can also use separate control data about safety-stocks or alternative MFS for rule-based adaption of material flow and logistic processes. If problems further exist after process adaptation another 'Alert' or 'Warning' are issued and a new regulation can be started.

3.4.5 Logistics-Cockpit

For 'supporting' logistic regulation some further functions and tools are needed like a ‘Logistic Cockpit’ to visualize the actual state of the virtual and real logistic world and the results of analyzation deviation, especially to issue 'Alerts' and to initiate evaluation of data using different ‘Data-Analytic’ tools.

Logistic Cockpit: The Logistic-Cockpit is like a central tower or dashboard to visualize the planned and actual state of MFOs and to the results analyzation of deviations and combination with additional data and information (s. fig. 8). The Logistic-Cockpit shows at the same time the planned and real status of MFOs and issues Warnings and Alerts depending on the grade of deviations so the reaction can be differentiated by the DCT.

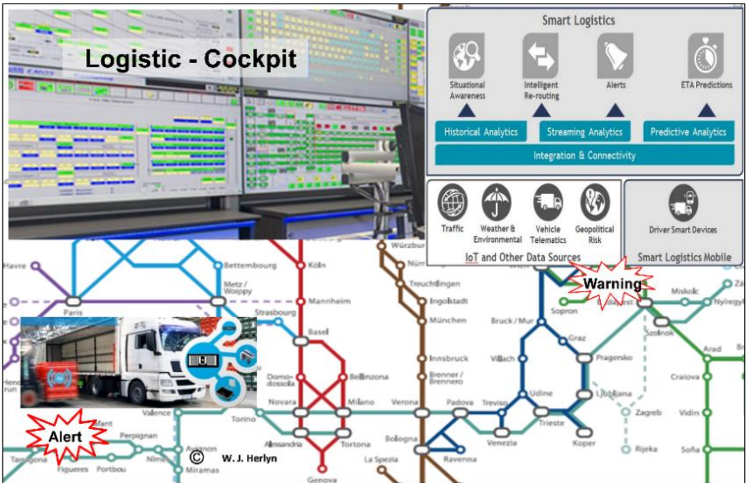


Figure 8: Logistic-Cockpit (exemplary show-case)

In case of an 'Alert' the Cockpit-Operator can zoom deeper into the 'problem' by changing the hierarchy level of PMF-Structure to get more detailed information. A prediction can be initiate what will happen in the nearest future if nothing changes. The operator can start a DA-tools to evaluate the situation or initiate a simulation to handle the problem in a different way. All of this is often called 'smart logistics'.

Data-Gravity-Center: The Data-Gravity-Center contains the complete history of all databases of the Repository and all results of DCT-Regulation including all values of Digital Trigger and Digital Shadows and all detected deviations and violations, alerts etc. The Data-Gravity-Center stores nothing else than the specific 'Big Data' of material flow objects and processes which can be exploited by 'Data Analytics Tools'.

Data Analytics: Data Analytics means all kinds of 'intelligent' tools to exploit data of the Data-Gravity-Center e.g. to analyze passed deviations or to detect systematic problems in the process. We can use the grid and DA also for alternative planning scenarios using different control data (e.g. with Min-LT and Max-LT) to see what will happen or to react in case of accidents or unusual events to initiate counter-measures in advance. Also, optimization tools can be used to solve certain underlaying tasks in a shorter time than planning tool or is not able to solve, e. g. to calculate the actual sequence of transportation means for a Jit-Process for far distant suppliers (Schwerdtfeger et al., 2018).

3.5 The DCT-System-Controller and Execution Rules

Because the DCT-System is always 'on air' we need a regulation of the DCT itself which is like an Operating System of a conventional IT-System but works in another way.

Execution instructions and rules. They define at which metering point a "warning" is to be issued in case of a target/actual deviation, which data evaluation is to be triggered and/or which simulation tool is to be used to solve an unforeseen problem. This is one of the biggest differences to existing ERP-Systems where the different IT-Modules are combined outside each Module by Job-Control-Procedure (JCP) that interprets the 'Return-Codes' or 'System-Status' of a Software-Program. The intelligence of a Job-Procedure of a conventional ERPS must be imbedded into the DCT System. Because the DCT-System is always ‘on air’ all execution rules, cycle-times and procedure dependences must be imbedded. The execution is carried out by a System-Controller, which works in a defined time cycle by means of control instructions and rules. The control instructions, rules and cycles are stored in a database that is maintained by experts from the specialist departments and can be changed every time. Experts have to define at which CP which kind of 'Warning or 'Alert has to be issued by which grade of deviation. And, whether and which tool of optimization or simulation should be initiate to react on a certain predefined deviation. And special 'tools' can be started automatically if the DCT-System detects an unexpected event, an unknown situation, or in-logical data. And in addition different tools can be started by an expert if there are new logistics tasks or new technical or environmental requirements or if a problem occurs outside the System like jams, strikes etc. so the rules, the disposition parameters and other control data must be changed or adjusted. Rules and control instruction as well as the selection of the appropriate regulation algorithm depends on the LT and the time horizon of a certain MFS and the specific logistic task and purpose (s. fig. 9).

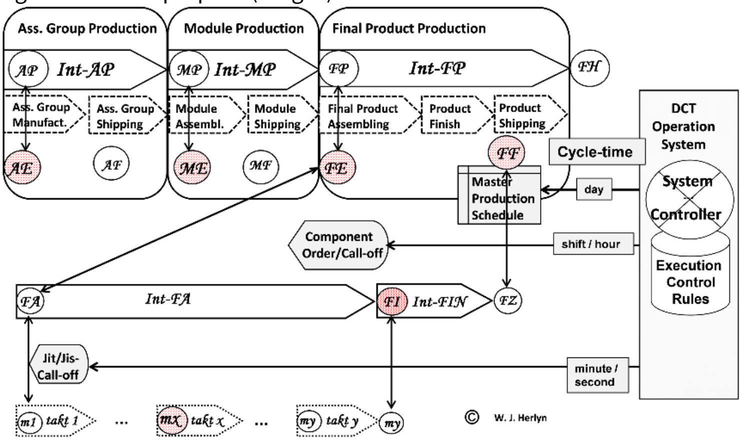


Figure 9: Different Logistic Tasks and Execution by Cycle Time

For example: The MPS will be started only once a day, while Call-offs for buy-parts are issued twice a day, and stock Call-offs for feeding of assembly

lines are issued every 15 minutes and JIT Call-offs are triggered every minute. The instant information when an MFO passes a certain CP, e.g. a car entered the Final Assembly Line') is generated by an equipment, a processor of a machinery or asset itself.
In general: The choice of algorithms and tools depends on the concrete task and the lead-time corresponding and the reaction time which depends itself on the level of PMF-Structure. For mid-run planning of MF a 'upper' level of CP is suitable and for short-run planning a lower-level is suitable: e.g. ‘Master Production Schedule’ runs on the plant-level, ‘Assembly Line Schedule’ runs on assembly-line-level which is a certain area of production only and JIT-Call-Offs runs on the level of a 'takt'. Planning and monitoring of delivery depend also on different levels of PMF-Structure and the corresponding RT of transportation means. It makes no sense to calculate Call-offs for buy-parts every hour if RT of delivering from a supplier is about half a day or longer.

4 Some Requirements and Limitations for a DCT-System

The described 'DCT'-System has some inherent limitations for application under real conditions. The DCT is a closed system that can work properly only if the closured properties are not destroyed or confused from 'outside' factors. The DTC-System can be run only if the logistic reality has been mapped completely and exactly and match with the real entire logistic world. If this cannot guarantee always and for every factory, component, or supplier the DCT cannot generate correct results.

The DCT can be applied only for a set of familiar products which use the same PMF-Structure and BoM, there should be no overlapping in terms of PMF-Structure, PS etc. with other products or components otherwise and for these non-familiar products we need another separated DCT-System to control and monitor the supply chain.

The DCT can only be performed for completely defined final products and not for roughly defined final products which are normally used in forecasting scenarios. Only if actual customer orders are available in the MPS for a certain period the DCT can calculate orders for components and can compare and harmonize the real and virtual logistic world for this time-window according to the LT for the required components.

5 Summary and brief conclusion

The presented concept of a Digital Control Twin for mastering the supply chain is a response to new technologies and software-tools of Industry 4.0 and the huge amount of collected and available data of material flow objects because existing System bases mainly on the MRP-II concept which is able to react quick enough and don't use appropriate algorithm and methods for the industry 4.0 environment. The emergence and implementation of DT-Concepts for engineered products must be complemented by an logistic-oriented DT-Concept for material flow objects. This concept bases on three main pillars: reality, repository, and regulation, whereby Digital Triggers represent the virtual world and Digital Shadow represent the real world of material flow objects. Based on this fundament a DCT-System can be designed to regulate and harmonize material flow of final products and its dependent components across the production and supply chain network. Regulation as the kernel of the DCT-System is not static but dynamic because target-actual-deviations must be balanced permanently along a timeline. For order calculation of components and balancing of MFO's the method of closed-loop-control is used whereby Digital Triggers represent target values and Digital Shadows represent actual values. Target-Actual-Deviations are analyzed, and the DCT-System can choose one of alternative delivery or manufacturing routes by rule-based regulation. 'Alerts' are generated if actual values violate defined boundaries of target values which make it possible to intervene in the process or to initiate other tools like simulation or optimization. All data are immediately stored in an integrated specific 'Data Gravity Center' that allows experts to use new software tools for data analysis like data mining, machine learning etc.

The DCT-System is a self-regulated and the execution rules are stored in a specific database of a System-Controller. Real and virtual logistic data are permanently present. Real and virtual processes are performed parallel in defined time cycles so current and planned status of material flow objects can be compared in time and as required.

Because the DCT-System includes material requirement planning and order calculation a separate MRP-System is not needed in the short run planning as long as actual sufficient customer orders are stored in the MPS. By this the DCT-System can be integrated into the ERP-System and the MRP-Module for inhouse-parts and buy-parts.

The implementation of such a logistic-oriented DCT-System can start with only some components and then extended to more components and more complex logistic processes. Finally, the DCT-system must be included all major components of final products to master material low for production, supplying and distribution of a company.

The presented concept is still in an early stage, as a next step a protype of a DCT must be designed and tested to get experience for concrete products and material flow in a real supply chain environment.

References

Anderl R, 2016, "A Digital Twin Perspective –A Methodology to Generate manufactured Component Instances from Part Types", Speech at German-Czech-Workshop (accessed, 8. June 2020)

Arnold D., Furmans K., 2009: “Materialfluss in Logistiksystemen”, 6. erweiterte Auflage, Springer Verlag, Berlin, S. 47 ff., http://dx.doi.org/10.1007/978-3-642-01405-5

Anupindi et al., 2012, “Managing Business Process Flow – Principles of Operations Management “, 3. Global Ed., Pearson Education Ltd., Prentice Hall

Bauernhansl et. al (Hrsg.) 2014, “Industrie 4.0 in Produktion, Automatisierung und Logistik", Springer Vieweg, http://dx.doi.org/10.1007/978-3-658-04682-8

Burduk A., Chlebus E., Nowakowski T., Tubis A., (eds), 2019, "Intelligent Systems in Production Engineering and Maintenance", Springer, http://dx.doi.org/10.1007/978-3-319-97490-3

Chankov S., Hütt M-T., Bendul J., 2016, "Synchronization in manufacturing systems: quantification and relation to logistics performance", in: International Journal of Production Research, http://dx.doi.org/10.1080/00207543.2016.1165876

Deuter A., Pethig F., 2019, "The Digital Twin Theory - A New View on a Buzzword", http://dx.doi.org/10.30844/I40M_19-1_S27-30

DHL, 2019, “Digital Twins in Logistics”, DHL Trend Research, 2018, available at: https://www.dhl.com/content/dam/dhl/global/core/documents/pdf/glo-core-digital-twins-in-logistics.pdf ; (accessed: 18 May 2020)

Gartner, 2018, "Top 10 Strategic Technology Trends for 2018”, available at: <https://www.gartner.com/smarterwithgartner/gartner-top-10-strategic-technology-trends-for-2018/ >, (accessed : 18. May 2020)

Farahani P., Meier C., Wilke J, 2019, "Digital Supply Chain Management 2020 Vision" (Whitepaper), Publisher SAP SE in collaboration with University of Applied Sciences and Arts, Northwestern Switzerland (FHNW),>

Fraunhofer IML, 20xx, Social Networked Industry- an integrated approach - Future Challenges in Logistics and Supply Chain Management", White paper, http://dx.doi.org/ 10.24406/IML-N-481736

Furmann R., Furmannova B., Więcek D., 2017, "Interactive design of reconfigurable logistics systems", TRANSCOM 2017, Procedia Engineering 192, 207 – 212, http://dx.doi.org/ 10.1016/j.proeng.2017.06.036

Grieves M., 2012, “Delivering on the promise of global growth”, available at: <http://www.apriso.com/library/white_papers/Delivering%20on%20the%20Promise%20of%20Global%20Growth%20-%20Cummins%20Inc.pdf > ;(accessed: 20. May 2020)

Grieves M., 2014, "Digital Twin - Manufacturing Excellence through Virtual Factory Replication”, Whitepaper, <https://www.researchgate.net/publication/275211047_Digital_Twin_Manufacturing_Excellence_through_Virtual_Factory_Replication> (accessed: May 2020)

Heizer J., Render B., Munson C., 2020, “Operations Management - Sustainability and Supply Chain Management”, 13. Ed., Pearson Education Ltd., Essex

Herlyn W., 2012, “PPS im Automobilbau - Produktionsprogrammplanung und -steuerung von Fahrzeugen und Aggregaten“, Hanser Verlag, München

Herlyn W., 2014, "The Bullwhip Effect in expanded supply chains and the concept of cumulative quantities”; in: “Innovative Methods in Logistics and Supply Chain Management”, Blecker Th. et al. (Ed.), epubli GmbH, Berlin, 2014, S. 513-528

Herlyn W., 2017, “Comprehensive MRP-concept for complex products in global production and supplying networks”, at:'OR-2017’ Conference, Stream: ‘Production and Operations Management’, <https://www.researchgate.net/publication/331975808_Comprehensive_MRP-Concept_for_complex_products_in_global_production_and_supplying_networks> (accessed : 18 May 2020)

Ivanov D. Dolgui A., 2020 "A digital supply chain twin for managing the disruption risks and resilience in the era of Industry 4.0, in: Production Planning and Control, May 2020; http://dx.doi.ord/10.1080/09537287.2020.1768450

Ivanov D. Dolgui A, Sokolov D., 2019,"Digital supply chain twins: Managing the Ripple effect, resilience and disruption risks by data-driven optimization, simulation, and visibility", in: Handbook of Ripple Effects in the Supply Chain, pp.309-332, http://dx.doi.org/10.1007/978-3-030-14302-2_15

Johns D. et. al , 2020, "Characterising the Digital Twin: A systematic literature review", in CIR, Volume 29, http://dx.doi.org/10.1016/j.cirpj.2020.02.002

Kritzinger W. Karner M., Traar G., Henjes J., Shin W., 2018, "Digital Twin in Manufacturing - A categorial Classification", in: IFAC Papers OnLine , 51-11 (2018) 1016–1022 , http://dx.doi.org/

Klug Florian, 2018, "Logistikmanagement in der Automobilindustrie", 2. Auflage, Springer Vieweg, 2018, p. 17 ff., http://dx.doi.org/10.1007/978-3-662-55873-7

Koppelberg S., 1989, “Interval Algebras", in: Monk J. D., Bonnet R. (Ed.) in: “Handbook of Boolean Algebra “, Vol. 1, North-Holland, Amsterdam, p. 241 ff.

Kunath M., Winkler H. 2018, "Integrating the Digital Twin of the manufacturing system into a decision support system for improving the order management process", in Procedia CIRP 72, http://dx.doi.org/ 10.1016/j.procir.2018.03.192

Jiewu Leng J., Hao Zhang, Douxi Yan, Qiang Liu, Xin Chen, Ding Zhang, 2018, "Digital twin-driven manufacturing cyber-physical system for parallel controlling of smart workshop", in: Journal of Ambient Intelligence and Humanized Computing, http://dx.doi.org/10.1007/s12652-018-0881-5

Luściński S., 2018, "Digital Twinning for Smart Industry", MMS 2018, November 06-08, EAI, http://dx.doi.org/ 10.4108/eai.6-11-2018.2279986

Plattform Industrie 4.0, 2019, "Themenfelder Industrie 4.0", <https://www.plattform-i40.de/PI40/Redaktion/DE/Downloads/Publikation/acatech-themenfelder-industrie-4-0.pdf?__blob=publicationFile&v=10beirat der Plattform Industrie 4.0, September 2019>, (accessed: 8. June 2020)

Rodicz B., 2017, "Industry 4.0 and the New Simulation -Modelling Paradigm",

SAP, 2019 „The Power of Digital Supply Chain and Intelligent Technologies“; available: https://www.sap.com/content/dam/site/events/emea/germany/assets/2019-04-01-de-email-power-digital-supply-chain-agenda.pdf;(accessed:18 May 2020)

Schönsleben P., 2016, “Integral Logistics Management", Fifth Edition, CRC Press, Boca Raton, p. 323 ff. http://dx.doi.org/10.4324/9781315368320

Schuh G., Stich V. (Hrsg.), 2013, "Logistikmanagement", 2. Aufl. Springer Vieweg, Berlin

Schwerdtfeger St., Boysen N., Briskorn D. (2018) “Just-in-time logistics for far-distant suppliers: Scheduling truck departures from an intermediate cross-dock terminal", in OR-Spectrum, http://dx.doi.org 40:1-21, 10.1007/s00291-017-0486-y

Stadler H., Kilger C., Meyr H. (Eds), 2015, "Supply Chain Management and Advanced Planning", 5. Ed., Springer, http://dx.doi.org/ 10.1007/978-3-642-55309-7

Stevenson W. J., 2018, "Operations Management", 13 Ed., McGraw-Hill, New York

Timm I. J., Lorig F., 2015, "Logistics 4.0 - A Challenge for simulation", in: Proceedings of the 2015 Winter Simulation Conference, http://dx.doi.org/ 10.1109/WSC.2015.7408428

Uhlemann T., Lehmann C., Steinhilper R., 2017, "The Digital Twin: Realizing the Cyber-Physical Production System for Industry 4.0", in: Procedia CIRP 61 (2017), 335 – 340, http://dx.doi.org/10.1016/j.procir.2016.11.152

Wiendahl H-P., 1997, “Fertigungsregelung", Carl Hanser Verlag, München Wien. S. 33 ff.

Wiendahl H-P., 2011, " Auftragsmanagement der industriellen Produktion", Springer Verlag, http://dx.doi.org/10.1007/978-3-642-19149-7

WiGeP, 2019, "Digitaler Zwilling, <http://www.wigep.de/fileadmin/Positions-_und_Impulspapiere/Positionspapier_Gesamt_20200401_V11_final.pdf > (Accessed: 8. June 2020)

Zadek H., Herlyn W. J., 2020, "Der Digitale Steuerungs-Zwilling"; in: ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 2020 115, special, 70-73; Hanser Verlag, http://dx.doi.org/10.3139/104.112338

Blockchain Technology in Germany: An excerpt of real use cases in logistics industry

Devis Bartsch [1] and Herwig Winkler [1]

1 – BTU Cottbus-Senftenberg

Purpose: Due to the large number of intermediaries in logistics networks there is a variety of possible failures, frictions and waste of time and money among the logistics process chain. With the ability to provide data securely in near real-time, like track and tracing data of goods to every participant, the Blockchain-Technology (BCT) can help to solve these problems.

Methodology: A structured literature analysis has been executed by using the databases Web of Science and Science Direct to find out current intermediary´s functions and real use cases. In addition, available other sources, like manufacturer websites, blog entries or whitepapers are searched for specific blockchain-based applications invented and used by German companies. The identified use cases are then qualitatively analyzed.

Findings: The first results showed that most of the business cases are still in the concept phase or are merely ideas how the BCT could solve existing problems. Additionally, we got results on the distribution of applications and economic benefits along the logistics chain. Furthermore, important conclusions on implementation problems can be derived from this.

Originality: In order to maintain Germany´s top economic position, it is necessary to push ahead with the adaption of the BCT. Our analysis contains first results in the area of real blockchain use cases of German companies. Initial comparisons between currently used and blockchain-based logistics networks are also possible.

First received: 14. Feb 2020 Revised: 15. Jun 2020 Accepted: 07. Jul 2020

1 Introduction

The complexity of logistics chains has increased with the growing number of intermediaries. They are used to organize, coordinate and perform actions and processes within the network and serve as enabler between the involved parties. This raising complexity makes the logistics chains slower and more expensive. This development can be regarded as independent of the market. However, there are changing customer demands, like cost reductions, shorter delivery times and improved traceability. In contrast, Loklindt et al. showed that a shipping container does not move half of the delivery time (Loklindt, Moeller and Kinra, 2018).Therefore, IBM and Maersk started a cooperation in 2016. They created a blockchain-based platform which unites all participants and intermediaries. The main target is supporting all parties with real-time information about every single cargo and its actual status in order to reduce costs, risks and lead time.
A blockchain is based on distributed ledger technology. That means all information are visible and spread throughout the whole network. Moreover, the blockchain is built as a peer-to-peer network, which enables new possibilities of storing and exchanging transaction data without the need of a trusted intermediary. Hence, a lot of roles within logistics networks will change and some participants as the customs officer will drop out by using the BCT with additional implementation of smart contracts (Dobrovnik et al., 2018). Smart contracts are protocols, which contain rules and logical connected terms of trade. Additionally, the smart contract implements individual trading rules between the parties. In practice it means conditions of payment, of forwarding goods or quality assurance can be described, e.g. the shipment container will just load in case the door lock is not damaged.

All of these information will recorded, analyzed and confirmed by both parties. The BCT in combination with smart contracts serves as a secure and immutable interface.

As part of the logistics networks the increasing complexity poses challenges to German companies. Currently a lot of human intermediaries are working along the logistics chain. They serve as important enablers between all other participants of the network in order to organize and coordinate all kinds of processes and actions within the network. Intermediaries come along in a big variety, from the customs officers, to the port manager, the logistics provider, to the chatter of the cargo ships, who transport the goods. On the other hand they are cost-casing and a point of failure. Due to the increasing spread of BCT, with its potential for disruptive change, the role of human intermediaries and the corresponding processes will change, e.g. no more paperwork for cross border shipments and therefore no need of any customs officers or more possibilities for effective routing by the distributer (Dickson, 2016).

The main target of our article is answering following research questions:

RQ1: Is the effect of disintermediation a possible factor for further adaptation of the Blockchain-Technology in German enterprises?

RQ2: What is the status quo of Blockchain-Technology adoption in German (logistics) companies by analyzing selected use cases?

To address the research questions we conduct a structured literature analysis on current functions of human intermediaries in logistics chains and real blockchain-based use cases in German logistics. The phenomenon of disintermediation is investigated in a separate research. Additionally we will execute a guided iterative screening of other available sources as the manufacturer's websites, whitepapers, blogs and websites focusing on

crypto currencies to gain more information. Furthermore we will analyze real use cases by employing Robert Stake´s approach for qualitative case study analysis, due to the lack of quantitative data (Stake, 1995).
The article is structured as follows. We will continue by first giving the theoretical background of the BCT as well as the phenomenon of disintermediation in logistics chains. In the methodology section we will present our framework for a multilevel literature research based on the tasks of human intermediaries in the logistics chain. Furthermore, we will explain why this is not appropriate for the identification of applications (Section 3.1) and give a brief description of the selected blockchain-based applications. The results sections starts with the cross-case analysis and leads to the within-case analysis, with our assumption of disintermediation probability, followed by a brief discussion of the results. Section 4.3 answers the question on the actual status quo of blockchain adoption in German companies. The last part contains conclusions and proposals for further research.

2 The blockchain-technology

Satoshi Nakamoto presented the BCT in 2009 by introducing the cryptocurrency Bitcoin (Nakamoto, 2008). Up to now Bitcoin is the most popular use case for BCT. Modern logistics chains originating a huge amount of information, like transaction data, tracking protocols and contracts just to address some of them. All these information need to be recorded, protected, proofed and shared if necessary. Hence, all participants permanently exchange information, which are important from their individual point of view. By focusing on logistics, especially on international cargo freight, it is obviously that these kind of information exchange rises shipping costs and lowers the competitiveness. Eventually, the participants in the logistics branch need shift the way they work (Iansiti and Lakhani, 2017).

2.1 How blockchain principles solve logistics problems

Since the existence of logistics chains, there are various problems that need to be solved. Kudlac et al. are clustering all problems in three groups. Group one describes knock-out problems, i.e. can the logistics chain be realized or not, including safety aspects or the transportability with different means of transport. The second problem group describes problems that are quantifiable over a certain period of time, such as costs incurred, delivery times or delivery reliability. Group three summarizes all problems that are likely to occur, such as cost overruns, delivery delays or changing customer requirements (Kudlac, Stefancova and Majercak, 2017). BCT can possibly solve the mentioned logistics chain problems.
The name blockchain is derived from the way how the data and information were stored. A predefined set of transactions will be recorded on one block. In this connection it does not play any role which kind of data or information are in a single transaction. Depending on the sort of blockchain a single block has a determined size, which cuts the number of possible stored transactions for a several block. Through scientific cryptography and digital signatures the transactions are protected and secured in a block. A block contains a timestamp of creation, a block number and a unique value, called block hash. The preceding block is connected with next block in the chain through their block hash values. Therefore, no third party is necessary to confirm the transaction. Due to the decentralized

character every participant has insight into the whole blockchain. This feature can cover the safety and trust issues, which is described concluded in group one. Nodes, a special group of clients, are connected to each block and responsible for confirmation through a consensus mechanism. For each transaction a private and a public key based on the calculated hash value is given to the user. Encrypting of data is just possible by having the right pair of public and private key. Further details of how the technology works can be found in (Christidis and Devetsikiotis, 2016). However, more important for the motivation of implementation of BCT into logistics systems are the blockchain-principles and their ability to solve current problems, e.g. high costs, trust and safety issues or inefficient processes along the logistics chain (Kudlac, Stefancova and Majercak, 2017).

Gupta and Iansiti/Lakthani summarize five principles of BCT. The most remarkable feature is the fact, that all blockchains are based on the distributed ledger technology. Particularly the availability of information increases, due to the fact that the whole ledger is completely shared, updated and replicated among all relevant participants. Based on the fact no central entity controls the blockchain all information are available in near real-time. There is no need for an intermediary for verification of transactions (Gupta, 2018; Iansiti and Lakhani, 2017).

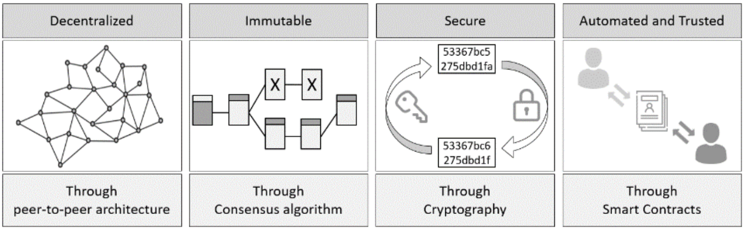


Figure 1: Basic blockchain principles (based on Hackius and Petersen, 2017)

Second, BCT offers the possibility to facilitate a peer-to-peer network, which underlines the decentralized character of the ledger. It means clients (nodes) communicate with each other directly within the network without a central node as found in classically organized business networks.

The blockchain is immutable. Therefore records cannot be altered after the transaction is verified and the blockchain is up to date. Every block is connected to the previous block. In order to close a block all participants have to find consensus through a defined consensus mechanism. In contrast to today´s status quo the BCT is absolutely transparent. To illustrate all associated clients of a transaction have access to the same database and therefore to the same records. Due to the high grade of transparency no trust is needed. Transactions can be verified within seconds without a trusted intermediary. As mentioned before every transaction is ordered by the time of verification and time-stamped.

One of the biggest problems in business is the need of trust or the need of a trusted intermediary, like a notary (Queiroz and Fosso Wamba, 2019). Both is time consuming and raises the costs for focused transaction. BCT is flexible and evolving. Moreover, BCT offers the possibility to implement smart contracts. The involved parties can implement one or more conditions to trigger the next step of their transaction. A new end-to-end solution is now available without the need of a trusted intermediary (Gupta, 2018; Iansiti and Lakhani, 2017).

2.2 Disintermediation as consequence of blockchain-technology

Due to the complexity of globally interlinked logistics networks with their involved intermediaries, inefficiencies and frictions increase. Under these conditions, certain business models are not possible, especially when many small transactions and very broad customer requirements are involved (Nowinski and Kozma, 2017). According to Allen, the original meaning of disintermediation is to invest money without the mediation of a bank or other controlling factors (Allen, 1996). A more recent definition, very appropriate for this article, is provided by Atkinson. He describes disintermediation as "the reduction or elimination of the role of retailers, distributers, brokers, and other middlemen in transactions between the producer and the costumer" (Atkinson, 2001). Another definition that applies to the technological properties of blockchain is provided by (Sampson and Fawcett, 2001). They describe disintermediation as a direct business relationship with the manufacturer without a middleman. Taking into account the different definitions of disintermediation, some conclusions can already be anticipated. There may be an increase in the number of contracts concluded between consumers using smart contracts (Jacquemin, 2019). Disintermediation of human intermediaries will lead to a disintermediation of processes and to the emergence of new and more efficient processes. Logistics networks will thus act more sustainably and become more competitive. Customers can be offered new services, such as an extended quality guarantee (Chang, Chen and Lu, 2019). The final consequence will be a re-engineering of the entire logistics chain with significantly fewer intermediaries than the current status quo. The first transformations of logistics chains through BCT can be observed worldwide. We use definitions provided by Atkinson and Samson & Fawcett to analyze these first re-engineering phenomena in logistics chains of German companies.

3 Methodology

To answer the first research question, we begin with a literature review of the tasks of human intermediaries currently used in logistics chains (section 3.1). The identified functions will later be used for the analysis (section 4.2) of the found blockchain-based applications in the following case study research. The results from section 3.1 are the functions of human intermediaries in logistic chains. The results on disintermediation (section 2.2) and from 3.1, serve for the analysis of the use cases found in section 3.2. Using the results of the within-case and cross-case analysis, RQ1 is then named. RQ2 is then answered in Section 4.3 (see figure 2).

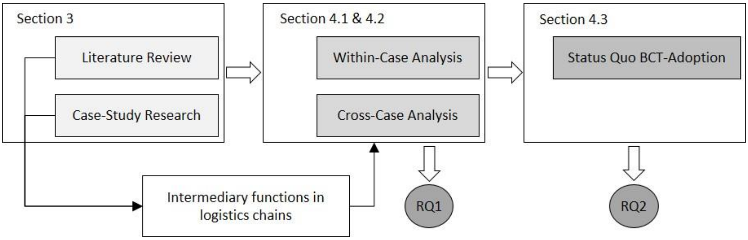


Figure 2: Process of research questions answering

3.1 Structured literature review

According to Webster and Watson (Webster and Watson, 2002), it is necessary to conduct a structured literature analysis in order to be able to answer the research questions. Usually the literature analysis is divided into different steps, which can be defined differently depending on the author. Nonetheless, the analysis proceeds from problem formulation, literature search, literature analysis and the subsequent interpretation of the sources (Moher et al., 2009). To obtain the necessary information, the scientific databases Web of Science and Science Direct were used for section 3.1. We got a total of 58 hits with the search algorithms used (asterisk symbol corresponds to a placeholder for the rest of the string to take into account different spellings; see Table 1). After removing the duplicates, 50 sources remained. The found references were transferred into literature management software Zotero, ranked and analyzed according to their usability for finding out the current functions of human intermediaries in logistics chains.

Table 1: Distribution of identified references for intermediary´s functions

Source	Algorithm	Hits	Hits (%)
Web of Science	Logistic* AND intermediar* AND funcion*	49	85,0
Science Direct	Logistics AND (intermediary OR intermediaries) AND (function or role)	9	15,0

We now present the results of the structured literature research as shown in Figure 2, with the aim of identifying the tasks of intermediaries in logistics chains as a basis for further analysis of the real use cases. As far as possible we also tried to find first starting points for the guided iterative search with regard to blockchain-based applications. The next part will have a closer look to the most common human intermediaries in logistics networks and which frictions and failures could cause through them. The distributed nature of data and information management enables the possibility of performing transactions between network parties without an intermediary (Underwood, 2016; Turban et al., 2015). However, most of the intermediaries are still needed, due to scalability issues, which makes high frequency use inappropriate at the moment. Most of today's networks, which are used in German companies, use human intermediaries who have to accomplish many tasks at the same time. Turban et al. postulates that central intermediaries take over tasks that can be automated and tasks that require the experience of the intermediary. So it is assumed that the focus by blockchain adoption is on tasks of the first category. Often manual, automatable tasks are providing information on supply and demands, prices and trading requirements. The wider focus lies on matching sellers and buyers (Turban et al., 2015). In doing so, the intermediary appears as a trustworthy agent for enabling business relationships between strangers (Zheng et al., 2019). In modern multilayer logistics chains there are also third and fourth party logistics provider (4PL), which offer value added services such as consulting, payment arrangements and transport of the physical goods (Turban et al., 2015). A 4PL can be seen as a neutral business partner and offers several services in order to increase the efficiency along the logistics chain. Figure 3 shows how the 4PL is implemented in the logistics chain as cross section function (Mehmann and Teuteberg, 2016). Therefore the 4PL as intermediary incorporates with a lot of participants of the logistics chain and seems to be a good point to start with BCT implementation. German companies facing a lot of uncertainties concerning import regulations, therefore some intermediaries have a regulatory function in order to avoid trade law violence and high contractual penalties.

Companies could come to the conclusion that the primary goal of blockchain implementation should be the reduction of the number of intermediaries in their supply chains. This phenomena is called disintermediation (Giaglis et al., 1999) (see section 2.2).

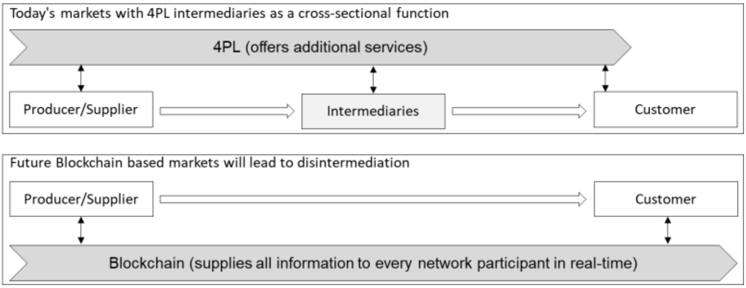


Figure 3: 4PL as cross section function intermediary (based on Giaglis et al., 1999)

3.2 Case study research

The second part of the research aims at identifying suitable use cases. Case study analysis is the most popular form of qualitative research (Recker, 2013), as it provides insights that other research methods do not allow (Rowley, 2002). For this article, the choice also falls on qualitative analysis, because the status quo of BCT adaptation is to be captured. This goal can only be achieved by examining use cases that are already in use in the real world. Thus, the transfer of laboratory results into the real world can be analyzed (Recker, 2013). However, there is criticism of this type of research methodology because it is not subjected to a codified design (Yin, 2009).

The use cases should only come from the logistics sector and be used by companies located in Germany. They should also be in real use and no longer have laboratory status to ensure of investigating a real world phenomenon. Furthermore, the number of cases is important to ensure sufficient scientific reliability. Pare postulates that the number of cases investigated depends on the object of investigation (Pare, 2004). Whereas Rowley

gives a defined range of 6-10 cases with different designs that have proven to be practicable (Rowley, 2002).
In order to find as many references as possible for use case identification, only the keywords "blockchain" and "Logist*" were used for the first research turn. After removing duplicates we got 248 hits in total, including all scientific areas. The second run additionally contained the search term "German*", which leads to 178 hits in total. After first screening of the abstracts 41 sources seemed to be relevant to the topic. A more detailed analysis showed that they are either theoretical concepts or the real case of application does not allow any conclusions for Germany. It also turned out that the Science Direct database in the advanced search mode also displays those publications for which the keyword "german" can only be found in the reference list. The second step in finding use cases is a Google search with the following search algorithm: ("blockchain and logistics") and german -supply chain, which returns 5,610 results. Attention was paid to the focus on logistics and not on the entire supply chain. After analyzing headlines, company websites, abstracts and articles, it turned out that this method has brought some use cases, but is very ineffective. The last step to find appropriate use cases was the iterative guided screening of various sources. The starting points were on the one hand the websites of the companies, whereby these hardly provide any further information. The second point of search are forums, blogs or relevant sites about crypto currencies, like BTC-Echo. These sites often provide various search options, where "snowballing" leads more effective to new sources with new content

(Brings et al., 2018). At this point the we use the analysis approach according to Stake, where the data analysis is "a matter of giving meaning to first impressions as well as to final compilations" (Stake, 1995), (see table 2).
To answer the research questions, 10 concrete use cases are analyzed in more detail. Most use cases come from medium to large enterprises. According to our research, we assume that this new technology requires significant financial resources for its implementation, which only a small number of companies have in their budget. They cover various fields of logistics in industries such as drug trade, chemicals, shipping, and transport in general, automotive, food trade and services (see Table 3 and 4). The tables show the respective blockchain application in the table header. The applications are numbered for a better overview (square brackets). The left column contains four clusters, which focusing on several features of the application.

Table 2: Distribution of identified references for real use cases

Source	Algorithm	Hits	Hits (%)
Web of Science	blockchain AND logist* AND german*	1	0,5
Science Direct	blockchain AND logistics AND german	178	91,3
Manufacturer websites		7	3,6
Blog entries		5	2,6
Crypto-web-sites		2	1,0
Whitepapers		2	1,0

The analysis of the areas "Intermediary functions", "Type of blockchain" and "Business model" is discussed in section 4.2. The cluster "Value proposition" is dealt with in section 4.1.

The functions of intermediaries have already been described in section 3.1 by employing the within-case analysis (see section 4.2) these functions are assigned to the respective blockchain-based application, e.g. taking over the trust building function of the human intermediary. The "Type of blockchain" and the "Business model" are also derived from the within-case analysis. For both clusters it is necessary to use several sources for the same application, which the structured literature analysis in the databases could not provide. If the blockchain is permissioned or permissionless depends on, which information are shared among the network partners. The "Business model" describes how the blockchain will act in each use case. The blockchain can act as an "Infrastructure provider", which only provides the blockchain to be used without further functionality. In case of a "Platform provider", a platform with additional functions will offered to the users. If the blockchain acts as an "Integrator", it connects legacy systems. The "Applications provider" provides the blockchain itself and a complete useable application as frontend.

Accenture and DHL [1] have established a blockchain solution that enables the pharmaceuticals to be tracked from the manufacturer to the end customer. This includes all necessary participants and thus prevents counterfeiting (Kückelhaus et al., 2018). The chemical manufacturer BASF and the two start-ups Ahrma and Quantoz [2] want to make the entire logistics chain more transparent for all parties involved. This is achieved by using sensor data and making the data available in the blockchain in almost real-time. The sensors are located on a pallet and record movement data and temperatures that are important for the chemical industry (Lacefield, 2017; Petersen, Hackius and See, 2018). Various players based in the port of Hamburg [3] and having different tasks have implemented a blockchain solution that serves as a common data platform. This is intended to improve the handling process from unloading the sea freight carrier to the transport of the containers by truck. Other participants like port terminals, truck companies and freight forwarders are also included (Hackius, Reimers and Kersten, 2019). Mosolf [4] is an automotive logistics service provider. It creates waybills and other documents in a blockchain solution and validates them with the help of smart contracts. The consulting company Etecture GmbH is responsible for the infrastructure conception. Lawa Solutions GmbH provides the necessary programming work (MOSOLF, 2019). Deutsche Bahn AG, in cooperation with IBM [5], wants to investigate into a blockchain-based traffic control solution. For this purpose a 57km long test field with 1 to 4 tracks will be used (Herrnberger, 2019; Wirminghaus, 2019). Two German automobile manufacturers are simultaneously trying to set up a blockchain, which primarily pursues the purpose of tracing where the cobalt for the accumulators of their electric cars comes from. The first manufacturer is BMW in cooperation with Circulor [6]. The cobalt needed for the new electric vehicles will be imported from Australia. It will first be chemically marked there. From this point on, counterfeiting is no longer possible (Lewis, 2018; Luckow, 2018; Scheider, 2019). Second, Mercedes Benz and Circulor [7] want to implement a blockchain to trace the route of its cobalt from recycling facilities entering the supply chain. In addition, working conditions and greenhouse gas emissions are to be monitored (Daimler, 2020; Pollok, 2020). Commerzbank, in cooperation with Daimler Truck [8], was the first bank in Germany to test a blockchain application, which serves to process fully automated machine-to-machine payments without the need for a trusted intermediary. The main focus is on payments at e-charging points and a truck (Commerzbank, 2019; Pollock, 2019). The MindSphere application is Siemens' [9] own cloud-based Internet of Things (IoT) software solution for monitoring the food and beverage supply chain. MindSphere offer users ready-made blockchain applications for registration and participation. Due to the given infrastructure it is possible to provide only the necessary data to the participant (Siemens, 2019). The Telekom subsidiary T-Systems [10] offers "Blockchain as a Service" on an independent marketplace. The services range from fully digital blockchain based monitoring of the entire logistics chain to the validation of cross-company business processes. The services can be purchased by interested companies at the relevant Telekom offices (Telekom, 2019).

Table 3: Assumption of possible features and benefits by shifting Status Quo to blockchain-based logistics solutions (based on Tönnissen and Teuteberg, 2020)

Blockchain-based application or leading companies	Accenture & DHL [1]	BASF, Quantoz & Ahrma [2]	Seaport Hamburg [3]	Mosolf & Etecture & Lawa Solutions [4]	Deutsche Bahn & IBM [5]
Intermediary functions					
Platform provider	X	X	X	X	X
Relevant information	X	X	X		X
Matching buyer/seller					
Trust	X		X	X	
Added value					
Complience/Governance	X			X	
Value proposition					
Cost reduction	X	X	X	X	X
Increased Transparency	X	X	X	X	
Process safety		X	X		X
Process efficiency		X	X	X	X
Tracebility	X	X	X	X	
Real-time processing	X	X	X		X
Type of Blockchain					
Permissioned	X	X	X	X	X
Permissionless					
Business model					
Infrastructure provider				X	
Platform provider	X				
Integrator		X			
Applications provider			X		X

Table 4: Assumption of possible features and benefits by shifting Status Quo to blockchain-based logistics solutions (based on Tönnissen and Teuteberg, 2020)

Blockchain-based application or leading companies	BMW & Circulor [6]	Mercedes Benz & Circulor [7]	Daimler Truck & Commerz-bank [8]	Siemens „MindSphere“ [9]	Telekom AG [10]
Intermediary functions					
Platform provider	X	X	X	X	X
Relevant information	X	X		X	X
Matching buyer/seller					X
Trust	X	X		X	
Added value	X	X			
Complience/Governance		X		X	
Value proposition					
Cost reduction	X	X	X	X	X
Increased Transparency	X	X	X	X	
Process safety					
Process efficiency			X		
Tracebility	X	X		X	
Real-time processing	X	X	X		
Type of Blockchain					
Permissioned	X	X	X	X	
Permissionless					X
Business model					
Infrastructure provider	X			X	X
Platform provider			X		X
Integrator					X
Applications provider		X			X

4 Results

For the analysis of the presented use cases, the websites of the participating companies, articles from journals, blog entries and relevant websites for crypto currencies were analyzed. Special focus was placed on the target figures summarized in tables 3 and 4: the possible functions as an intermediary of the blockchain application, the value proposition for the customer, the type of blockchain and which business model will be adopted with it. The analysis shows which of the respective use cases has the potential to eliminate human intermediaries from the logistics chain.

4.1 Cross-case analysis

In order to find out meaningful value propositions we use Stake's analysis approach, which is based on the intuition of the researcher on the one hand and on the assumption that there is no concrete point in time from which data are collected on the other (Stake, 1995). The aim of the cross-case analysis is to identify the value proposition by adopting BCT. First, all applications were roughly analyzed for their properties according to Stake. Then, their obvious value propositions were identified. This was followed by a second analysis run with reference to the work of Tönnissen and Teuteberg (Tönnissen and Teuteberg, 2020). Thus similar value propositions could be identified. Despite the multi-stage analysis, no new value propositions could be identified that could not be subsumed under the six already identified value propositions (see Table 3 and 4). The whole analyzing process is illustrated in figure 4.

The most important value propositions are cost reduction, increased transparency and traceability. The value proposition that occurs in every case examined is cost reduction through the elimination of human intermediaries and the associated errors and frictions. The increasing transparency value proposition is based on the permanent availability of all relevant, immutable data in real-time. The increased traceability is based on the same blockchain properties, extended by the peer-to-peer network and integrated smart contracts.

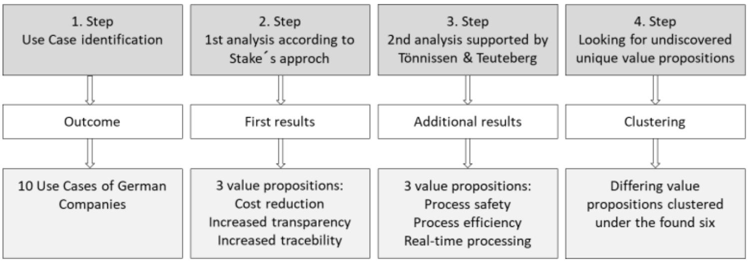


Figure 4: Analyzing process for value proposition identification

4.2 Within-case analysis

Accenture & DHL [1]: Primarily this application is a permissioned blockchain. However, the analysis is not quite clear, since the end customer can also be part of the network to check the authenticity of his pharmaceuticals. As an intermediary, it can be spoken here primarily of a platform provider, since additional functions are made available, thus human intermediaries become superfluous. Its value proposition is an increased transparency and high traceability of the pharmaceuticals. Cost reduction can also be mentioned, as the proportion of drugs to be replaced is decreasing. This application is a platform provider business model, since in addition to the blockchain, the service of authentication is offered to the end customer and user management to the distributors (Kückelhaus et al., 2018).

BASF, Quantoz & Ahrma [2]: Here the blockchain serves as an intermediary in the form of a platform provider. Due to the objectives of the three partners, this goal becomes clear. In addition, the solution should provide relevant information on the state of the load. This information is collected by the sensors attached to the pallets. With regard to the value proposition, cost savings are expected through better use of the pallets. In addition, the traceability of stolen and damaged pallets is significantly simplified. At the time of the analysis, access to blockchain is limited to the three project partners, who probably designed this blockchain as an integrator solution (Petersen, Hackius and See, 2018; Lacefield, 2017).

Seaport Hamburg [3]: The use case in the port of Hamburg is very complex due to the multitude of different participants. The blockchain is used here as a central intermediary that supplies all participants with information. This results in new functions that are directly reflected in the value proposition. Since all information are available completely and in real-time, the loading and unloading process can be made much more efficient. Cost and significant time savings have already been evaluated. In addition, it is clear at all times where the freight container being sought is located. The blockchain is only accessible for participating companies. Since there are some deficits among the logistics providers, the application has to be created from scratch. The blockchain is therefore designed here as an application provider (Hackius, Reimers and Kersten, 2019).

Mosolf, Etecture & Lawa Solutions [4]: With the introduction of BCT, a new intermediary is created, which opens up new functions and makes human personnel obsolete at some points in the logistics chain. There is always a high time pressure in the automotive industry and information on the delivery status must be available quickly. The customer can now call up the desired information himself. He no longer has to trust the statements of the employee. The value proposition is expressed in various dimensions, such as cost reduction or process reliability. As in the automotive sector, the analyzed blockchain is also access restricted. It is no information available on the business model, but it appears that the legacy software solutions will continue to be successful, it can be assumed that the blockchain has an integrator function (Pieringer, 2019; MOSOLF, 2019).

Deutsche Bahn & IBM [5]: This permissioned blockchain solution serves as a platform provider over which the traffic control should run autonomously. For this purpose, all information concerning to driving services must be available in real-time. The autonomously managed driving services offer high potential for cost reduction through personnel reduction and thus a high potential for increasing the efficiency of the entire railway operations. Until 2017 most of the scheduling activities were processed via Excel, fax and telephone, therefore it can be assumed that the blockchain solution will have to be created from scratch and can therefore only be an applications provider solution (Herrnberger, 2019).

BMW & Circulor [6]: BMW and Circular provide very little information for analysis. However, it is clear that the blockchain application will be structured as a platform provider according to the definition used here. New functionalities must be made available in order to be able to trace the path of the cobalt without any gaps. In addition, trust should be created across all participants in the logistics chain. Due to the complexity of this multi-layer logistics chain, many cost-intensive and more or less trustworthy intermediaries are involved. The value proposition consists on the one hand in the reduction of intermediaries and thus cost savings and on the other hand in an increase in process efficiency. It can be assumed that due to a lack of IT standards, the blockchain is designed as an infrastructure provider (Pollock, 2019; Lewis, 2018).

Mercedes Benz & Circulor [7]: The approach of Mercedes Benz and Circulor is to implement a platform provider through the blockchain. In the role of a central intermediary, the blockchain also takes on the tasks of providing relevant information to all parties involved, generating trust, maintaining and controlling compliance and legal standards. Mercedes Benz pursues the goal of closed material cycles and CO2 neutral production. The traceability of the origin and quantity of recycled cobalt as well as the measurement and storage of the quantities of greenhouse gases produced are to be solved with the blockchain application. The blockchain is permissioned. Due to the large number and complexity of the objectives pursued, it will probably be an application provider. Mercedes Benz does not give any further details (Daimler, 2020; Pollock, 2019).

Daimler Truck & Commerzbank [8]: The need for human intermediaries to initiate payments lowers process efficiency along the entire logistics chain. With the new "Cash on Ledger" function, the blockchain application can be identified as a platform provider that eliminates the need for human intermediaries. This makes the entire logistics process more efficient and secure. Currently the blockchain is permissioned. With the further expansion of capacities, access for additional participants will be made possible. The blockchain, in the sense of the business model, acts here as a platform provider (Commerzbank, 2019).

Siemens [9]: Through the integration of blockchain application into the MindSphere frontend, the user is provided with new functions in the form of a new platform provider. In addition, the blockchain forms a non-human intermediary that builds trust throughout the entire logistics chain, all the way to the end customer. The value proposition for the customer is increased transparency, traceability and process reliability. Secondary benefits include cost savings and a more efficient process. The blockchain is access restricted. Since MindSphere already exists as an application, the blockchain serves as an infrastructure provider (Siemens, 2019).

Telekom [10]: This blockchain application differs from the others examined in that, Telekom offers the “Blockchain as a service" tailored to the customer. Accordingly, the blockchain, as a new intermediary, can take over all the tasks of the existing intermediaries. However, it can be assumed that it will be implemented at least as a platform provider with new services and functions at the customer's premises. The value proposition depends on which project the customer is pursuing, as well as whether there will be access restrictions. The business model that the blockchain adopts remains variable (Telekom, 2019).

Based on the analysis, the first research question: "Is the effect of disintermediation a possible factor for further adaptation of the blockchain-Technology in German enterprises?" can be answered. The implementation of the BCT leads to the emergence of a new type of intermediary - here described as a platform provider, which provides new functions and services to the user, which did not exist before. The elimination of human intermediaries can be seen as a major consequence on the logistics chain by introducing blockchain-based solutions. Each of the analysed applications removes human intermediaries in the corresponding area of the company or logistics chain. It is possible that the intermediaries either change their role or take over other tasks as intermediaries (Giaglis et al., 1999). These effects will not be discussed in detail here. The within-case analysis and tables 3 and 4 show which tasks the BCT can take over and replace human intermediaries (see Table 5 and 6). Especially the possible cost savings and the reduction of human intermediaries make a further adaptation of the BCT interesting for German companies. Since the business model of most German companies requires cross-border, multidimensional logistics chains, BCT can help to make processes more efficient and secure, fight against counterfeiting of raw materials and products, and sustainably increase the trust of business partners among themselves and of end customers.

Table 5: Disintermediation probability of analyzed use cases

Probability of disintermediation of human intermediaries	Accenture & DHL	BASF, Quantoz & Ahrma	Seaport Hamburg	Mosolf, Etecture & Lawa Solutions	Deutschte Bahn & IBM
	[1]	[2]	[3]	[4]	[5]
High			X	X	X
Medium	X				
Low		X			

Table 6: Disintermediation probability of analyzed use cases

Probability of disintermediation of human intermediaries	BMW & Circulor	Mercedes Benz & Circulor	Daimler Truck & Commerz Bank	Siemens "MindSpehre"	Telekom AG
	[6]	[7]	[8]	[9]	[10]
High			X		X
Medium	X	X		X	X
Low					X

4.3 Blockchain adoption at the beginning

In contrast to RQ1, the second research question: "What is the status quo of Blockchain-Technology adoption in German (logistics) companies by analyzing selected use cases?" cannot be answered quite so clearly. It is clear that the potential of BCT has now been recognized and is gaining in importance beyond the financial sector (Shermin, 2017). The results so far imply a further increase of blockchain-based applications in German companies in the logistics sector. The analysis of the search results from the scientific databases Web of Science and Science Direct only provided initial clues to real use cases in Germany, but did not name them specifically. Further research in alternative sources and on the websites of the companies led to evaluable results. Surprisingly, most of the projects are only available as concepts and that there are no real applications. Some projects that have already taken shape are still in the laboratory stage and therefore not representative. Some of the applications identified in the first research did not stand up to further analysis (see Section 4.2) and had to be replaced. Finding and replacing them is very time-consuming. Considering all the real use cases found and the enormous effort for identification, it can be assumed that the status of blockchain adaptation of German companies in the logistics sector is still in its infancy. This can also be interpreted on the basis of the unavailable quantitative data for individual applications.

5 Discussion

Blockchain-Technology can cause a paradigm shift in the logistics industry. First of all, the BCT must gain more acceptance in order to prevail (Kückelhaus et al., 2018). The basis for a breakthrough is, among other things, the analyzed first use cases and the quantitative data they will provide in the future. The Port of Hamburg in particular is a prime example of the advantages and disadvantages of BCT. Here, the loading and unloading process becomes much more efficient and secure, but some stakeholders see problems in maintaining business privacy. Since all information are available for each participant, competitors can draw conclusions about business relationships and trading volumes (Hackius, Reimers and Kersten, 2019). The BCT is only accepted when a critical mass of stakeholders recognizes the predominant advantages (Dobrovnik et al., 2018; Shermin, 2017).

The use cases already show that there will not be a comprehensive blockchain solution, but a multitude of permissioned blockchains depending on which cooperation partners have joined. In some cases the blockchain is used as an integrator to connect legacy systems. From this the necessity of a uniform industry standard can be derived. Even more, this is necessary in order to be able to work across company's borders and thus use the full potential of BCT (Kückelhaus et al., 2018). Mosolf [4] has already recognized the potential of BCT in conjunction with smart contracts and has integrated them into their process. This has considerably reduced the need for administrative tasks and paperwork (MOSOLF, 2019). In particular, the value proposition of reducing costs and avoiding errors by human intermediaries is significantly reduced or practically eliminated, if the contract is logically programmed and properly implemented on the chain (Christidis and Devetsikiotis, 2016). Not only freight documents but also payments can be made without delay and a trusted intermediary, as Daimler Truck & Commerzbank [8] have already tested (Commerzbank, 2019). The application is remarkable against the background that companies wait on average of 42 days for the receipt of an invoice. The use of BCT with smart contracts leads to an increase in profits of between 2% and 4% while reducing costs simultaneously (Nelson et al., n.d.).

6 Conclusion and further investigations

This article has taken a closer look at two aspects of BCT. Firstly, it should be analyzed to what extent disintermediation is seen as the driving force behind the implementation of BCT. It was found that the blockchain itself acts as a new intermediary. On the other hand, the status quo of blockchain adaptation in Germany was examined on the basis of the search methodology and real use cases. Due to the data situation, a final answer is not possible, but it can be stated that the adaptation is still in an early stage.

Future research should concentrate on two topics. First continue on the identification of real cases of application and, once a critical number of cases has been reached, draw an international comparison. Based on the relative development of real applications in Germany compared to other economies, a more comprehensive answer to the status quo of Block-chain adaptation in Germany can be given. Second, the role of BCT as a new intermediary should be exposed with a focus on value propositions for the user as well as on technical characteristics that can change process chains and business models.

References

Allen, G., 1996. Disintermediation: A Disaster or a Discipline? Online Information Proceedings of the International Online Information Meeting see IR056 631, p.5.

Atkinson, R.D., 2001. The revenge of the disintermediated. Progressive Policy Institute Policy Paper (Jan. 2001), www. ppionline. org/documents/disintermediated. pdf.

Brings, J., Daun, M., Kempe, M. and Weyer, T., 2018. On Different Search Methods for Systematic Literature Reviews and Maps: Experiences from a Literature Search on Validation and Verification of Emergent Behavior. Proceedings of the 22nd International Conference on Evaluation and Assessment in Software Engineering 2018, Available at: <https://doi.org/10.1145/3210459.3210463>.

Chang, S.E., Chen, Y.-C. and Lu, M.-F., 2019. Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process. Technological Forecasting and Social Change, 144, pp.1–11.

Christidis, K. and Devetsikiotis, M., 2016. Blockchains and Smart Contracts for the Internet of Things. Ieee Access, 4, pp.2292–2303.

Commerzbank, 2019. Commerzbank testet erstmals Blockchain-basierte Maschine-zu-Maschine-Zahlung. [Companysite] commerzbank.de. Available at: <https://www.commerzbank.de/de/hauptnavigation/presse/pressemitteilungen/archiv1/2019/quartal_19_03/presse_archiv_detail_19_03_82762.html> [Accessed 23 Apr. 2020].

Daimler, 2020. Mercedes-Benz Cars drives ‘Ambition2039’ in the supply chain: blockchain pilot project provides transparency on CO2 emissions. [Firmenseite] Available at: <https://media.daimler.com/marsMediaSite/en/instance/ko/Mercedes-Benz-Cars-drives-Ambition2039-in-the-supply-chain-blockchain-pilot-project-provides-transparency-on-CO2-emissions.xhtml?oid=45528015> [Accessed 22 Apr. 2020].

Dickson, B., 2016. Blockchain has the potential to revolutionize the supply chain. Techcrunch.com. Available at: <https://techcrunch.com/2016/11/24/blockchain-has-the-potential-to-revolutionize-the-supply-chain/>.

Dobrovnik, M., Herold, D., Fürst, E. and Kummer, S., 2018. Blockchain for and in Logistics: What to Adopt and Where to Start. Logistics, 2, p.18.

Giaglis, G.M., Klein, S., O'Keefe, R.M. and O'keefe, R.M., 1999. Disintermediation, reintermediation, or cybermediation? The future of intermediaries in electronic marketplaces. In: Global Networked Organizations, Proceedings 12 th Electronic Commerce Conference, Moderna organizacija. Citeseer.

Gupta, M., 2018. Blockchain for dummies. 2nd ed. Hoboken, NY: Wiley.

Hackius, N. and Petersen, M., 2017. Blockchain in logistics and supply chain : trick or treat? In: Hamburg International Conference of Logistics (HICL) 2017. [online] pp.3–18. Available at: <http://tubdok.tub.tuhh.de/handle/11420/1447>.

Hackius, N., Reimers, S. and Kersten, W., 2019. The Privacy Barrier for Blockchain in Logistics: First Lessons from the Port of Hamburg. In: C. Bierwirth, T. Kirschstein and D. Sackmann, eds. Logistics Management. Cham: Springer International Publishing.pp.45–61.

Herrnberger, S., 2019. Deutsche Bahn investiert in Blockchain-Technologie. Blockchainwelt.de. Available at: <https://blockchainwelt.de/deutsche-bahn-investiert-in-blockchain/> [Accessed 4 Dec. 2019].

Iansiti, M. and Lakhani, K.R., 2017. THE TRUTH ABOUT BLOCKCHAIN. Harvard Business Review, 95(1), pp.119–127.

Jacquemin, H., 2019. Consumers contracting with other consumers in the sharing economy: fill in the gaps in the legal framework or switch to the blockchain model? Idp-Internet Law and Politics, (28), pp.44–55.

Kückelhaus, M., Chung, G., Gockel, B., Acar, T. and Forster, M., 2018. BLOCKCHAIN IN LOGISTICS.

Kudlac, S., Stefancova, V. and Majercak, J., 2017. Using the Saaty Method and the FMEA Method for Evaluation of Constraints in Logistics Chain. In: G. Bureika, I. Yatskiv, O. Prentkovskis and P. Maruschak, eds. Transbaltica 2017: Transportation Science and Technology. Amsterdam: Elsevier Science Bv.pp.749–755.

Lacefield, S., 2017. Pilot project connects blockchain and 'smart' pallets. Supply Chain Quarterly, [online] 3. Available at: <https://www.supplychainquarterly.com/news/20170830-pilot-project-connects-blockchain-and-smart-pallets/>.

Lewis, B., 2018. UK firm pilots using blockchain to help BMW source ethical cobalt. Reuters.com. Available at: <https://uk.reuters.com/article/us-mining-bmw-blockchain/uk-firm-pilots-using-blockchain-to-help-bmw-source-ethical-cobalt-idUKKBN1GH2UP> [Accessed 8 Dec. 2019].

Loklindt, C., Moeller, M.-P. and Kinra, A., 2018. How Blockchain Could Be Implemented for Exchanging Documentation in the Shipping Industry. pp.194–198.

Luckow, A., 2018. Use Case #2: Sichere Rohstoff-Quellen dank Blockchain. [Companysite] Available at: <https://www.bmw.com/de/innovation/blockchain-automobilindustrie.html> [Accessed 8 Dec. 2019].

Mehmann, J. and Teuteberg, F., 2016. The fourth-party logistics service provider approach to support sustainable development goals in transportation–a case study of the German agricultural bulk logistics sector. Journal of Cleaner Production, 126, pp.382–393.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G. and the PRISMA Group, 2009. Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. Annals of Internal Medicine, 151(4), pp.264–269.

MOSOLF, 2019. MOSOLF nutzt Blockchain für Frachtbriefe. [Firmenseite] Available at: <https://www.mosolf.com/en/news-media/press-releases/news-detail-view/mosolf-nutzt-blockchain-fuer-frachtbriefe.html> [Accessed 24 Apr. 2020].

Nakamoto, S., 2008. Bitcoin: A Peer-to-Peer Electronic Cash System. [online] Available at: <https://bitcoin.org/bitcoin.pdf> [Accessed 21 Aug. 2019].

Nelson, S., Henderson, S., Jones, G., Roon, M., Zargham, M., Bulkin, A., Brukhman, J. and Rowe, K., n.d. A blockchain-based protocol stack for global commerce and supply chains.

Nowinski, W. and Kozma, M., 2017. How Can Blockchain Technology Disrupt the Existing Business Models? Entrepreneurial Business and Economics Review, 5(3), pp.173–188.

Pare, G., 2004. Investigating Information Systems with Positivist Case Research. Communications of the Association for Information Systems, 13(18), p.34.

Petersen, M., Hackius, N. and See, B. von, 2018. Mapping the sea of opportunities: Blockchain in supply chain and logistics. it - Information Technology, [online] 60(5–6). Available at: <https://www.degruyter.com/view/journals/itit/60/5-6/article-p263.xml>.

Pieringer, M., 2019. Automobillogistik: Mosolf fährt auf die Blockchain ab. logistik-heute.de. Available at: <https://logistik-heute.de/news/automobillogistik-mosolf-faehrt-auf-die-blockchain-ab-16626.html> [Accessed 24 Apr. 2020].

Pollock, D., 2019. Blockchain Becoming Integral To Leading Vehicle Brands With The Future In Mind. forbes.com. Available at: <https://www.forbes.com/sites/darrynpollock/2019/08/31/blockchain-becoming-integral-to-leading-vehicle-brands-with-the-future-in-mind/#15c4754d1062>.

Pollok, D., 2020. Mercedes Leveraging Blockchain As Part Of Its Ambition2039 Initiative. forbes.com. Available at: <https://www.forbes.com/sites/darrynpollock/2020/01/31/mercedes-leveraging-blockchain-as-part-of-its-ambition2039-initiative/#5bd6b2594b8a> [Accessed 22 Apr. 2020].

Queiroz, M.M. and Fosso Wamba, S., 2019. Blockchain adoption challenges in supply chain: An empirical investigation of the main drivers in India and the USA. International Journal of Information Management, 46, pp.70–82.

Recker, J., 2013. Research Methods. In: J. Recker, ed. Scientific Research in Information Systems: A Beginner's Guide. [online] Berlin, Heidelberg: Springer Berlin Heidelberg.pp.65–110. Available at: <https://doi.org/10.1007/978-3-642-30048-6_5>.

Rowley, J., 2002. Using Case Studies in Research. Management Research News, 25(1), p.12.

Sampson, S.E. and Fawcett, S.E., 2001. The impact of disintermediation in retail supply chains.

Scheider, D., 2019. BMW setzt für ethische Kobalt-Produktion auf Blockchain. btc-echo.de. Available at: <https://www.btc-echo.de/bmw-setzt-fuer-ethische-kobalt-produktion-auf-blockchain/> [Accessed 8 Dec. 2019].

Shermin, V., 2017. Disrupting governance with blockchains and smart contracts. Strategic Change, 26(5), pp.499–509.

Siemens, 2019. Blockchain und das Internet der Dinge Vertrauenswürdige Rückverfolgbarkeit. Available at: <https://new.siemens.com/global/de/branchen/nahrungs-genussmittel/exklusive-inhalte/blockchain-iot.html> [Accessed 27 Apr. 2020].

Stake, R., 1995. The art of case study research. Thousand Oaks, CA: SAGE publications.

Telekom, 2019. Telekom macht Blockchain für Geschäftskunden einfach. [Companysite] telekom.com. Available at: <https://www.telekom.com/de/medien/medieninformationen/detail/telekom-macht-blockchain-fuer-geschaeftskunden-einfach-583650> [Accessed 2 Mar. 2020].

Tönnissen, S. and Teuteberg, F., 2020. Analysing the impact of blockchain-technology for operations and supply chain management: An explanatory model drawn from multiple case studies. International Journal of Information Management, 52, p.UNSP 101953.

Turban, E., King, D., Lee, J.K., Liang, T.-P. and Turban, D.C., 2015. E-Commerce: Mechanisms, Platforms, and Tools. In: E. Turban, D. King, J.K. Lee, T.-P. Liang and D.C. Turban, eds. Electronic Commerce: A Managerial and Social Networks Perspective. [online] Cham: Springer International Publishing.pp.51–99. Available at: <https://doi.org/10.1007/978-3-319-10091-3_2>.

Underwood, S., 2016. Blockchain beyond bitcoin. ACM New York, NY, USA.

Webster, J. and Watson, R.T., 2002. Analyzing the Past to Prepare for the Future: Writing a Literature Review. MIS Quarterly, 26(2), pp.xiii–xxiii.

Wirminghaus, N., 2019. Das sind die Vorreiter der Blockchain-Technologie. Capital.de. Available at: <https://www.deutschebahn.com/de/Digitalisierung/technologie/Neue-Technologien/blockchain-3241170> [Accessed 4 Dec. 2019].

Yin, R., 2009. Case Study Research - Design and Methods. 4th ed. Applied Social Research Methods Series. Los Angeles, CA: SAGE publications.

Zheng, M., Wu, K., Sun, C. and Pan, E., 2019. Optimal decisions for a two-echelon supply chain with capacity and demand information. Advanced Engineering Informatics, 39, pp.248–258.

Preventing Mental Strain for Logistics Workers: Guideline Development

Patrick Schwarz [1] and Matthias Klumpp [2]

1 – FOM Hochschule

2 – Universität Göttingen, Fraunhofer IML, FOM Hochschule

Purpose: The purpose of this paper is to discuss and analyze the introduction of a guideline, which aims to help prevent mental strain for logistics workers in an increasingly digitalized work environment. The guideline originates from the findings of computer science experimental rooms (IR) and expert workshops, which were analyzed in three German companies and are part of the INQA-project DIAMANT as well as from literature findings.

Methodology: Mental strain and stress are identified from interviews and questionnaires in three experimental rooms as well as from literature review (and discussions with the logistics workforce of the German companies). The identified factors are then translated into a guideline with recommendations for reaching and maintaining a healthy digitalized work environment in logistics.

Findings: The guideline “Case Studies Digitalization” shows the (interim) results of the three experimental rooms of the INQA-project DIAMANT. This paper offers insights regarding certain elements of the guideline and how the different recommendations were created.

Originality: The paper provides interesting insights into the development process of a guideline that focuses on requirements for healthy digitalized work in logistics. Along with these requirements, the challenges today’s logistics workforce faces in a quickly changing work environment are exposed.

First received: 14. Feb 2020 Revised: 15. Jun 2020 Accepted: 07. Jul 2020

1 Introduction

In the context of an ever-increasing level of digitalization in logistics, sick days due to mental health issues are on the rise (Knieps and Pfaff, 2019, p. 146). The growing digitalization has changed the work environment, and job strain is transforming from physical to psychological strain (Kadir et al., 2019; Lang et al., 2019). These changes include, for example, converting work hours, higher complexity and responsibility, as well as, rising job demands that lead to excessive demand or concentration disorders (Grosse et al., 2017). Furthermore, the implementation of new technologies is associated with a higher work intensity (Böckelmann and Seibt, 2011, pp. 207, 210-211; Meyer, Tisch, and Hünefeld, 2019, p. 219). Additionally, the potential perceived data overload and extended availability might block creativity and lead to increased stress, boundary-blurring and reduce the ability to enter mental relaxing phases (Nöhammer and Stichelberger, 2019, p. 1192). Therefore, the question arises how to prevent mental strain in (logistics) workers and sustain a healthy and motivated workforce. This paper will share advanced insights into the INQA-project DIAMANT to show the (interim) results of three experimental rooms. After the project and the purpose of the guideline are introduced in section 1, a literature review (section 2) on mental strain and increasing digitalization (in logistics) is going to give insights on the challenges for mental health that come along with an increasing level of digitalization. The development considerations for the guideline are introduced in section 3. In section 4 project findings will then support and underline the literature findings and lead to the content of the guideline. Section 5 and 6 show the limitations and implications of this paper, as well as a conclusion and an outlook.

The INQA-project DIAMANT tries to answer the question of how the rising digital working world can be innovatively organized and designed to gain advantages for companies and workers. Therefor three German companies are accompanied in their journey of digitalizing their work processes and evaluating mental challenges their workforce faces in a more and more digitalized work environment. During the project, an E-Coaching-System is developed and implemented to further support workers in their skills development. On top of that, the project team is also going to develop and implement a digital-ideas-management-software with the companies to help accumulate ideas of workers in a standardized way and reach continuous improvement. The three companies operate in the fields of retail, logistics, and production and thus provide a diverse background (online information at: diamant.digital).

2 Literature Review on Mental Strain and Increasing Digitalization in Logistics

Mental strain is defined as the “Entirety of all detectable influences that psychologically impacts humans from the outside”. It includes positive as well as negative emotional and behavioral requirements (Böckelmann and Seibt, 2011, p. 209; Deutsches Institut für Normung e.V., 2015, p. 9). Positive stress is given when a person is in a challenging situation but is confident to successfully master the task or situation. Negative stress, in contrast, is present when a person is in a situation where he or she is unable to succeed. Positive stress can lead to adrenaline kicks and feelings of success, whereas negative stress often leads to anxiety, muscle tension, high blood pressure and weakened capacity to recover (Berlin and Adams, 2017, p. 111).

The implementation of Industry 4.0 concepts, in general, causes a lot of change in today’s work environments. Communication between users and Cyber Physical Systems (CPS) leads to higher importance and interaction of human-machine-interfaces (Dombrowski and Wagner, 2014, p. 102). Industry 4.0, however, has to be distinguished from Logistics 4.0 or the increasing digitalization in logistics. Industry 4.0 applications deal, for example, with intelligent machine-user-interfaces, digital visualizations of machine or production conditions, or remote-maintenance of machines. Many of these applications have their routes in production processes and have no certain relevance for logistics processes. Logistics 4.0, in contrast, deals with telematics-applications, integrated freight exchanges, intelligent containers, or autonomous vehicles. Industry 4.0 and Logistics 4.0 still have the combined aim to optimize material flows through digital- or information-networking (Bousonville, 2017, pp. 13-14). The increasing use of new technologies comes along with new tasks and expectations towards logistics workers. As work tasks get more complex and autonomous, the demand for cognitive and communication skills grows. Workers change from executors to evaluators (Klumpp et al., 2019a, p. 72). These changing demands in Industry/Logistics 4.0 lead to higher psychological job demands.

Mayerl et al. analyzed the relationship of psychological job demand and mental strain through two surveys. In their research, they described mental strain to consist of three constructs: Irritation, exhaustion, and alienation. Their research confirmed that high psychological job demands resulted in higher levels of mental strain, which is associated with poor health (Mayerl et al., 2016, pp. 1, 5). Back in 1979, Karasek already described the connection of job demands, job decision latitude, and mental strain. He found out that lower work demands are associated with increased satisfaction. However, in combination with low decision latitude, low work demands would lead to a higher risk of mental health problems. His conclusion was that by increasing decision latitude, job strain could be reduced, regardless of changes in workload demands (Karasek, 1979, pp. 302-304; Meyer, Tisch and Hünefeld, 2019, pp. 208-209).

In the past years, there have often been concerns that the growing digitalization may result in future job loss due to automation (Arntz, Gregory and Zierahn, 2016, p. 4). Furthermore, in their research on workplace changes, Nikolova et al. found out that qualitative job insecurity due to workplace changes leads to emotional exhaustion (Nikolova et al., 2019, p. 14). These findings could lead to additional mental strain in workplaces due to perceived job insecurity through workplace changes and rising automation.

Various studies have recently dealt with possible job losses due to automation and have come to a wide variety of results. In their famous 2013 study, Frey and Osborne estimated that about 47% of total US employment is at high risk (>70%) of being automatable perhaps over the next one or two decades (Frey and Osborne, 2013, pp. 37-38). Arntz, Gregory, and Zierahn, however, determined that only nine percent of jobs in OECD countries (nine percent is also the figure for the US) are at high risk (>70%) of being substituted due to automation in an analysis across 21 OECD countries. The risk ranges from six percent in Korea to twelve percent in Austria and Germany (Arntz, Gregory and Zierahn, 2016, pp. 8, 15-16). Dengler and Matthes (2019) furthermore evaluated that the risk of automation is not the only important factor when considering potential job loss. They state that even though the share of jobs at high risk is rising, the substitution potential cannot directly be translated into job loss potential. Even though the substitution potential is high for logistics jobs, the possibility of job loss remains low due to ethical hurdles, higher profitability, flexibility, or better quality of human operators (Dengler and Matthes, 2019, p. 56). Koleva and Andreev (2018) additionally stated that the workers' role in an industry 4.0 (or in this case logistics 4.0) environment should not be underestimated as the technology should not be seen as a threat and substitute but as a helping hand. Due to automation, employees can focus on operations that bring bigger added value and do not have to cope with routine tasks (Koleva and Andreev, 2018, p. 2). Even though that the risk of automation may be high, managers could communicate the stated advantages of human operators and the lower association with real job loss to their workforce to prevent mental strain due to perceived job insecurity.

Though there seems to be a growing interest, discussion and understanding of the negative aspects of digitalization for managers and workers in recent literature, there seems to be a research gap regarding easy-to-follow advice to promote mental health and evaluate mental strain in a growing digitalized working environment. This is important for research and management to know as such guideline knowledge regarding digital implementation issues could lower the hurdle for firms and workers alike to enter digitalization projects. This paper therefore analyzes and accumulates recommendations on healthy digitalized work and tries to enable decision makers to easier address this topic as an example of how to arrive at such relevant change management process knowledge for digital logistics.

3 Creating a Guideline on Healthy Digitalized Work in Logistics

Especially firms and logistics managers require easy-to-use methods and materials to enhance the workers' health protection, and mitigation of health risks as this is not the focus of many decision perspectives. Though there is a number of law regulations prohibiting too much also mentally exhausting work, evaluation and assessment are not high on the most corporate priority lists. Therefore, a time-saving approach is required to support fast decisions and checking for specific workplaces and digital logistics work areas. This guideline, therefore, provides managers and other persons in charge with easy-to-use advice.

3.1 Methodology

To generate recommendations and requirements for a healthy digitalized work environment, the project findings and relevant literature are analyzed. The results will include positive findings as well as negative findings, which were transformed into recommendations. The findings and so the future contents of the guideline are then combined and presented in a shortened form. The literature research focuses on studies and papers that recommend certain practices to promote mental health and avoid mental strain in the workplace. This includes general as well as specific findings. The project findings originate in large part from risk assessments and interviews, which were performed in the three companies.
The databases which were used for the literature review are the EBSCO database, SpringerLink and Google Scholar. The main search terms were:

Mental strain, industry 4.0, logistics 4.0, mental stress, digitalization, scrum, design thinking, cobot, healthy digitalized work and mental health promotion. The findings also originate from interviews which were conducted in the partner companies of the DIAMANT project in 2019 and 2020. In these interviews, workers were asked about their mental health status, their decision latitude, the organizational climate and mental stress and strain through as well as the acceptance of new technologies.
For the development of the guideline content, a design thinking approach was used in order to better understand what is required to prevent mental strain and reach a healthy digitalized work environment. The design thinking approach prescribes a human/user-centered innovation process (Bicen and Gudigantala, 2019, p.10; Becker et al., 2020, p. 279). Innovators are guided on a personal journey that transforms their minds from that of experts to that of users building emotional commitment and allowing them to see and share new possibilities. After rearranging their mindset, they come together in dialogue-based conversations to reach alignment in what matters most from a user perspective. In a hypothesis-driven method, critical assumptions behind the newfound ideas are evaluated and visualized through various design tools. After all, they are implemented in experiments and tested in action. Through design thinking, innovators adopt the perspective of the end-user and can understand the needs, which are valuable to it. In gaining insights into the minds of those, being designed for the innovator builds emotional commitment and is able to bring in better higher order solutions into the discussions. In the experimentation and visualization phases, the innovator gains feedback from users and confidence in which solutions work best (Liedtka, 2020, pp. 55-57).

Another important methodology in the development process was a scrum. According to Gloger and Margetich (2018), a scrum does not break down the development process but the product. The overall project is split into mini-projects called sprints. These sprints have a maximum duration of four weeks. During a sprint, there are scheduled review sessions, and feedback of customers is used to continuously develop the product. A scrum ideally consists of seven persons with the following roles: the scrum-master, the product owner, and a development team of five. These cross-functional teams work according to the pull-principle and are responsible for how much work they plan to do in a determined period. After every sprint, the team has to present solutions to the determined sprint-tasks. The three roles have the following tasks during a scrum:

The development team: Delivering the product in the specified quality and under the circumstances of the agreed standards and processes.

The product owner: Working with and directing the development team. He or she has the vision and responsibility that the team develops the appointed functions.

The scrum-master: Helping the team reach its goals. He or she assists the team at reaching their goals, helps to solve problems, and trains them to understand and fulfill their roles (Gloger and Margetich, 2018, pp. 61-62).

This method is mostly used in product and software development but can be adapted to almost any field and is especially suitable for projects and teams in complex environments. Additionally, to the three roles in a scrum, there are four formally prescribed events: sprint planning, the daily scrum, sprint review, and sprint retrospective. During the sprint planning, the whole team is discussing and setting a sprint goal that can realistically be reached and has to be considered in every step. The daily scrum is a daily 15-minute meeting of the development team to synchronize activities and develop a plan for the next 24 hours. After the completion of a sprint, a sprint review with the scrum team and invited stakeholders is held. An evaluation of what has been achieved during the sprint is made, and work that is required to finish the sprint in the given time frame is identified. The last event is the sprint retrospective, which is held after the completion of one and before the start of another sprint. The focus during this event lies on analyzing the last sprint and developing a plan to improve the working procedures for the next sprint (Gonçalves, 2018, pp. 40-42).

3.2 Target Group

This paper and the resulting guideline are created to support companies and researchers in all fields and sizes of institutions and companies regarding digitalization changeovers. There is, however, a focus on companies in retail, logistics, and production due to the fields of action of the project partners. Due to the diverse background of the three companies, the literature findings, and the researchers, the results should still be applicable to various sectors that are dealing with a growing digitalized work environment. There seems to be a need for easy-to-follow advice in companies dealing with change connected to digitalization. Processes are shifting from Computer Integrated Manufacturing to the combination of automated processes and manual tasks (performed through humans) in hybrid systems. Executive production tasks are decreasing, and future work tasks require comprehensive process thinking and self-organization (Dombrowski and Wagner, 2014, p. 102). Another important development regarding hybrid systems is the implementation of collaborative robots (cobots) into work systems. Cobots combine a robot's strength and repetitive performance with the ability and skills of humans (Syberfeldt and Ekblom, 2019, p. 108). Therefore, the cobot cooperates with humans and is easily accessible for a human operator. It also contains integrated safety features and sensors to protect human operators when they get to close or in the motion of the cobot (Poór, Basl and Broum, 2019, p. 43). These hybrid systems demand different mental challenges for the human operator, and therefore, the content of this paper is also relevant for workers in that kind of systems.

3.3 Development Considerations

To gain superior ideas, solutions, and recommendations for the guideline, the design thinking method that was described in 3.1 was implemented and adjusted to the special conditions of the DIAMANT project. Some elements of the scrum-approach were also implemented, but the physical distance of the project team made it easier to stick more to the design thinking approach. To adopt the mindset of the workers (who are the end-users in this case), the researchers held several discussions and workshops with them in order to understand what the specific problems and needs were and where they originated. Doing so also resulted in an emotional commitment to try to reach better work conditions for the workers. The gathered solutions that were visualized and implemented are now in an experimentation phase. After wrapping up this phase, feedback will be collected to optimize and further personalize the solutions in the different companies. This last step will be covered in further literature after the DIAMANT project has finished. Beckman and Barry (2007) visualized this innovation process of problem and solution finding and selecting in their work on embedded design thinking. Figure 1 is based on their visualization and was modified according to the needs of the DIAMANT project.

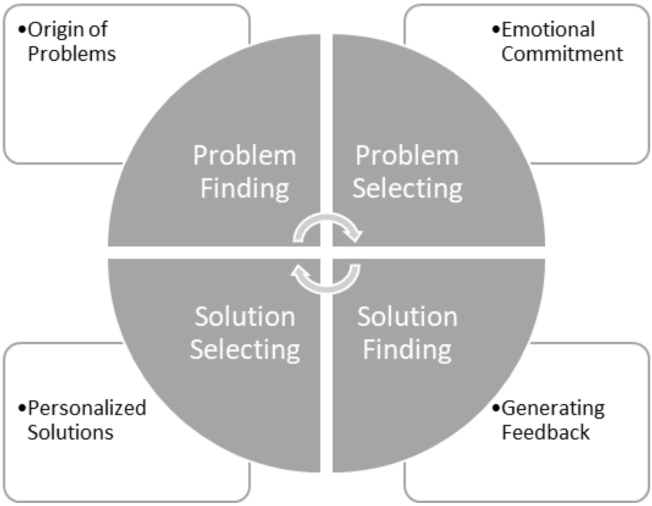


Figure 1: The Innovation Process as Problem and Solution Finding and Selecting (Based on: Beckman and Barry, 2007, p. 44).

4 Requirements and Recommendations for a Healthy Digitalized Work Environment

In this section, specific requirements and recommendations from the project and literature findings are presented. After the presentation, the resulting content of the guideline is introduced, and further ideas for the guideline will be discussed. The literature findings originate from various studies on mental health, mental strain, and work performance. General implications for mental health promotion are shown as well as more specialized implications for digitalized work environments.

4.1 Literature Findings

In regards to general mental health promotion, Seaton et al. (2019) analyzed mental health promotion in Canadian male-dominated workplaces through consultations and interviews and came up with suggestions to strengthen mental well-being in these workplaces. Four themes emerged, which should be promoted as follows:

(a) Reduce stigma through addressing misinformation, providing information on mental illnesses like depression, and showing the importance of mental health for workplace safety.

(b) Build social cohesion in supporting a culture of “having each other`s backs”. This is also achieved by promoting fun group activities in the workplace.

(c) Foster enjoyable activities that are supported by the top of the organization (like going bowling as a team in the afternoon).

(d) Support mental well-being through a consistent and ongoing focus on wellness and regular events. It is more important what happens on a day-to-day or week-to-week basis than what happens once or twice a year (Seaton et al., 2019, pp. 546-548).

Even though these findings should promote mental health in men-dominated workplaces, they can be viewed as general advice to promote mental well-being in every workplace.

In their work to support optimal human performance, Berlin and Adams (2017) referred to the following, more precise, advice for cognitive support and a healthy digitalized work environment:

(a) Provide good lighting, minimize noise, use haptic signals, and provide redundancy in sensory stimuli.

(b) Minimize the need for keeping too much information in the short-term memory.

(c) Aid perception using visual cues, pattern recognition, and consistency in design.

(d) Avoid information overload and use standardized work.

(e) Provide each workstation with work instructions.

(f) Use poka yoke methods; pick by light or voice, or andon.

(g) Simplify product designs to aid assemblers.

(h) Minimize the occurrence and effects of negative stress.

(i) Provide support for workers to handle stress – consider the cognitive needs of the individual.

(j) Strive to match the levels of control, demands, decision latitude, support, and supervision to the individual’s skill, experience, and maturity to allow workers to make their own decisions.

(k) Use design models at different stages of the design process to stimulate the workers to discuss and give ideas – this fosters solution ownership, innovation, and acceptance (Berlin and Adams, 2017, p. 266).

Mayerl et al. (2016) stated similar conclusions to promote mental health and prevent mental strain. They suggested three things as most important: (1) Fight overwhelmingly psychosocial job demands, (2) Reduce symptoms of mental strain through interventions, including strategies for cognitive behavior or relaxation techniques, and (3) Enlarge resources through the improvement of labor conditions and the strengthening of physical, mental, and social resources (Mayerl et al., 2016, p. 9). Böckelmann and Seibt (2011) support these findings but get a little more specific. According to their conclusions, optimization of psychological strain, health promotion, and growth of resources can be achieved through (1) Optimization of working conditions, design, organization, diversity, decision latitude, qualification potential, and coping strategies. (2) Professional and emotional support through colleagues and supervisors, and (3) Promotion of workers' competencies through professional and social qualification, cognitive control conviction, positive self-instruction, and personal relaxing techniques (Böckelmann and Seibt, 2011, p. 218).

4.2 Project Findings

Findings of the first stages of the DIAMANT project and an expert-workshop have shown similar results and recommendations on a healthy digitalized work environment. This has accomplished a detailed expectation and challenges analysis in the status quo. As a next step, digitalization changeovers in experimental settings will be implemented on the basis of this knowledge. The most common problems that occurred were that:

(a) Digitalization was often only referred to as avoiding and reducing the use of paper.

(b) The given hardware was limited to computers, smartphones, and scanners.

(c) The rising use of technical solutions increased strain through: growing time pressure, the complexity of a task surpassing the skill level, continuous reachability, using inflexible and unapproved technical solutions, and a higher possibility of being controlled through others.

(d) Learning demands were regarded as too high, and that could result in a refusal due to cognitive overload.

Positive findings of the project that have been collected so far are:

(a) Workers view it as positive when they are involved in the development of technical processes.

(b) They view rising digitalization as a risk reducer through the reduction of errors due to the use of technical assistant systems.

(c) Modern and better hardware is viewed as a sign of appreciation.

(d) Technical visualization is associated with simplifying work tasks.

The following things are seen as critical factors for a successful digitalization: (1) Performing a detailed analysis of requirements and involved processes and persons, (2) Ensuring an open communication of all steps with all persons involved, (3) Granting enough time for training and implementation that also results in higher acceptance rates, (4) Providing early communication of the positive aspects of the digitalized-option and appreciation and praise in case of successful implementation and use (Klumpp et al., 2019a, pp. 76-78; Klumpp et al., 2019b, p. 3694).

4.3 Guideline Content

The structure and content of the guideline have been made up of the literature and project findings. In the introduction, four fundamental questions are answered: (1) What is the purpose of this guideline?, (2) Who is this guideline dedicated to?, (3) Which themes are covered in this guideline?, and (4) Who are the authors of this guideline?

In summarizing the literature and project findings the following themes, advice and practices to prevent mental strain and support mental health have been determined as most important:

(a) Layout important information that supports mental health at the workplace/work station through:

(1) Providing general information material on mental illness, mental health, and mental well-being.

(2) Providing detailed work instructions at every workplace.

(3) Providing workers with positive self-instruction, relaxing techniques, and information on how to deal with and fight against the occurrence of negative stress.

(b) Optimize the workplace/work station design to support mental health through:

(1) Providing good lighting, minimizing noise, and working with haptic signals.

(2) Using visual cues, pattern recognition, consistent and simplified design, and standardized work.

(3) Using poka yoke, pick by light/voice or andon.

(4) Providing needed and state-of-the-art hard- and software and technical assistant systems to support technical visualization and simplifying work tasks.

(c) Train and promote cohesion and individual strengths and work on weaknesses and needs through:

(1) Building social cohesion and supporting fun group activities in the workplace.

(2) Fostering enjoyable activities outside of work with the support of the top of the organization.

(3) Consistent and ongoing focus on wellness and regular events.

(4) Providing support to handle negative stress (e.g., coping strategies and relaxing techniques) while considering individual cognitive needs.

(5) Matching a workers skill/experience/maturity to the level of control and trying to increase workers' decision latitude in general.

(d) Holistic involvement of workers through:

(1) Involving workers in every phase of the planning and implementation of technical processes and using design models to stimulate workers, support discussion, and in-crease acceptance.

(2) Supporting an open communication of all steps with all persons involved in the process.

(3) Communicating the positive aspects of digitalized options, appreciate, and praise them after a successful implementation.

5 Limitations and Implications

Even though the analysis of factors for a healthy digitalized work environment considered the results of the DIAMANT project and contains a wide variety of literature, it is important to state that not all advice and requirements have been tested during the project yet. However, the ones that were not fully implemented and tested yet originate from the literature findings and emerged from various studies. Furthermore, they will be subject to further evaluations and studies in the proceeding of the project. It is also important to acknowledge that despite the holistic approach of the presented guideline, it will be key to consider individual strengths, weaknesses, and particularities of workers, managers, workplaces, and companies in the process of implementing and applying this guideline. Individual factors play an important role while dealing with the treatment, support, and prevention of mental health (problems)/mental strain, and when in doubt, professional support should be consulted. Moreover, the findings are originating from German business settings, and therefore the transferability of results might be limited. Obviously, further research is required regarding in-depth guidelines for digitalization steps in logistics processes. Further company insights, additional industries, or country contexts could be analyzed for generalized findings.

6 Conclusion and Outlook

The aim of this paper was to provide insides on the creation of a guideline to prevent mental strain in logistics processes and for logistics workers. Through an analysis of relevant literature and findings from the associated project themes, requirements, and advice on healthy digitalized work emerged. The structure and content of the guideline were successfully created out of this analysis. Managers, researchers, and workers are provided with a guideline that offers hands-on advice on how to prevent mental strain and sustain a healthy digitalized work environment. The findings, however, are not limited to support the field of logistics and should furthermore be able to provide help in a wide field of Industry 4.0 environments. The most crucial aspects that became visible in this paper to sustain a mentally healthy workforce in a digitalized environment are open communication, an optimal workplace design, training of individual strengths and needs as well as a holistic involvement of workers. As one of the most useful advice items on how to prevent mental strain in the workplace, an increase in decision latitude seems to be promising.

As for further research, there seems to be a lack of knowledge in the field of promoting women's health in female-dominated workplaces. Similar to the Canadian study of Seaton et al. (2019) on promoting men's health in male-dominated workplaces, such research should be pursued. After the DIAMANT project, there should be further evaluation of the guideline content based on the experiences gained in the next phases of the project.

References

Arntz, M., Gregory, T. and Zierahn, U., 2016. The Risk of Automation for Jobs in OECD Countries: A Comparative Analysis. OECD Social, Employment and Migration Working Papers No. 189. Paris: OECD Publishing. https://dx.doi.org/10.1787/5jlz9h56dvq7-en.

Becker, F., Meyer, M., Redlich, B., Siemon, D. and Lattemann, C., 2020. Open KMU: Mit Action Design Research and Design Thinking gemeinsam innovieren. In: HMD 57, pp. 274–284. Springer. https://dx.doi.org/10.1365/s40702-020-00604-z.

Beckman, S. L. and Barry, M., 2007. Innovation as a Learning Process: Embedding Design Thinking. California Management Review, 50(1), pp. 25-56. http://dx.doi.org/10.2307/41166415.

Berlin, C. and Adams, C., 2017. Production Ergonomics: Designing Work Systems to Support Optimal Human Performance. London: Ubiquity Press. https://dx.doi.org/10.5334/bbe.

Bicen, P. and Gudigantala, N., 2019. Designing the Way Forward: The Role of Design Thinking in the Era of Digital Creativity. Journal of Strategic Innovation and Sustainability, 14(5), pp. 10-19. http://dx.doi.org/10.33423/jsis.v14i5.2518.

Böckelmann, I. and Seibt, R., 2011. Methoden zur Indikation vorwiegend psychischer Berufsbelastung und Beanspruchung – Möglichkeiten für die betriebliche Praxis. Z. Arb. Wiss. 65, pp. 205-222. https://dx.doi.org/10.1007/BF03373839.

Bousonville, T., 2017. Logistik 4.0 – Die digitale Transformation der Wertschöpfungskette. Wiesbaden: Springer Gabler Fachmedien Wiesbaden GmbH 2017. http://dx.doi.org/10.1007/978-3-658-13013-8.

Dengler, K. and Matthes, B., 2019. Digitalisierung in Deutschland: Substituierbarkeitspotenziale von Berufen und die möglichen Folgen für die Beschäftigung. In: R. Dobischat, B. Käpplinger, G. Molzberger, D. Münk, eds. Bildung 2.1 für Arbeit 4.0?, Bildung und Arbeit, 6. Wiesbaden: Springer Fachmedien Wiesbaden GmbH. pp. 49-62. https://dx.doi.org/10.1007/978-3-658-23373-0_3.

Deutsches Institut für Normung e.V., 2015. Ergonomische Grundlagen bezüglich psychischer Arbeitsbelastung - Teil 1: Allgemeine Konzepte und Begriffe (ISO/DIS 10075-1:2015). Berlin: Beuth Verlag GmbH.

Dombrowski, U. and Wagner, T., 2014. Mental strain as field of action in the 4th industrial revolution. Procedia CIRP, 17, pp. 100-105. https://dx.doi.org/10.1016/j.procir.2014.01.077.

Frey, C. B. and Osborne, M. A., 2013. The Future of Employment: How Susceptible are Jobs to Computerisation? [PDF] Oxford: Oxford Martin Programme on Technology and Employment. Available at: https://www.oxfordmartin.ox.ac.uk/downloads/academic/The_Future_of_Employment.pdf [Accessed 29 April 2020].

Gloger, B. and Margetich, J., 2018. Das Scrum-Prinzip. Stuttgart: Schäffer-Poeschel Verlag.

Gonçalves, L., 2018. Scrum. Controlling & Management Review 62, pp. 40-42. https://dx.doi.org/10.1007/s12176-018-0020-3.

Grosse, E. H., Calzavara, M., Glock, C. H. and Sgarbossa, F., 2017. Incorporating human factors into decision support models for production and logistics: current state of research. IFAC-PapersOnLine, 50(1), pp. 6900-6905. https://dx.doi.org/10.1016/j.ifacol.2017.08.1214.

Kadir, B. A., Broberg, O. and Souza da Conceição, C., 2019. Current research and future perspectives on human factors and ergonomics in Industry 4.0. Computers & Industrial Engineering, 137, 106004. https://dx.doi.org/10.1016/j.cie.2019.106004.

Karasek, R. A. Jr., 1979. Job Demands, Job Decision Latitude, and Mental Strain: Implications for Job Redesign. Administrative Science Quarterly, 24(2), pp. 285-309.

Klumpp, M., Hagemann, V., Ruiner, C., Neukirchen, T. J. and Hesenius, M., 2019a. Arbeitswelten der Logistik im Wandel – Gestaltung digitalisierter Arbeit im Kontext des Internet der Dinge und von Industrie 4.0. In: B. Hermeier, T. Heupel, S. Fichtner-Rosada eds., 2019. Arbeitswelten der Zukunft. Wiesbaden: Springer Fachmedien Wiesbaden GmbH. pp. 67-85. https://dx.doi.org/10.1007/978-3-658-23397-6.

Klumpp, M., Hesenius, M., Meyer, O., Ruiner, C. and Gruhn, V., 2019b. Production logistics and human-computer interaction-state-of-the-art, challenges and requirements for the future. The International Journal of Advanced Manufacturing Technology 105, pp. 3691–3709. https://dx.doi.org/10.1007/s00170-019-03785-0.

Knieps, F. and Pfaff, H., 2019. BKK Gesundheitsreport 2019 – Psychische Gesundheit und Arbeit. [online] Available at: < https://www.bkk-dachverband.de/publikationen/bkk-gesundheitsreport.html> [Accessed 31 March 2020].

Koleva, N. and Andreev, O., 2018. Aspects of Training in the Field of Operations Management with Respect to Industry 4.0. 2018 International Conference on High Technology for Sustainable Development. pp. 1-3. http://dx.doi.org/10.1109/HiTech.2018.8566581.

Lang, S., Kota, M. S. S. D., Weigert, D. and Behrendt, F., 2019. Mixed reality in production and logistics: Discussing the application potentials of Microsoft HoloLensTM. Procedia Computer Science, 149, pp. 118-129. https://dx.doi.org/10.1016/j.procs.2019.01.115.

Liedtka, J., 2020. Putting Technology in Its Place: Design Thinking's Social Technology at Work. California Management Review 2020, 62(2), pp. 53-83. https://dx.doi.org/10.1177/0008125619897391.

Mayerl, H., Stolz, E., Waxenegger, A., Rásky, É. and Freidl, W., 2016. The Role of Personal and Job Resources in the Relationship between Psychosocial Job Demands, Mental Strain, and Health Problems. Frontiers in Psychology, 7, 1214. http://dx.doi.org/10.3389/fpsyg.2016.01214.

Meyer, S.-C., Tisch, A. and Hünefeld, L., 2019. Arbeitsintensivierung und Handlungsspielraum in digitalisierten Arbeitswelten – Herausforderung für das Wohlbefinden von Beschäftigten? Industrielle Beziehungen. Zeitschrift für Arbeit, Organisation und Management, 2-2019, pp. 207-231. https://dx.doi.org/10.3224/indbez.v26i2.06.

Nikolova, I., van Dam, K., Van Ruysseveldt, J. and De Witte, H., 2019. Feeling Weary? Feeling Insecure? Are All Workplace Changes Bad News? International Journal of Environmental Research and Public Health, 16(10), 1842. http://dx.doi.org/10.3390/ijerph16101842.

Nöhammer, E. and Stichlberger, S., 2019. Digitalization, innovative work behavior and extended availability. Zeitschrift Für Betriebswirtschaft, 89(8/9), pp. 1191-1214. https://dx.doi.org/10.1007/s11573-019-00953-2.

Poór, P., Basl, J. and Broum, T., 2019. Role of Collaborative Robots in Industry 4.0 with Target on Education in Industrial Engineering. 2019 4th International Conference on Control, Robotics and Cybernetics, Tokyo, pp. 42-46. http://dx.doi.org/10.1109/CRC.2019.00018.

Seaton, C. L., Bottorf, J. L., Oliffe, J. L., Medhurst, K. and DeLeenheer, D., 2019. Mental Health Promotion in Male-Dominated Workplaces: Perspectives of Male Employees and Workplace Representatives. Psychology of Men & Masculinities, 20(4), pp. 541-552. http://dx.doi.org/10.1037/men0000182.

Syberfeldt, A. and Ekblom, T., 2019. Improved Automatic Quality Inspections through the Integration of State-of-the-Art Machine Vision and Collaborative Robots. In: Yan Jin, Mark Price (ed.), Advances in Manufacturing Technology XXXIII: Proceedings of the 17th International Conference on Manufacturing Research, incorporating the 34th National Conference on Manufacturing Research, September 10–12, 2019, Queen's University Belfast, UK. Amsterdam: IOS Press. Advances in Transdisciplinary Engineering. pp. 107-112. https://dx.doi.org/10.3233/ATDE190020.

Shared Digital Twins: Data Sovereignty in Logistics Networks

Hendrik Haße [1], Hendrik van der Valk [2], Norbert Weißenberg [1],

and Boris Otto [1]

1 –Fraunhofer-Institut für Software- und Systemtechnik ISST

2 – TU Dortmund Lehrstuhl für Industrielles Informationsmanagement

Purpose: Digital Twins attract much attention in science and practice, because of their capability to integrate operational data from a wide variety of sources. Thus, providing a complete overview of an asset throughout its entire life cycle. This article develops and demonstrates a Digital Twin, which enables a sovereign and multilateral sharing of sensitive IoT data based on proven standards.

Methodology: The design described in this paper is developed following the design science research methodology. Current challenges and solution objectives are derived from literature and the solution approach is implemented and demonstrated in a central artefact. The findings are evaluated and iterated back into the design of the central artefact.

Findings: For multilateral data exchange of sensitive operational data, standards are needed that allow for interoperability of several stakeholders and for providing a secure and sovereign data exchange. Therefore, the designs of the Plattform Industrie 4.0 Asset Administration Shell and the International Data Spaces are merged in this contribution. In this way, Digital Twins can be used in cross-company network structures.

Originality: Multilateral data sharing is still associated with considerable security risks for the companies providing the data. Therefore, the consideration of data sovereignty aspects for Digital Twins is very limited. Furthermore, Digital Twins are seldom addressed in the context of cross-company data sharing.

First received: 14. Feb 2020 Revised: 15. Jun 2020 Accepted: 07. Jul 2020

1 Introduction

A Digital Twin integrates and provides data from a wide variety of sources and in a multitude of formats over the entire life cycle of an asset or process. Besides static data, Digital Twins also contain dynamic process data and are therefore able to generate a comprehensive digital representation of a real object or process (Schroeder, et al., 2016, p. 13). Thus the Digital Twin forms an integrated and centralized knowledge base, which makes a valuable contribution to the improvement of business processes (Wang and Wang, 2019, p. 3895). In addition to the extensive generation of information and knowledge, a Digital Twin is characterized by the combination of information with meta-information, which allows a complete semantic description of an asset (Rosen, et al., 2015, p. 568). Therefore, a Digital Twin is a valid tool for data collection and data integration and a viable technology to solve the problem of data disruption between distributed systems. (Wang and Wang, 2019, p. 3894).

Currently, the use of Digital Twins is mainly limited to internal organizational processes, in which the Digital Twin is used to exchange data between different systems within a company (Schroeder, et al., 2016; Tao, et al., 2019, pp. 2409). Digital Twins also offer the opportunity to improve cross-company collaboration processes and represent a feasible instrument for data exchange between different stakeholders (Wagner, et al., 2017, p. 7; Schleich, et al., 2018, p. 7). However, inter-organizational data sharing is largely unconsidered in the literature on Digital Twins, which is reflected in the limited number of relevant examples on this subject. One example is the contribution by Wang and Wang (2019, p. 3894) describing the sharing of a Digital Twin between different stakeholders. In particular, the consideration of security concepts to restrict access to the contents of the Digital Twin plays a decisive role (Steinmetz, et al., 2018, p. 157; Tao, et al., 2019, p. 2412). An essential building block for implementing collaborative data sharing is the Shared Digital Twin (SDT). An SDT is a specific instance of a Digital Twin that allows for sharing sensitive operational data within a production or supply network or even within a data ecosystem (Cappiello, et al., 2020). However, this lack of concepts for inter-organizational data sharing based on Digital Twins forms the problem-centered approach and thus the research entry point based on the Design Science Research Methodology (DSRM) according to Peffers et al. (2007). In this context, Capiello et al. (2020) encourage an expansion of the research effort in the area of SDTs, leading to the first research objective:

RO1: Development of an SDT based on standards and existing concepts for data sovereignty and interoperability.

Even a bilateral data exchange requires extensive agreements between the partners involved. In the case of multilateral data sharing, the effort involved is more extensive and requires the consideration of uniform standards (Fukami, 2019, p. 1; Wagner, et al., 2019, p. 93). This applies in particular to Digital Twins, requiring a uniform framework for their holistic use (Wagner, et al., 2019, p. 93). Efforts to achieve uniform standardization are ongoing within the Industrial Internet Consortium (IIC) and the German Plattform Industrie 4.0 (Lin, et al., 2017; Seif, Toro and Akhtar, 2019, p. 498). With the Asset Administration Shell (AAS), the Plattform Industrie 4.0 develops a logical construction that consists of several submodels and is explicitly not designed as an encapsulated object based on a monolithic data model (Wagner, et al., 2017, p. 5). In particular, the platform-independent interface of the AAS is a decisive component, as it offers various services and properties, which in turn are associated with the asset (Wenger, Zoitl and Muller, 2018, p. 75). The development of an SDT based on existing concepts and standards is the central artefact of this paper according to the DSRM by Peffers et al. (2007). Therefore, RO1 serves as the prime objective of this contribution.

RO2: Application of the SDT in a logistics scenario.

This scenario demonstrates how an SDT enables data sharing in a collaborative logistics network. For the implementation of such a scenario, the authors define the roles of data consumer and data provider sharing data via the SDT. The basis for this approach is an IoT-architecture, which processes raw data into key performance indicators (KPIs) in real-time. The IoT-architecture is, in turn, connected to an AAS, providing all data generated. In combination with security gateways, described in DIN SPEC 27070, the data provider controls the consumer's access to data by using AAS mechanisms (Teuscher, et al., 2020, p. 11). This experiment aims to demonstrate the feasibility and to highlight the benefits of an SDT for the individual roles of the collaborative network. The AAS enables data sharing, but for secure multilateral collaboration, it needs a multi-sided platform. Here the authors employ the approaches of the International Data Spaces (IDS) and show how a combination of AAS standards and IDS standards provides a sound basis for SDTs. RO2 bases on the development of an SDT within RO1 and describes the demonstration of the central artifact according to the DSRM by Peffers et al. (2007).

2 Theoretical Background

Based on the DSRM, according to Peffers et al. (2007), this chapter deals with the identification of standards and approaches for inter-organizational interoperability and data sovereignty. Before discussing these approaches in more detail, the concept of the Digital Twin must first be explained. The technologies identified in this chapter serve as the framework for instantiating an SDT and therefore forms the objective of a solution according to the DSRM.

2.1 Digital Twins: Origin and Definitions

The Digital Twin was introduced by Michael Grieves (2014) as a concept for the product life cycle. In 2003, Grieves (2014) proposed a concept of a physical product with a corresponding virtual product and a linkage through data and information connections between both products. Later Grieves and Vickers (2017) extended the concept, stating that the virtual product describes the physical product in every detail and contains information from a micro to a macro level, integrating all current data into the virtual product.

Coming from first usages of the twin concept at NASA during the Apollo project, Glaessgen and Stargel (2012, p. 7) define the Digital Twin "as an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin" (Rosen, et al., 2015, p. 568). This definition of a Digital Twin is the most common one and appears in numerous publications (Karakra, et al., 2019, p. 2).

Furthermore, Glaessgen and Stargel (2012) stress the importance of integrating data sources like historical data, sensor data or complementary data (Glaessgen and Stargel, 2012, p. 7). Finally, the definition given by Tao, et al. (2018) is equally important, according to which “a Digital Twin consists of three parts: physical product, virtual product, and connected data that tie the physical and virtual product” (Tao, et al., 2018, p. 3566). All definitions stress the data connection between a physical and a digital part, as well as the integration of additional data from various sources. In summary, the authors consider a virtual model of a physical system containing a bidirectional data link between the virtual and the physical part as the archetypal core of a Digital Twin. Therefore, the further use of the term Digital Twin in this publication refers to the content described in this section.
The concept of a Digital Twin is characterized by its permanent connection between the real asset and its virtual representation. This, in turn, requires an extensive IoT environment to ensure this connection (Koulamas and Kalogeras, 2018, p. 96). Particularly well-known IoT reference architectures come from the international organization Industrial Internet Consortium (IIC) and the German strategic initiative Plattform Industrie 4.0 (Lin, et al., 2017, p. 1).

International Internet Consortium (IIC)

The IIC developed the Industrial Internet Reference Architecture (IIRA), which is a standards-based open architecture for Industrial Internet of Things (IIOT-)systems (Lin, et al., 2017, p. 4). IIRA is characterized by its focus on different business and technical perspectives and emphasizes broad applicability and interoperability (Lin, et al., 2017, pp. 1-3). IIC considers the concept of Digital Twins as a central component of the IIOT and identifies eight general reference characteristics for Digital Twin data models, described by assets, components, environment, models and descriptions, control parameters, behavioral data, environmental data and finally connectivity parameters. Depending on the particular use case, Bächle and Stefan (2019, p. 10) emphasize that Digital Twin data models must also be interoperable across company boundaries.

Plattform Industrie 4.0

The endeavors of the IIC and the Plattform Industrie 4.0 are closely linked together (Lin, et al., 2017, p. 2). The Plattform Industrie 4.0 proposes the Reference Architectural Model Industrie 4.0 (RAMI 4.0) as a guideline for the adaption of Industry 4.0 and its related technologies (Chilwant and Kulkarni, 2019, p. 15). In contrast to IIRA, RAMI 4.0 focuses on digitization and interoperability in the area of manufacturing. RAMI 4.0 comprises three dimensions, consisting of *layers*, *hierarchy levels* and *life cycle value stream*. Whereas *layers* and *hierarchy level* deal with properties and system structures respectively with the functional hierarchies of a factory, the dimension *life cycle value stream* focuses on life cycle aspects of an asset (Lin, et al., 2017, pp. 3-5).

The AAS is a central component of the Plattform Industrie 4.0 and describes the most mature data model of a Digital Twin (Bächle and Stefan, 2019, p. 3). The AAS describes different assets in a standardized format over their entire life cycle. This specification is an important basis for interoperability. It enables the digital integration of assets, creates the technical prerequisites of a decentralized industry 4.0 and is the concept of a Digital Twin as an open accessible and interoperable interface. The AAS is intended to become the central standardized integration plug of any asset to digital ecosystems, using a common language.

The information model of the AAS supports a modular asset description with formally describable semantics and is defined by using UML class diagrams (Bader, et al., 2019). These classes allow for the creation of a concrete AAS data model. The AAS covers a wide variety of data formats like XML, JSON, RDF, AutomationML or OPC-UA in order to share information between different systems (Bader, et al., 2019).
Figure 1 illustrates the principles of this coming AAS data standard and shows how to transform proprietary data models to AAS-conformant models. On the left side, it shows a straightforward proprietary data model, named *MODEL*, representing a proprietary Digital Twin of a machine and below it an instantiation of that model to describe a machine *m1*. The authors only display one attribute to focus on the mechanisms of how to translate this model to an AAS submodel. The simplified generic AAS model is shown in the middle column of Figure 1, whereas the right side shows its instantiation to describe the sample model. Each submodel, which is composed of *SubmodelElements,* has an Internationalized Resource Identifier (IRI), an *idShort*, *descriptions in different languages* and a *kind,* distinguishing type from instances.
For all attributes of the given model an AAS Property is added to the AAS submodel. A Property is a name-value pair with additional metadata. Here, the semantic annotation via attribute *semanticId* is very important for automatic interpretation.

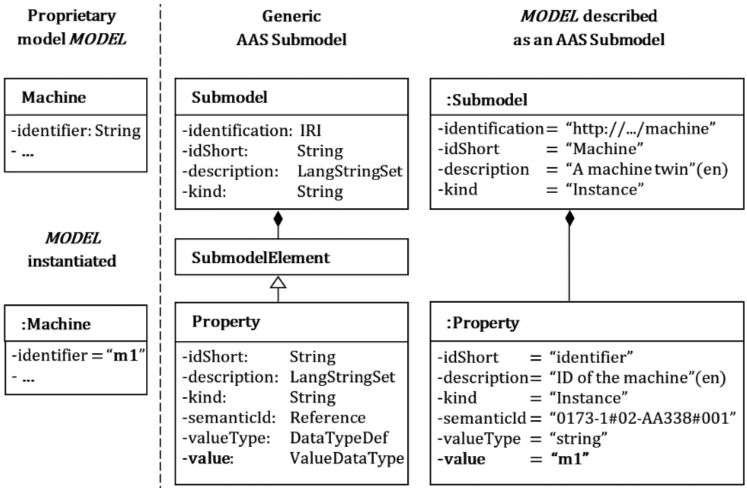


Figure 1: Transformation of proprietary models to AAS models

In this example, an International Registration Data Identifier (IRDI) points to an attribute defined by the eCl@ss standard. Alternatives for semantic annotation are an IRI referencing a standard property of a well-known ontology, or an IEC 61360-1 conformant *ConceptDescription* stored within the AAS (IEC 61360-1, 2017). The last attributes are *valueType* and *value*. The value appears only if *kind=Instance*.

An asset can be composed of other assets, leading to the construction of a composite AAS, listing all its parts. These contained assets are either co-managed by the composite AAS or are self-managed, by having their own AAS. In this way, complex AAS structures evolve, reflecting the physical asset structure.

An essential aspect of the AAS is to enable data exchange between different stakeholders. However, this requires taking into account various security aspects that protect the data of the AAS from unauthorized access (Bächle and Stefan, 2019, p. 3). Therefore, the AAS uses attribute-based access control (ABAC), a security model protecting e.g., the REST-API of an AAS. ABAC is an extension of role-based access control, considering not only the role of the subject but also attributes of the subject, the objects and the context conditions holding when checking access right (Wang, Wijesekera and Jajodia, 2004, p. 45). For each subject, being role or user, it can be specified, which object, submodels or even properties, the user is allowed or denied to read or to modify. This can even be specified using expressions over attributes of the subject, the object and the context.

2.2 Concepts for Sovereign Data Sharing

The ongoing digitization process and the associated increase in data volume present companies with the challenge of reconsidering their business models and sharing data across companies (Zrenner, et al., 2019, p. 477). According to a PWC study, the majority of the companies surveyed recognize a steadily increasing need for cross-company data exchange, but at the same time express concerns about non-existent data sovereignty (PwC, 2018, p. 40). Data sovereignty is the ability of a natural and legal person to exercise exclusive self-determination over the economic asset data (Otto, et al., 2019, p. 116). With the objective of data sovereignty in business ecosystems, the IDS initiative provides key concepts and technologies that enable companies to exchange and to share data with business partners while retaining the right of self-determination over their data (Otto, et al., 2019, p. 116).

Data sharing describes a vertical and horizontal collaboration between companies to achieve common goals and therefore differs from the term data exchange, where the exchange of data takes place in the sense of vertical cooperation between companies. One example of collaborative data sharing is predictive maintenance, in which both the company providing the data and the company consuming it benefit from each other through improved services and an improved data basis, leading to a mode of collaboration towards coopetition (Otto, et al., 2019, p. 15).

International Data Spaces (IDS)

The IDS represents a multi-sided platform for secure and trusted data exchange (Otto and Jarke, 2019, p. 561). This initiative is governed by an institutionalized alliance of different stakeholder organizations bundled in the International Data Spaces Association (IDSA). To ensure the self-determination with regard to data, the IDS initiative proposes a Reference Architecture Model (IDS-RAM). It describes a software architecture for enforcing data sovereignty in business ecosystems and value-added networks. IDS-

RAM includes the IDS Information Model and the architecture of IDS Connectors.

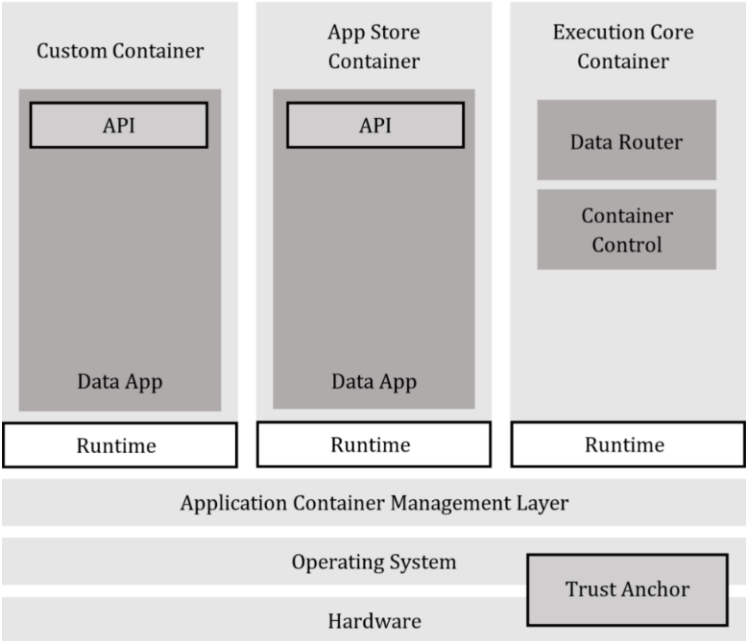


Figure 2: Building Blocks of a Security Gateway according to DIN SPEC 27070 (Teuscher, et al., 2020, p.11)

The IDS information model describes all concepts and artifacts needed for the implementation of IDS-based ecosystems and networks, including conditions for the usage of data and for describing the IDS Connector as a software component. The IDS Connector, representing standardized interfaces for receiving, sending and transforming data sets (Otto and Jarke, 2019;

Zrenner, et al., 2019, p. 481). It has three key functions comprising of exchanging data between a data provider and a data consumer, enabling secure and trusted execution of software and finally executing trusted software packages. It therefore acts as a secure, trusted gateway and a secure, trusted execution environment for apps (Otto, et al., 2019; Otto and Jarke, 2019; Teuscher, et al., 2020, p. 11). The DIN-compliant IDS Connector architecture appears in Figure 2.

3 Research Methodology

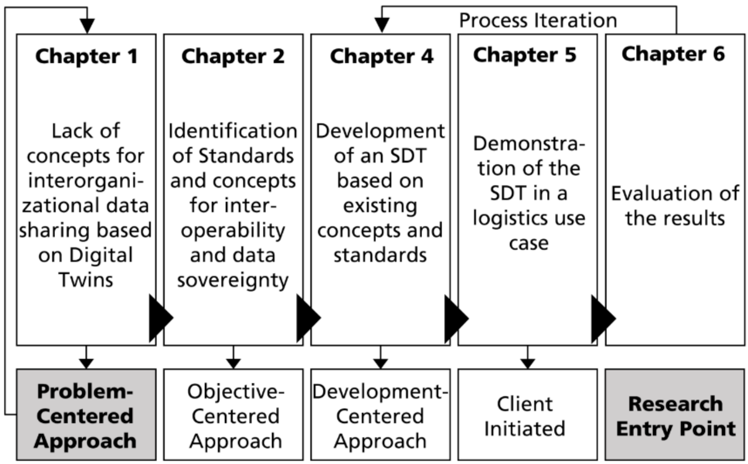


Figure 3: The DSRM for the development of an SDT by Peffers et al. (2007)

For this contribution, the authors follow the DSRM by Peffers et al. (2007). This Methodology synthesizes common steps of design science research and is divided into six different steps (Rhyn and Blohm, 2017, p. 2660). These steps consist of problem identification and motivation, the definition of the objectives for a solution, the design and development of a central artefact, the demonstration of the central artefact, the evaluation and finally the communication of the results (Peffers, et al., 2007, pp. 12-14). This paper focuses on the development and instantiation of an SDT, representing the central artifact in this contribution. The approach corresponds to the order of the chapters, where Chapter 1 addresses the lack of concepts for using Digital Twins in collaborative networks. Chapter 2, therefore, examines various concepts and approaches for the implementation of an SDT which are finally designed and instantiated in Chapter 4. A demonstration in the context of a logistics use case follows in Chapter 5. The final evaluation of the results leads to a process iteration step, including the reconsideration of policy enforcement concepts. Step 6 of the DSRM consists of communicating the results, which is fulfilled by presenting the findings in this publication.

4 Development of a Shared Digital Twin

The focus of this research project is the development of an SDT, which follows the approaches and concepts mentioned in Chapter 2. The aim is to connect the information model of an AAS with that of an IDS Connector. The SDT represents the central artefact according to the DSRM by Peffers et al. (2007).

The foundation for the development is a proprietary Digital Twin in combination with an IoT-architecture, which processes sensor data into KPIs in real-time. In addition to the generated KPIs, the raw data and the corresponding metadata are also provided in this proprietary Digital Twin. Building on this, it is now a matter of making these data sets available in a B2B data ecosystem while preserving data sovereignty. The authors argue that proprietary approaches cannot offer a suitable solution, especially regarding the existing interoperability requirements. The bilateral exchange of data already requires high implementation effort, as well as the agreement on common interfaces (Elgarah, et al., 2005, p.19). If, as described here, a collaborative approach to sharing data is pursued, it is necessary to use existing approaches that allow for easy implementation of the framework. For this purpose, the authors adopt the AAS concept and combine it with the architecture for security gateways described in DIN SPEC 27070 in order to ensure the necessary interoperability on the one hand and the required data sovereignty of the data provider on the other (Teuscher, et al., 2020, p. 11). The implementation of such a system requires three steps:

1. Mapping the Proprietary Data Model to the AAS Data Model
Figure 1 illustrates the mapping of data models of a proprietary Digital Twin

to an AAS-conformant data model. Here, additional metadata and semantic annotations of all concepts and properties need to be added, which a proprietary Digital Twin often does not yet provide. A further prerequisite for the combination of AAS and IDS is the integration of their data models. IDS messages contain AAS-compliant data with references to IDS resources.

2. Implementing an AAS-conformant REST-API using IDS
The second step is the implementation of the AAS-REST API. However, since IDS controls the AAS-REST API and all AAS resources, for example the files described in the *Documentation* submodel, there are some IDS-specific additions necessary. These include the verification of REST headers.

3. Implementing an AAS ABAC Model synchronized with IDS
The AAS ABAC security model protects the AAS-REST API and is synchronized with the IDS contracts. These contracts are used to protect the IDS resources by defining usage control rules. IDS resources describe the data exchanged via the IDS, namely the AAS submodels and the documents contained in the AAS *Documentation* submodel. The submodels of the AAS are thus protected by both mechanisms.

Resulting Architecture

Figure 4 shows the resulting architecture of this approach, which turns a proprietary Digital Twin into a standardized SDT that supports data sovereignty by combining AAS and IDS standards based on DIN SPEC 27070. It uses a proprietary Digital Twin that obtains raw data via MQTT to implement an AAS-compliant REST-API as an IDS Data App, which in turn is accessed over the IDS-managed HTTPS endpoint. This design complies with DIN SPEC 27070. The authors argue that this pattern suits for developing SDTs for data ecosystems. It allows to convert proprietary Digital Twin to a sovereign Digital Twin according to the standard (AAS) by providing an IDS-AAS wrapper. By skipping the step of data model conversion, even newly developed Digital Twins can apply this framework. Any number of ecosystem participants can access the data in a standardized way, while the data owner retains control of the data. The data owner determines who is allowed to access which data and for what purposes.

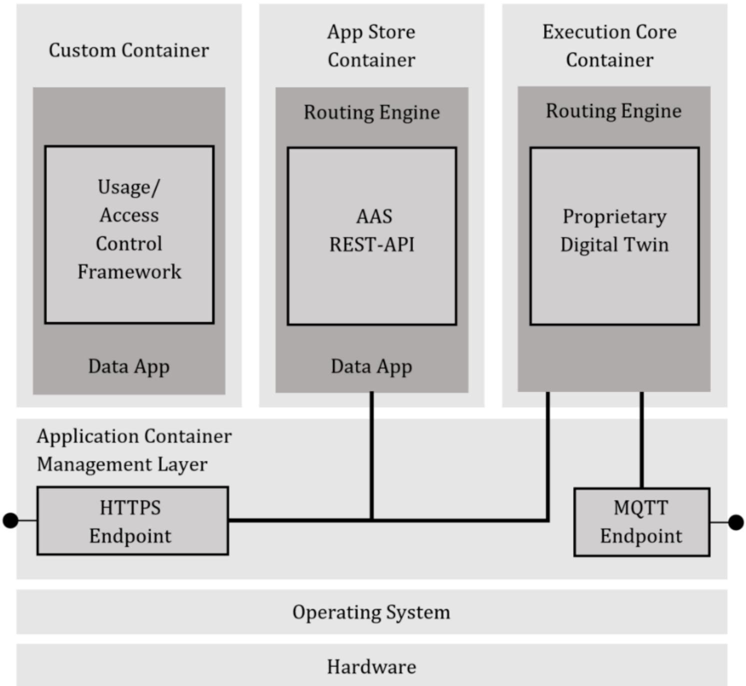


Figure 4: Architecture of an IDS-AAS for a proprietary Digital Twin

5 Demonstration of the Shared Digital Twin

In order to validate the functionality of the developed architecture, the authors conduct an experiment within the scope of this research endeavor, which demonstrates, in particular, the implementation of combined AAS and IDS security concepts. In the context of the DSRM by Peffers et al. (2007), this section aims to prove the developed SDT in a logistics use case. In general, the demonstration of the central artefact developed in the previous step aims to show that the proposed solution solves one or more instances of the problem (Peffers, et al., 2007, p. 13). An essential aspect is to enable multilateral data sharing on the basis of a Digital Twin, which is possible with the artefact developed.

In this experiment, the authors equip remote control (RC) forklifts with a sensor system that records their acceleration values. An IoT architecture captures the raw data of the RC forklifts and processes this data to KPIs. These KPIs include, primarily, workload, the detection of shocks and the calculation of maintenance intervals based on the current workload. The basis for the real-time calculation of KPIs is RIOTANA® (Real-Time Internet of Things Analytics), an IoT architecture that captures all data in a proprietary Digital Twin (Haße, et al., 2019, p. 20). Here, the main purpose of the proprietary Digital Twin is to provide a real-time virtual representation of the forklift trucks. RIOTANA® uses an ontology to describe all relationships between forklifts, the sensors attached to them and the KPIs determined from raw data, which eased the semantic annotation of AAS data.

The aim of this attempt is the sovereign sharing of the KPIs generated by the IoT architecture. This exchange takes place between a server and a client. With this experiment, the most diverse roles of a collaborative ecosystem can be assumed. The concept of collaborative data sharing describes an innovative approach that creates added value for all participants within the value chain (Tavanapour, et al., 2019, p. 7). The logistics use case described here takes into account a two-tier value chain that is expandable to any extent due to the use of neutral standards. The test simulates the interaction between a manufacturer of industrial trucks and an operator of industrial trucks. The operator purchases the industrial trucks from the forklift manufacturer. All forklift trucks continuously generate data via an active sensor system, which RIOTANA® processes into KPIs.

Forklift Fleet Operator

The utilization of the forklift fleet generates data, which in turn is available in the AAS of the fleet, where each forklift is a co-managed asset. Via a user interface, the operator of the fleet has a complete overview of all data generated. In addition, the forklift operator has full control over all data and can, therefore, restrict access to it by defining ABAC rules (Figure 6).

Forklift Manufacturer

The forklift manufacturer can access the AAS of the operator's forklift fleet using the AAS-REST-API. The manufacturer can access some submodels of the AAS, which contain the KPIs, the master data and a complete meta-data description. The manufacturer can only access the data authorized by the operator using ABAC. With authorized access to the operator's data, the manufacturer gains insight into the use of its assets and is thus able to analyze this data (Figure 5).

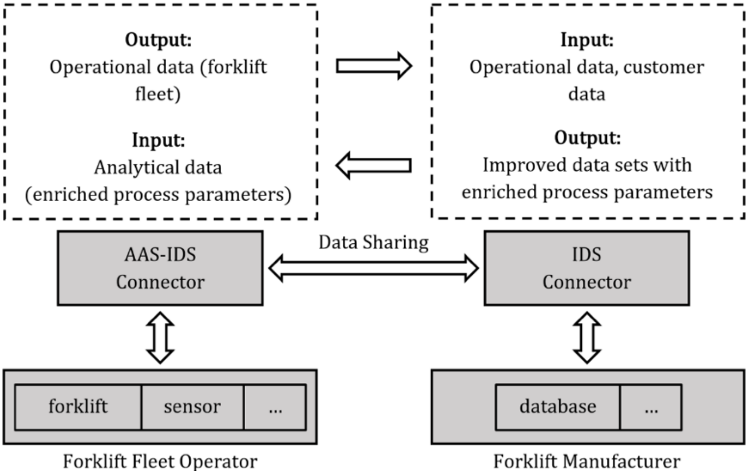
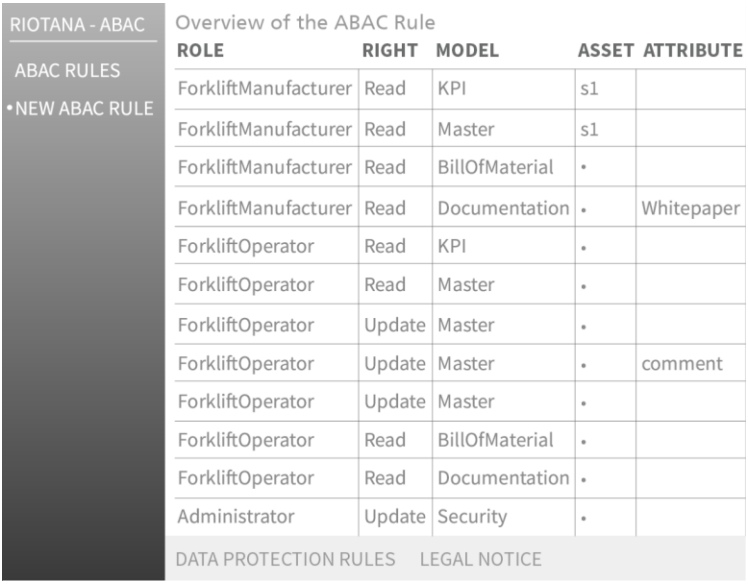


Figure 5: Application Scenario

Benefits

The operator can benefit from the manufacturer's additional services without disclosing its operational confidentiality. The operator decides which data to release and which services the operator wants to receive from the forklift manufacturer. In principle, the operator benefits from the controlled release of operating data, which in turn results in an optimization of the fleet management, improved reliability of the forklift fleet and the possibility of optimizing the environmental parameters of the warehouse.



ROLE	RIGHT	MODEL	ASSET	ATTRIBUTE
ForkliftManufacturer	Read	KPI	s1	
ForkliftManufacturer	Read	Master	s1	
ForkliftManufacturer	Read	BillOfMaterial	•	
ForkliftManufacturer	Read	Documentation	•	Whitepaper
ForkliftOperator	Read	KPI	•	
ForkliftOperator	Read	Master	•	
ForkliftOperator	Update	Master	•	
ForkliftOperator	Update	Master	•	comment
ForkliftOperator	Update	Master	•	
ForkliftOperator	Read	BillOfMaterial	•	
ForkliftOperator	Read	Documentation	•	
Administrator	Update	Security	•	

Figure 6: Defining ABAC Rules via a user interface

In general, the forklift manufacturer benefits greatly from the operating data of the forklifts, to which the manufacturer would otherwise never have had access. The forklift manufacturer gains a deep insight into the use of the industrial trucks and can thus improve the requirement profiles of its products. Based on the actual utilization, the forklift manufacturer can offer improved maintenance intervals. By evaluating this data, the forklift manufacturer can establish proactive spare parts management and, at the same time, optimize its warehouse logistics. In principle, this form of collaboration increases customer loyalty, which results in improved service performance.

6 Discussion and Conclusion

Companies increasingly recognize the relevance of cross-company data sharing but hesitate to implement it due to security concerns. Together, companies can extract more value from their data. That is especially the case for companies whose core competence is not in data management, but whose processes generate a large amount of data. In the future, these companies will be increasingly dependent on drawing more information and knowledge from their process data and will thus be dependent on strategic partners. This necessity may be expressed by the fact that companies collaborate more closely with each other along a value chain, associated with added value for all actors involved. However, this requires technological building blocks that enable interoperability across companies while at the same time preserving the sovereignty of the companies providing the data. With an SDT based on standards, the authors develop a concept of a Digital Twin that is particularly suitable for such collaborative networks.
Two aspects in particular play an essential role in this regard. On the one hand, in the context of collaborative data sharing, there are high requirements for multilateral interoperability. Becoming a standardized data ecosystem plug, the AAS is an important entry point for this. On the other hand, there are special requirements for security and usage control for data sharing. The information model of the IDS plays a decisive role here. By combining the information models of the IDS and the AAS, it is expected that it will not only be possible to regulate access to the data, but also to provide the data with usage policies. In this way, it will be possible to ensure that the company providing the data remains sovereignty over its data and at the

same time profit from its data. In summary, this contribution addresses two main research objectives.

RO1 addresses the development of an SDT based on existing standards and approaches for data sovereignty and interoperability. In addition to the actual development of an SDT, the main focus is on the description of existing approaches for the realization of these requirements. Here the authors identify the data model and REST-API of the AAS of the Plattform Industrie 4.0 to ensure interoperability across companies, and additionally the concepts of IDS to ensure data sovereignty. The authors have succeeded in combining both information models and both security concepts to instantiate an SDT.

RO2 addresses the application of the SDT developed in this research project in a logistics scenario. Here the authors describe the possible collaboration between a forklift manufacturer and a forklift operator within a simulated IoT environment. By using the results of RO1, an existing proprietary logistics Digital Twin was converted to a standard-conformant sharable SDT. The emphasis of this project lies in particular in the description of security concepts, which are implemented in this pilot with attribute-based access control, an AAS concept which was integrated with the corresponding IDS concepts (namely IDS contracts).

Key Findings

The SDT is an essential component for implementing collaborative data sharing. It is based on the fundamental concepts of a general Digital Twin, which are essentially characterized by the integration of various data formats from distributed data storage and by the description of data with meta information (Cappiello, et al., 2020, p. 120). Hence, an SDT describes the extension of the archetypal characteristics of a Digital Twin by the functions of interoperable and sovereign use in collaborative networks. This extension essentially includes the consideration of a standardized data model, which in particular contains the uniform description of interfaces. The respective data model must enable manufacturer-neutral and cross-company interoperability.

Scientific Implications

Several scientific implications result, which, in addition to the creation of an SDT based on the combination of existing approaches, also manifest themselves through the integration of a proprietary Digital Twin into a standardized data model of a Digital Twin. In this way, existing Digital Twin approaches can be subsequently adapted to the AAS data model. The authors moreover propose a combination of AAS data models with IDS data models. The application possibilities of SDTs are very extensive and cover a wide range of different use cases.

Managerial Implications

Managerial implications result mainly from the ability of collaborative data sharing and the associated possibility of participating in a data ecosystem. By using an SDT as described, for example by combining AAS and IDS, the data owner retains sovereignty over provided data. The concepts and approaches described in this paper are particularly of a technical nature. Nevertheless, the authors argue that the strong emphasis on data sovereignty aspects is crucial to create incentives for collaborative data sharing. As already described in the introduction of Chapter 6, it is having security concerns that make companies hesitant to share data with other companies.

Limitations

Limitations of the work described arise, primarily through the application of access control instead of usage control. While access control describes the terms that apply to data before it is released, usage control describes how the data is handled after its release (Bussard, Neven and Preiss, 2010, p. 1).

Future Research

Since usage control is essential for the implementation of data sovereignty, the future implementation of usage control is an iteration step according to the DSRM by Peffers et al. (2007) (Zrenner, et al., 2019, p. 486). In addition, the concept of the AAS is currently undergoing continuous development, resulting in a correspondingly high implementation effort. Furthermore, research in the field of digital twins continuously expands. There are already contributions dealing with the basic dimensions and characteristics of Digital Twins (van der Valk, et al., 2020). It is therefore of fundamental importance to investigate the extent to which an SDT differs from the basic characteristics of Digital Twins. Further implications for future research include the systematic collection of requirements for SDTs and the derivation of design principles for them.

Acknowledgement

This research was supported by the Excellence Center for Logistics and IT funded by the Fraunhofer-Gesellschaft and the Ministry of Culture and Science of the German State of North Rhine-Westphalia

References

Bächle, K. and Stefan, G., 2019. Digital Twins in Industrial Applications: Requirements to a Comprehensive Data Model. [online] Available at: <https://www.iiconsortium.org/news/joi-articles/2019-November-JoI-Digital-Twins-in-Industrial-Applications.pdf> [Accessed 23 March 2020].

Bader, S., Barnstedt, E., Bedenbender, H., Billmann, M., Boss, B. and others, 2019. Details of the Asset Administration Shell: Part 1 - The exchange of information between partners in the value chain of Industrie 4.0 (Version 2.0). [online] Available at: <https://www.zvei.org/presse-medien/publikationen/details-of-the-asset-administration-shell/> [Accessed 25 March 2020].

Bussard, L., Neven, G. and Preiss, F.-S., 2010. Downstream Usage Control. IEEE International Symposium on Policies for Distributed Systems and Networks. http://dx.doi.org/10.1109/POLICY.2010.17.

Capiello, C., Gal, A., Jarke, M., Rehof, J., 2020. Data Ecosystems: Sovereign Data Exchange among Organizations (Dagstuhl Seminar 19391). http://dx.doi.org/10.4230/DAGREP.9.9.66.

Chilwant, N. and Kulkarni, M. S., 2019. Open Asset Administration Shell for Industrial Systems. Manufacturing Letters, [e-journal] 20, pp. 15-21. http://dx.doi.org/10.1016/j.mfglet.2019.02.002.

Elgarah, W., Falaleeva, N., Saunders, C. C., Ilie, V., Shim, J. T. and Courtney, J. F., 2005. Data exchange in interorganizational relationships. ACM SIGMIS Database, [e-journal] 36(1), pp. 8-29. http://dx.doi.org/ 10.1145/1047070.1047073.

Fukami, Y., 2019. Standardization for Innovation with Data Exchange. International Conference on Data Mining Workshops (ICDMW), pp. 1-4. http://dx.doi.org/10.1109/ICDMW.2019.00008.

Glaessgen, E. and Stargel, D., 2012. The Digital Twin Paradigm for Future NASA and U.S. Air Force Vehicles. In: Structures, Structural Dynamics, and Materials and Co-located Conferences. 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference. Reston, USA: American Institute of Aeronautics and Astronautics, pp. 1-14.

Grieves, M., 2014. Digital Twin: Manufacturing Excellence Through Virtual Factory Replication. [online] Available at: <https://www.researchgate.net/publication/275211047_Digital_Twin_Manufacturing_Excellence_through_Virtual_Factory_Replication> [Accessed 26 March 2020].

Grieves, M. and Vickers, J., 2017. Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behaviour in Complex Systems. In: F.-J. Kahlen, S. Flumerfelt, and A. Alves, eds. 2017. Transdisciplinary Perspectives on Complex Systems. New Findings and Approaches. Cham, Switzerland: Springer, pp. 85-113.

Haße, H., Li, B., Weißenberg, N., Cirullies, J. and Otto, B., 2019. Digital Twin for real-time data processing in logistics. http://dx.doi.org/10.15480/882.2462.

International Electrotechnical Commission, 2017. IEC 61360-1:2017 Standard data element types with associated classification scheme - Part 1: Definitions - Principles and methods. [online] Available at: < https://webstore.iec.ch/publication/28560#additionalinfo> [Accessed 26 April 2020].

Karakra, A., Fontanili, F., Lamine, E. and Lamothe, J., 2019. HospiT'Win: A Predictive Simulation-Based Digital Twin for Patients Pathways in Hospital. In: 2019 IEEE EMBS International Conference on Biomedical & Health Informatics (BHI). Chicago, IL, USA: IEEE, pp. 1-4.

Koulamas, C. and Kalogeras, A., 2018. Cyber-Physical Systems and Digital Twins in the Industrial Internet of Things. *Computer*, [e-journal] 51(11), pp. 95-98. http://dx.doi.org/10.1109/MC.2018.2876181.

Lin, S.-W.; Murphy, B., Clauer, E., Loewen, U., Neubert, R., Bachmann, G., Pai, M.; Hankel, M., 2017. Architecture Alignment and Interoperability: An Industrial Internet Consortium and Plattform Industrie 4.0 Joint Whitepaper. [online] Available at: <IIC:WHT:IN 3:V1.0:PB:20171205> [Accessed 10 March 2020].

Otto, B., ten Hompel, M., Wrobel, S., 2019. Industrial Data Space. Referenzarchitektur für die Digitalisierung der Wirtschaft. In: R. Neugebauer, ed. 2019. Digitalisierung. Schlüsseltechnologien für Wirtschaft & Gesellschaft. München: Springer Vieweg. pp. 113-133.

Otto, B. and Jarke, M., 2019. Designing a multi-sided data platform: findings from the International Data Spaces case. *Electronic Markets*, [e-journal] 29(4), pp. 561-580. http://dx.doi.org/10.1007/s12525-019-00362-x.

Otto, B.; Steinbuß, S.; Teuscher, A., Lohmann, S., 2019. Reference Architecture Model of the International Data Spaces. [online] [Accessed 27 March 2020].

Peffers, K; Tuunanen, T., Rothenberger, M. A., Chatterjee, S., 2007. A Design Science Research Methodology for Information Systems Research, [e-journal] 24 (3), pp. 45 - 77. https://doi.org/10.2753/MIS0742-1222240302.

PwC, 2018. Data exchange as a first step towards data economy. [online] Available at: <https://www.pwc.de/en/digitale-transformation/data-exchange-as-a-first-step-towards-data-economy.pdf> [Accessed 26 March 2020].

Rhyn, M and Blohm, I., 2017. Combining Collective and Artificial Intelligence: Towards a Design Theory for Decision Support in Crowdsourcing. In: Proceedings of the 25th European Conference on Information Systems (ECIS), Guimarães, Portugal, June 5-10, 2017, pp. 2656-2666. ISBN 978-0-9915567-0-0 Research-in-Progress Papers.

Rosen, R., Wichert, G. von, Lo, G., Bettenhausen, K. D., 2015. About The Importance of Autonomy and Digital Twins for the Future of Manufacturing. IFAC-PapersOnLine, [e-journal] 48(3), pp. 567-572. http://dx.doi.org/10.1016/j.ifacol.2015.06.141.

Schleich, B., Wärmefjord, K., Söderberg, R., Wartzack, S., 2018. Geometrical Variations Management 4.0: towards next Generation Geometry Assurance. Procedia CIRP, [e-journal] 75, pp. 3-10. http://dx.doi.org/10.1016/j.procir.2018.04.078.

Schroeder, G. N., Steinmetz, C., Pereira, C. E. and Espindola, D. B., 2016. Digital Twin Data Modeling with AutomationML and a Communication Methodology for Data Exchange. *IFAC-PapersOnLine*, [e-journal] 49(30), pp. 12–17. http://dx.doi.org/10.1016/j.ifacol.2016.11.115.

Seif, A., Toro, C., Akhtar, H., 2019. Implementing Industry 4.0 Asset Administrative Shells in Mini Factories. Procedia Computer Science, [e-journal] 159, pp. 495-504. http://dx.doi.org/10.1016/j.procs.2019.09.204.

Steinmetz, C., Rettberg, A., Ribeiro, F. G. C., Schroeder, G., Pereira, C. E., 2018. Internet of Things Ontology for Digital Twin in Cyber Physical Systems. Symposium on Computing Systems Engineering (SBESC), pp. 154-159. http://dx.doi.org/10.1109/SBESC.2018.00030.

Tao, F., Cheng, J., Qi, Q., Zhang, M., Zhang, H. and Sui, F., 2018. Digital Twin-Driven Product Design, Manufacturing and Service with Big Data. The International Journal of Advanced Manufacturing Technology, 94(9-12), pp. 3563-3579. http://dx.doi.org/10.1007/s00170-017-0233-1.

Tao, F., Zhang, H., Liu, A. and Nee, A. Y. C., 2019. Digital Twin in Industry: State-of-the-Art. *IEEE Transactionson Industrial Informatics*, [e-journal] 15(4), pp. 2405-2415. http://dx.doi.org/10.1109/TII.2018.2873186.

Tavanapour, N., Bittner, E. A. C. and Brügger, M., 2019. Theory-Driven-Design for Open Digital Human Collaboration Systems. In: *Americas Conference on Information Systems* (AMCIS 2019). Cancún, Mexico.

Teuscher, A., Brost, G., Brettner, U., Böhmer, M., Fraune, B., Haas, C. and others, 2020. DIN SPEC 27070:2020-03. Anforderungen und Referenzarchitektur eines Security Gateways zum Austausch von Industriedaten und Diensten. [online] Available at: <https://www.beuth.de/de/technische-regel/din-spec-27070/319111044> [Accessed 12 February 2020].

Van der Valk, H.; Haße, H.; Möller, F.; Arbter, M.; Henning, J.-L. and Otto, B., 2020. A Taxonomy of Digital Twins. *26th Americas Conference on Information Systems (AMCIS 2020)*. Salt Lake City, USA.

Wagner, C., Grothoff, J., Epple, U., Drath, R., Malakuti, S., Gruner, S., Hoffmeister, M. and Zimermann, P., 2017. The role of the Industry 4.0 asset administration shell and the digital twin during the life cycle of a plant: Septmeber 12-15, 2017, Limassol, Cyprus, pp. 1-9. http://dx.doi.org/10.1109/ETFA.2017.8247583.

Wagner, R., Schleich, B., Haefner, B., Kuhnle, A., Wartzack, S., Lanza, G., 2019. Challenges and Potentials of Digital Twins and Industry 4.0 in Product Design and Production for High Performance Products. Procedia CIRP, [e-journal] 84, pp. 88-93. http://dx.doi.org/10.1016/j.procir.2019.04.219.

Wang, L., Wijesekera, D. and Jajodia, S., 2004. A logic-based framework for attribute based access control. FMSE '04: Proceedings of the 2004 ACM workshop on Formal methods in security engineering, [e-journal], pp. 45-55. http://dx.doi.org/10.1145/1029133.1029140.

Wang, X. V. and Wang, L., 2019. Digital twin based WEEE recycling, recovery and remanufacturing in the background of Industry 4.0. *International Journal of Production Research*, [e.journal] 57(12), pp. 3892-3902. http://dx.doi.org/10.1080/00207543.2018.1497819.

Wenger, M. Zoitl, A., Müller, T., 2018. Connecting PLCs With Their Asset Administration Shell For Automatic Device Configuration. In: 2018 IEEE 16th International Conference on Industrial Informatics (INDIN), pp. 74-79. http://dx.doi.org/10.1109/INDIN.2018.8472022.

Zrenner, J., Möller, F. O., Jung, C., Eitel, A. and Otto, B., 2019. Usage Control architecture options for data sovereignty in business ecosystems. *Journal of Enterprise Information Management*, [e-journal] 32(3), pp. 477-495. http://dx.doi.org/10.1108/JEIM-03-2018-0058.

A Holistic Digitalization KPI Framework for the Aerospace Industry

Felix Krol [1], Muhammad Amad Saeed [1], and Wolfgang Kersten [1]

1 –Hamburg University of Technology - Department of Business Logistics and General Management

Purpose: The aerospace supply chain is characterized by a high degree of small and medium-sized suppliers. To stay competitive, suppliers are facing high pressures to digitalize their business but have limited resources available. Furthermore, aerospace suppliers lack a framework to measure their current state of digitalization. Therefore, this paper provides a holistic digitalization KPI framework for manufacturing aerospace companies.

Methodology: The framework is based on a top-down and bottom-up development approach. Within the top-down approach, 42 digitalization maturity models are being analyzed to identify relevant dimensions. To reveal digitalization indicators, a comprehensive literature review is being used as a bottom-up approach. Indicators are then assigned to the sub-dimension. Finally, indicators are grouped to similar indicators and merged to digitalization KPI.

Findings: The developed KPI framework encompasses 89 digitalization KPI among nine dimensions: Strategy and Organizational Leadership, Governance and Transformation Management, Digital Skills/Human Capital, Smart Product, Customer Focus, Smart Process/Operations, Digital Technology, Financial Focus, and Network and Security.

Originality: The presented digitalization KPI framework provides a scientific foundation for measuring the digitalization maturity level of aerospace companies. Therefore, maturity models and benchmarking tools can incorporate the developed (sub-) dimensions and KPI to measure and compare the digital readiness of aerospace companies as well as to derive guidance for areas of improvement.

First received: 14. Feb 2020 Revised: 15. Jun 2020 Accepted: 07. Jul 2020

1 Introduction

In recent years, the global aerospace industry was characterized by strong market growth, mainly due to the increased demand in the Asian markets (Esposito, et al., 2019, p. 1). Therefore, it is not surprising that the German aerospace industry is one of the high-selling branches achieving annual growth rates of 5% and above (Initiative Supply Chain Excellence, 2017, p. 10). Concurrently, increasing global competition forces aerospace companies to transform and optimize their business processes to reduce costs and to stay competitive (Esposito, et al., 2019, p. 2). Moreover, the coronavirus pandemic in the first half of 2020 has significantly weakened the economic situation of almost all aerospace suppliers. 63 % of all suppliers expect an extensive impact, 26 % even fear an existence-threatening impact (Santo and Wenzel, 2020, pp. 7–8). Normalization of the previous production volume is expected earliest 2023 which will cause challenges in price fights due to over capacities (Santo and Wenzel, 2020, p. 23).
The German aerospace supplier landscape is highly dominated by small and medium-sized enterprises (SMEs). According to a study by Initiative Supply Chain Excellence (2017, p. 9), 76% of German aerospace suppliers are classified as SMEs. Often, these suppliers are highly specialized, focusing on assembly tasks, and mainly act as Tier-2 and Tier-3 suppliers within the supply chain Initiative Supply Chain Excellence, 2017, pp. 9-10, p. 13). Currently, aerospace original equipment manufacturers (OEMs) aim to reduce their total number of suppliers by consolidating their supplier base drastically and re-insource strategic components (Roland Berger, 2018, pp. 10–13; Santo, et al., 2019, p. 10). In the future, a small number of Tier-1 suppliers will receive more comprehensive work packages and will manage

their sub-supply chains individually (Initiative Supply Chain Excellence, 2017, p. 12; Santo, et al., 2019, p. 10). Hence, many Tier-2 and Tier-3 suppliers aim to develop themselves upstream among the value chain (Initiative Supply Chain Excellence, 2017, p. 15).

To be considered as a potential aerospace supplier in the future and to cope with changing requirements of OEMs, SMEs need to adopt modern, flexible, and agile production processes as well as to increase their digital maturity (Initiative Supply Chain Excellence, 2017, p. 27). Compared to the automotive industry, manufacturing in the aerospace industry is characterized by small batch sizes (up to batch size 1) and a lower degree of automation (Guffarth, 2015, p. 130; Hansen, 2016). Hence, companies need to utilize new (Industry 4.0) technologies and digitalize their business on the one hand but have limited resources and knowledge of business digitalization on the other hand. Even though 71 % of the aerospace suppliers have developed a general digital awareness, only 37 % have started to digitalize their processes and functions (Santo, et al., 2019, p. 21). For the successful digitalization of the supply chain, aerospace suppliers agree that costs for SMEs need to stay bearable (Stegkemper, 2016, p. 11).

Thus, especially in the current economic situation, it is more important than ever that SME classified aerospace suppliers can determine their digital maturity on a sound basis. The evaluation of digital maturity allows a purposeful prioritization of the next steps and the related investments. To assess digital maturity, a standardized and structured digitalization Key Performance Indicator (KPI) framework is needed (HAMBURG AVIATION e.V., 2020).

Therefore, this paper aims to answer the following research questions (RQ):
RQ1: *Which dimensions and sub-dimensions should a digitalization KPI framework for aerospace companies comprise?*
Based on the framework developed, measurable indicators for evaluating digital maturity are required. Thus, the second RQ is:
RQ2:*What are applicable KPI for developing a digitalization maturity model?*
The paper is structured as follows: First, definitions for the digital transformation of supply chains and KPI measurement systems are presented. Subsequently, the paper describes the KPI framework development approach in the methodology chapter. The developed digitalization KPI framework is shown in the results. Finally, we conclude by stating implications and limitations as well as providing an outline for further research.

2 Theoretical background

For developing a digitalization KPI framework for aerospace companies, a general understanding of digitalization and the digital transformation of supply chains is required. Therefore, a short definition of these terms is given before defining KPI and KPI frameworks.

2.1 Digitalization and digital transformation of supply chains

The upcoming term 'Digitalization' is not a new phenomenon. However, the term is often equated with the term 'Digitization' and therefore needs to be differentiated. Digitization describes the transforming of analog data into digital data (Bitkom, 2016, p. 7; Wolf and Strohschen, 2018, p. 58). Thus, from a technical perspective, analog data, e.g. temperature, conditions, voice, or written text, is gathered and transferred into digital data which can be used by computers or devices for digital signal processing (Wolf and Strohschen, 2018, p. 58). However, digitalization in a business context does not only describe data transformation but comprises the change of value creation processes at a company level by refining existing and implementing new digital technologies (Kersten, Schröder and Indorf, 2017, p. 51). Furthermore, this development requires adjustments of company strategies based on new digital business models as well as the acquisition of required competencies and qualifications (Kersten, Schröder and Indorf, 2017, p. 51).

Next to the company level, digitalization has a significant impact on the transformation of production as well as on the supply and value chain of goods (Baum, 2013, p. 38; Kersten, Schröder and Indorf, 2017, p. 51). The

digital transformation aims to increase flexibility, productivity, and transparency of all supply chain partners accompanied by focusing on changing customer needs for digital products and services (Kersten, Schröder and Indorf, 2017, p. 48, p. 51). A digitized supply chain is realized by implementing cyber-physical systems (CPS) that embed software and electronics (e.g. sensors and actuators) into items and link them via the internet (Hausladen, 2016, p. 77). Thus, single machines as well as production systems can interact with their environment linking the physical with the virtual world.
As previously mentioned, aerospace companies that are aiming to implement digitalization tools need to determine their digital maturity. Therefore, a standardized digitalization KPI framework is required. Hence, before presenting the developed framework, a short definition of KPI and KPI frameworks will be provided.

2.2 KPI and KPI frameworks

According to Parmenter (2015, pp. 7–8), “Key Performance Indicators (KPI) are those indicators that focus on the aspects of organizational performance that are the most critical for the current and future success of the organization.” Indicators provide three basic functions, namely control, communication and improvement (Franceschini, Galetto and Maisano, 2019, p. 9). Thus, KPI can be utilized to control and communicate the company’s performance to internal and external stakeholders as well as to identify potential gaps between actual performance and targets to derive improvements.

By nature, KPI are measured frequently and have a major impact on the critical success factors of an organization (Parmenter, 2019, p. 15). Therefore, an organization needs to determine whether the indicator is considered as a key performance indicator according to the individual corporate strategy and its targets. Indicators that are measured on a less frequent basis (e.g. monthly, quarterly, or bi-annually) and are not crucial to the business are defined as performance indicators (PI) (Parmenter, 2019, p. 13). PI support and complement KPI and are therefore important to the business.
The selection of relevant indicators for companies and the determination of an indicator being a PI or a KPI is complex and highly individual to the applying company (Franceschini, Galetto and Maisano, 2019, p. 85). Hence, this paper does not distinguish between PI and KPI but provides a full set of indicators (in the further course denoted as KPI). The final selection of the relevant (Key) Performance Indicators is up to future respective users. However, in this paper, we propose an indicator subset based on the rated importance of aerospace companies which may be considered as KPI from aerospace companies.
For evaluating the overall performance of an area of activity, a business unit, or an organization, a set of KPI, respectively a KPI framework is needed. In literature, KPI frameworks are often referred to as ‘performance measurement systems’ which are defined as a “set of metrics used to quantify both the efficiency and effectiveness of actions” (Neely, Gregory and Platts, 1995, pp. 80–81).

3 Methodology

The KPI framework developed is based on a top-down and bottom-up approach (see **Fehler! Verweisquelle konnte nicht gefunden werden.**). The top down-approach aims to identify relevant dimensions and sub-dimensions forming the structure of the KPI framework. This approach applies a literature review based on scientific literature, international standards and guidelines as well as industry reports and documents revealing 42 KPI frameworks/maturity models. The KPI frameworks identified are then analyzed according to their applicability in determining the digital maturity of an aerospace company resulting in the selection of 19 relevant KPI frameworks. Analyzing the frameworks for key subjects results in 9 main dimensions and 30 underlying sub-dimensions.

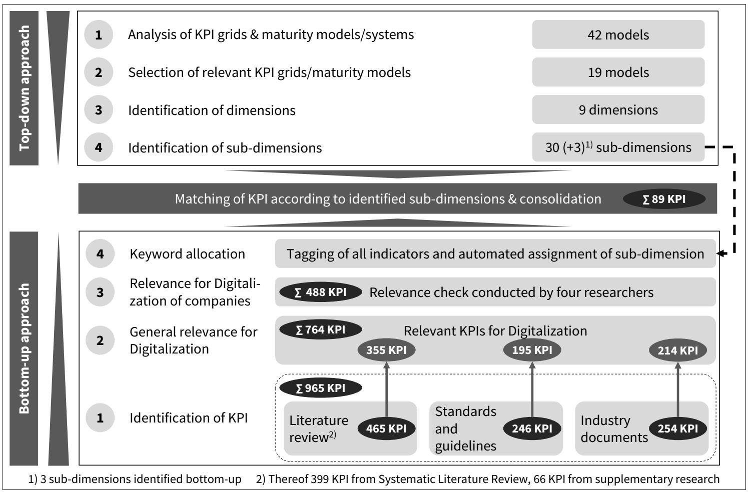


Figure 1: Development Approach of the Digitalization KPI Framework

The bottom-up approach aims to identify relevant KPI for measuring the current state of digitalization. The method deploys a systematic literature review (SLR) based on Fink (2014) revealing 399 KPI as well as a supplementary literature research (snowball method) revealing 66 KPI. In total, 465 KPI are derived from the scientific literature review. For the search string of the SLR as well as the databases used, see Figure 2. The detailed procedure of the SLR can be inferred from Figure 3. Next to scientific literature, standards and guidelines (e.g. international norms) as well as industry documents (e.g. white papers from management consultancies) are included in the body of literature. The analysis of these documents results in 246 KPI from standards and guidelines as well as 254 KPI from industry reports and documents. Thus, 965 KPI are identified in total (cf. Figure 1). Within the next step, the KPI are analyzed according to their general relevance to digitalization resulting in the exclusion of 201 KPI. Subsequently, a relevance check for the remaining 764 KPI is conducted by four researchers individually. Every indicator is scrutinized based on the question: "Is the indicator relevant for the digital transformation of the aerospace industry?" An indicator is included in the framework when a consensus from at least three researchers is achieved. Remaining indicators without a consensus are the basis for discussion within two researcher's workshops. Following, 488 KPI are included in the final set for developing the KPI framework. Furthermore, the bottom-up approach reveals three additional sub-dimensions that are not covered by the 19 KPI grids/maturity models analyzed. Therefore, these sub-dimensions are added to the 30 sub-dimensions (see Figure 5).

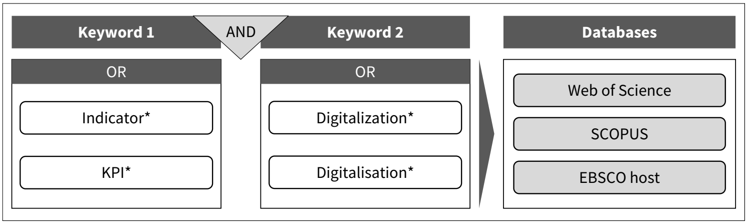


Figure 2: Search String and Sources of Systematic Literature Review

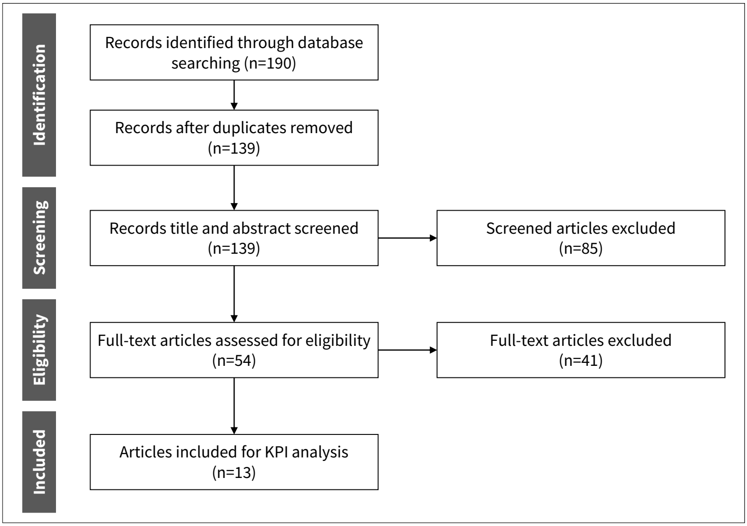


Figure 3: Flowchart of Systematic Literature Review

To link the bottom-up approach with the top-down approach, a keyword assignment procedure is applied (see Figure 4). All 488 KPI are assigned with three keywords based on the KPI text. Concurrently, all 33 sub-dimensions are classified with keywords according to their definitions within a keyword assignment matrix. With an Excel-based macro, the KPI are automatically assigned to a sub-dimension according to their keywords. Based on this approach, 446 KPI can be classified automatically whereas 42 KPI need a manual classification. Afterward, all assigned sub-dimensions are reviewed independently and, if required, refined by two researchers. Finally, synonymous KPI within each sub-dimension are grouped and summarized to 89 meaningful and measurable KPI, whereof 58 KPI are qualitative and 31 KPI are quantitative.

To identify the most important KPI for the aerospace industry from the KPI framework, a workshop with 18 experts from aerospace companies was

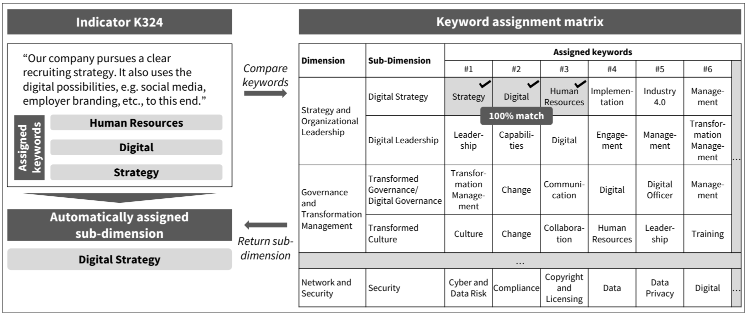


Figure 4: Keyword assignment approach (example for indicator K324)

conducted. Experts were individually asked to select 30 out of 89 KPI which are "most important for the successful digital transformation of aerospace companies". The most important KPI are derived by summing up the total votes for every KPI. Due to several draws in the number of votes, the shortlisted KPI framework comprises 33 KPI.

4 Results

This paper aims to develop a structured digitalization KPI framework for aerospace companies as well as the corresponding (sub-) dimensions. First, according to RQ 1, a basic framework of dimensions and sub-dimensions is required for developing a holistic digitalization KPI framework. Thus, answering RQ 1, the framework developed is presented in Figure 5 showing the dimensions and sub-dimensions as well as the number of KPI per (sub-) dimension. Furthermore, this chapter provides a short definition of each dimension and sub-dimension. Following, applicable KPI need to be developed. Thus, answering RQ 2, the corresponding digitalization KPI and their assigned (sub-) dimensions are presented in Table 1 (see appendix).

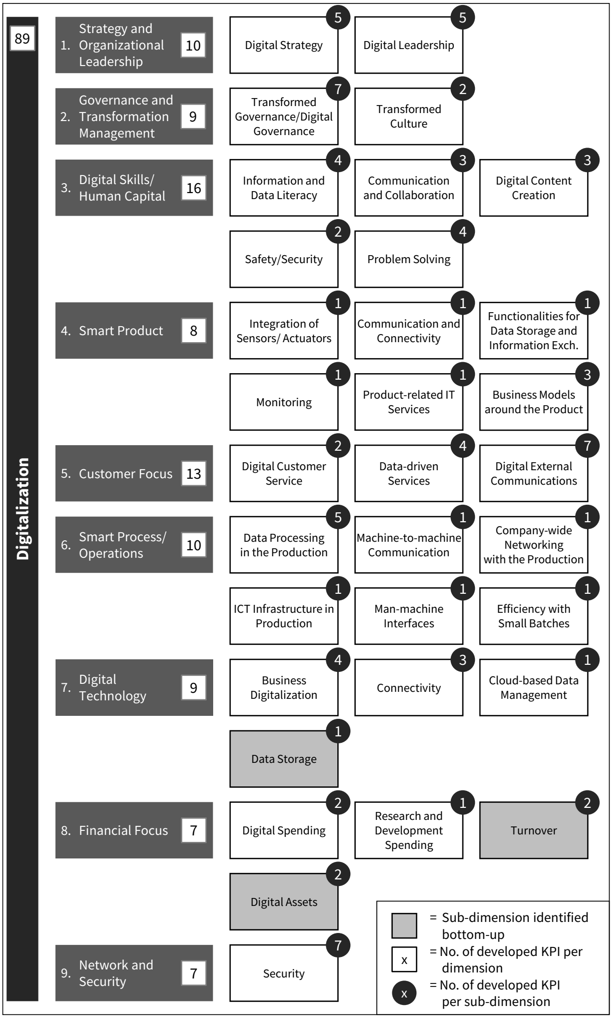


Figure 5: Structure of the Digitalization KPI Framework

Dimension 1: Strategy and Organizational Leadership

The dimension 'Strategy and Organizational Leadership' describes a company's ability to develop and implement new business models to strategically align the company for upcoming challenges related with the company's digitalization (Lichtblau, et al., 2015, p. 29; Berghaus, Back and Kaltenrieder, 2017, p. 29). Therefore, the efficient provision of the right digital competences and resources is of high importance.

Sub-dimension 1.1: Digital Strategy

A digital strategy links information systems with management strategies and business models to cope with disruptive technological developments and changes in customer behavior (Azhari, et al., 2014, p. 39; Deloitte, 2018, p. 10; Waspodo, Ratnawati and Halifi, 2018, p. 1). Therefore, a digital strategy needs to be transparent, easily understandable and clearly communicated across the entire organization (Azhari, et al., 2014, p. 39; KPMG, 2016). Digital strategies aim to utilize new digital technologies to generate sustainable increases in performance and higher competitiveness (BSP Business School Berlin, 2016, p. 8; Berghaus, Back and Kaltenrieder, 2017, p. 27).

Sub-dimension 1.2: Digital Leadership

Digital leadership integrates the digital change into existing leadership concepts (Buhse, 2014, p. 230). The middle and top management need to learn how to deal with new technologies and promote a company culture that encourages employees to generate new ideas, innovation and organizational development (EFQM, 2012, p. 6; Azhari, et al., 2014, p. 39). To convince employees from the need for digital change, the management has to act as a role model for its value and ethics (EFQM, 2012, p. 6; BSP Business School Berlin, 2016, p. 7).

Dimension 2: Governance and Transformation Management

The dimension 'Governance and Transformation Management' encompasses success criteria for implementing the digital strategy by motivating and incorporating all employees into the change process (Strategy & Transformation Consulting; KPMG, 2016, p. 2). Consistent, supportive change management, as well as professional project management is essential for effective transformation management aiming a high value-added through digital processes (Strategy & Transformation Consulting; Jodlbauer and Schagerl, 2016, p. 1478).

Sub-dimension 2.1: Transformed Governance/Digital Governance

Transformed governance, resp. digital governance is a comprehensive, top-down driven process for the digital transformation of an organization (Fitzgerald, et al., 2013, p. 40; Azhari, et al., 2014, p. 49; Kompetenzzentrum Öffentliche IT, 2016; Berghaus, Back and Kaltenrieder, 2017, p. 39). The top management needs to lead the digital transformation by supporting and training employees to develop a common vision and to establish new ways of working (Fitzgerald, et al., 2013, pp. 53–54; Geissbauer, Vedso and Schrauf, 2016, p. 9; Berghaus, Back and Kaltenrieder, 2017, p. 39).

Sub-dimension 2.2: Transformed Culture

The transformed culture acts as a basis for an agile innovative and entrepreneurial environment by creating openness and appreciation for digital technologies (Fitzgerald, et al., 2013, p. 49; Azhari, et al., 2014, p. 39; BSP Business School Berlin, 2016, p. 7; KPMG, 2016, p. 3; Berghaus, Back and Kaltenrieder, 2017, p. 37). Furthermore, the transformed culture comprises decentralized decision-making processes and transparent communication processes that facilitate change within short reaction times (Azhari, et al., 2014, p. 39, p. 47; BSP Business School Berlin, 2016, p. 7).

Dimension 3: Digital Skills/Human Capital

Digital skills and human capital are a central component for the success of the company's digital transformation (BSP Business School Berlin, 2016, p. 7; Geissbauer, Vedso and Schrauf, 2016, p. 9). Therefore, employees need to have relevant information and communication technology (ICT) skills but also a willingness for lifelong learning, openness to new technology and interdisciplinary thinking (Lichtblau, et al., 2015, p. 52; BSP Business School Berlin, 2016, p. 7; Schumacher, Erol and Sihn, 2016, p. 164; Kotarba, 2017, p. 127; European Commission, 2019). Organizations need to offer appropriate training, education and autonomy to recruit, retain, develop and utilize their employees (Azhari, et al., 2014, p. 39; Lichtblau, et al., 2015, p. 52; Geissbauer, Vedso and Schrauf, 2016, p. 9; KPMG, 2016, p. 4; Schumacher, Erol and Sihn, 2016, p. 164).

Sub-dimension 3.1: Information and Data Literacy

Information and data literacy comprises skills to retrieve and analyze digital data, information, and content (Carretero, Vuorikari and Punie, 2017, p. 19). Thus, these skills encompass the basic IT skills for working in a digitized environment, e.g. internet user skills (European Commission, 2019).

Sub-dimension 3.2: Communication and Collaboration

Communication and collaboration skills encompass the ability to communicate and collaborate through digital technologies (IBF Intranet Benchmarking Forum, 2010, p. 11; Berghaus, Back and Kaltenrieder, 2017, p. 33; Carretero, Vuorikari and Punie, 2017). These skills support flexible forms of working, seeking knowledge and sharing ideas with other employees as well as throughout the entire value chain (Nabitz, Klazinga and Walburg, 2000, p. 13; IBF Intranet Benchmarking Forum, 2010, p. 11; Berghaus, Back and Kaltenrieder, 2017, p. 33).

Sub-dimension 3.3: Digital Content Creation

Digital content creation skills are required to create, edit, and integrate digital information and content into business processes (Carretero, Vuorikari and Punie, 2017). These skills also comprise to create value from data by applying data analytics technology (Lichtblau, et al., 2015, p. 54; Geissbauer, Vedso and Schrauf, 2016, p. 17).

Sub-dimension 3.4: Safety/Security

Safety and security skills in a digitized human resource context relate to the protection of the physical and psychological health of employees in the transformed working environment (Nabitz, Klazinga and Walburg, 2000, p. 13; Carretero, Vuorikari and Punie, 2017). Employees need to be aware of the impact of digital technologies on social well-being and must respect and support a culture of mutual support and diversity.

Sub-dimension 3.5: Problem-solving

Problem-solving skills allow employees to resolve problems in a digital environment independently (Carretero, Vuorikari and Punie, 2017). Next to technical knowledge, these skills also comprise systems thinking and process understanding (Lichtblau, et al., 2015, p. 54). For developing problem-solving skills and keeping up-to-date, continued education and training are required (Carretero, Vuorikari and Punie, 2017).

Dimension 4: Smart Product

Smart products are digitized products equipped with ICT, e.g. sensor or RFID technology which facilitates the collection of data from manufacturing and usage phase as well as recording the own status (IHK München und Oberbayern, 2015a; Lichtblau, et al., 2015, p. 11, p. 44, p. 68; Schumacher, Erol and Sihn, 2016, p. 164). Smart products can be either expansion of existing products or new digitized products providing fully integrated solutions (Geissbauer, Vedso and Schrauf, 2016, p. 6). By offering smart products, companies can provide further data-driven-services like predictive maintenance (Lichtblau, et al., 2015, p. 44).

Sub-dimension 4.1: Integration of Sensors/Actuators

Smart products contain sensors or actuators which provide computing capacities to measure and control the current state of technical systems and the environment (IHK München und Oberbayern, 2015a; VDMA, 2016, p. 14). Products can evaluate and react to data generated from sensors autonomously, e.g. by requesting service offerings or triggering purchase orders automatically (IHK München und Oberbayern, 2015b).

Sub-dimension 4.2: Communication and Connectivity

By equipping smart products with communication interfaces, resp. connectivity functionality, machines, systems, and processes can communicate with each other (IHK München und Oberbayern, 2015a; VDMA, 2016, p. 14). The connectivity is realized by field bus, ethernet, or internet interfaces and can also be upgraded to existing machines without internet access (IHK München und Oberbayern, 2015a).

Sub-dimension 4.3: Functionalities for Data Storage and Information Exchange

Products provide the functionality to store and exchange data, e.g. by using barcodes and rewritable data storage. Therefore, units can receive and share information autonomously and store data within their own data storage (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 14).

Sub-dimension 4.4: Monitoring

Monitoring enables products to self-detect failures as well as to record their status (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 14). Therefore, products can perform diagnoses autonomously as well as determining their own functional and operational capabilities independently.

Sub-dimension 4.5: Product-related IT Services

Product-related IT services can either be coupled or decoupled from the physical product (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 14). Decoupled services can be online portals, e.g. for ordering spare and consumables, whereas coupled services are embedded into the product and the IT infrastructure (IHK München und Oberbayern, 2015b). Thus, products can access services (e.g. condition-based maintenance services) independently (VDMA, 2016, p. 14).

Sub-dimension 4.6: Business models around the product

Technological innovations enable companies to develop new business models providing further business and revenue opportunities (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 14). The sources of additional revenues encompass consulting services, individualization of products, product-related services as well as flexible pay-per-use solutions (IHK München und Oberbayern, 2015b).

Dimension 5: Customer Focus

The dimension 'Customer Focus' describes the company's ability to understand the needs and requirements of their digital customers (EFQM, 2012, p. 4; Berghaus, Back and Kaltenrieder, 2017, p. 23). Therefore, companies adjust their on- and offline interaction with customers as well as the customer experience based on their customers (Berghaus, Back and Kaltenrieder, 2017, p. 23; Deloitte, 2018). Customers benefit from higher service levels enabling them to achieve higher value propositions and better competitiveness (EFQM, 2012, p. 4; Jahn and Pfeiffer, 2014, pp. 84–85).

Sub-dimension 5.1: Digital Customer Service

Digital customer service is the fulfillment of customer needs through digital omni-channels such as e-mails, chats, self-service portals, and social media (Dimmel, 2016; Geissbauer, Vedso and Schrauf, 2016, p. 29). Companies, therefore, need to apply a digital customer relationship management for anticipating customer requirements and for individualizing sales and marketing activities (Jahn and Pfeiffer, 2014, p. 90; BSP Business School Berlin, 2016, p. 7; Geissbauer, Vedso and Schrauf, 2016, p. 29).

Sub-dimension 5.2: Data-driven Services

Data-driven services drive the after-sales and service business by incorporating and analyzing product data generated during the usage phase (Lichtblau, et al., 2015, p. 13). Thus, companies can generate additional revenue by combining product and services into an integrated platform solution (e.g. selling machines with a maintenance contract guaranteeing a system availability through predictive maintenance) (Lichtblau, et al., 2015, p. 47; Geissbauer, Vedso and Schrauf, 2016, p. 6).

Sub-dimension 5.3: Digital External Communications

Effective digital external communication is realized through tools such as communication and interaction platforms, co-creation and self-customization platforms, feedback instruments as well as data analytics (Jahn and Pfeiffer, 2014, pp. 84–85). Thus, customers can be incorporated closer to operations by including personal customer data into product improvement and development (Geissbauer, Vedso and Schrauf, 2016, p. 16).

Dimension 6: Smart Processes/Operations

Smart processes/operations are the requirements for the interconnectedness of the horizontal and vertical supply chain (Lichtblau, et al., 2015, p. 39, p. 68). Processes should be automated, decentralized and designed end-to-end integrating all systems and regarding components (EFQM, 2012, p. 16; Lichtblau, et al., 2015, p. 39, pp. 66–67; Schumacher, Erol and Sihn, 2016, p. 164; Berghaus, Back and Kaltenrieder, 2017, p. 31). Therefore, it is crucial to connect processes not only within the own company but along the whole value chain from suppliers to the customers (Lichtblau, et al., 2015, p. 39).

Sub-dimension 6.1: Data Processing in the Production

Data processing in the production is required to connect the physical production equipment of the factory with the virtual world (Lichtblau, et al., 2015, p. 13). Data from production is gathered, stored and processed for autonomous production process planning and steering (IHK München und Oberbayern, 2015b; Lichtblau, et al., 2015, p. 13; VDMA, 2016, p. 16).

Sub-dimension 6.2: Machine-to-machine Communication (M2M)

Machine-to-machine communication is enabled through data interfaces, e.g. field bus, ethernet, and web interfaces, which facilitate autonomous information exchange (VDMA, 2016, p. 16). Thus, information and location can be separated allowing to establish production compounds between companies in the value chain (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 16).

Sub-dimension 6.3: Company-wide Networking with the Production

For developing efficient and standardized workflows, networking and data exchange is not only required within the production but also between production and other company units (VDMA, 2016, p. 16). By using consistent file formats and unified IT solutions, business units like procurement or sales can link production data to their information and data (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 16).

Sub-dimension 6.4: ICT Infrastructure in Production

Exchanging production data between partners within the value chain requires reliable and consistent information and telecommunication infrastructure in production (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 16). ICT infrastructure in production is a central requirement for implementing applications targeting technical and organizational process improvements (VDMA, 2016, p. 16).

Sub-dimension 6.5: Man-machine Interfaces

Innovative man-machine interfaces enable employees to receive the relevant information of the production units at the right time at the right place (IHK München und Oberbayern, 2015b; VDMA, 2016, p. 16). Therefore, companies need to provide mobile terminals such as tablets or data glasses simplifying operational processes and enhancing production efficiency (IHK München und Oberbayern, 2015b).

Sub-dimension 6.6: Efficiency with Small Batches

The customer requirement for highly individualized goods results in small batch sizes implying higher complexity of production processes (VDMA, 2016, p. 16). Thus, high efficiency with small batches becomes crucial for the competitiveness of manufacturing companies. The production process, therefore, needs to be designed flexible and modular closely linking production planning with order planning and processing (IHK München und Oberbayern, 2015b).

Dimension 7: Digital Technology

Digital transformation requires the identification, evaluation, and implementation of digital technologies (BSP Business School Berlin, 2016, p. 7; KPMG, 2016, p. 4; Lipsmeier, et al., 2018, p. 32). Therefore, companies need to own applicable IT competencies and infrastructures (BSP Business School Berlin, 2016, p. 7; KPMG, 2016, p. 4; Schumacher, Erol and Sihn, 2016, p. 164; Lipsmeier, et al., 2018, p. 32). To support employees and enable flexible forms of working, IT infrastructure needs to be kept up to date and adjusted regularly (KPMG, 2016, p. 4; Schumacher, Erol and Sihn, 2016, p. 164; Berghaus, Back and Kaltenrieder, 2017, p. 33).

Sub-dimension 7.1: Business Digitalization

The digitization of companies is realized through networked digital technologies which can increase the efficiency of the company and reduce costs (IHK München und Oberbayern, 2015b; Kotarba, 2017, p. 128). Furthermore, higher service levels and improved communication with customers can be obtained (Geissbauer, Vedso and Schrauf, 2016, p. 19; Kotarba, 2017, p. 128). Business digitization is supported by technologies such as data analytics, cloud technologies, agile IT systems, and the use of sales platform (IHK München und Oberbayern, 2015b; Geissbauer, Vedso and Schrauf, 2016, p. 19, p. 30; Kotarba, 2017, p. 128; European Commission, 2019).

Sub-dimension 7.2: Connectivity

Internet-based interconnectedness of an enterprise requires a certain quality of the fixed and mobile connection (Kotarba, 2017, p. 127; European Commission, 2018a, p. 1; 2018b, p. 3). A high-performance connection ensures competitiveness and networking of all relevant units, employees, and customers of the company (IHK München und Oberbayern, 2015b; Kotarba, 2017, p. 127).

Sub-dimension 7.3: Cloud-based Data Management

Cloud-based data management is facilitated through an internet-based infrastructure to provide data storage, computing power, or software (IHK München und Oberbayern, 2015b; Lichtblau, et al., 2015, p. 43). It enables the scalability of computing power, data storage space, and access at any time from anywhere (Shi, et al., 2010, pp. 47–48; IHK München und Oberbayern, 2015b; Lichtblau, et al., 2015, p. 43). Therefore, it is an important instrument for managing the increasing volume of data (Lichtblau, et al., 2015, p. 44).

Sub-dimension 7.4: Data Storage

Next to physical inhouse servers, data can be also stored on virtual cloud solutions enabling more flexible disk space (Lichtblau, et al., 2015, p. 43). To fulfill legal and security requirements, virtual data storage solutions need to meet a defined set of the company's requirements for being trustworthy.

Dimension 8: Financial Focus

The dimension financial focus examines the financial management associated with capital-intensive digitalization and Industry 4.0 projects (Lichtblau, et al., 2015, p. 62). Therefore, the financial strategy needs to support the overall digitalization strategy of the company by providing the required resources and investments enabling long-range planning (EFQM, 2012, p. 14).

Sub-dimension 8.1: Digital Spending

Digitalization requires significant investments into hardware and software (e.g. manufacturing execution software) as well as into the ICT infrastructure (Geissbauer, Vedso and Schrauf, 2016, p. 9; Kotarba, 2017, pp. 132-

133). The majority of companies expect a positive return of these investments within two years (Geissbauer, Vedso and Schrauf, 2016, p. 9).

Sub-dimension 8.2: Research and Development Spending

The success and therefore the impact of new products shows a significant positive correlation to the research and development (R&D) spending (Robert G. Cooper and Elko J. Kleinschmidt, 2007, p. 63, p. 65). Therefore, the company's R&D spending on digital technologies strongly drives the success of the digitized company.

Sub-dimension 8.3: Turnover

Digitalization provides various opportunities to increase turnover through the use of new technologies (Lichtblau, et al., 2015, p. 18). Increased turnover can be obtained from higher product value for customers or new digital sales channels higher (VDMA, 2016, p. 12). Higher product margins can be generated through individualized products as well as additional services derived from data analytic insights (Lichtblau, et al., 2015, p. 18; Geissbauer, Vedso and Schrauf, 2016, p. 14).

Sub-dimension 8.4: Digital Assets

Digital assets refer to the monetary value of the digital asset stock (Kotarba, 2017, p. 132). This contains hardware assets (e.g. the value of computers and servers) and software assets (e.g. purchased software licenses).

Dimension 9: Network and Security

Trust in the security of digital ecosystems is the main prerequisite for a successful digital transformation of a company (Geissbauer, Vedso and Schrauf, 2016, p. 5). Trust is based on transparency, legitimacy, and effectiveness and is related to the confidence in the security of internal and external data storage, communication and data exchange (Lichtblau, et al., 2015, p. 43; Geissbauer, Vedso and Schrauf, 2016, p. 5, p. 20).

Sub-dimension 9.1: Security

Organizations need to undertake measures to protect data and communication channels against manipulation and unauthorized access (Lichtblau, et al., 2015, p. 43; Geissbauer, Vedso and Schrauf, 2016, p. 20; Jodlbauer and Schagerl, 2016, p. 1477). These measures should not only target the internal IT but also external channels and mobile devices (Lichtblau, et al., 2015, p. 43).

5 Conclusion

Concluding the paper, we will present implications from our research. Furthermore, we state limitations accompanied by our research design and provide an outline for further research opportunities and potential advancements of the digitalization KPI framework.

5.1 Implications

This paper presents a holistic, scientific digitalization KPI framework, applicable for all partners across aerospace supply chains. We contribute to existing theory by providing a cross-departmental digitalization framework covering technological, safety- and strategy-related as well as organizational and human-related aspects. Thus, we provide a future basis for researchers and managers to evaluate the digital maturity of companies. Therefore, the KPI framework can be incorporated into existing or new maturity models expanding them by digitalization aspects. Maturity models can be utilized for a standardized benchmarking process. Hence, managers can evaluate the digital maturity of their own company but might also compare the results with peer groups. Especially in the light of the ongoing consolidation of aerospace supply chains and the increasing pressure on Tier-2 and Tier-3 suppliers, a distinct digital maturity might become an important selection criterion for aerospace OEMs and therefore a competitive advantage for SMEs in future.

5.2 Limitations and further research

Even though we highly adhered to the defined methodology, this paper comes along with some limitations. First, due to the actuality and novelty of digitalization KPI, scientific literature available is currently still limited. To develop a comprehensive digitalization KPI framework, it was highly necessary to include grey literature such as company reports and industry guidelines. However, we assume that combining scientific with grey literature will increase the quality of the KPI framework and ensure higher applicability for prospective users. Second, the full list of 89 KPI was shortlisted by 18 aerospace experts within a three-part workshop. A higher number of participants may have generated more resilient results. Furthermore, it must be noted that due to practicability and segmentation into dimensions, the amount of KPI among each part of the workshop was not equally distributed which might distort the shortlisted result. Third, the developed KPI framework was neither verified nor validated in practice. Thus, we cannot make a point on the applicability or practical measurability of the developed KPI. Fourth, in this paper we assumed all indicators being KPI. As stated in the theoretical background, some indicators might also be considered as PI which is, however, highly individual to the user. Last, this paper presents a holistic digitalization KPI framework. Thus, (sub-) dimensions may not be distinct but might overlap in their meaning.

The presented digitalization KPI grid provides a scientific basis for developing a digitalization maturity model for aerospace companies. Based on a single KPI or a subset of KPI, different digital maturity levels might be developed, e.g. in cooperation with aerospace experts. Therefore, workshops or focus groups may be a suitable methodology. Furthermore, discussions during the conducted shortlisting workshop have shown a different perception of importance regarding the different dimensions. Hence, we suggest determining a weighting vector/approach when developing a future maturity model, e.g. based on a pairwise comparison of each (sub-) dimension. Another research opportunity is the re-examination of the perceived importance of KPI, e.g. in a quantitative large-scale study with aerospace experts. Next to a higher validity of rated importance, this study could also provide evidence on indicators being KPI or PI.

Finally, since our findings are solely based on literature, we suggest discussing and, if necessary, refining the developed digitalization KPI together with aerospace experts to ensure better practical applicability and measurability.

Financial Disclosure

The presented framework is part of the German-Canadian research project DIMLA (Digitalization and Internationalization Maturity Level in Aerospace). We gratefully thank the Federal Ministry of Education and Research (BMBF) and Project Management Jülich (PtJ) for the project funding.

Appendix

ID	SL1	Key Performance Indicator (KPI)	Sources
1. Strategy and Organizational Leadership			
1.1. Digital Strategy			
D1.1.1	X	Is your digital strategy documented, regularly updated, and communicated transparently to all employees?	[1]; [2]
D1.1.2	X	Is a strategic roadmap/strategy process for digital transformation included in the corporate strategy?	[1]; [2]; [3]; [4]
D1.1.3	X	Is the implementation status of your digital strategy measured and tracked regularly (e.g. through indicators)?	[1]; [5]; [6]
D1.1.4	X	Does your company have sufficient resources (e.g. financial resources, human resources) and a clear recruiting strategy to implement your digital strategy?	[1]; [7]; [8]
D1.1.5	X	Does your employee development strategy consider digital expertise as a central component?	[1]; [3]
1.2. Digital Leadership			
D1.2.1	X	Does your company have the capability to identify & solve digital competence gaps in your company?	[2]; [9]; workshop
D1.2.2		Does your company apply a cross-channel operational leadership with external stakeholders?	[3]; [10]
D1.2.3		Does your company continuously develop the leadership culture as well as document and communicate efforts in your company?	[1]; [7]; workshop

1 Shortlist (SL) determined from expert workshop

ID	SL1	Key Performance Indicator (KPI)	Sources
D1.2.4		Does your senior/top management improve the company's management system and performance and manage change effectively?	[3]; [10]; [11]
D1.2.5		Does your middle management develop the Mission, Vision, Values, and Ethics and act as a role model?	[3]; [4]; [10]
2. Governance & Transformation Management			
2.1. Transformed Governance/Digital governance			
D2.1.1		Does your company have defined quality criteria and targets for your digital activities which are evaluated regularly?	[1]; [3]
D2.1.2		Does your internal IT department proactively ensure the use of the digital technologies relevant to your company to meet changing requirements?	[3]; [4]
D2.1.3		Do your executives take risks for potential improvements of your core competencies by using innovative digital solutions?	[3]
D2.1.4		Percentage of jobs that include digitized processes (incl. back-office and front-office processes)	[2]; [4]
D2.1.5	X	Do you apply the latest digital methods to automate your routine and core processes?	[1]; [3]
D2.1.6	X	Do you have defined internal experts (e.g. a Chief Digital Officer) for the implementation of digital transformation?	[1]; [3]; [12]
D2.1.7		Does your organizational flexibility enable a decentralized decision-making process?	[1]; [2]; [3]

2.2. Transformed Culture

ID	SL1	Key Performance Indicator (KPI)	Sources
D2.2.1		Does your company's culture promote consistent change, creativity, and exchange between employees, e.g. by new forms of work?	[1]; [3]; [4]; [7]
D2.2.2	X	Do you evaluate and proactively communicate errors and lessons learned from failed digital projects within the company?	[3]
3. Digital Skills/Human Capital			
3.1. Information and Data Literacy			
D3.1.1		Percentage of employees using computers at work (incl. tablets and smartphones)	[2]; [5]; [8]; [13]; [14]; [15]; workshop
D3.1.2		Percentage of individuals in the company using the internet	[2]; [5]; [16]; [17]; [18]
D3.1.3		Percentage of employees with basic digital skills (e.g. internet usage, copying files and folders, browsing, evaluating, and searching data, using formulas in spreadsheets)	[2]; [5]; [9]; [19]; [20]; [21];
D3.1.4		Percentage of employees in the ICT sector (incl. software, hardware, telecommunication, services)	[22]
3.2. Communication and Collaboration			
D3.2.1	X	Percentage of employees collaborating through digital technologies, e.g. by interacting and sharing on digital collaboration platforms?	[3]; [4]; [9]; [23]
D3.2.2		Percentage of employees using digital communication tools, e.g. video calls and social networks?	[2]; [4]

ID	SL1	Key Performance Indicator (KPI)	Sources
D3.2.3		Percentage of employees using the internet for communication uses, e.g. for sending/receiving emails, video calls, messaging services, social networks?	[19]; workshop
3.3. Digital Content Creation			
D3.3.1		Percentage of employees applying tools for analyzing and developing digital content to support the day-to-day business?	[1]; [2]; [9]
D3.3.2	X	Percentage of employees with special digital expertise (e.g. ICT specialists, STEM graduates, programmer)	[1]; [2]; [3]; [4]; [9]; [20]; [24]
D3.3.3	X	Percentage of employees capable of creating value from data, e.g. by integrating and re-elaborating digital content?	[9]; [11]
3.4. Safety/Security			
D3.4.1	X	Are your employees aware of important rules regarding IT security (e.g. protecting personal data and privacy, managing digital identity, netiquette) and monitored regularly (e.g. through external audits)?	[3]; [9]; [11]
D3.4.2		Does your company have defined rules and guidelines to protect the health and well-being of employees?	[9]
3.5. Problem Solving			
D3.5.1		Percentage of employees taking online courses and use the internet for training and education?	[2]; [19]; [25]
D3.5.2	X	Does your company offer continuous training for your employees in digital competence development?	[1]; [7]; [17]
D3.5.3	X	Percentage of employees taking industry-based training for digital requirements (e.g. IT infrastructure, Automation technology,	[1]; [6]; [14]

ID	SL1	Key Performance Indicator (KPI)	Sources
		Data analytics, Data security/communications security, Development or application of assistance systems, Collaboration software, process understanding)	
D3.5.4		Percentage of employees with ICT problem-solving skills (e.g. connecting and installing new ICT devices)?	[9]; [19]
4. Smart Product			
4.1. Integration of Sensors/Actuators			
D4.1.1		Are your company's products equipped with sensors and actuators?	[7]; [26]
4.2. Communication and Connectivity			
D4.2.1	X	Are your company's products equipped with communication interfaces that enable connections to other systems?	[7]; [26]
4.3. Functionalities for Data Storage and Information Exchange			
D4.3.1		Are your company's products equipped with data storage and information exchange functionalities?	[7]; [26]
4.4. Monitoring			
D4.4.1	X	Are your company's products equipped with IT-supported condition monitoring (e.g. self-reporting, automatic identification, assistance systems)?	[6]; [7]; [26]
4.5. Product-related IT Services			
D4.5.1		Does your company provide new or additional product-related IT services next to its products?	[7]; [26]
4.6. Business Models around the Product			
D4.6.1	X	Does your company use and analyze data from digitized products (customer data, product, or machine-generated data) for your	[3]; [11]; [12]; [17]

ID	SL1	Key Performance Indicator (KPI)	Sources
		business model, e.g. for modifying products and services using prototypes?	
D4.6.2	X	Does your company actively integrate ideas from employees, customers, and partners into the development of new digital innovations?	[3]; [23]
D4.6.3	X	Does your company actively evaluate new technologies and changes in customer behavior to identify and promote digital innovations?	[1]; [2]; [3]; [14]; [17]; [24]; [27]
5. Customer Focus			
5.1. Digital Customer Service			
D5.1.1		Does your company actively include your customers to deliver a consistent best-in-class experience on digital and non-digital channels?	[2]; [3]; [23]
D5.1.2		Does your company apply digital technologies to offer digital customer service and post-sale service?	[2]; [4]; [7]; [27]; [28]
5.2. Data-driven Services			
D5.2.1		Does your company collect and analyze customer data from the product usage phase to increase customer insight (e.g. for personalized offers, for design & engineering)?	[6]; [11]
D5.2.2		Does your IT & data architecture enable your company to gather, aggregate, and interpret real-time manufacturing, product, and sales data?	[7]; [11]; [25]
D5.2.3		Does your company apply analytics for data evaluation to provide a real-time customer experience?	[3]; [23]
D5.2.4		Does your company apply customer and interaction data for marketing, sales, and communication activities?	[3]; [28]

ID	SL1	Key Performance Indicator (KPI)	Sources
5.3. Digital External Communications			
D5.3.1		Does your company perform online activities and consume online content?	[21]
D5.3.2		Does your company actively use social media to inform on current topics?	[2]; [4]; [17]; [18]; [29]; [30]
D5.3.3		Does your company personalize digital external communication with customers and suppliers?	[3]; [18]; [28]
D5.3.4	X	Does your company institutionalize collaboration on digital topics with external partners (e.g. academia, industry, suppliers, and customers)?	[2]; [3]; [11]
D5.3.5	X	Does your company apply standardized and efficient processes within the collaboration with external partners (e.g. external contractors, start-ups, or research institutes)?	[3]
D5.3.6		Does your company consolidate, analyze, and integrate customer and interaction data from multiple digital channels (e.g. website, blogs, forums, social media platforms) into your communications and service processes?	[2]; [3]; [4]; [11]
D5.3.7		Does your company communicate to customers the use of their personal data?	[3]
6. Smart Process/Operations			
6.1. Data Processing in the Production			
D6.1.1	X	Does your company use insights from the data and information generated during the production?	[3]; [4]; [6]; [7]; [26]; [28]
D6.1.2		Do production processes in your company respond automatically in real-time or have a fast response time?	[6]; [7]

ID	SL1	Key Performance Indicator (KPI)	Sources
D6.1.3		Do you have use cases in the production of products in which a workpiece guides itself autonomously?	[6]
D6.1.4		Does the purchasing in your company base on the high-quality master data?	[7]
D6.1.5		Does your company ensure the consistency and control of all material master data?	[7]
6.2. Machine-to-machine Communication (M2M)			
D6.2.1		Does your company describe machine-to-machine (M2M) communication in the production environment?	[6]; [7]; [26]
6.3. Companywide Networking with the Production			
D6.3.1	X	Does your production share information with other business units or central units?	[6]; [7]; [26]; workshop
6.4. ICT Infrastructure in Production			
D6.4.1		How advanced is the ICT infrastructure for your production equipment?	[2]; [3]; [4]; [7]; [26]
6.5. Man-machine Interfaces			
D6.5.1		Does your company describe man-machine interaction in the production environment?	[7]; [26]; [28]
6.6. Efficiency with Small Batches			
D6.6.1		Does your company use flexible production systems to efficiently produce even small batch sizes?	[7]; [26]

7. Digital Technology

7.1. Business Digitalization

ID	SL1	Key Performance Indicator (KPI)	Sources
D7.1.1	X	Percentage of businesses using digital technologies (such as e.g. sensor technology, RFID, real-time location systems, e-invoices, cloud technologies, electronic information sharing, embedded IT systems, M2M communications)	[2]; [6]; [11]; [13]; [16]; [17]; [18]; [22]; [24]; [28]; [29]; [31]; [32]
D7.1.2	X	Percentage of businesses using software systems (such as CAD, CAM, PLM, CMSS, ERP, MES, PDM, PPS, PDA, MDC, SCM and internet platforms) to improve internal processes and ensure continuous data and information exchange	[2]; [3]; [6]; [7]; [11]; [16]; [20]; [29]; workshop
D7.1.3	X	What is the degree of digitalization of your vertical and horizontal value chain?	[1]; [2]; [11]; [12]; [13]
D7.1.4	X	Does your company evaluate the current as well as the future use of digital technologies?	[17]; [31]
7.2. Connectivity			
D7.2.1		Percentage of businesses with internet access (including fixed broadband, mobile broadband)	[2]; [5]; [7]; [13]; [15]; [17]; [18]; [21]; [25]
D7.2.2		Percentage of business with an extranet	[5]
D7.2.3		Are your company's networks easy to access and use?	[2]; [5]; [8]; [17]; [25]
7.3. Cloud-based Data Management			
D7.3.1		Does your company use cloud-based services (such as cloud-based software for data storage and analysis)?	[6]; [7]; [20]; [29]

7.4. Data Storage

ID	SL1	Key Performance Indicator (KPI)	Sources
D7.4.1		Are trusted data storage and processing available in your company?	[2]; [8]
8. Financial Focus			
8.1. Digital Spending			
D8.1.1		Total investment in e-commerce	[5]; [6]; [15]
D8.1.2	X	Total investment in Information and Communication Technologies (ICT), incl. Software (e.g. ERP systems), hardware (e.g. broadband access, data storage) and IT services spending (e.g. IT consulting)	[2]; [3]; [5]; [19]; [23]; [25]
8.2. Research and Development Spending			
D8.2.1	X	Relative investment in Research and development (R&D) in Information and Communication Technologies (ICT)	[2]; [6]; [22]; workshop
8.3. Turnover			
D8.3.1	X	Relative revenue generated from digital products and services	[1]; [2]; workshop
D8.3.2		Relative revenue generated from selling online/e-commerce	[15]; [20]; [29]; workshop
8.4. Digital Assets			
D8.4.1		Total monetary value of hardware assets, e.g., computers and servers	[2]
D8.4.2		Total monetary value of software assets, e.g., purchased software licenses	[2]

9. Network & Security			
9.1. Security			

ID	SL1	Key Performance Indicator (KPI)	Sources
D9.1.1	X	To which extent are your IT systems secured (e.g., IT security for production, secured internal data storage, secured cloud storage, secured internal and external data exchange) in your company?	[3]; [4]; [6]; [11]; [18]; [28]
D9.1.2		Total number of ICT patents in your company	[9]; [22]
D9.1.3		Software piracy rate in your company	[17]; [18]
D9.1.4		Total number of security loopholes identified in your company (e.g., number of issues on client data protection, cybercrimes)	[2]; [15]; [33]
D9.1.5		Total number of electronic privacy issues identified in your company	[8]; [30]
D9.1.6	X	Does your company implement a security strategy to avoid employees' and contractors' carelessness, cybercrime, terrorist organizational hackers' attacks, and state-organized attacks?	[7]
D9.1.7		Does your company have defined rules and guidelines to protect devices?	[9]

References

Azhari, P., Faraby, N., Rossmann, A., Steimel, B. and Wichman, K. S., 2014. Digital Transformation Report. Köln. <https://www.wiwo.de/downloads/10773004/1/DTA_Report_neu.pdf> [Accessed 8 April 2020].

Baum, G., 2013. Innovationen als Basis der nächsten Industrierevolution. In: U. Sendler, ed. 2013. Industrie 4.0. Beherrschung der industriellen Komplexität mit SysLM. Berlin, Heidelberg: Springer Vieweg, pp. 37–53.

Berghaus, S., Back, A. and Kaltenrieder, B., 2017. Digital Maturity & Transformation Report 2017. St. Gallen. <https://crosswalk.ch/digital-maturity-and-transformation-report> [Accessed 8 April 2020].

Bitkom, 2016. Industrie 4.0 – Status und Perspektiven. Berlin. <https://www.bitkom.org/sites/default/files/file/import/160421-LF-Industrie-40-Status-und-Perspektiven.pdf> [Accessed 20 February 2020].

BSP Business School Berlin, 2016. Mitelstand im Wandel - Wie ein Unternehmen seinen digitalen Reifegrad ermitteln kann. <http://kommunikation-mittelstand.digital/content/uploads/2017/01/Leitfaden_Ermittlung-digitaler-Reifegrad.pdf> [Accessed 10 April 2020].

Buhse, W., 2014. Management by Internet: Neue Führungsmodelle für Unternehmen in Zeiten der digitalen Transformation; Unternehmen im Wandel, digitale Medien als Werkzeugkoffer für Veränderer, Vernetzung, Offenheit, Partizipation und Agilität als Werte einer neuen Unternehmenskultur. Kulmbach: Plassen.

Carretero, S., Vuorikari, R. and Punie, Y., 2017. DigComp 2.1: The digital competence framework for citizens with eight proficiency levels and examples of use. Luxembourg: Publications Office.

Deloitte, 2018. Digital Maturity Model: Achieving digital maturity to drive growth. <https://www2.deloitte.com/content/dam/Deloitte/global/Documents/Technology-Media-Telecommunications/deloitte-digital-maturity-model.pdf> [Accessed 16 November 2018].

Dimmel, B., 2016. What is “Digital Customer Service”, and What Will it Will Mean in the Future? [online] Available at: <https://inthechat.com/what-is-digital-customer-service-and-what-will-it-will-mean-in-the-future/> [Accessed 10 April 2020].

EFQM, 2012. EFQM Excellence Modell. Brussels: European Foundation for Quality Management.

Esposito, M., Lazoi, M., Margarito, A. and Quarta, L., 2019. Innovating the Maintenance Repair and Overhaul Phase through Digitalization. Aerospace, [e-journal] 6(53), pp. 1–14. http://dx.doi.org/10.3390/aerospace6050053.

European Commission, 2018a. Länderbericht Deutschland - Index für die digitale Wirtschaft und Gesellschaft, 2018. <https://ec.europa.eu/information_society/newsroom/image/document/2018-20/at-desi_2018-country-profile-lang_4AA58FEB-0517-6054-404FC1F4332A6159_52342.pdf> [Accessed 10 April 2020].

European Commission, 2018b. The Digital Economy and Societyx Index (DESI): Connectivity - Broadband market developments in the EU. [online] Available at: <https://ec.europa.eu/digital-single-market/en/desi> [Accessed 10 April 2020].

European Commission, 2019. The Digital Economy and Societyx Index (DESI): Integration of Digital Technology. [online] Available at: <https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=59979> [Accessed 8 April 2020].

Fink, A., 2014. Conducting research literature reviews: From the internet to paper. Thousand Oaks, California: SAGE.

Fitzgerald, M., Kruschwitz, N., Bonnet, D. and Welch, M., 2013. The Digital Advantage: How digital leaders outperform their peers in every industry. <https://www.capgemini.com/wp-content/uploads/2017/07/Digital_Transformation__A_Road-Map_for_Billion-Dollar_Organizations.pdf> [Accessed 10 April 2020].

Franceschini, F., Galetto, M. and Maisano, D., 2019. Designing Performance Measurement Systems: Theory and Practice of Key Performance Indicators. Cham: Springer International Publishing.

Geissbauer, R., Vedso, J. and Schrauf, S., 2016. Industry 4.0: Building the digital enterprise. <https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf> [Accessed 20 November 2018].

Guffarth, D., 2015. Ambidextrie in Netzwerken komplexer Produkte. Dissertation.

HAMBURG AVIATION e.V., 2020. Kanada-Kooperation: Die Luftfahrtstandorte Hamburg und Montréal haben eine offizielle Kooperation gestartet. [online]. Hamburg. Available at: <https://www.hamburg-aviation.de/kanada-kooperation.html> [Accessed 10 April 2020].

Hansen, S., 2016. Industrie 4.0 in der Luftfahrt: Intelligente Fabrikation in der Luftfahrtindustrie. <https://aeroreport.de/de/innovation/industrie-4-0-in-der-luftfahrt> [Accessed 17 June 2020].

Hausladen, I., 2016. IT-gestützte Logistik: Systeme - Prozesse - Anwendungen. 3rd ed. Wiesbaden: Springer Gabler.

IBF Intranet Benchmarking Forum, 2010. Digital Workplace Maturity Model. <https://www.scribd.com/document/293841194/Digital-Workplace-Maturity-Model> [Accessed 10 April 2020].

IHK München und Oberbayern, 2015a. Industrie 4.0 - Glossar. [online] Available at: <https://ihk-industrie40.de/glossar/> [Accessed 10 April 2020].

IHK München und Oberbayern, 2015b. Selbstcheck - Industrie 4.0 Muenchen.

Initiative Supply Chain Excellence, 2017. Supply Chain Excellence in der deutschen Luftfahrtindustrie: Status Quo und Perspektiven für den Luftfahrtstandort Deutschland. <https://www.german-aerospace.de/wp-content/uploads/2017/07/240606_Studie-SCE-in-Deutschland.pdf> [Accessed 23 January 2020].

Jahn, B. and Pfeiffer, M., 2014. Die digitale Revolution — Neue Geschäftsmodelle statt (nur) neue Kommunikation. Marketing Review St. Gallen, [e-journal] 31(1), pp. 79–93. http://dx.doi.org/10.1365/s11621-014-0323-5.

Jodlbauer, H. and Schagerl, M., 2016. Reifegradmodell Industrie 4.0: Ein Vorgehensmodell zur Identifikation von Industrie 4.0 Potentialen. In: H. C. Mayr, M. Pinzger, and H. C. Mayr, eds. 2016. Informatik 2016. Bonn: Gesellschaft für Informatik e.V, pp. 1473–1487.

Kersten, W., Schröder, M. and Indorf, M., 2017. Potenziale der Digitalisierung für das Supply Chain Risikomanagement: Eine empirische Analyse. In: M. Seiter, L. Grünert, and S. Berlin, eds. 2017. Betriebswirtschaftliche Aspekte von Industrie 4.0. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 47–74.

Kompetenzzentrum Öffentliche IT, 2016. Digitale Governance - Ein Diskussionspapier. [online] Available at: <https://www.oeffentliche-it.de/documents/10181/14412/Digitale+Governance+-+Ein+Diskussionspapier> [Accessed 10 April 2020].

Kotarba, M., 2017. Measuring Digitalization - Key Metrics. Foundations of Management, [e-journal] 9, pp. 123–138. http://dx.doi.org/10.1515/fman-2017-0010.

KPMG, 2016. Digital Readiness Assessment. <https://atlas.kpmg.de/business-assessments/digital-readiness-assessment.html> [Accessed 14 April 2020].

Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millac, A., Schmitt, K., Schmitz, E. and Schroeter, M., 2015. Industrie 4.0 Readiness. Aachen, Cologne. <https://industrie40.vdma.org/documents/4214230/26342484/Industrie_40_Readiness_Study_1529498007918.pdf/0b5fd521-9ee2-2de0-f377-93bdd01ed1c8> [Accessed 8 April 2020].

Lipsmeier, A., Bansmann, M., Roeltgen, D. and Kuerpick, C., 2018. Framework for the identification and demand-orientated classification of digital technologies. In: 2018. 2018 IEEE International Conference 2018, pp. 31–36.

Nabitz, U., Klazinga, N. and Walburg, J., 2000. The EFQM excellence model: European and Dutch experiences with the EFQM approach in health care. International Journal for Quality in Health Care, [e-journal] 12(3), pp. 191–202. http://dx.doi.org/10.1093/intqhc/12.3.191.

Neely, A., Gregory, M. and Platts, K., 1995. Performance measurement system design. International Journal of Operations & Production Management, [e-journal] 15(4), pp. 80–116. http://dx.doi.org/10.1108/01443579510083622.

Parmenter, D., 2015. Key performance indicators: Developing, implementing, and using winning KPIs. Hoboken: Wiley.

Parmenter, D., 2019. Key Performance Indicators: Wiley.

Robert G. Cooper and Elko J. Kleinschmidt, 2007. Winning Businesses in Product Development: The Critical Success Factors. Research Technology Management, 50(3), p. 52–52. <https://search.ebscohost.com/login.aspx?direct=true&db=edsjsr&AN=edsjsr.24135136&lang=de&site=eds-live&authtype=ip,uid>.

Roland Berger, 2018. Aerospace & Defense Radar 2018: disruption as a threat to traditional business models. München. <https://www.rolandberger.com/en/Publications/Aerospace-defense-disruption-as-a-threat-to-traditional-business-models.html> [Accessed 2 June 2020].

Santo, M., Maire, S., Schmid, J., Maisonneuve, F., Wenzel, S., Dintrans, O. and Offergeld, F., 2019. Competitiveness of European Aerospace Suppliers: A Joint Analysis of France and Germany. <https://huz.de/wp-content/uploads/2019/03/20180425-hz_KeaPartners-Aerospace-supplier-study-_released-final-small8061.pdf> [Accessed 20 February 2020].

Santo, M. and Wenzel, S., 2020. Studie: Auswirkungen der Corona-Pandemie auf die deutsche mittelständische Luftfahrtzulieferindustrie. Berlin/München. <https://www.bavairia.net/fileadmin/Redaktion/Anlagen___Downloads/Corona/20200417_BDLI_Studie_Covid-19_Luftfahrtzulieferindustrie_-_h_z_lang.pdf> [Accessed 2 June 2020].

Schumacher, A., Erol, S. and Sihn, W., 2016. A Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises. Procedia CIRP, [e-journal] 52, pp. 161–166. http://dx.doi.org/10.1016/j.procir.2016.07.040.

Shi, Y., Meng, X., Zhao, J., Hu, X., Liu, B. and Wang, H., 2010. Benchmarking cloud-based data management systems. In: X. Meng. Proceedings of the second international workshop on Cloud data management. the second international workshop. Toronto, ON, Canada, 10/30/2010 - 10/30/2010. New York, NY: ACM, p. 47–47.

Stegkemper, 2016. Digitalisierung der Aerospace Supply Chain – Komplexe Aerospace-Supply-Chain-Netzwerke erfolgreich steuern. <https://www.supplyon.com/img/Studie_Digitalisierung_Aerospace-Supply-Chain_2016_DE.pdf> [Accessed 2 June 2020].

Strategy & Transformation Consulting. Transformations-Management. [online] Available at: <https://www.strategy-transformation.com/kompetenzen-transformations-management/> [Accessed 10 April 2020].

VDMA, 2016. Guideline Industrie 4.0: Guiding principles for the implementation of industrie 4.0 in small and medium sized businesses. <https://www.plattform-i40.de/PI40/Redaktion/EN/Downloads/Publikation/vdma-guideline-industrie-40.pdf> [Accessed 8 April 2020].

Waspodo, B., Ratnawati, S. and Halifi, R., 2018. Building Digital Strategy Plan at CV Anugrah Prima, an Information Technology Service Company. In: 2018. The 6th International Conference on Cyber and IT Service Management (CITSM 2018), pp. 1–4.

Wolf, T. and Strohschen, J.-H., 2018. Digitalisierung: Definition und Reife. Informatik-Spektrum, 41(1), pp. 56–64.

References Appendix (Digitalization KPI Framework)

1 Azhari, P., Faraby, N., Rossmann, A., Steimel, B. and Wichman, K. S., 2014. Digital Transformation Report. Köln. <https://www.wiwo.de/downloads/10773004/1/DTA_Report_neu.pdf> [Accessed 8 April 2020].

2 Kotarba, M., 2017. Measuring Digitalization - Key Metrics. Foundations of Management, [e-journal] 9, pp. 123–138. http://dx.doi.org/10.1515/fman-2017-0010.

3 Berghaus, S., Back, A. and Kaltenrieder, B., 2017. Digital Maturity & Transformation Report 2017. St. Gallen. <https://crosswalk.ch/digital-maturity-and-transformation-report> [Accessed 8 April 2020].

4 Strategy & Transformation Consulting. Digital Maturity Assessment (DMA) . [online] Available at: <https://www.strategy-transformation.com/digital-maturity-assessment/> [Accessed 8 April 2020].

5 Hanafizadeh, P., Hanafizadeh, M. R. and Khodabakhshi, M., 2009. Extracting core ICT indicators using entropy method. [e-book]. Available at: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-70449640053&doi=10.1080%2f01972240903028490&partnerID=40&md5=2fc0e6e47f84654826d46756d957d4c3> [Accessed 10 April 2020].

6 Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millac, A., Schmitt, K., Schmitz, E. and Schroeter, M., 2015. Industrie 4.0 Readiness. Aachen, Cologne. <https://industrie40.vdma.org/documents/4214230/26342484/Industrie_40_Readiness_Study_1529498007918.pdf/0b5fd521-9ee2-2de0-f377-93bdd01ed1c8> [Accessed 8 April 2020].

7 IHK München und Oberbayern, 2015. Digitalisierung im Mittelstand - Leitfaden Industrie 4.0. <https://ihk-industrie40.de/selbstcheck/> [Accessed 18 May 2020].

8 McConnell International and Witsa, 2001. Ready? Net. Go!: Partnerships Leading the Global Economy. <http://www.mcconnellinternational.com/ereadiness/ereadiness2.pdf> [Accessed 24 November 2018].

9 Vuorikari, R., Punie, Y., Carretero Gomez S. & Van den Brande, G., 2016. DigComp 2.0: The Digital Competence Framework for Citizens: The Conceptual Reference Model. <https://publications.jrc.ec.europa.eu/repository/bitstream/JRC101254/jrc101254_digcomp%202.0%20the%20digital%20competence%20framework%20for%20citizens.%20update%20phase%201.pdf> [Accessed 8 April 2020].

10 EFQM, 2012. EFQM Excellence Modell. Brussels: European Foundation for Quality Management.

11 pwc. Industry 4.0 - Enabling Digital Operations Self Assessment. [online] Available at: <https://i40-self-assessment.pwc.de/i40/landing/> [Accessed 8 April 2020].

12 HNU-Hochschule Neu-Ulm. Digitalen Reifegrad Ihres Unternehmens. [online] Available at: <http://reifegradanalyse.hs-neu-ulm.de/questions.php#firstPage> [Accessed 24 November 2018].

13 Žwaková, M., 2018. The conditions for digitalization and industry 4.0 development in selected European states: S. 484 - 497. [e-book]. Available at: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85051421329&partnerID=40&md5=46f8211014869c32a756ca1a370ac938> [Accessed 8 April 2020].

14 Dudzeviciute, G., Simelyte, A. and Liucvaitiene, A., 2017. The Application of Smart Cities Concept for Citizens of Lithuania and Sweden: Comperative Analysis. Independent Journal of Management & Production (IJM&P), [e-journal] 8(4), pp. 1433–1450. http://dx.doi.org/10.14807/ijmp.v8i4.659.

15 Colecchia, A., 2000. Defining and Measuring Electronic Commerce: Towards the development of an OECD methodology. OECD, Paris. Available at: <https://docplayer.net/12163491-Defining-and-measuring-electronic-commerce-towards-the-development-of-an-oecd-methodology.html> [Accessed 10 April 2020].

16 Falk, M. and Biagi, F., 2017. Relative demand for highly skilled workers and use of different ICT technologies. [e-book]. Available at: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-84983080851&doi=10.1080%2f00036846.2016.1208357&partnerID=40&md5=7715e4943a344adc041e5a5eddb21de6> [Accessed 10 April 2020].

17 World Economic Forum, 2016. The Global Information Technology Report 2016: Innovating in the Digital Economy. [online] Available at: <http://www3.weforum.org/docs/GITR2016/WEF_GITR_Full_Report.pdf> [Accessed 18 May 2020].

18 Cámara, N. and Tuesta, D., 2016. DiGiX: The Digitization Index. Available at: <https://www.bbvaresearch.com/en/publicaciones/digix-the-digitization-index/> [Accessed 10 April 2020].

19 Evangelista, R., Guerrieri, P. and Meliciani, V., 2014. The economic impact of digital technologies in Europe. Economics of Innovation & New Technology, [e-journal] 23(8), pp. 802–824. http://dx.doi.org/10.1080/10438599.2014.918438.

20 Dobrolyubova, E., Alexandrov, O. and Yefremov, A., 2017. Is Russia Ready for Digital Transformation? Communications in Computer and Information Science, (745), pp. 431–444. http://dx.doi.org/10.1007/978-3-319-69784-0.

21 Bumbac, R. and Vasilcovschi, A., 2016. Digitalization Progresses in European Catching-up Countries - The Case of Romania. Basiq International Conference: New Trends in Sustainable Business and Consumption 2016, pp. 40–49. Available at: <http://conference.ase.ro/wp-content/uploads/2018/01/BASIQ_Volume2016.pdf> [Accessed 10 April 2020].

22 Corrocher, N. and Ordanini, A., 2002. Measuring the digital divide: a framework for the analysis of cross-country differences. JOURNAL OF INFORMATION TECHNOLOGY, [e-journal] 17(1), pp. 9–19. http://dx.doi.org/10.1080/02683960210132061.

23 Forrester. Digital Transformation Assessment. [online] Available at: <https://forrester.co1.qualtrics.com/jfe/form/SV_7WZBAU12u0dJbWl?Q_JFE=qdg> [Accessed 8 April 2020].

24 Soldatos, J., Gusmeroli, S., Malo, P., and Di Orio, G., 2016. Digitising the Industry – Internet of Things Connecting the Physical, Digital and Virtual Worlds. In: P. Friess, ed. 2016. Digitising the industry: internet of things connecting the physical, digital and virtual worlds.

25 Andersen, K. V., Beck, R., Wigand, R. T., Bjùrn-Andersen, N. and Brousseau, E., 2004. European e-commerce policies in the pioneering days, the gold rush and the post-hype era. Information Polity: The International Journal of Government & Democracy in the Information Age, 9(3/4), pp. 217–232. Available at: <https://search.ebscohost.com/login.aspx?direct=true&db=buh&AN=17109068&lang=de&site=ehost-live> [Accessed 18 May 2020].

26 VDMA, 2016. Guideline Industrie 4.0: Guiding principles for the implementation of industrie 4.0 in small and medium sized businesses. <https://www.plattform-i40.de/PI40/Redaktion/EN/Downloads/Publikation/vdma-guideline-industrie-40.pdf> [Accessed 8 April 2020].

27 Sánchez-Cañizares, S. M., Ángel Ayuso Muñoz, M. and López-Guzmán, T., 2007. Organizational culture and intellectual capital: a new model. Journal of Intellectual Capital, [e-journal] 8(3), pp. 409–430. http://dx.doi.org/10.1108/14691930710774849.

28 Digital in NRW - Kompentenzen für den Mittelstand. Quick Check Industrie 4.0 Reifegrad. Available at: <https://indivsurvey.de/umfrage/53106/uHW7XM> [Accessed 10 April 2020].

29 European Commission, 2019. The Digital Economy and Societyx Index (DESI): Integration of Digital Technology. [online] Available at: <https://ec.europa.eu/newsroom/dae/document.cfm?doc_id=59979> [Accessed 8 April 2020].

30 Parycek, P., Rinnerbauer, B. and Schossböck, J., 2017. Democracy in the digital age: Digital agora or dystopia. International Journal of Electronic Governance, 9(3-4), pp. 185–209. Available at: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-85037084745&doi=10.1504%2fIJEG.2017.088224&partnerID=40&md5=3b4836e330164f18e9cb35b1cacb3b38> [Accessed 14 April 2020].

31 H&D International Group, 2018. White Paper Industrie 4.0 – Wandel in Unternehmen: Der Versuch eines Leitfadens. <https://www.hud.de/wp-content/uploads/2019/08/hud-whitepaper-industrie.pdf> [Accessed 8 April 2020].

32 Wang, H.-I. and Yu, C.-C., 2011. Measure the performance of reducing digital divide - The BSC and AHP approach. [e-book]. Available at: <https://www.scopus.com/inward/record.uri?eid=2-s2.0-79953093775&doi=10.4304%2fjcp.6.3.389-396&partnerID=40&md5=306a9a0eb78172672ed002233e7ecbe5> [Accessed 8 April 2020].

33 ISO, 2013. ISO/IEC 27001:2013. Available at: <https://www.iso.org/standard/54534.html> [Accessed 18 May 2020].

V.
Platform Economy and innovative Business Models

Success Factors for Online Food Retail Logistics

Anne Beckmann [1], Julia Kleineidam [1], and Frank Straube [1]

1 – Technische Universität Berlin

Purpose: While e-commerce in general has been growing rapidly for years, food e-commerce is lagging behind in Germany. The common approach of using traditional logistics systems and fulfilment concepts does not lead to long-term success. Considering this problem, success factors are needed as a guideline for developing effective fulfilment concepts for online food supply chains in the future.
Methodology: Based on industry performance indexes as well as an extensive search via the google search engine about 20 case studies on online food fulfilment concepts are identified. The case studies are evaluated using a performance measurement concept. Information from the highest performing companies is used to deduct success factors for good practices in online food fulfilment.
Findings: Three main groups of suppliers were identified: Full-range provider, niche suppliers (selective assortment with a specific focus) and supplier of cooking boxes. The fulfilment concept of online grocery retailers is described using thirteen categories. Three success factors could be derived: Reduction of complexity, focus on online fulfilment, and offering a unique product-service mix.
Originality: This paper contributes to the research areas of e-commerce and of logistics and supply chain management, especially online food supply chains. In this area only little original scientific research exists. Also, the approach of using secondary case studies is relatively new in this area of research and has yielded interesting results.

First received: 19. Mar 2020 Revised: 16. Jun 2020 Accepted: 10. Jul 2020

1 Introduction

E-commerce continues to grow: Since 1999, turnover in German business-to-consumer (B2C) e-commerce has increased more than fifty-fold from 1.1 billion euros to 53.6 billion euros. At the same time, annual growth rates are still under 10 percent. (Statista 2019a) In most industries, the sale of goods via the Internet now accounts for a significant share. The online share in the “Fashion & Accessories” segment for instance is around 25 percent, just as for “Consumer Electronics”. In the “Home & Living” segment, online sales account for around 10 percent of the total market. (IFH Institut für Handelsforschung GmbH 2017) Only the sale of food via the Internet seems to be falling sharply behind.

Online food retail in Germany continues to stagnate at under one percent of the total food market share (share of slightly over 1 billion euros online versus a total market share of 123.1 billion euros (Statista 2019b)). This is in spite of high growth rates in recent years of over 15 percent (Statista, 2019c) and despite various studies repeatedly forecasting online food retail as imminent. A study by EY from 2014, for instance, predicts an online share of 10 percent for 2020 (Wagner and Wiehenbrauk 2014), while a 2010 study by OC&C Strategy Consultants estimated an online share of 1-2 percent or 2-3 billion euros by 2015 (OC&C Strategy Consultants 2010).

Online food retail is therefore regarded as the "last bastion" of B2C e-commerce. Logistics and supply chain management have already been identified as particularly critical for e-commerce with regard to groceries. In contrast to other industries, the handling of perishable goods (maintenance of the cold chain), the use of reusable packaging (e.g. returnable bottles and cooling equipment) and a precise delivery (the customer must be at home to receive the goods) are particularly demanding.

The aim of this paper is therefore to derive success factors for good practices in online food logistics and supply chain management. We deliberately use the term good practices instead of best practices to emphasize that, firstly, our research is not a comprehensive benchmark and that, secondly, the online food retail market in Germany is not settled and still undergoing frequent changes like founding of new companies, mergers of existing companies and bankruptcies.

Following this introduction, the theoretical background for the paper is presented. This includes a definition of fulfilment, a description of the online food retail industry as well as a brief history of German food e-commerce. Next we present our research design, which comprises the data collection and analysis of the case studies. Subsequently, we list our research findings, which include a description of the German e-commerce food market, the logistics and supply chain management concepts currently used in this market and the good practices that could be derived from the success factors. The paper finishes with a short conclusion and the limitations of our research.

2 Theoretical background

Logistics and supply chain management are inherent parts of the business model when selling goods via the Internet, since the sold items need to be delivered to the customer. (Mahlke 2001) This process is also referred to as e-logistics or e-fulfilment. It includes the entirety of all processes and functions, which must be performed to deliver the order and the accompanying information to the customer and also to pick it up from the customer again if necessary. This includes payment, storage, transport and delivery, after-sales services, returns management and waste disposal. (Merz 2002)

In order to analyze the online food retail market and its players, it is first necessary to give a definition of online food retail to be able to make a distinction which companies to include and which to exclude as possible case studies. In this paper, we only consider companies that deliver food in a narrower sense of the word, i.e. goods for eating or drinking, which are part of the daily needs of life, to end customers. Companies that distribute ready-to-eat meals are excluded. This means that no catering services or online delivery services such as Deliveroo or Delivery Hero (Foodora) are included, since they deliver prepared meals from restaurants.

Distributing food via a distance selling channel is not a new phenomenon in the German food market. Catalogue mail order companies such as Otto or Neckermann always had food in their catalogues, even though these were usually longer-lasting products such as wine, chocolate and canned sausage. The first attempts to sell supermarket products over the Internet were made in Germany around the turn of the millennium, by Tegut and Otto among others. However, these projects were soon stopped again, as the time for online food retail seemed to not yet have come. (Seidel et al. 2015)

About ten years later, start-ups and established food retailers began to push into the online food market. Froodies, allyouneedfresh.de, supermarkt.de and food.de were founded. Rewe and Kaisers-Tengelmann (Bringmeister) started their own delivery services. This development can be explained by the increasing establishment of online trade in other industries as well as the spread of online food retail at that time in other European countries such as France and Great Britain (Seidel et al. 2015).

In 2010, the online food retail in Germany had a turnover of 0.15 billion euros, which corresponded to about 0.1 percent of total turnover for food in Germany and 1.2 percent of online sales. (Nielsen 2011) The announcement to plan the entry into the food market of Amazon in 2013 and later with the actual start of the services Amazon Prime Now and Amazon Fresh in 2017 led to an increase in the awareness of online food retail in Germany. However, the forecasts for growth and development of the market to date have mostly not materialized, which is why the market is still regarded as a manageable niche in which mainly pilot projects are being tested and small suppliers are operating. Figure 1 summarizes this development.

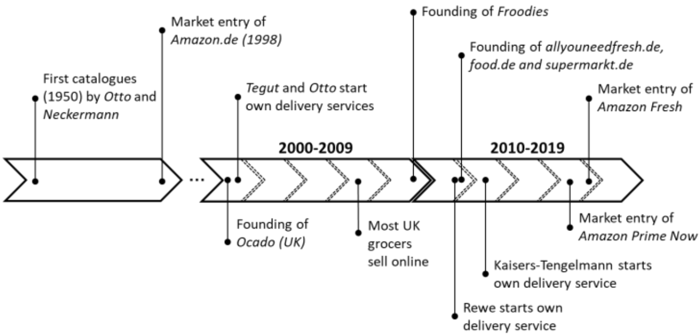


Figure 1: Historical development of online food retail in Germany

At the same time, the food retail market overall is regarded as a stagnating market. (Nitsche, Figiel 2016) Meanwhile, attractive growth potential is emerging in online food retailing, rendering this market seemingly very valuable. In addition, most experts assume that online food retail will become accepted in Germany sooner or later, as it did for other product categories. (Seitz 2013) Our aim is thus to identify success factors which allow companies to profitably operate in the food online retail in the German market and suggest good practices for logistics and supply chain management.

3 Research design

The data collection of this study is based on a secondary multiple case study according to the example of Herden and Bunzel. (Herden and Bunzel 2018) Based on selected case studies, success factors of the business model from a logistics perspective were derived by using qualitative content analysis.

3.1 Data Collection

The first step in this study was to identify the top-selling online food retailers in the German market. The results of a study conducted by the EHI Retail Institute and Statistia on the 20 top-selling online shops in the food segment in Germany in 2016 were used for this purpose. (Statista 2018) In addition, a search string was used to search for reports on online food retailers who are no longer on the market in order to be able to compare the different business models. Here, the 10 most frequently named companies were included as case study objects. Thus, 30 case studies were selected for data collection.

As the research question requires a concrete description of the business models used by the companies concerned, it was not possible to rely on scientific databases. Therefore, the approach used by Herden and Bunzel was applied. (Herden and Bunzel 2018) Key words for an online search were selected based on the principles described above. The search was conducted in German, since we are analyzing the German market. Synonyms for logistics (Logistik, Distribution, Lieferdienst, Lieferservice) and the respective company name were used. The google news search engine was used as the search engine. Personalized search results were deactivated. This search was conducted in December 2018. All articles available at that time were included in the analysis. Cases for which less than five articles were available were excluded from further investigation. Hence, 23 company cases formed the basis for the data analysis. Furthermore, the websites of all remaining companies were examined for analysis-relevant information. According to the snowball sampling method, studies mentioned in the articles found were also included in the data analysis.

3.2 Data Analysis

An adapted form of the EFRFQ model by Aramyan et al. was used for the data analysis. This performance measurement model has been developed specifically for evaluation in the context of food supply chains. (Aramyan et al. 2007) The proposed assessment model provides four categories within which KPIs are evaluated. For the present study, appropriate indicators were deduced based on the above described factors for the online food market.

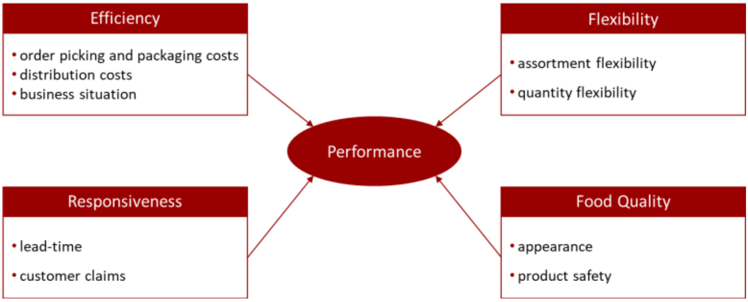


Figure 2: Adapted EFRFQ model to measure the performance of online food retailers.

The four categories are efficiency, flexibility, responsiveness and food quality. A classic Likert scale from -2 to 2 was used for the evaluation. The indices used were given the following descriptions:
-2: several major inefficiencies
-1: minor inefficiencies in all aspects or major inefficiencies in some aspects
0: several minor inefficiencies, or one major weakness in one aspect
1: efficient with few inefficiencies
2: Particularly efficient, competitive advantage over other approaches
In the efficiency category, KPIs order picking and packaging costs, distribution costs and business situation were evaluated. For the KPI order picking and packaging costs, the available information was evaluated with regard to aspects of the order picking system used, weight and volume of handled products, diversity of the product spectrum and necessary temperature zones. For the assessment of the distribution costs, the aspects distribution services (internal or external), delivery area and volumes as well as delivery costs for the customer were evaluated. With regard to the business situation, depending on the information available, the following aspects were

used for the valuation: market value, information on financing rounds and investors, as well as the current business situation and customer base.

Within the flexibility category, both the assortment flexibility and quantity flexibility KPIs were evaluated. With regard to assortment flexibility, the aspects of assortment range and alternative variety for individual products were examined. Concerning quantity flexibility, the aspects of minimum order value or minimum order quantity, maximum order weight and quantity limits were evaluated.

Within the responsiveness category, the lead-time and customer claims KPIs were considered. Concerning lead-time, the following information was taken into account: time interval between order and delivery, possibilities of limiting the delivery windows including the day and the duration of the time window. With regard to customer claims, the aspects of contact channels on the company's homepage and statements on customer claims in the reports examined were included in the evaluation.

Within the food quality category, the appearance and product safety KPIs were evaluated. The appearance aspect was evaluated in terms of how customers perceive the external quality of the food delivered. With regard to product safety, statements were evaluated within the articles that relate to maintaining the cold chain and securing the goods against contamination during transport.

Each KPI and category was assigned a rating factor in order to determine a valuation factor after the evaluation.

The authors carried out the evaluation of the case companies independently of each other. The evaluation schemes were then compared and differences were discussed until the authors achieved a uniform Likert score. The evaluation factors for the company cases were then determined from this assessment. In order to check the robustness of the resulting evaluation ranking, a sensitivity analysis was conducted. The sensitivity analysis showed that the five best-rated companies do not change in the event of a major change in the weighting factors. These case studies were selected as good practice for deriving success factors. For this purpose, all available information from the data collection was again intensively scanned.

4 Review results

The analysis of the 23 case studies gave a relatively comprehensive picture of the German online food retail market. It is characterized by a variety of vendors, which can be distinguished into three major groups:

(1) The first group summarizes companies offering a full range of products, which includes frozen food (e.g. ice cream), chilled food (e.g. yoghurt), fruits and vegetables, packaged food articles not needing special treatment with regards to temperature or handling (e.g. canned goods), beverages packed in crates (e.g. beer) as well as non-food articles typically found in a supermarket (e.g. toiletries).

(2) Niche providers, which focus on a specific kind of product or product range and thus only offer an excerpt of a typical supermarket assortment, are the second group. The variety of niche providers is great, so that a further division into subcategories like delicatessen vendors, beverage vendors, vendors of health and superfoods etc. could be attempted with more case studies in the future. However, it became obvious during the research that the biggest subdivision in this category are companies offering food and non-food articles with a long shelf life, which are easy to store and distribute.

(3) The third group includes vendors of cooking boxes or meal kits. Modelled on the Swedish company Middagsfrid, vendors of cooking boxes sell food that is pre-packaged according to the ingredients for a specific recipe. Customers can order the box and cook dinner without having to worry about the necessary amounts. In 2010, seven such companies started in Germany of which three are still in the market in 2020: HelloFresh, Marley

Spoon and Kochhaus, although the latter had to file for insolvency, suggesting that this business model is a niche in which only a few players can operate profitably.

The analysis of the case studies further enabled us to gain a deep understanding of the current business model and fulfilment concepts. In order to aggregate the information, we used the morphological box shown in figure 3. We broke the fulfilment concepts down into several categories shown in the first column and summarized our findings into groups representing the case studies. For example, there are three basic types of delivery cost models: (1) a monthly or yearly flat rate, (2) a fixed delivery fee, and (3) a dynamic delivery fee, which can depend on factors such as delivery date and time window or minimum order value. The minimum order value is typically around 40-50€ or 50-100€ for pricier goods like wine. However, there are some vendors charging less than 40€ or more than 100€, resulting in five different characteristics for this category.

The morphological box can be used to compare the fulfilment concepts of the different online food retailers. From this, we were able to conclude, firstly, that for companies offering a full range of products, there does not appear to be a typical fulfilment concept yet, i.e. there is no typical path taken through the morphological box. This supports our motivation for this paper by suggesting that online food retailing especially for a full range of products is still new and the market quite immature, so that no successful concept has yet emerged and the deduction of success factors would be beneficial to implementing a profitable fulfilment concept. Secondly, the fulfilment concept of companies offering food and non-food articles with a long shelf life is quite similar for most companies. The distribution is usually outsourced to a logistics service provider (LSP) like DHL or Hermes, the orders are processed in a multi-channel distribution center and can be delivered nationwide to a home address or pick-up station. Due to the long shelf life delivery usually takes two to three days and there is a minimum order value of 40-50€ with no extra surcharges.

<table>
<tr><td>Type of provider</td><td colspan="3">Start-up</td><td colspan="2">Online retailer</td><td colspan="3">Food retailer</td></tr>
<tr><td>Cooperation partner</td><td colspan="2">Food retailer</td><td colspan="2">Food wholesaler</td><td colspan="2">Small shops</td><td colspan="2">None</td></tr>
<tr><td>Type of distribution</td><td colspan="4">Outsourcing to LSP
(DHL, Hermes, DPD or others)</td><td colspan="4">Own delivery service</td></tr>
<tr><td>Distribution center</td><td colspan="3">Own existing DC
(multi-channel)</td><td colspan="2">Own DC "dark store"
(only online food retail)</td><td colspan="3">Bricks-and-mortar store</td></tr>
<tr><td>Depth of product range</td><td colspan="2">≤ Ø supermarket
(10.000 SKU)</td><td colspan="2">2-3x Ø supermarket
(20-30.000 SKU)</td><td colspan="2">5-10x Ø supermarket
(50-100.000 SKU)</td><td colspan="2">> 100.000 SKU</td></tr>
<tr><td>Delivery area</td><td colspan="2">Nationwide</td><td colspan="2">Many regions, but not nationwide</td><td colspan="2">Some cities and surrounding area (3-10)</td><td colspan="2">Few cities and surrounding area (2-3)</td></tr>
<tr><td>Delivery location</td><td colspan="3">Home (adress)</td><td colspan="2">Click-and-collect (store)</td><td colspan="3">Pick-up station or store</td></tr>
<tr><td>Delivery options</td><td>Same-day</td><td colspan="2">Day with <1h window</td><td>Day with 1-2h window</td><td>Day with halfday window</td><td colspan="2">Day</td><td>2-3 days</td></tr>
<tr><td>Delivery cost model</td><td colspan="3">Flatrate</td><td colspan="2">Fixed delivery fee</td><td colspan="3">Dynamic delivery fee</td></tr>
<tr><td>Min. order value</td><td colspan="2">No
min. order value</td><td colspan="2">Min. order value
< 40 €</td><td colspan="2">Min. order value
40-50 €</td><td colspan="2">Min. order value
>50 €</td></tr>
<tr><td>Free shipping possible?</td><td>No</td><td colspan="2">Min. order value
< 40 €</td><td>Min. order value
40-50 €</td><td>Min. order value
50-100 €</td><td colspan="3">Min. order value
>100 €</td></tr>
<tr><td>Surcharges</td><td colspan="2">None</td><td colspan="2">Beverage crates</td><td colspan="2">Fresh goods</td><td colspan="2">Frozen goods</td></tr>
<tr><td>Cold chain</td><td colspan="3">Active cooling
(delivery vehicle)</td><td colspan="2">Passive cooling
(packaging)</td><td colspan="3">None</td></tr>
</table>

Figure 3: Morphological box of fulfilment concepts

By means of an adapted form of the EFRFQ model we identified the top five online food retailers in our 23 case studies. Three of the top five companies are niche providers. The first company offers mainly organic müsli (granola) and cereal mixtures with a mass customization production concept. The product assortment was diversified to include juices, tees, coffee and milk alternatives. The company also operates a smaller number of brick-and-mortar stores in bigger cities. The second company is a leading supplier of high-quality wines and champagnes, which also sells other alcoholic beverages online. The third niche company is a large direct distributor of frozen food and ice cream. Founded in the 1960s, it has a long history in the distance selling market providing catalogues to the customers and taking orders by telephone and fax before the onset of the Internet. The fourth company in the top five online food retailers offers cooking boxes in eleven different countries. In Germany, three different boxes are offered for two to four persons with three to five meals a week. The last company in the top five offers the product range of a typical supermarket except for beverages in crates. It is relatively new to the German market. So far, the service is offered - in contrast to other online supermarkets - only in densely populated regions of western Germany, but not in major cities like Berlin, Hamburg or Munich let alone in more rural areas.

With regard to the online food retail market, logistics and supply chain management (often also referred to as order fulfilment or delivery in the literature) is frequently listed as a key success factor to building a competitive advantage. (Keh and Shieh 2001; Feindt et al. 2002; Duffy and Dale 2002; Laosethakul et al. 2006) However, there are rarely any details given on how to design the operations or what to focus on. In the following, we want to focus on three success factor that we were able to identify from the evaluation of the case studies:

(1) All of the companies in our top 5 reduce the complexity of the sale and delivery of foods via the online channel by a specific measure. Some focus on a specific product range (müsli, wine and frozen goods), which reduces

the effort for handling the orders, since there is no need for different temperature zones. The products are similar with regard to their weight, volume and robustness, which also facilitates the packaging. The company selling cooking boxes reduces complexity by offering a standardized packaging and a limited number of different meals, which can be ordered each week. The online supermarket uses fixed delivery routes and time slots and has been compared to the principle formerly used by milkmen. This is less flexible for the customer, but greatly reduces the complexity in creating delivery routes and calculating cost for delivery.

(2) Four of the five companies in our top 5 use the Internet as their main sales channel. The vendor of wines and other alcoholic beverages is the exception. This leads us to conclude that a focus on online fulfilment and the expectations of online customers is another success factor. This might also explain why traditional supermarkets, which operate the food delivery service as a side business, are not performing as well. This point is further corroborated by the case of the müsli vendor. The company started to open numerous stores in different German cities. However, most of them were eventually closed again after a few years. To operate a multi- or omni-channel business model in the food retail market appears to be even more difficult than a pure-player approach.

(3) All five vendors pursue a competitive advantage through differentiation, offering their customers a unique product-service mix creating a customer value specific to their company offer. The top performing company offers only organic müsli products. Customers are able to customize their individual product out of billions of possibilities. This differentiates the

company from competitors and offers them higher profit margins. Similarly, the distributor of frozen food and ice cream offers a very wide assortment with special products which cannot be found at supermarkets. They are also able to charge higher prices for this differentiated offer.

5 Implications

In the following, we draw implications for practitioners and for academics given the results of our research and the methodology employed.

5.1 Implications for practice

Competition in the online food retail market is fierce. Many start-ups and other players had to give up their business after a few years. Of the remaining companies many do not generate any profit. Thus, success factors to operate profitably in the market are needed. Our research yielded three success factors for online food retailers operating in the German market, which can be used to evaluate the business model currently used or if planning to enter into the market.

5.2 Implications for academics

Our findings contribute to the research areas of e-commerce and of logistics and supply chain management. The approach of using secondary case studies has yielded interesting results and is easily applicable. The adapted EFRFQ model by Aramyan et al. can be used in the future to analyze other cases of online food retailers. A further adoption to measure the performance for other online vendors could be an option for future research projects. The morphological box derived from the case studies systematizes the different fulfilment concepts. It can be used as a framework to analyze branches of online retail in forthcoming research endeavors.

6 Conclusion

In this paper, we investigate the German online food retail market by examining 23 secondary case studies. The market is characterized by three different types of retailers with regard to their product portfolio:
(1) vendors offering a full supermarket assortment,
(2) niche providers offering a selective range of product with a specific focus (e.g. product type or luxury segment) and
(3) companies selling cooking boxes.
Logistics and supply chain management are one of the most import factors of an online business model. The fulfilment concept of online food retailers can be described by thirteen categories, e.g. namely the type of distribution, the delivery are or the delivery cost model. Three success factors could be deduced from the top five case studies: (1) reduction of complexity, (2) focus on online fulfilment and (3) using differentiation to offer a unique product-service mix.

7 Limitations

The research results presented were collected using a secondary case study analysis based on media reports on the selected case companies that were publicly available at the time of the survey. For this reason, it was not possible to collect as much information as required for all case study companies, so that some had to be excluded from the analysis. For further investigation, additional sources of information should be used to validate the results obtained.

The evaluation using the presented evaluation model was carried out by two scientists with experience in logistics research. For further research, it would be reasonable to have the similar procedure carried out by practitioners, since their practical experience could allow a further perspective to influence the evaluation.

Acknowledgements

The authors would like to acknowledge the support of the Technische Universität Berlin and the Chair of Logistics for this project.

References

Aramyan, L.H., Alfons, G.J.M., Lansink, O., van der Vorst, J.G.A.J. and van Kooten, O., 2007. Performance measurement in agri-food supply chains: a case study. Supply Chain Management: An International Journal, 12(4), pp.304-315. https://doi.org/10.1108/13598540710759826

Duffy, G. and Dale, B.G., 2002. E-commerce processes: a study of criticality. Industrial Management & Data Systems, 102(8), pp.432-441. https://doi.org/10.1108/02635570210445862

EHI Retail Institute, Statista, 2018. Umsatz der größten Online-Shops im Segment Lebensmittel in Deutschland im Jahr 2016. [online] Available at: https://www.handelsdaten.de/lebensmittelhandel/ranking-umsatz-groesste-online-shops-lebensmittel-deutschland-2016 [Accessed 8 April 2020].

Feindt, S., Jeffcoate, J. and Chappell, C., 2002. Identifying Success Factors for Rapid Growth in SME E-Commerce. Small Business Economics, 19(1), pp.51-62. DOI: 10.1023/A:1016165825476

IFH Institut für Handelsforschung GmbH (Eds.), 2017. Handelsreport Lebensmittel Online: Fakten zum Online-Lebensmittelhandel 2017. [online] Handelsverband Deutschland (HDE e.V.). Available at: https://einzelhandel.de/index.php?option=com_attachments&task=download&id=9350 [Accessed 7 April 2020].

Herden, T.T. and Bunzel, S., 2018. Archetypes of Supply Chain Analytics Initiatives - An Exploratory Study. Logistics, 2(10), pp. 1-20. https://doi.org/10.3390/logistics2020010

Keh, H.T. and Shieh, E., 2001. Online Grocery Retailing: Success Factors and Potential Pitfalls. Business Horizons, 44(4), pp.73-83. https://doi.org/10.1016/S0007-6813(01)80050-1

Laosethakul, K., Oswald, S. and Boulton, W., 2006. Critical Success Factors for E-commerce in Thailand: A Multiple Case Study Analysis. Proceedings of the 12th Americas Conference on Information Systems, 423. http://aisel.aisnet.org/amcis2006/423

Mahlke, C.W., 2001. Logistik als Erfolgsfaktor für E-Commerce, pp.271-279. In: Hermanns, A., Sauter, M. (Eds.), Management-Handbuch Electronic Commerce: Grundlagen, Strategien, Praxisbeispiele, Vahlen-Verlag.

Merz, M., 2002. E-Commerce und E-Business: Marktmodelle Anwendungen und Technologien. Heidelberg: dpunkt-Verlag.

Nielsen, 2011. Handel, Verbraucher, Werbung. [online] Available at: http://www.acnielsen.de/site/documents/Nielsen_D2011_internet_23.08.pdf [Accessed 7 April 2020].

Nitsche, B. and Figiel, A., 2016. Zukunftstrends der Lebensmittellogistik: Herausforderungen und Lösungsimpulse. Straube, F. (Eds.), Universitätsverlag der TU Berlin. Available at: https://www.logistik.tu-berlin.de/fileadmin/fg2/Publikationen/160818_Zukunft_der_Lebensmittel.pdf [Accessed 7 April 2020].

OC&C Strategy Consultants, 2010. Online-Lebensmittel in Deutschland – steht das Geschäftsmodell in Deutschland vor dem Durchbruch? Ein OC&C-Insight, Düsseldorf.

Seidel, S., Mareï, N. and Blanquart, C., 2016. Innovations in e-grocery and logistics solutions for cities. Transportation Research Procedia, 12, pp.825-835. https://doi.org/10.1016/j.trpro.2016.02.035

Seitz, Ch., 2013. E-Grocery as New Innovative Distribution Channel in the German Food Retailing. Active Citizenship by Knowledge Management & Innovation: Proceedings of the Management, Knowledge and Learning International Conference, 2013, ToKnowPress.

Statista, 2019a. Umsatz durch E-Commerce/Onlinehandel in Deutschland bis 2019. [online] Available at: https://de.statista.com/statistik/daten/studie/3979/umfrage/e-commerce-umsatz-in-deutschland-seit-1999/ [Accessed 8 April 2020].

Statista, 2019b. Umsatz im Lebensmitteleinzelhandel in Deutschland bis 2018. [online] Available at: https://de.statista.com/statistik/daten/studie/161986/umfrage/umsatz-im-lebensmittelhandel-seit-1998/ [Accessed 8 April 2020].

Statista, 2019c. Statistiken zum Lebensmittelkauf im Internet. [online] Available at: https://de.statista.com/themen/2052/lebensmittelkauf-im-internet/ [Accessed 8 April 2020].

Wagner, W. and Wiehenbrauk, D., 2014. Cross Channel: Revolution im Lebensmittelhandel. EY (Eds.) [online] Available at: https://www.unternehmeredition.de/wp-content/uploads/2014/02/EY-Cross-Channel-Die-Revolution-im-Lebensmittelhandel.pdf [Accessed 8 April 2020].

Selecting the Right Platform – The Perspective of Logistics Service Providers

Jonas Haas [1] and Mischa Seiter [2]

1 – IPRI – International Performance Research Institute

2 – Ulm University / IPRI – International Performance Research Institute

Purpose: Digital platforms provide logistics service providers (LSPs) the opportunity to increase their capacity utilization. Since there are a large number of reasonable alternatives, LSPs should be able to systematically assess different platforms. However, there is little knowledge on specific dimensions for such an assessment. Thus, the objective of this paper is to identify important dimensions to assess digital platforms from the perspective of LSPs.

Methodology: We conducted semi-structured interviews with LSPs and platform operators. Based on a qualitative content analysis we identify specific dimensions for assessment of digital platforms.

Findings: We find four specific dimensions for assessing platform potential. First, matching mechanisms that facilitate transaction processes and reduce search costs. Second, gatekeeping mechanisms that assure the quality of platform actors and increase trust. Third, pricing mechanisms that affect direct costs, and fourth, factors that lead to lock-in-effects.

Originality: There are a large number of studies on criteria to select business partners, e.g., suppliers. Although the number of platform users increases rapidly, and their disruptive potential is high, there is only little knowledge on platform-specific evaluation criteria. In this paper, we identify relevant platform-specific dimensions for the selection of suitable platforms as an extension of existing partner selection criteria.

First received: 19. Mar 2020 Revised: 16. Jun 2020 Accepted: 10. Jul 2020

1 Introduction

Digitalization is rapidly changing the structure of entire industries. Within this transformation, digital platforms offer novel potential for success, but also increasingly threaten established business models with their disruptive character (Sucky and Asdecker, 2019). This development and transformation is similarly affecting the logistics industry, where the cooperation between logistics service providers (LSPs) and shippers is undergoing lasting changes (Zimmermann, 2017).

LSPs face the challenge of increasing their efficiency due to highly competitive pressure from numerous competitors and growing operating costs (Zhang, et al., 2017; Xu, Zhong and Cheng, 2019). High fuel prices and rising personnel costs continue to impose a negative impact on logistics service provider margins, which are without exception low (Xu, Zhong and Cheng, 2019). Cooperation between LSPs has long been used to optimize individual capacity utilization in the transport sector (Pan, et al., 2019). Nevertheless, in 2018, 37.1 percent of the transport kilometers of German trucks were empty runs on which no goods were transported (Kraftfahrt Bundesamt, 2018).

Digital platforms in the logistics sector offer tremendous potential for further reducing empty runs through the coordination of actors in the platform ecosystem (Sucky and Asdecker, 2019). By providing additional services, such platforms enable LSPs to optimize internal processes and provide customers with improved service quality. However, the increasing presence of digital platforms in the logistics industry is a controversial issue. Contrary to the advantages of digital platforms for some service sectors, in the traditional logistics industry, there is often skepticism and uncertainty about changing conventional business models and use of the innovative structures provided by digital platforms (Hofmann and Osterwalder, 2017). For example, there is concern regarding the disclosure of sensitive company data and new forms of dependency imposed by digital platforms reinforce this effect (Grotemeier, C., Lehmacher, W., Kille, C., Meißner, M., 2016).

For LSPs, the disruptive nature of digital platforms means that, in addition to innovative potential, these new platforms also introduce new challenges and risks that can impact their existing business models (Grotemeier, C., Lehmacher, W., Kille, C., Meißner, M., 2016). Due to numerous platforms with different service offerings, LSPs need to make a precise selection of suitable platforms. The selection of partners, e.g., suppliers, in traditional business models has been a widely researched area since the 1990s. A positive influence of systematic selection processes on the efficiency of supply chains has already been demonstrated in several studies (Vonderembse and Tracey, 1999; Liu and Fong-Yuen, D., Vinol, L., 2000; Chang, Chang and Wu, 2011). While the selection criteria apply specifically to traditional business models, there are as yet no platform-specific selection criteria. Due to the growing importance of platforms in the logistics industry and platform-specific opportunities and risks for LSPs, the objective of this paper is to identify important dimensions to assess digital platforms from the perspective of LSPs.

The remainder of this paper is structured as follows. In section 2, the theoretical background of digital platforms is considered in order to analyze platform-specific characteristics. Platforms differ from conventional business models due to their role as intermediary and platform-specific market mechanisms. To evaluate platforms in detail, a fundamental analysis of platform-specific mechanisms in the logistics sector is necessary. A literature analysis is carried out for this purpose. In section 3, we describe the literature analysis and qualitative content analysis method, which is used to evaluate and analyze interviews in this study. Additionally, our sample selection is explained. In section 4, platform-specific dimensions are identified based on the expert interviews. In section 5, the study results are discussed and a conclusion is drawn in section 6.

2 Theoretical Background

2.1 Characteristics of digital platforms

Digital platforms have been an essential part of business management research since the turn of the millennium. In the literature, there are two key research focuses for digital platforms: An economic view taking into account platform-specific market mechanisms and a technical view (Gawer, 2014). Due to the increasing presence of digital platforms in various industries, such as banking, health care, energy, manufacturing, logistics and transport, the scope and diversity of this research area is growing rapidly (de Reuver, M., Sørensen, C., Basole, R. C., 2018). However, there is no common definition of digital platforms.

In principle, digital platforms can be described as socio-technical systems of two- or multisided markets, which enable and simplify value-adding interactions between platform players by providing a digital infrastructure (Gawer, 2014; Parker, van Alstyne and Choudary, 2017; de Reuver, M., Sørensen, C., Basole, R. C., 2018). The goal of digital platforms is to create value for all players by bringing platform players together, thereby maximizing the value of the entire platform ecosystem (Parker, van Alstyne and Choudary, 2017). As intermediaries, digital platforms are detached from the ownership of physical assets, which leads to a fundamental distinction from traditional organizations (Engels, G., Plass, C., Rammig, F. J., 2017).

Platform ecosystems combine the expertise and services of numerous independent platform players that may act in different roles. A platform ecosystem comprises the platform operator, the core service providers, the demanders and the complementors (Jacobides, Cennamo and Gawer, 2018).

Suppliers and demanders are actors on a platform that functions as an intermediary which enables the main interaction (Smedlund, A., Faghankhani, H., 2015). The main interaction is the most important activity that takes place on the platform and motivates most actors to use it (Choudary, 2015; Parker, van Alstyne and Choudary, 2017). Suppliers provide the core service and create value that can be demanded and traded on the platform. Demanders consume the services offered, which are often bundles of services from providers and complementors.

Depending on platform design, the roles of the players can change from demand to supply and vice versa. However, this role change is usually dependent on various interactions, thus the role taken does not change during a specific interaction (Parker, van Alstyne and Choudary, 2017). The platform operator provides the infrastructure for interaction between the players. In addition, the platform operator controls and monitors the interactions and the actors. Appropriate design and control are key factors for a successful orchestration of platform ecosystems with all its stakeholders (Smedlund, A., Faghankhani, H., 2015). Even the platform operator is not bound to the role of a mere operator (Tiwana, 2014). In addition, the platform ecosystem includes complementors. These actors provide products and services complementary to the core service, which allows the platform offering to be expanded and optimized (Smedlund, A., Faghankhani, H., 2015).

A key characteristic of digital platforms is the multi-sidedness of the platform ecosystem, in which each actor can be assigned to a specific group of stakeholders brought together by the platform (Tiwana, 2014). Successful platforms use implemented matching mechanisms that can automate and optimize the process of bringing together stakeholders on the platform (Sutherland and Jarrahi, 2018). Matching mechanisms use data from the stakeholders to match supply and demand according to requirements, skills and preferences (Zimmermann, 2017). The better these algorithms are designed, the more efficient the exchange and value generation via the platform (Parker, van Alstyne and Choudary, 2017). For platform actors, efficient matching mechanisms mean enormous savings in terms of search and transaction costs (Tiwana, 2014). Consequently, joining an existing platform ecosystem offers the chance to reach new markets and partners. The benefit of a group of actors in multi-sided markets increases with the growth of their own group of actors as well as of a group of actors that differ from them (de Reuver, M., Sørensen, C., Basole, R. C., 2018). These are so-called network effects.

The benefits of a digital platform depend on the number of actors actively interacting on it. Network-effects describe the change in benefit for each individual platform actor through the entry of an additional actor into the platform ecosystem (Tiwana, 2014). Each additional platform actor increases the number of actors with whom it is potentially possible to interact. Network effects can only occur effectively in a platform ecosystem if a sufficiently large number of platform actors have been reached (McIntyre and Srinivasan, 2017). The minimum number of platform actors at which network effects occur effectively is called the critical mass or tipping point (Tiwana, 2014).

2.2 Digital platforms in logistics industry

Digital platforms in the logistics industry are undergoing a process of change due to digital transformation. Traditional freight exchange platforms are increasingly threatened by digital platforms that offer additional innovative services (Zimmermann, 2017). These platforms implement digital technologies and go beyond the mere offer of a marketplace (Sucky and Asdecker, 2019). On the one hand, established freight exchange platforms are expanding their functionalities, while on the other hand, start-ups are increasingly pushing into the market. Worldwide investment in logistics start-ups increased 243 percent from $3.5 billion in 2017 to $12 billion in 2018 (Wyman 2018).

In logistics platforms, shippers act as suppliers of goods to be transported and as buyers of transport capacities. LSPs act as demanders to obtain new transport orders and as providers of free capacities (Zimmermann, 2017). In this case, free transport capacity is offered, which shippers and other LSPs can access (Pan, et al., 2019). As mentioned before, the role of platform players can change. Depending on platform design, it may be possible for LSPs to share transport orders with carriers on horizontal level (Zhang, et al., 2017). As shown in Figure 1, interaction on platforms can take place in different ways. Both shippers and LSPs can offer freight orders. These freight orders can be requested by LSPs or carriers.

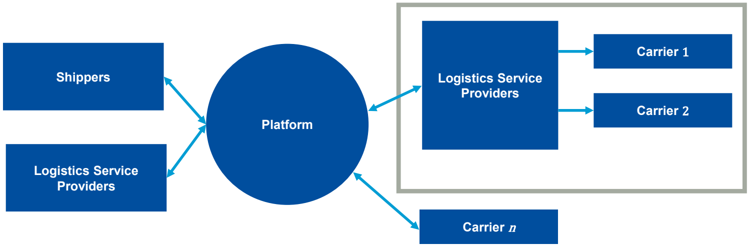


Figure 1: Structure of Logistics Platforms (own representation based on Witkowski, 2018)

Two types of logistics platforms can be distinguished: Open and closed platforms. Open platforms are available to all interested shippers, LSPs and carriers for one-off transactions on the spot-market. Transport orders can be traded by simple registration. In this way, short-term capacity fluctuations can be compensated. Closed platforms are dedicated to specific companies with long-term relationships and freight orders are tendered in a closed network (Moroz, et al., 2014). The use of these platforms has a long-term character and is often subject to contractual regulations.

In addition to trading freight orders, platforms increasingly offer additional functionalities (Fanti, et al., 2017). Additional functionalities include automatic matching mechanisms, where transport-relevant data, such as vehicle size, vehicle position, load weight, transport schedule and freight-specific requirements are analyzed using algorithms to bring together suitable platform actors (Sucky and Asdecker, 2019). High-quality matching mechanisms can reduce search costs for platform actors and enormously increase the efficiency of cooperation (Parker, van Alstyne and Choudary, 2017; Rosano, et al., 2018). The principle of matching mechanisms is shown in Figure 2.

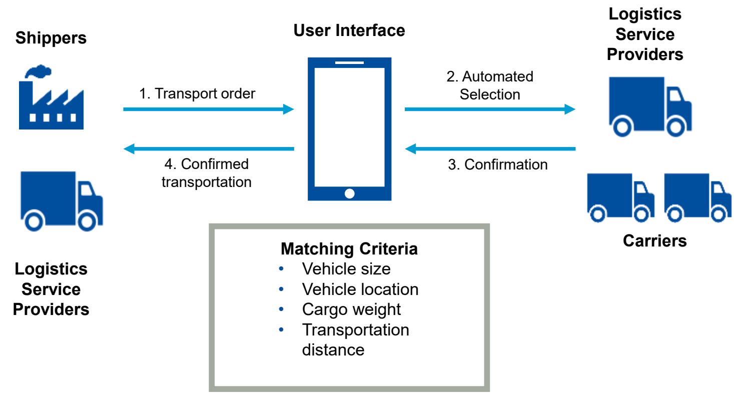


Figure 2: Automated Matching (own representation based on Zimmermann, 2017)

(1) Shippers or LSPs first enter transport orders into the platform system. (2) The algorithm then selects suitable LSPs or carriers based on vehicle size and position, load weight, transport distance and other influencing factors, and contacts them automatically. (3) Transporters can now accept or reject the order offer using order management. (4) Depending on the decision, the order is confirmed or rejected for the shipper (Zimmermann, 2017).

Platforms can also include Time Slot Management (TSM) which allows actors to agree on preferred times to load and unload trucks. This leads to reduced waiting times and optimized internal, as well as external, processes (Witkowski, 2018). In addition to matching mechanisms based on real-time data, platforms can include automated price determination. This functionality calculates prices based on transport-specific factors such as transport route, transport volume as well as fuel and personnel costs (Zimmermann, 2017).

Tracking and tracing mechanisms enable event-based or real-time tracking during transport as well as additional data services for visibility (Möller, F., Bauhaus, H., Hoffmann, C., Niess, C., Otto, B., 2019). For platform actors, this increases process transparency and optimizes time management for loading and unloading processes (Giannopoulos, 2004). Moreover, this real-time data can be used to calculate optimal transport routes and the estimated time of arrival by adding information on traffic or weather conditions. (Grotemeier, C., Lehmacher, W., Kille, C., Meißner, M., 2016). In addition to time management functions, several platforms offer central document management. Transport documents, such as proof of delivery, can be made available via smartphone and also provide photographs (Zimmermann, 2017). This information can be viewed and shared directly via the central user interface. Further services can be provided in the form of credit checks to ensure high-quality cooperation partners on the platform. Moreover, performance ratings can be used for evaluations and to display payment behavior (Rosano, et al., 2018). These ratings help the platform operator to increase the level of trust between cooperation partners (Grotemeier, C., Lehmacher, W., Kille, C., Meißner, M., 2016).

2.3 Opportunities and risks for LSPs

Joining an existing platform ecosystem can lead to access to new markets and players that would not be possible in an independent organization or only at great expense (Tiwana, 2014). The most important advantage of platforms for LSPs is the reduction of empty runs (Witkowski, 2018). In particular, on the way back, the consolidation of cargo with other actors of a platform can enormously reduce empty runs. Accordingly, the more actors that use the platform, the more possibilities there are to find suitable cargo. Digital platforms open up new communication and sales channels (Engels, G., Plass, C., Rammig, F. J., 2017). Central communication channels of the platform offer LSPs the potential to enormously reduce administrative costs (Witkowski, 2018). Small LSPs with few personnel can outsource sales activities to the platform. The better that the matching works on platforms, the less manual searching is required, which increases efficiency (Cambra-Fierro and Ruiz-Benitez, 2009). Moreover, platforms create transparency about market prices. This can be an advantage on the one hand, but on the other hand it increases pure price competition.

Several platforms offer vehicle insurance services, route optimization, vehicle leasing services, factoring services in pre-financing, e.g., fuel purchases to secure the liquidity of LSPs (Witkowski, 2018). These new or extended market services offer LSPs the opportunity to focus on their core competencies and to increase customer benefit by offering service bundles. The potential advantages of platform utilization, however, must be weighed against the risks that can arise from joining an existing platform ecosystem. Platform users run the risk of losing direct access to customers. Platform business models in which the interaction between LSPs and shippers takes place exclusively via the platform can have a negative impact on customer loyalty (Engels, G., Plass, C., Rammig, F. J., 2017).

The increased transparency on digital platforms also forces the interchangeability of LSPs. Especially in the logistics industry with largely homogeneous services and little potential for differentiation, this quickly leads to pure price competition. The consequence is a loss of margins (Engels, G., Plass, C., Rammig, F. J., 2017). The expense of the margins achieved depends on the cost of platform utilization. On the one hand, platforms may include subscription pricing, i.e., through regular payments independent of transactions. On the other hand, transactions can be priced by charging a transaction fee, which has a direct impact on the margin achieved. Mixed forms of these pricing models can also be found (Witkowski, 2018).

A central risk is the dependency of the platform actors. So-called lock-in effects are to be considered mainly in the form of increased switching costs. An increase in this risk results from specific investments and the outsourcing of important processes to the platform (Tiwana, 2014; Engels, G., Plass, C., Rammig, F. J., 2017). A further aspect of the dependency is the disclosure of sensitive company-specific data, which makes know-how and confidential information visible (Grotemeier, C., Lehmacher, W., Kille, C., Meißner, M., 2016). In addition, there is the risk of losing this data when leaving the platform ecosystem. This risk is particularly prevalent in closed platforms. Therefore, regulated security mechanisms that increase confidence in the use of digital platforms are of enormous importance (Choudary, 2015)

3 Method

We use an explorative nature approach. First, a literature review was done to identify actors and platform functionalities as well as opportunities and risks for LSPs. We conducted the literature review in three steps: planning, conducting and evaluate (Tranfield, et al., 2003).

The literature review was based on our guiding research question: Which platform-specific dimensions are relevant for the selection of logistics platforms from the perspective of LSPs? Therefore, the database "google scholar" was used for a preliminary overview. In addition, the search was conducted in the database "ScienceDirect". The following keywords were included: "digital platforms", "digital platforms in logistics", "digital platforms for logistics service providers", "assessment of digital platforms in logistics" and "digital platforms for freight exchange". Various combinations were used for this purpose, the number of results for every the number of results is shown in brackets: "digital platforms AND freight exchange" (651), "digital platforms AND logistics service providers" (2.544), "digital platforms AND logistics" (4.137), "digital platforms AND assessment AND logistics" (3096). Due to the large number of publications between 2009 and 2020, only papers from this period were included.

The existing literature examines digital platforms mostly in the B2C context and has only little reference to logistics-specific platforms. Due to the large number of papers investigating the functions and mechanisms of digital platforms independent of industry sectors and only few logistics-specific publications, both publications from general platform literature and logistics-specific publications were analyzed. The advantage is the transferability of generally valid functions and mechanisms of digital platforms to the logistics-specific application. The titles and abstracts of the publications were screened in order to select thematically appropriate publications. We identified 28 Papers that served as a basis of our platform-specific literature review. Based on a systematic review of the content, the functionalities and mechanisms of platforms in the logistics context as well as opportunities and risks of platforms for LSPs could be identified. These results serve as a basis for the following interview study.

Second, a study was done using a multiple semi-structured interview methodology. The semi-structured interview design allows flexibility to adapt to specific, but initially unknown circumstances in practice, especially in topics where little comprehensive knowledge is available. The semi-structured interviews are carried out on the basis of an interview guideline focusing on the identification of relevant dimensions to assess platform potentials. A partial standardization of the interviews allows for comparison and evaluation of the interviews (Mayring, 2015). The interviews were conducted via telephone or personally in German. Every interview was audio-recorded, fully transcribed and anonymized. The disclosure of internal company information is therefore not attributable to the respective persons or companies.

We selected interview partners who represent different roles on logistics platforms. As mentioned in Section 2, LSPs can act both as suppliers and purchasers of freight orders. To this end, we interviewed LSPs who use platforms to optimize their capacity through the demand for freight orders and, which also offer excess capacity to other LSPs or carriers. Furthermore, the use of platforms is highly dependent on the size of the LSPs. Small LSPs use platforms as a central distribution channel, whereas large LSPs often use platforms only sporadically. Accordingly, we interviewed small, medium and large LSPs. This sampling provides a comprehensive view of LSPs to identify relevant dimensions for platform evaluation. In addition, the focus was on whether LSPs use open or closed platforms in order to derive possible distinctions.

We also interviewed operators of logistics platforms, which provides an extended view of relevant aspects of digital logistics platforms from the operator's perspective. Here we interviewed providers of open and closed platforms. In addition, platforms of different sizes were included. In order to take into account the functionality of new platforms, a platform start-up was also part of the study. This enabled analysis of platforms that are new on the market and growing rapidly. The selected interview partners are shown in Table 1.

Table 1: Interview Partners

Interview	Role	Platform Type	Size/Scope	Duration
01	Managing Director LSP	Open Platform	Medium/European	60 Minutes
02	Managing Director LSP	Open and closed platform	Large/European	45 Minutes
03	Managing Director LSP	Open Platform	Medium/European	45 Minutes

Interview	Role	Platform Type	Size/Scope	Duration
04	Project Manager LSP	Open Platform	Medium/European	60 Minutes
05	Project Manager LSP	Open and closed platform	Large/Worldwide	45 Minutes
06	Platform operator	Closed platform	Medium/European	60 Minutes
07	Platform operator	Open and closed platform	Large/Worldwide	60 Minutes
08	Platform operator CEO/Founder	Platform Start-Up	Small/European	45 Minutes

In order to identify relevant dimensions for the evaluation of logistics platforms, the interviews were analyzed according to grounded theory. This is particularly suitable for the theoretical construction of previously unexplored areas and does not focus on the description of existing theories (Silverman, 2017). The interviews were examined in detail using a qualitative content analysis according to Mayring (2015). The process of identifying the dimensions comprises three main steps: first, categories are developed from the data collected and constantly compared. Therefore, the experts’ statements are reduced to their core statements, paraphrased and subsequently generalized. Second, the paraphrases are assigned to different thematic categories using a keyword analysis. These categories are then evaluated on the basis of further cases up to saturation to determine relevance. In a third step, the identified categories are generalized and the theoretical model is built (Charmaz, 2006).

4 Findings

Based on the interviews conducted, the opportunities and risks of joining platforms were first analyzed from the perspective of LSPs. This results in the fact that opportunities arise primarily through increased efficiency. LSPs can use digital platforms to optimize capacity utilization and act more efficiently. This is a key success factor, particularly in the heavily cost-driven logistics sector. Horizontal cooperation between LSPs has long been a means of avoiding empty runs. In particular, identified matching mechanisms can significantly simplify cooperation, and increase cooperative efficiency. However, there are serious differences between matching mechanisms. Some platforms do not include automated matching mechanisms, so the manual effort for cooperation remains the same. Potential arises mainly from algorithms that can be used to match suitable partners and dramatically reduce search costs. Another dimension identified to evaluate efficiency is pricing mechanisms. Different mechanisms exist, which clearly differentiate the costs of platform use. Furthermore, it became apparent that cooperation with partly unknown partners requires trust. This can be strengthened by gatekeeping mechanisms. In this case, only actors with certain quality criteria are allowed on platforms. With regard to the risks associated with joining a platform, the interviews revealed dependencies on platforms. In the area of dependencies, the dimension of lock-in effects can be identified. Through platform-specific mechanisms, LSPs are faced with the challenge of evaluating dependencies that may arise from platform use. The identification of the dimensions are shown in Figure 3 and are further explained in this section.

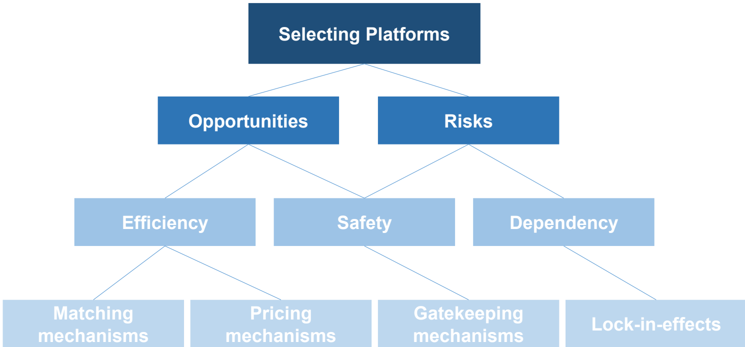


Figure 3: Theoretical Model: Dimensions to Select Platforms

4.1 Matching mechanisms

Matching mechanisms are one opportunity to optimize cooperation processes via digital platforms. The potential for efficient cooperation is increased by matching freight offers according to capacity and capability. A distinction can be made between logistics platforms where orders must be manually entered into the system and those where transportation service providers must be selected. Orders are coordinated via the platform by manual selection after a search effort. In comparison, there are platforms that offer automated matching mechanisms. These offer LSPs the potential to automatically propose freight offers and requests for cargo based on capacity, route and capability-compliant factors. This leads to more efficient cooperation processes. In addition, these mechanisms significantly increase the placement rate. It should be emphasized that the interviews identified that there are serious differences in existing logistics platforms in the area of matching mechanisms.

In practice, logistics platforms can be found in which no matching mechanisms are implemented. The input of capacities, routes and time windows for transport services is done manually. The selection of freight offers from shippers must also be carried out manually by dispatching personnel. There is no potential here to make cooperation processes more efficient. Negotiations on freight orders continue to be conducted by telephone or e-mail. In this type of platform, only a few offers lead to an actual order.
A further characteristic of matching mechanisms became apparent from other interviews. Here the input of transport orders is still partly done manually. However, the allocation of orders is based on capacity requirements, recipient location and a time window is automated. Orders are suggested to suitable LSPs, which greatly reduces the search effort. LSPs are then able to accept or reject the suggested orders. The partially-automated matching process results in increased potential for the LSPs by making cooperation processes more efficient and at reduced costs. Optimized matching mechanisms already exist which generate orders and assign such orders to suitable partners. The matching of supply and demand can be done by using real-time GPS-data based on the current locations of the LSPs and the goods to be loaded, which reduces empty runs. This feature was identified as the maximum potential of matching mechanisms. There is neither the effort to enter information about transport orders into the platform system, nor do suitable offers have to be selected manually. Orders are concluded directly via the platform. Due to stored tariffs, there is no negotiation and LSPs receive orders directly from the platform. In this case the number of orders received via the platform increases enormously.

4.2 Gatekeeping mechanisms

A further central factor in assessing potential is to ensure that the platform players are of a correspondingly high quality and reliability. Cooperation via the platforms means an exchange of information about the platform actors as well as money flows. Gatekeeping mechanisms ensure that actors only meet high-quality cooperation partners. From the perspective of LSPs, it must be ensured that potential cooperation partners are reliable for secure interactions and transactions. This is particularly important when LSPs cooperate with other carriers as providers of cargo. Therefore, security mechanisms must also be implemented by the platform operator. First, fundamental factors such as legal requirements and the necessary insurance coverage need to be identified. Second, specific criteria are necessary, e.g., for the transport of special goods such as hazardous substances. Especially for non-mass-produced goods, gatekeeping mechanisms are the prerequisite for cooperation. The assurance of these quality characteristics, which is necessary as a prerequisite for joining a platform ecosystem, increases the confidence and trust of the actors. Gatekeeping mechanisms are especially important on open platforms. Here, the cooperation between many unknown actors takes place in an open network. It is also important in closed platforms, but the cooperation takes place in a closed network with mostly well-known partners.

Gatekeeping can include user authentication and certification as well as actor verification by simple registration up to the requirement of quality certifications. Users of logistics platforms often have to undergo verifications and credit checks. The examination of the platform actor by the platform operator ensures that potential cooperation partners are exclusively high-quality and genuine carriers.

4.3 Pricing mechanisms

Pricing models can be identified as a further influencing factor for the evaluation of platforms. From the LSPs point of view, the potential of a platform only arises if the costs of platform use are lower than the sales potential. Furthermore, this dimension is based on the enormous cost pressure in the logistics industry with decreasing margins. It became apparent that existing platforms contain different pricing models.

Pricing models can basically be divided into transaction-based costs and subscription models. Transaction-based costs are incurred proportionately to the transactions carried out. LSPs pay a percentage of the transaction sum to the platform operator. If no transaction is carried out, no costs are incurred.

Subscription costs are transaction-independent fixed costs per time interval. These fixed costs can often appear as license fees. Every employee who uses the platform must have such a license. Depending on the intensity of use, it is important for LSPs to evaluate which pricing model has the least impact on the margins achieved. Furthermore, asymmetric pricing models can offer additional potential. Especially in closed platforms it is possible for LSPs to process transactions via the platform without incurring platform usage costs. Depending on platform design, LSPs can be subsidized by shippers, who bear the costs of using the platform.

The pricing of the platform has to be in proportion to the benefits that the platform brings. These additional costs for cooperation must be recovered through process optimization. Furthermore, the different cost models can be linked to the resulting flexibility of platform use. The loss of flexibility is a core problem of LSPs in the strategic use of platforms. A differentiation can be made between the low flexibility of platform usage through regularly fixed usage fees, which makes the inevitable use of the platform necessary for pure cost recovery. On the other hand, there is the potential of a flexible platform usage, which is given by purely transaction-dependent costs.

4.4 Lock-in-effects

In addition to dimensions that serve to increase efficiency and security, many LSPs regard logistics platforms with reservations. The usage of platforms and the role of LSPs on these platforms can lead to new dependencies. The lower the dependency on the logistics platform, the higher the potential for LSPs. There are different factors that lead to lock-in effects.

One factor is the loss of direct customer contact. Information flows are usually handled by the platform operator as the central intermediary. As the platform assumes the contact function, there is a risk of losing direct contact with customers. Different forms of customer contact on platforms were identified. Many platforms make offers visible and transparent, but contracts are concluded in personal contact between the parties. In this case the platform acts to provide a comparison function for offers. As direct customer contact continues to exist, there is no dependency on the platform.

Meanwhile, closed platforms create a high dependency. Shippers who use closed platforms lead LSPs on platforms. The contact between shipper and

LSP then remains exclusively via the platform. LSPs lose contact with existing customers who process orders exclusively via the platform when they don’t join or leave the platform ecosystem. Special attention must be paid to contractual regulations that allow interaction with customers exclusively via the platform. As a consequence of these regulations, interaction with customers is often no longer possible without using the platform. Leaving the platform ecosystem is tantamount to breaking off business relations with these customers. Often, an admission contract must be signed, binding the user to the platform's requirements. This does not only mean that you can simply enter the platform, it also means that you cannot leave it without effort.

Specific investments increase the dependency on platform actors if these investments are only suitable for one platform. Interview partners stated, that especially for closed platforms, add-ins that were developed for integration into a platform are often costly. One would not switch to another platform operator if the implemented add-in no longer has any value there. If investments are to be made in interface development, these should be compatible with other platforms. Otherwise, interfaces would have to be built up again for joining another platform. In order to analyze the potential for reducing the dependency on a specific platform, standardized interfaces are one way to avoid specific investments. Moreover, investments in the development of interfaces to connect transport management systems with the platform infrastructure could also be identified as platform-specific investments. In addition, consideration must be done when individual value-added processes of the LSPs, which are essential for their business model, are outsourced to the platform. Thus, the increasing outsourcing of value-added processes leads to a transformation of a fully-fledged freight forwarder into a fully-dependent service provider.

5 Discussion

The dimensions identified in this study for the evaluation of logistics platforms from the perspective of LSPs represent an extension of existing evaluation dimensions in a platform-specific context. Matching mechanisms are pointed out in the literature as an important criterion for the potential of platforms. High-quality matching mechanisms can reduce search costs for platform actors and enormously increase the efficiency of cooperation (Parker, van Alstyne and Choudary, 2017). Currently, however, only a few platforms contain automated mechanisms. A distinction between different forms of matching could not be identified in the literature. It is still necessary to analyze in detail the functioning of the matching mechanisms in order to make concrete distinctions about their potential. In addition, it became clear that automated matching not only offers potential, but the required data increases transparency and that LSPs have reservations about disclosing sensitive company data. In the future, it will therefore be necessary to weigh up the disclosure of sensitive data against improvements in search effort.

A central concern that emerges from the study interviews is ensuring the trustworthiness of platform cooperation partners. Trust is a central success factor from both the user and from the operator's point of view (Shaughnessy, 2015; Evans and Schmalensee, 2016). To evaluate this, the dimension of gatekeeping was derived from the interviews. Gatekeeping mechanisms are an established function of platform operators to control platform actors (Tiwana, 2014). The logistics industry is characterized by personal relationships between LSPs and shippers, which function on a horizontal

level (Verdonck, et al., 2013; Agarwal, Jain and Karabasoglu, 2018). To ensure the security of transactions with unknown partners on platforms, these security aspects are an important factor. However, one of the benefit of platforms depends on active users on the platform. In order to attract as many users to a platform as possible, the security mechanisms have to be critically scrutinized. From the point of view of platform operators, new users are a positive, but too few security controls can lead to lower trust.
Traditional business models are concerned with developing and protecting resources that cannot be imitated in order to secure competitive advantages. Meanwhile, platform operators strive to engage players in a platform ecosystem in order to generate as many interactions as possible and thereby maximize the value of the platform ecosystem (Parker, van Alstyne and Choudary, 2017). Accordingly, the competitive strategies of platform operators also focus on securing essential skills and resources to avoid the multihoming of platform users. Multihoming is the action of platform actors participating in several existing and competing platform ecosystems with similar capabilities. In order to avoid multihoming, platform operators strive to generate switching costs for platform actors through various lock-in mechanisms (Tiwana, 2014; Parker, van Alstyne and Choudary, 2017). Switching costs arise when switching from one platform to another involves costs for the platform user. High switching costs lead to lock-in effects for the platform user (Farrell, J., & Klemperer, P., 2007). Such lock-in-effects are also a critical factor for LSPs to consider regarding logistics platforms. In particular, closed platforms must be critically weighed from the perspective of LSPs. If shippers decide to tender freight contracts exclusively via platforms, LSPs are often forced to join the platform, otherwise

the business relationship with these partners is lost. Consequently, this dimension cannot always be assessed without difficulty.

6 Conclusion

Platforms in the logistics industry are developing rapidly. Digital transformation in particular offers new functionalities that create added value for the logistics industry. In addition to the potential to optimize capacity utilization and to obtain new cooperation partners with little effort, new types of risks may arise on platforms. In order to evaluate these opportunities and risks in detail and to select a suitable platform, four dimensions serve as a systematic basis to evaluate platform-specific criteria. These dimensions go beyond existing criteria to select cooperating partners and include platform-specific factors. By assessing potential, LSPs can evaluate the possibility of joining a specific platform ecosystem and, based on this, constantly question and optimize their existing business model. For long-term application, the dimensions must be continuously optimized in order to meet the rapidly evolving range of logistics platforms offered by digital technologies.

Our study has several limitations. First, general applicability is limited with regard to the very heterogeneous range of existing logistics platforms, whose complete evaluation on the basis of all relevant factors for potential analysis is difficult to depict in single dimensions. The identified dimensions should be seen as a first approach to include platform-specific factors in the assessment of business models. Second, it should be noted, that an assessment of platforms with the identified dimensions can only be carried out using externally-visible evaluation criteria. The clear delimitation of the potential is partially problematic due to the limited knowledge of functionalities. The dimensions have to be used as decision support for the selection of suitable platforms. In order to decide on the actual entry, further detailed analyses in the identified dimensions have to be carried out, which go beyond the global character of the dimensions in this study. Therefore, it is also important to evaluate the identified dimensions based on a larger set of data. The evaluation criteria must be adapted to changes in platform service offerings. As the development of freight exchanges into digital platforms shows, digital transformation will continue to have a major influence on the future of the logistics sector.

Acknowledgement

This paper is based on a research project that is part of the so-called “Industrial collective research program” (IGF no. 20802 N). It is funded by the Federal Ministry for Economic Affairs and Energy (BMWi) through the AiF (German Federation of Industrial Research Associations eV), based on a decision made by the German Bundestag.

References

Agarwal, Y., Jain, K. and Karabasoglu, O., 2018. Smart vehicle monitoring and assistance using cloud computing in vehicular Ad Hoc networks. International Journal of Transportation Science and Technology, 7(1), pp. 60–73.

Cambra-Fierro, J. and Ruiz-Benitez, R., 2009. Advantages of intermodal logistics platforms: Insights from a Spanish platform. Supply Chain Management: An International Journal, 14(6), pp. 418–421.

Chang, B., Chang, C.-W. and Wu, C.-H., 2011. Fuzzy DEMATEL method for developing supplier selection criteria. Expert Systems with Applications, 38(3), pp. 1850–1858.

Charmaz, K., 2006. Constructing grounded theory: A practical guide through qualitative analysis. London: Sage.

Choudary, S. P., 2015. Platform scale: How an emerging business model helps startups build large empires with minimum investment. Boston: Platform Thinking Labs Pte. Ltd.

de Reuver, M., Sørensen, C., Basole, R. C., 2018. The Digital Platform: A Research Agenda. Journal of Information Technology, 33(2), pp. 124–135.

Engels, G., Plass, C., & Rammig, F. J., 2017. IT-Plattformen für die Smart Service Welt. Verständnis und Handlungsfelder. München.

Evans, D. S. and Schmalensee, R., 2016. Matchmakers: The new economics of multisided platforms. Boston, Massachusetts: Harvard Business Review Press.

Fanti, M. P., Iacobellis, G., Mangini, A. M., Precchiazzi, I. and & Ukovich, W., 2017. A Flexible Platform for Intermodal Transportation and Integrated Logistics. IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), pp. 224–229.

Farrell, J., & Klemperer, P., 2007. Coordination and lock-in: Competition with switching costs and network effects. Handbook of industrial organization, 3, pp. 1967–2072.

Gawer, A., 2014. Bridging differing perspectives on technological platforms: Toward an integrative framework. Research Policy, 43(7), pp. 1239–1249.

Giannopoulos, G.A., 2004. The application of information and communication technologies in transport. European Journal of Operational Research, 152(2), pp. 302–320.

Grotemeier, C., Lehmacher, W., Kille, C., Meißner, M., 2016. Die Plattform-Ökonomie: Chancen und Herausforderungen für den Wirtschaftsbereich Logistik. Logistik trifft Digitalisierung. Auswirkungen auf die Entwicklung. Gipfel der Logistikweisen- zur Prognose der Entwicklung des Logistikstandortes Deutschland, pp. 74–81.

Hofmann, E. and Osterwalder, F., 2017. Third-Party Logistics Providers in the Digital Age: Towards a New Competitive Arena? Logistics, 1(2), pp. 1–28.

Jacobides, M. G., Cennamo, C. and Gawer, A., 2018. Towards a theory of ecosystems. Strategic Management Journal, 39(8), pp. 2255–2276.

Kraftfahrt Bundesamt, 2018. Inlandskilometer durch Leerfahrten deutscher Lastkraftfahrzeuge im Jahr 2018 nach Gebiet der Fahrzeugzulassung und Verkehrsart. [online] Available at: <https://www.kba.de/DE/Statistik/Kraftverkehr/deutscherLastkraftfahrzeuge/Inlandsverkehr/2018_vd3_leer.html?nn=652360> [Accessed 23 May 2020].

Liu, J. and Fong-Yuen, D., Vinol, L., 2000. Using data envelopment analysis to compare suppliers for supplier selection and performance improvement. Supply Chain Management: An International Journal, 5(3), pp. 143–150.

Mayring, P., 2015. Qualitative Inhaltsanalyse: Grundlagen und Techniken. 12th ed. Weinheim: Beltz.

McIntyre, D. P. and Srinivasan, A., 2017. Networks, platforms, and strategy: Emerging views and next steps. Strategic Management Journal, 38(1), pp. 141–160.

Möller, F., Bauhaus, H., Hoffmann, C., Niess, C., Otto, B., 2019. Archetypes of Digital Business Models in Logistics Start-Ups. Proceedings of the 27th European Conference on Information Systems (ECIS). Uppsala and Stockholm: Sweden.

Moroz, M., Nicu, C.-C., Pavel, I. and Polkowski, Z., 2014. The transformation of logistics Into e-logistics with the example of electronic freight exchange. Zeszyty Naukowe Dolnośląskiej Wyższej Szkoły Przedsiębiorczości i Techniki. Studia z Nauk Technicznych, 3, pp. 111–128.

Pan, S., Trentesaux, D., Ballot, E. and Huang, G. Q., 2019. Horizontal collaborative transport: survey of solutions and practical implementation issues. International Journal of Production Research, 57(15-16), pp. 5340–5361.

Parker, G., van Alstyne, M. and Choudary, S. P., 2017. Platform revolution: How networked markets are transforming the economy - and how to make them work for you. New York, London: W.W. Norton & Company.

Rosano, M., Demartini, C. G., Lamberti, F. and Perboli, G., 2018. A mobile platform for collaborative urban freight transportation. Transportation Research Procedia, 30, pp. 14–22.

Shaughnessy, H., 2015. Shift: A user's guide to the new economy. London: The Disruption House through Tru Publishing.

Silverman, D., 2017. Doing qualitative research. 5th ed. Los Angeles, London, New Delhi, Singapore, Washington DC, Melbourne: Sage.

Smedlund, A., Faghankhani, H., 2015. Platform Orchestration for Efficiency, Development and Innovation. 48th Hawaii International Conference on System Sciences, pp. 1280–1388.

Sucky, E. and Asdecker, B., 2019. Digitale Transformation der Logistik – Wie verändern neue Geschäftsmodelle die Branche? In: W. Becker, B. Eierle, A. Fliaster, B. Ivens, A. Leischnig, A. Pflaum, and E. Sucky, eds. 2019. Geschäftsmodelle in der digitalen Welt. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 191–212.

Sutherland, W. and Jarrahi, M. H., 2018. The sharing economy and digital platforms: A review and research agenda. International Journal of Information Management, 43, pp. 328–341.

Tiwana, A., 2014. Platform ecosystems: Aligning architecture, governance, and strategy. Waltham, MA: Morgan Kaufmann.

Tranfield, D., Denyer, D., and Smart, P. 2003. Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British journal of management, 14(3), pp. 207-222.

Verdonck, L., Caris, A. N., Ramaekers, K. and Janssens, G. K., 2013. Collaborative Logistics from the Perspective of Road Transportation Companies. Transport Reviews, 33(6), pp. 700–719.

Vonderembse, M. A. and Tracey, M., 1999. The Impact of Supplier Selection Criteria and Supplier Involvement on Manufacturing Performance. Journal of Supply Chain Management, 35(2), pp. 33–39.

Witkowski, J., 2018. Electronic Freight Exchange and Logistics Platforms in Building of Supply Chains. CLC 2018: Carpathian Logistics Congress: Conference Proceedings. TANGER.

Xu, S. X., Zhong, R. Y. and Cheng, M., 2019. Carrier collaboration based on market design. Computers & Industrial Engineering, 132, pp. 223–231.

Zhang, M., Pratap, S., Huang, G. Q. and Zhao, Z., 2017. Optimal collaborative transportation service trading in B2B e-commerce logistics. International Journal of Production Research, 55(18), pp. 5485–5501.

Zimmermann, F., 2017. Uber-inspirierte Plattformkonzepte in der Logistik: Bedrohen neue Transportkonzepte etablierte Geschäftsmodelle? Retail & Consumer, (11), pp. 1–44.

Impact of Digitalization on Logistics Provider Business Models

Sascha Stradner [1] and Uwe Brunner [1]

1 – University of Applied Sciences Kapfenberg, Austria

Purpose: Digitalization and its technologies enables especially logistics startups to enter the market with low barriers. Well-established enterprises potentially suffer from this development by overlooking the ongoing technological leap. Therefore, the paper includes a research to point out current dynamic of the market and potential risks and chances for current enterprises.

Methodology: For this purpose, an overview of the market development and the fundamental re-thinking of logistics business models based on a literature research is given and reflected. It focuses on technologies, entry barriers for startups and re-thinking of current business models. Subsequently, the impact for current enterprises should be shown up.

Findings: The research points out the dynamic of the business and the risks for well-established enterprises on the market. Startups accelerate the market dynamic by introducing new technologies on the market, which are seen either as risk or chance for enterprises. Organisational inflexibility could lead to a replacement of market leaders.

Originality: Using modern technology business models can be absolutely re-defined. While an abundance of startups could mostly cover performance spectrum of established enterprises in a new way, the latter suffers from rigid company structure. By conducting the research, the current state and risks and chances for current enterprises should be outlined.

1 Introduction

Material flows and supply chains are definitely changing. This trend is mainly triggered by the development of technology in the last years. New products and services changed the way of business and how supply chains are designed (Hermes, 2019). *Industry 4.0* and the development in the area of digital technologies, is often mainly mentioned in the context of production and its processes (Dietrich and Fiege, 2017). The explicit view of *Industry 4.0* on logistics and transport management is not given from the beginning of this revolution.

This mindset is also confirmed by different studies. In 2016 the consultancy *Bearingpoint* showed that 61% of the surveyed managers think of innovative technology, tools, features and automation in the context of production, when speaking about *Industry 4.0*. They focus of this concept has always been a production-oriented approach. Furthermore, just 33% of the participants think that digital technologies in the context of *Industry 4.0* could also change other business models, what is basically understood as digital transformation (Bearingpoint, 2016).

Meanwhile *Industry 4.0* is also arrived in logistics. The term itself is derived from the 4th industrial revolution. Nowadays researchers defined the area of *Logistics 4.0*, which can be described as the impact of digital technologies on the area of transport and supply management (Manners-Bell and Lyon, 2019).

But *Logistics 4.0* can be also seen as the 4th development step of logistics. Therefore, *Stölzle and Burghardt* (2016) describe the first step of logistics as the functional specification, which is known as transport, material handling and warehousing. The second development step is the design of material and information flows within enterprises and their relevant organizational departments, the so called management of logistics. The third development step complements the management of logistics by the customer-oriented value creation within and between enterprises, where logistics is seen as part of supply chain management. In the last step, which is called Logistics 4.0, logistics is seen as a digital value network of all supply chain partners by using real time data and cyber physical systems. This means that digital technologies are enabler for seamless material and information flows along the supply chain in order to increase efficiency and customer satisfaction.

As in many practical examples, use cases in production and other areas of companies, digitalization also offers new possibilities in supply chain management. Processes are re-designed and data is provided to ensure a high level of interlinking and transparency (Kille, 2018). This re-design is essential due to the changes triggered by the production and customer side. New products and services are designed to satisfy the new customer behavior and expectation. This change also has a deep impact on the supply chain itself, which have to be more flexible and adaptable, due to the fast changing customer needs. Therefore, digital technologies offer a lot of potentials to handle this challenge.

The application of concepts like *Big Data*, *Advanced Analytics* and many more is just the first step for further improvements in distribution and logistics. Older web solutions in the context of digitalization like eCommerce and eBusiness are already established in different variations and became part of the digital or virtual value chain in the age of internet economy (Scheer and Loos, 2002). This enlargement of communication channels is not just seen as improvement of processes in order to increase profitability and efficiency in customer order processes, it is more a change in the enterprise's business model to expand customer groups or building up strong relationships with partners (Osterwalder and Pigneur, 2011).

Especially logistics providers have to re-think their business due to the digital transformation. Therefore, they have to learn how to realign their business to meet customer's expectations. Digital transformation has to be seen as more than technical innovation, automation and *Internet of Things* (IoT). Collaborative and agile approaches, as well as new working cultures for the development of value-added services help to break boarders within as well as between collaborating companies (Dietrich and Fiege, 2017).

A wave of digital disruption is about to hit the branch which could change the whole competition and have the potential to overturn the dominant position of established logistics providers, which may not be able to implement collaborative and agile approaches to develop their business. Especially startups have a huge impact on the competition. Technology know how and huge investments into small companies lower the entry barriers in the branch (Riedl, et al., 2018). Established companies suffer from a lack of technology know how and are driven by logistical core competence like the coordination of complex supply chains. But the alignment of processes and new services due to the utilization of digital technology is indispensable. Therefore, the potential of technology should be realized to revolutionize the branch sustainably for future (Suckey and Asdecker, 2019).

This research requires a description of the actual market situation to show up the need for further researches in this area. Subsequently a demarcation of logistics providers and the impact of digitalization on their business models is given. The entrance of new technologies and startups should be shown up to give an overview of potentials and threats through digital technology on established companies in the business and how they can create profit out of these disruptive change. The literature research is conducted in three essential steps. In general, the research is including studies, research papers and statistics searched on different data bases (Google Scholar, Springer Link, Emerald, Statista), which have been published within the last 5 years to ensure actuality of the research object. Depending on the step of the research, filter conditions like type of the paper, language (mainly German and English) and focus have been changed.

2 Increased Outsourcing of Logistics Activities

To understand the recent market development and change in business models of logistics providers it is essential to analyze the requirements of industrial or trading companies. Over the past few years, there are significant changes in customer's behavior and expectations. In the following part of this research paper, the development is explained by screening relevant studies and statistics about outsourcing activities and the relevance of logistics providers. Afterwards a clear demarcation of the term logistics providers is given to focus in the further sections of this research paper.

Logistics Providers profited from a market pressure and the resulting outsourcing of logistics activities by industrial and trading companies. While companies often organized transport by using own assets like warehouses and vehicles, nowadays there is a trend to outsource this activities (Arnold, et al., 2008 and Bolumole, 2001, p. 88). This trend is also part of a variety of subsequent studies and surveys. Therefore, in 2015 the *Industriewissenschaftliche Institut* made a research on the behavior of logistics outsourcing. 62.5 % of the 56 participating companies in the Austrian districts Salzburg and Upper Austria were already outsourcing transport and logistics activities to logistics providers. Just 3.6 % indicated that transports are mainly operated by their own. (Brunner et al., 2015).

Further studies in Germany confirmed this trend. The *Miebach-Outsourcingstudie published by Hoffmann (2017)* shows that based on German shippers' perspective, transport is the most suitable activity to outsource. 67 % of the participants already outsourced transport, while 17 % planned to outsource transport activities in future. In this context, companies have

seen a risk in outsourcing. 60 % of the surveyed companies are afraid of losing control and competence. The dependence of logistics providers is also seen as one challenge in outsourcing, whereby this study was done in 2017 when new technologies for more transparency were still in its infancy.
Often outsourcing of logistics-related tasks is traced back to a lack of competencies or technical infrastructure. Own studies of the *Institute for Industrial Management* on the state of transport logistics of small and medium-sized enterprises (SME) in Austria (Brunner and Obmann, 2019) strengthen this assumption. In the area of transport planning the most dominant software products are still MS Excel, SAP or company-specific solutions. 23 out of 138 surveyed companies even do not use software or platform for efficient planning, which is shown in figure 1.

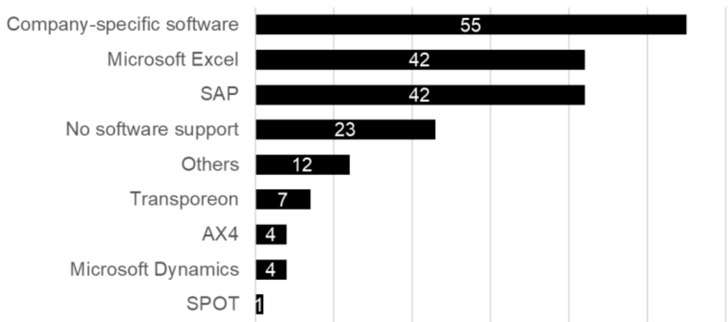


Figure 1: Which software/platform are used for planning of transports? (n=138; multiple response allowed; own elaboration)

Moreover, just 19 % of the surveyed managers apply software to reduce transport costs. 16 % out of the 19 % of the companies are considering real-time data for the planning. A chi square test shows, that enterprises with more than 550 employees more often use software or platforms for the optimization of transport costs than companies with less employees. The significance value of 0.01072 shows the strong relation between this results. (Brunner and Obmann, 2019).

Especially costs are the biggest leverage in transport. This is also recognizable in studies on logistics cost structures, raised by *Fraunhofer* and published by *DVZ* (2018). The figure below points out the potential for savings. With around 46 % of total costs of logistics, transport is seen as the main cost driver. This is a further reason to optimize processes or to outsource processes of transportation to more efficient logistics providers with a deep knowledge in the branch.

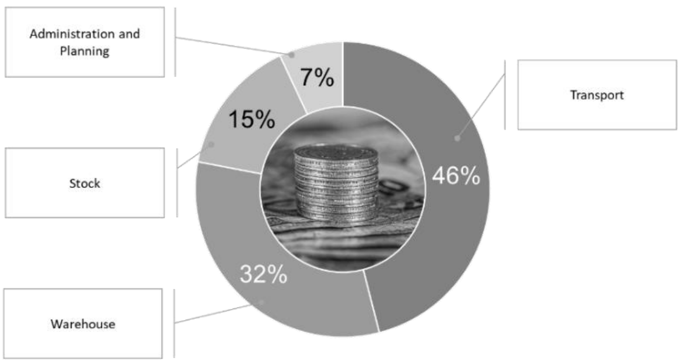


Figure 2: Allocation of Logistics Costs 2018 in Europe (Cost Center View) (DVZ, 2019); own elaboration

To sum up, the trend of outsourcing transport and other related activities is ongoing due to cost structure and a lack of competencies. Logistics is seen as a strategic success factor in global competition. Outsourcing seems to be an alternative for target-oriented logistics management (Nissen and Bothe, 2002).

The cost reduction is just one aspect of this success factor. Moreover, seasonal fluctuations or variability of overhead costs are seen as additional benefits (Schäfer-Kunz 1998). This trend also led to the fact, that logistics providers additionally offer value-added services (Gabriel, 2019). On the one hand they provide assembling of parts or ready-made products, on the other hand the service can also include planning and managing of the whole logistics processes of the customer. Therefore, the knowledge of the logistics provider is insatiable for the customer, who is additionally able to reduce costs due to the realization of economy of skills (Suckey and Abdecker, 2019).

3 Digital Business Models in Logistics

A successful business model describes a future-oriented value proposition. Moreover, activities are based on customer segmentation and defined value specification as well as adequate value chain structure. Also the realization of turnover and earnings is described, which is generated through the positioning in the value network. (Hausladen, 2011)
Logistics providers offers different services to create turnover and earnings. To understand this different services, a demarcation of the service portfolio is given based on literature to concretizes the focus of this research.

3.1 Demarcation of Logistics Providers

Within the macro logistical system there can be identified three essential logistical institutions. The logistics department of companies and logistics providers form the so-called micro logistical system. Beside this micro logistical system, the logistical infrastructure is the third part of this macro logistical system, providing roads, railway systems, air ways and pipeline systems often regulated by legal and political factors. To concretizes the focus of this research paper, the group of logistics providers have to be classified into five substantial types of services.
In literature this demarcation is described in many different ways. Basically there are carriers, freight forwarder, third and fourth party logistics providers (3/4PL) and lead logistics providers (LLP - combination of 3PL and 4PL). Carriers are responsible for the physical transport of goods from delivery point to receiving point based on the freight contract between consigner or consignee (based on the applied Incoterm 2020) and the carrier. Based on

a forwarding contract the freight forwarder originally has to organize the transport of goods. Therefore, the forwarding contract includes the freight forwarder, consigner, carrier and consignee. The selection of the carrier is based on the mode of transportation and the economic (freight charges and tariffs) as well as ecological factors. In contrast to freight forwarder,3PLs also assume other logistics services and processes like warehousing, commissioning and disposition of goods and other extended services by using their own assets. In practice this service is also known as contract logistics. Similar to 3PLs, 4PLs offer the coordination of material and information flows along the whole supply chain, whereby they do not have own assets. In practice this kind of services provider is rarely applied. The LLP combines special equipment with knowledge of complex supply chains and offers a broad service for industrial and trading logistics. This concept offers scale effects and wins in rationalism due to specialized logistics knowhow of the provider. (Brunner and Hanusch, 2014, p. 13f and Schulte, 2009, p. 186f)

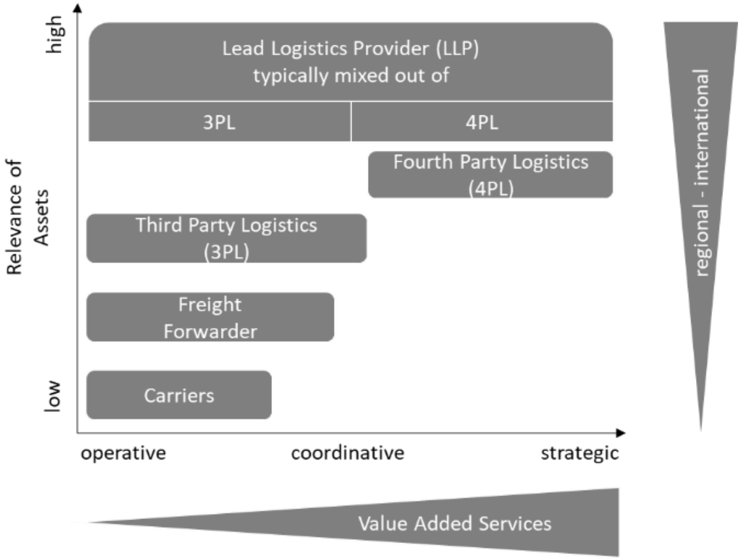


Figure 3: The four-dimensional Demarcation of Logistics Providers; own elaboration modified from Baumgarten and Thoms (2002) and Brunner and Hanusch (2014).

Apparent in the structure above, logistics providers can be identified by four dimensions. While the service portfolio of carriers and freight forwarders are more operational, LLP's competence is covering coordinative and strategic issues on top. The second dimension depends on the relevance of logistics assets like trucks, warehouses or handling equipment. While carriers are often locally operating companies, concentrating on certain areas and transport routes, LLPs are focusing on complex and international supply chains. Therefore, the geographical aspect of service has to be considered to allow a demarcation without overlaps. The added-value like additional services provided, is another demarcation factor of logistics providers.

In this context, the relevance of 3PLs is clearly visible in researches on European transport and logistics services by *Schwemmer* (2017). In the industrial area the overall cost for contract logistics in Europe is estimated with 231 billion EUR. In Germany further researches estimated the costs by around 77.6 billion EUR (Schwemmer, 2018). Especially this type of logistics providers is challenged by new disruptive business models and digital technologies (Hofmann and Osterwalder, 2017). But also the traditional freight forwarder business is changing due to disruption in many areas (Riedl, et al., 2018 and Gabriel, 2019).

3.2 Digitalization in the Logistics Providers Business

By thinking of business models in the context of digitalization, two substantial aspects have to be regarded:

"How will digitalization change business models and which impact will this change have on business processes?"

In this context, it is important to understand the implementation of digital technology for commercial utilization. It enables in a first step the digitization of analogue to digital data and furthermore the digitalization of whole processes within the own company. This is what we understand as digitalization in a narrow sense (Suckey and Asdecker, 2019).

Digitalization in a broader sense means the development of digital business models based on digitized data and business processes. The digital transformation describes the change of value chains based on the improvement of existing or implementation of new digital technologies, adaption of enterprise strategies based on digital business models as well as the acquisition of relevant competences and qualifications. (Kersten, et al., 2017).
The expansion of existing business models considering the digital transformation means the development of new customer services. To reach this objective, companies have to use creative innovation methods like *Service Engineering* (Hausladen, 2011). It is seen as a standardized concept for the development of new services by using process models, creativity methods and tools and allows an agile approach and environment to develop new services. The concept stands for the re-creation and development of service solutions within interdisciplinary strategy and creativity processes (requirement analysis, idea generation, value and benefit etc.) and the model-based and applied implementation of new service solutions (planning, integration, positioning and development of business and profit models) as part of the value-oriented business development. (Richter and Tschandl, 2017)
Before established companies can start with the development of new services, they have to analyze the potentials of new technologies and the market development in their business. As mentioned before, a successful business model describes a future-oriented value proposition and a unique positioning in the value network. Therefore, models like *Porter's five forces* should be applied for upstream analysis phases. However, this concept is explained frequently in literature, turned out as outstanding tool and is part

of different studies about digital business models in logistics. Therefore, the focus of this research paper concerns the impact of different types of companies on logistics providers. Especially focusing on freight forwarders, which are the due to their limited service portfolio and local activities the most threatened logistics providers due to digitalization.

3.3 Impact of Digitalization on Business Models

Especially technology-driven startups trigger the change within the logistics business. They are characterized by transparent services and reduced operational costs. First business models were created in the business-to-customer (B2C) branch triggered by the changed consumer's expectation. (Manke and Funder, 2017). Not only the need for flexible delivery services or even same-day-delivery-concepts (SDD) are part of the changed expectation. Moreover, the necessity in terms of sustainability and increased commodity flows in cities are part of this development. Therefore, data and technology-driven concepts emerged in the area of transport logistics to handle the last mile. In the area of parcel and small packages delivery startups created new solutions to outpace its established competitors. *Liefery* or *Tiramizoo* took their chance to re-create the business by implement one-stop-shops solutions. Other solutions exploit the potential of crowd-based concepts to increase flexibility in delivery. Therefore, private courier can be steered high efficiently by using platforms. *Deliv* or *Amazon's "Flex*" are just a few examples in the B2C business. (Dietrich and Fiege, 2017).

Also in the B2B business startups are the key for the changing environment. Low entry barriers and technology knowledge enables startups to enter the market with innovative business models that streamline the customer expectation and provide greater visibility into the supply chain. Moreover, the attractiveness of the B2B business cannot be contested by looking on the market structure of freight forwarders. *DHL* had a market share of 17 % in 2017. Overall less than 50 % of all sea and air freight forwarded goods are accounted by the top five companies. The rest is distributed on small and local freight forwarders. Therefore, it is not surprisingly that this business is also attractive to venture capitalists. More than $ 3.3 billion were invested into digital shipping and logistics startups from 2012 to 2017. (Riedl, et al., 2018, p. 3). Especially in the United States high financial flows are recognizable.

Startups try to penetrate rapidly the market in areas, where established logistics providers offer standardized mass business. *CB Insights* tried to unbundle the service portfolio of FedEx to visualize the danger for established companies. The competition on the market is rising clearly due to the fact, that startups could cover mostly all services of established logistics service providers especially in the areas of shipping, tracking and general management of transports. Startups manage to focus on the positive customer experience. Customer-oriented business models are the key for future logistics in B2B and B2C area. The change of customer behavior is also traced back to a change of mindset due to the predominant amount of millennials in managing positions of companies. The demographical change is part of researches of *KfW* in 2016. Therefore, decisions in B2B purchasing are mostly made by millennials. Furthermore, in 2016 1.6 million entrepreneurs were older than 55 years, consequently business is handed over to the next generation. (KfW, 2016).

4 Applications for New Business Models

Digitalization in a narrow sense describes the digitization of analogue data to digital data and furthermore the digitalization of whole processes within the own company. Supply chains are characterized by a high number of media breaks or human coordination processes. Many processes are still based on human communication (Phone, Mail, etc.) which harms the digitization and automation of process along the whole supply chain. Automation of processes requires a fully integration of suppliers, customers and other external partners by EDI (electronic data interface) or other standardized data interchange formats (Hausladen, 2011, p. 64f). The integration of partners is complicated by the amount of different IT systems and standards of all partners and especially of the frequent changes of the partners along the whole supply chain. In the context of platform business models *Amazon*, *Ebay* or *Alibaba* settled standards for processes and bypass interface complications which causes a big competitive advantage in their area (Wurst, 2020, p. 2).

Studies show that the automation of manual processes could reduce costs by up to 40%, while digitizing significant parts of the sales process could reduce related direct costs even more. Especially in the air and sea freight forwarding, there is a high number of manual processes. Companies still rely on email, personal handoffs as well as faxes to convey shipping documents. This is confirmed by the study of *FREIGHTOS*, which have found out that only 5 out of the top 20 forwarder in this branch send automated confirmation emails. This manual and time expensive processes could lead to human errors and subsequently to additional costs. By taking into account the high number of customers and transactions, there is a big potential for optimization. (Riedl, et al., 2018, p. 1).

The automation of processes as starting point enables tremendous cost reductions potentials in operative processes to customers and partners. Due to digitalization of processes, companies are able to extend their portfolio or improve existing services more customer-oriented. The combination of fast and mobile networks and high-performance hardware combined with new possibilities of data analysis and artificial intelligence leads to accelerating changes of business (Giersberg, 2018). By screening the literature again following trends can be recognized in the branch. Some of this concepts are mainly introduced of startups with high affinity of digital technologies, which also shows the importance of the new and often small players on the market. By offering new solutions, established companies can either make use of this solutions by integrating into the business model or be displaced from the market by forward or backward integration. The focus in this step is on research papers and reports. The literature screening also showed that the mentioned concepts below are often mentioned and seen as the future perspective of the branch.

4.1 Transparency and Control along the Supply Chain

Digitalization enables more transparency of supply chain processes. Nevertheless, in the area of transport operations traditionally transportation orders are reported back to the system manually. By using *Supply Chain Event Management Systems* (Hausladen, 2011) automatic identification and localization of objects in the supply chain by using active (GPS) or passive

(RFID) technology is implemented. Based on events in the supply chain, information on temperature or shocks of goods can be traced. By providing this information new pricing models for freight transport can be implemented to offer customers performance-oriented pricing. In this context, transport costs could be calculated based on the condition of goods during the transportation. Needed data can be collected by using blockchain technology to ensure quality aspects as part of pricing.

4.2 Market Places for Price Comparison and Tendering

For a successful positioning on the market, three essential factors have to be given: a valid pricing model, reliability of the service and a unique selling proposition (USP) by offering new functionalities. Due to the high percentage of transport on the overall logistics costs, new services in this area are very popular as long as the price for the utilization of new platform is below the price of current freight exchange platforms. (Manke and Funder, 2017).
An example for lackluster customer experience is shown by a study of *FREIGHTOS*. Shippers asking for a quote at a selected air or see freight forwarder can wait as long as 100 hours. This definitely shows the length of traditional offline quotations and bookings. Furthermore, in a traditional offline process, the checking of shipping documents is a time-consuming procedure. Due to missing tracking technology the desired control of supply chain in real time is not realizable. Customers still not have the possibility to react on delays in the shipment to ensure their cargo will arrive according to plan. (Riedl, et al., 2018)
Matching the demand with supply is one example for new digital business models. Different market places like *FREIGHTO*, *mycargorates*, *Colo21* or

Truckin offer platforms to meet the customer needs. Shippers can find easily free capacity for their cargo by getting detailed information of capacity providers such as carriers and freight forwarders. These platforms enable shippers to book capacities immediately online at a given rate. (Riedl, et al., 2018).

They represent independent platforms in an intermediary role between shipper and carrier. In the background of these platforms, algorithms and machine learning allow the automated allocation of capacities. For transactional processes with sensitive data, the blockchain technology is a possibility to provide data to all partners in the supply chain. In maritime logistics, *IBM* and *Maersk* are providing cloud-based platforms to provide real-time data and to allow data and document management across companies (Suckey and Asdecker, 2019). As mentioned before, its role is seen as intermediary, which means that usually the providers neither assume no liability nor responsibility for transport problems or damages. The advantages are primarily seen in the price transparency, real time availability of capacities and recessions of former transportations. This factors should strengthen thrust and relationship between shipper and carrier (Dietrich and Fiege, 2017).

4.3 Digital Carriers

So called digital freight forwarders (DFFs) offer a broad range of logistics services and is comparable to the portfolio of typical freight forwarder. A so called one-stop-shop which covers the whole transport process and provides data in real time. (Dietrich and Fiege, 2017) DFFs are aggregating in-

formation of shipped goods to provide a seamless user experience by replacing manual processes and paperwork. Instant price quotations and standardized document management are just one piece of their core value proposition. Easy access to real time data and tracking of the shipment enables the customers and partners to get more transparency and control of transported goods (Riedl, et al., 2018).
The objective of DFFs is the improvement of usability. Transparency and automatization of processes also leads to process improvements in operation and administration. Transports are often processed by partners like located carriers. (Dietrich and Fiege, 2017). The advantage of outsourcing transport to carriers is the reduction of operational complexity. They trust in smaller and locally based carriers with operational know-how and physical assets to avoid attendant costs and operational complexity. However, this also means forgoing direct control and less possibilities to standardize and streamline processes. From the business model's perspective, less standardization and streamlined processes lead to inflexible business models, whereby these companies have to concentrate on simple shipments and transactional customers like *Flexport* does. To provide a large geographical coverage of service, own assets and operational processes, however under the consumption that the provided services more limited in comparison to DFFs with external partners. (Riedl, et al., 2018).
Within the business of DFF, it has to be differentiated between two distinct models. On the one hand, digital forwarder operational capabilities are in-house, on the other hand they can also rely on partners for operations. Nevertheless, both models can be seen as threat to established freight forwarding business.

5 Chances and Risks for Established Companies

New platforms have not changed the business yet. But the revolution of the business is starting due to the broad portfolio of services and digital solutions on the market. Many of them are concentrating on niches, whereby none of them offers a complete portfolio of services. Therefore, established businesses have the chance to dive into the development now. Visible in the previous analysis of the market and the impact of new services, startups are accelerating the digital transformation. Especially freight forwarders are threatened by this development. They are seen in a sandwich position and have to fear the loss of customer and network sovereignty. Therefore, they have to decide which strategic direction they want to pursue in future. (Manke and Funder, 2017)

Challenging their current business models is indispensable. *"What stands out the current business model regarding the customer centricity?"* and *"How developed are operative, technological and digital skills in the company and do employees have the essential skills?"* are just some exemplary questions for challenging by *Dietrich and Fiege (2017)*, which clearly show the most relevant prerequisites for the digital transformation of logistics providers.

The strategical mindset of building masterplans for digitalization is outdated. Agile working methods like *Scrum* offer the possibility to create strategic guidelines. Within this guidelines flexibility and creativity are insatiable assets for future success. It enables to define how the customer can be focused, which role in ecosystem should the company play in future and which value is created by this new strategic orientation. This helps to reduce organizational barriers regarding the digital transformation. (Dietrich and Fiege, 2017). Typical elements of modern change management are part of this development to ensure a successful change within the whole organization by acceptance of the employees to ensure competitive readiness for future. (Kreutzer et al., 2016).

The implementation of digital technologies also requires the appropriate infrastructure. *Internet of Things*, automation, digitalized processes or data lakes can be implemented by offering a scalable IT infrastructure. Often logistics providers are facing challenges in the conquering old data stocks and inherited infrastructural burdens in sense of heterogeneous IT systems. The interlinking of different systems and applications to create and collect data for further customer-oriented analysis is the prerequisite for new business models. (Dietrich and Fiege, 2017)

To develop the underdeveloped awareness for digitalization within the company, employees have to be qualified to accelerate the digital transformation. Therefore, digital skills and working culture have to be developed. Technical and technological knowledge, data science and awareness for agile working culture are as important as the logistics provider specific branch knowledge. Experimental methods like *Co-Creation* with customers are as important as the open handling of errors to drive the improvement as part of a fail fast-culture

Startups often place enhanced attention on employer branding, to win the war for talents. The demographically change also have an impact on the choose of employer. Young talent's mindset has changed due to the generation of millennials. Flexible working conditions (time and place) have changed. Established companies have to be competitive in this war to ensure a successful recruitment. (Dietrich and Fiege, 2017).

6 Concluding Remarks

The reflection of the current dynamic on the market and the impact of digital technologies clearly shows the need for action. The trend of outsourcing logistics activities is ongoing due the cost pressure and missing competences and resources of industrial or trading companies.

For this reason, the potential market for logistics providers is increasing and market entry barriers are lowered due to big investments into startups with a high affinity of digital technology. The market entrance of these startups should be seen as a chance for established companies. They accelerate the digital transformation of logistics by implementing new digital technologies and create new digital business models for specialized solutions in niche markets.

Nevertheless, freight forwarders are the most threatened business area of these startups. The landscape of freight forwarder will definitely undergo significant changes. Companies which are not able to provide incremental value or transform into digital freight forwarders (DFF) will fade away from the market due to the dynamic change of services. They have to digitize their business to be well positioned on a global market. This will happen by building up an agile organization organically or by consolidation or partnerships. Merge and acquisition activities of freight forwarders or other logistics providers are not excluded. Digital knowledge, motivated employees and innovative ideas can be acquired with different approaches. An organic approach assumes, that companies challenge their current business models. They have to decide on which strategic focus should be considered and how the digital transformation should be pushed within the company.

Therefore, the expertise of the market development and digital technology are the prerequisites for further development.

This research finally shows a deep managerial impact. To achieve a successful market proposition in future, logistics providers will have to rethink their business. This paper is limited on the market dynamic to demonstrate the need for further researches in the application of technologies for logistics, in the area of innovation and change management and business creation to provide managers a toolbox and procedure model in future to manage this change

References

Arnold, D., Isermann, H., Kuhn, A., Furmans, K. and Tempelmeier, H. eds., 2008. Handbuch Logistik. 3rd ed., Berlin: Springer.

Baumgarten, H. and Thoms, J., 2002. Trends und Strategien in der Logistik: Supply Chains im Wandel. Berlin: Technische Universität Berlin.

Bearingpoint, 2016. Digitalisierungmonitor 2016. Available at: <https://www.bearingpoint.com/files/BEDE16_1110_RP_DE_Digitalisierungsmonitor_final.pdf?hash=8487e77bd9ae9e0b3bcdab2c267064db1b610ba5b6a8ac78> [Accessed 6 May 2020].

Bolumole, Y., 2001. The Supply Chain Role of Third-Party Logistics Providers. The International Journal of Logistics Management, 12(2), pp.87–102.

Brunner, H., Luptacik, P. and Schneider, H., 2020. Logistik als volkswirtschaftlicher Multiplikator für den Wirtschaftsstandort Österreich. Available at: <https://iwi.ac.at/iwi-studie-logistik-als-volkswirtschaftlicher-multiplikator-fuer-den-wirtschaftsstandort-oesterreich/> [Accessed 28 Apr. 2020].

Brunner, U. and Hanusch, S., 2014. Logistik und Supply Chain Management. Wien: Linde Verlag.

Brunner, U. and Obmann, G., 2019. Novize oder Champion? Wie reif und digitalisiert ist die österreichische Industrie in der Transportlogistik? Kapfenberg: Industrial Management.

Dietrich, A. and Fiege, F., 2017. Digitale Transformation des Speditionsgeschäfts umfasst mehr als Spedition 4.0. Wirtschaftsinformatik & Management, 9(3), pp.36–45.

DVZ, 2019. Aufteilung der Logistikkosten in Europa im Jahr 2018 nach Kostenstellen. Available at: <https://de.statista.com/statistik/daten/studie/72704/umfrage/verteilung-der-logistikkosten-in-europa/> [Accessed 19 May 2020].

Gabriel, P., 2018. PAiCE-Monitor. Available at: <https://www.digitale-technologien.de/DT/Redaktion/DE/Downloads/Publikation/PAiCE_Monitor.html> [Accessed 19 May 2020].

Giersberg, G., 2018. Die Digitalisierung rollt. FAZ, 8 Jan., p.15.

Hausladen, I., 2014. IT-gestützte Logistik: Systeme - Prozesse - Anwendungen. 2nd ed. Wiesbaden: Springer Gabler.

Hermes, 2019. Supply Chain Management - Das sind die Trends 2019. Available at: <https://www.hermes-supply-chain-blog.com/supply-chain-management-das-sind-die-trends-2019/> [Accessed 6 May 2020].

Hoffmann, R., 2017. Miebach-Outsourcingstudie 2017. Available at: <https://www.miebach.com/de/insights/veroeffentlichungen/?country=DE> [Accessed 28 Apr. 2020].

Hofmann, E. and Osterwalder, F., 2017. Third-Party Logistics Providers in the Digital Age: Towards a New Competitive Arena? Logistics, 1(2), pp.9–46.

Kersten, W., Schröder, M. and Indorf, M., 2017. Potenziale der Digitalisierung für das Supply Chain Risikomanagement: Eine empirische Analyse. In: M. Seiter, L. Grünert and S. Berlin, eds. Betriebswirtschaftliche Aspekte von Industrie 4.0. Wiesbaden: Springer Fachmedien.pp.47–74.

KfW, 2016. Demografischer Wandel im Mittelstand. Frankfurt: KfW.

Kille, C., 2018. Digital Supply Chain Management. In: L. Fend and J. Hofmann, eds. Digitalisierung in Industrie-, Handels- und Dienstleistungsunternehmen: Konzepte - Lösungen - Beispiele. Wiesbaden: Springer Fachmedien.pp.111–121.

Kreutzer, R.T., Neugebauer, T. and Pattloch, A., 2017. Digital Business Leadership: digitale Transformation - Geschäftsmodell-Innovation - agile Organisation - Change-Management. Wiesbaden: Springer Gabler.

Manke, K. and Funder, J., 2017. Uber-inspirierte Plattformkonzepte in der Logistik - Bedrohen neue Transportkonzepte etablierte Geschäftsmodelle. Available at: <http://www.iihd.de/index.php/publikationen/18-forschung/publikationen/58-red-paper-publikationsreihe> [Accessed 6 May 2020].

Manners-Bell, J. and Lyon, K., 2019. The logistics and supply chain innovation handbook: disruptive technologies and new business models. New York: Kogan Page Ltd.

Nissen, V. and Bothe, M., 2002. Fourth Party Logistics – ein Überblick. Logistik Management, 4, pp.16–26.

Osterwalder, A. and Pigneur, Y., 2011. Business Model Generation: ein Handbuch für Visionäre, Spielveränderer und Herausforderer. Translated by J.T.A. Wegberg. Frankfurt New York: Campus Verlag.

Richter, H.M. and Tschandl, M., 2017. Service Engineering – Neue Services erfolgreich gestalten und umsetzen. In: M. Bruhn and K. Hadwich, eds. Dienstleistungen 4.0: Konzepte – Methoden – Instrumente. Band 1. Forum Dienstleistungsmanagement. Wiesbaden: Springer Fachmedien Wiesbaden.pp.157–184.

Riedl, J., Chan, T., Schöndorfer, S., Schröder, F. and Sonderby, M., 2018. The Digital Imperative on Freight Forwarding. Available at: <https://image-src.bcg.com/Images/BCG-The-Digital-Imperative-in-Freight-Forwarding-Nov-2018_tcm108-207934.pdf> [Accessed 19 May 2020].

Schäfer-Kunz, J., 1998. Make-or-Buy-Entscheidungen in der Logistik. Wiesbaden: Deutscher Universitätsverlag.

Scheer, C. and Loos, P., 2002. Internetbasierte Geschäftsmodelle. In: Modelle im E-Business,. 4. Paderborner Frühjahrstagung des Fraunhofer-Anwendungszentrums für Logistikorientierte Betriebswirtschaft. Paderborn.pp.27–38.

Schulte, C., 2009. Logistik: Wege zur Optimierung der Supply Chain. 5th ed. München: Vahlen.

Schwemmer, M., 2017. TOP 100 der Logistik 2017/2018. Hamburg: DVV Media Group GmbH.

Schwemmer, M., 2018. TOP 100 der Logistik 2018/2019. Hamburg: DVV Media Group GmbH.

Stölzle, W. and Burghardt, J., 2016. Thesen zu Logistik 4.0. In: O. Gassmann and P. Sutter, eds. Digitale Transformation im Unternehmen gestalten. München: Hanser Verlag.

Sucky, E. and Asdecker, B., 2019. Digitale Transformation der Logistik – Wie verändern neue Geschäftsmodelle die Branche? In: W. Becker, B. Eierle, A. Fliaster, B. Ivens, A. Leischnig, A. Pflaum and E. Sucky, eds. Geschäftsmodelle in der digitalen Welt. Wiesbaden: Springer Fachmedien Wiesbaden.pp.191–212.

Wurst, C., 2020. Chancen von Logistik 4.0 nutzen. Controlling & Management Review, 64(2), pp.34–39