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Adapting to the Future:

Maritime and City Logistics in the

Context of Digitalization

and Sustainability

Prof. Dr-Ing. Carlos Jahn
Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Christian M. Ringle
(Editors)

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Preface

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

This year's edition of the HICL proceedings complements the last year's volume – Data science in maritime and city logistics: data-driven solutions for logistics and sustainability. 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 adapting to the future in logistics. It contains manuscripts by international authors providing comprehensive insights into topics such as Maritime Logistics, Business Analytics, Port Logistics or Sustainability and offers 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 2021

Prof. Dr-Ing. Carlos Jahn
Prof. Dr. Dr. h. c. Wolfgang Kersten
Prof. Dr. Christian M. Ringle

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Urban Fulfillment Centers – Perceptions and Expectations from Retailers

Marike Kellermayr-Scheucher [1], Maria Niedermeier [1], Patrick Brandtner[1] and Oliver Schauer[1] 1 – University of Applied Sciences Upper Austria

Purpose: *Delivering goods to consumers and stores in dense urban environments is a challenging endeavor. Rising expectations in terms of speed, flexibility and choice of delivery further increase the intricacy of urban deliveries. This paper provides insights into how European retailers think about urban fulfillment centers (UFCs) in the context of Omnichannel retailing.*

Methodology: *Based on a literature review, a questionnaire was developed for the empirical survey (semi-structured interviews) with twelve European retailers from different trade sectors. To analyze the interviews, MAXQDA and MS EXCEL were used. Interviews were also conducted with European logistics service providers as market experts and potential operators of UFCs.*

Findings: *The results of the study reflect the different perceptions of UFCs among retailers. The extent to which UFCs are expected to play a role in future retail varies across interview partners: while some stated a positive impact and a high relevance of this concept in the near future, others expect no significant impact of UFCs and are not planning to invest into this concept in the next few years.*

Originality*: The present results show an overview of the expectations and perceptions of European retailers regarding UFCs. To our knowledge, this is the first empirical survey to address this topic.*

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1 Introduction

Trade is change - a statement that has been true for several decades. In recent years, however, change has accelerated massively and affects the entire supply chain of retail companies, from global sourcing to changing customer needs and expectations, both in eCommerce and at the Point of sale (POS). It is not possible to make a general statement about what the changes will look like in the next few years. With regard to the supply chain, therefore, trends are becoming evident that point to a possible development.

The vdw ZukunftsInstitut (Rodenhäuser Ben and Rauch Christian, 2015) has defined central megatrends for the future. Because of neo-ecology (1), more and more customers want to purchase products from companies that operate in a sustainable manner. These in turn use this trend as a strategic lever to ensure innovation in the supply chain. Another trend is connectivity (2). Here, the focus is on digitalization in all areas of daily life, as well as the digitalization of supply chains. Due to globalization (3), not only the supply chain has become global to the focal company, but also the sales of the companies, as the demand for products is now also global. However, the goal is to be able to respond flexibly and quickly to changing demands despite a global supply chain. Regardless of where products are purchased, the trend towards individualization (4) is nevertheless present. The products of the future should reflect the individuality of consumers. The last trend for supply chains in 2025 is mobility (5). This trend is developing primarily because cities are growing, and the resulting traffic is increasing even more.

This raises the question: How can the growing cities be supplied with goods and services quickly, efficiently and in accordance with demand? (Rodenhäuser Ben and Rauch Christian, 2015) Many years retailers and logistics service providers are trying to reach this with Urban Distribution Centers (UDC) or Urban Consolidation Center (UCC). The main goal of those is to create transshipment centers. The UDCs or UCCs consolidate the flow of goods that come into cities. This one is collected, consolidated, and efficiently transported to the end node in the UDC/UCC. Logistics service providers usually bring the goods to the UDCs/UCCs, which are located a little outside the city center (usually a few kilometers). The last mile is then usually carried out with smaller and more sustainable means of transport, in contrast to the main run. The use of environmentally friendly vehicles is mostly a result of the restrictions imposed by the cities. Companies that do not use UDCs/UCCs have to pay tolls at the city entrance, for example. (Lagorio, Pinto and Golini, 2016a) The mentioned concepts are like a cooperation between shippers and retailers. With this cooperation they plan deliveries in a way that less trips were needed to deliver (Tario Joseph D., 2011).

The concepts of UDC/UCC have different advantages. One benefit is that those facilitate the relief of public space which increases the chance of finding parking spaces and reduces the number of large trucks in the city center. Another advantage is the decrease of traffic jam caused by trucks blocking streets and the enablement of using smaller vehicles for deliveries to the city or non-road transport modes (Carvalho, et al., 2019).

UDC and UCC have been widely considered in research. Much attention has been paid to why UDC have failed in the past or what factors have contributed to the success of a UDC project. Lagorio et al. analyzed a total of 83 UDC projects with regard to their success or their success factors in a study. However, a special focus was placed on those projects that have closed their operations and the reasons behind them. Although some of the projects analyzed show some characteristics of successful projects, some of the projects analyzed have not achieved efficiency and have been closed or abandoned. The main reasons for the failure of Urban Distribution Centers are the high costs, especially high operating costs. High costs are often due to the lack of involvement of freight forwarders who do not provide a sufficiently high flow of goods. There is also a lack of participants in failed projects (Lagorio, Pinto and Golini, 2016b).

Other common topics in research related to UDC are location factors and location planning (Agrebi, Abed and Omri, 2015; Sopha, et al., 2016; Musolino, et al., 2019). Some papers also focus on the stakeholders or environmental impacts of UDC (Stathopoulos, et al., 2011; Lin, Chen and Kawamura, 2016; Carvalho, et al., 2019).

Besides UDC/UCC, there is another concept that supports the retailers omnichannel with more functions. It is called an Urban Fulfillment Center (UFC). In the context of this study, a UFC is defined as a (highly automated) fulfillment center in an urban area or close to a city, which ensures the supply of end customers (e-commerce) as well as the delivery to stores. The intention is to be closer to the customers, faster and thus enable short delivery times (e.g., same day). Additionally there are other value added services like cross docking or packing (Hidayat, 2019). Instead of a dedicated UFC there would also be the possibility of creating a hyperconnected one, so that operation costs and CO2 emissions are going to be reduced (Kim, et al., 2021). Urban Fulfillment Centers make it possible to deliver to shops and end customers (e.g., when ordering online) within a few hours (and with environmentally friendly means of transport, such as cargo bikes). The company JLL, a provider of real estate services, also suggests using vacant retail properties for urban fulfillment centers. Then use of multi-level buildings would also be possible with today's technologies (Weber Frank, Gliem Werner, Schneiders Alexander, 2020). UFCs have so far been a minor topic in scientific publications., if then more about Fulfillment centers in general. Although the concept sounds promising, there have hardly been any retail implementations of UFC so far. It is also unclear which functions/services - in addition to the functions of UDC - a UFC should offer. This study therefore answers the following research questions:

- RQ1: Is there a demand on UFCs for European retailers?
- RQ2: Which services should a UFC offer?

The remainder of this paper is structured as follows: Section 2 gives an overview of our research design. Subsequently the three steps of our research approach are described. In section 3, the results of expert interviews are presented. Implications and Outlook are presented in section 4, followed by limitations and conclusion in section 5.

2 Methodology

This section provides an overview of the research methodology applied in the paper. The paper aims at analysing the perceptions and expectations of practitioners regarding Urban Fulfilment Centers. Hence, the aim is to collect, analyse and present the knowledge of domain experts. A suitable research method for this purpose are expert interviews (van Audenhove and Donders, 2019). Expert interviews are qualitative, semi-structured or open interviews with a person holding particular expert knowledge (i.e., the expert). They are especially useful when the goal of the research study is to gain insights into a specific context, which requires expert knowledge to be understood. Additionally, expert interviews are also well suited when implicit domain knowledge is required for the study, which would be impossible to collect or identify via standard quantitative approaches like surveys (Döringer, 2021).

The preparation of expert interviews comprises three main steps: i) identification and selection of experts, ii) definition of data collection procedure and iii) definition of data analysis procedure. These steps are subsequently presented in detail.

2.1 Selection and Identification of Experts

Basically, there are two possible ways of identifying and selecting participants for expert interviews. The first approach – random sampling – is particularly suitable when the goal is to produce generalizable results for entire populations. However, random sampling has its drawbacks when very specific, particular areas are under investigation. The second approach – information-oriented sampling – is especially useful when the number of experts is small but can be targeted and defined well. The strength of the second approach is the obtain implicit and detailed domain knowledge from a small sample size in specific and focused areas (Flyvbjerg, 2006).

In accordance with the aim of our study, we selected information-oriented sampling as the more suitable approach for expert identification and selection. This allows for the selection of actual experts in retail and at logistics service providers in the context of Urban Fulfilment Centers. At the same time, this approach allows for generating more detailed and deeper insights into perceptions and expectations of practitioners from smaller samples. In total, 17 experts (12 from the retail domain and five from logistics service providers) took part in the interviews. Regarding retail experts, the participants were from fashion (5), sportswear (2), consumer electronics (2), DIY (2) and the drugstore sector (1). Participants were mainly based in central Europe (8), southern Europe (2) and northern Europe (2). The following table provides an overview of the retail experts participating in the study:

Table 1: List of experts Retail

No	Region	Retail sector	Position / Role	Years in company
1	CE	Sportswear	Logistics Development & Execution	6 years
2	SE	DIY	Director of Logistics Operations	11 years
3	CE	Fashion	Head of Digital- und Omnichannel Management	3 years
4	CE	Drugstore	Logistics Manager	24 years
5	CE	Consumer Electronics	Head of Logistics Department	-
6	SE	Fashion	Head of Logistics Engineering & Robotics	-
7	CE	Sportswear	Head of HR and SCM	21 years
8	NE	DIY	Head of Logistics Development	4 years
9	CE	Consumer Electronics	Sales Director / Co-COO	3 years
10	CE	Fashion	Program Manager Logistics Strategy	-
11	NE	Fashion	Director of Logistics	5 years

No	Region	Retail sector	Position / Role	Years in company
12	CE	Fashion	Director Logistics Development	4 years

Regarding experts from logistics service provider, five experts agreed to participate in the interviews. Their backgrounds and positions as well as their working experience is shown the following table:

Table 2: List of Experts Logistics service providers

No	Position / Role	Years in company
1	Controlling	9 years
2	Manager	6 years
3	Project Manager Contract Logistics	10 years
4	Head of Automation	23 years
5	Director of Operations	13 years

2.2 Procedure of Data Collection

In order to ensure a systematic and structured data collection, we applied the four instruments of expert interviews as defined by Kurz et al.: i) introductionary questionnaire, ii) interview guideline, iii) recording of the interviews and iv) transcription of audio recordings (Kurz, et al., 2007).

At the beginning of each interview, a short introductionary questionnaire including questions about general background information of the participant and his organization as well as the role and position of the expert. This allowed for double-checking and ensuring the actual expert role of interview participants.

Second, an interview guideline was developed to guide the expert interviews and ensure a more discussion-oriented but complete answering process throughout the interview. The guideline consisted of three main questions blocks focusing on the current situation of UFC applications, the future plans in this context and third the requirements and designs options from practitioners' point of view.

The interview guideline-based approach on the one hand provided interviewers with a framework that guided through the interviews. On the other hand, this approach enabled a more natural processing of questions following the natural flow of the interview. In each interview, all questions were addressed, however, the sequence of the single questions varied based on the flow of the respective interview. This provided the interviewer with a navigation route through the questions and at the same time didn't disturb the natural flow of expert argumentation (Mayer, 2013).

In addition to the notes of the interviewer alongside the interview guideline, audio recordings were produced. Together with the notes, the transcriptions of the audio recordings allowed for a complete and detailed data collection (Witzel, 2000).

2.3 Procedure of Data Analysis

Based on the notes of the interviewer and the transcriptions of the audio recordings, data analysis was done applying MAXQDA and MS Excel. MAXQDA is a software tool for computer-assisted qualitative text and data analysis and was used for coding the interview results. More precisely, it was applied to assign codes in advance for the three main blocks of the interview guideline as well as for the respective sub questions (Kuckartz and Rädiker, 2019). The assigned codes were used to analyze the interview transcriptions and notes. Subsequently, MS EXCEL was applied to create tables and graphs to visualize the results, mainly focusing on frequencies and distribution of responses.

3 Results of Expert Interviews

Selected results of the survey are presented below. The results of the survey of logistics service providers have been added at the relevant points. Accordingly, the results of the two parts of the survey are not presented separately but complement each other in the respective sections.

3.1 Future Customer Expectations

Future customer expectations are often seen as a key trigger for what service retailers want to offer in the future. This also applies to UFCs, which can enable even faster and more flexible delivery to customers and stores. When asking the retailers about future expectations of end customers, free or low-cost delivery is still in first place: Eight out of twelve retailers see this expectation. Five of the retailers also think that customers expect (even) faster delivery. In contrast, three retailers assume that accurate delivery is more important than speed. This relates on the one hand to the fact that delivery promises are really kept, and on the other hand also to the possibility that customers can choose the delivery time themselves or reroute at short notice. In summary, this results in expectations in the categories "price", "speed", "delivery accuracy and flexibility".

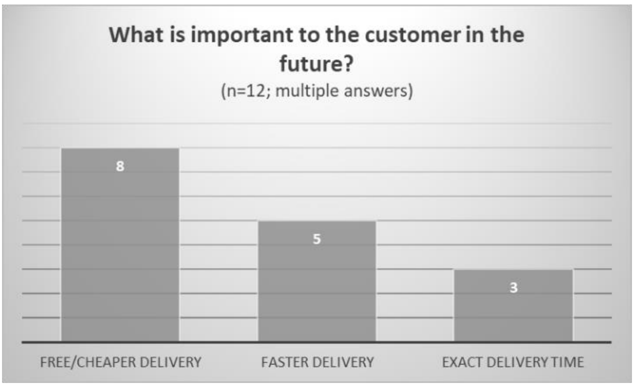

Figure 1: Future customer expectations from the retailer's perspective

Most logistics service providers answered the question about the future expectations of end customers with "choice options". These include the choice of delivery window or delivery location. It was also mentioned that deliveries would also be desired late into the night. Price will also be an important criterion in the future. Two of the respondents also believe that deliveries should be even faster in the future, whereas one logistics service provider believes that the delivery time currently offered is sufficient. This one believes that the customer will not need the goods as quickly as possible. It was also mentioned that reliability and real-time information will play a role for the customer.

To be able to meet the future expectations of customers, all retailers are working on improving delivery service and delivery time. Three of the retailers surveyed already offer same-day delivery in selected metropolitan areas. Three other retailers want to establish this service in the next few years, although same-day delivery seems to make sense exclusively for urban areas.

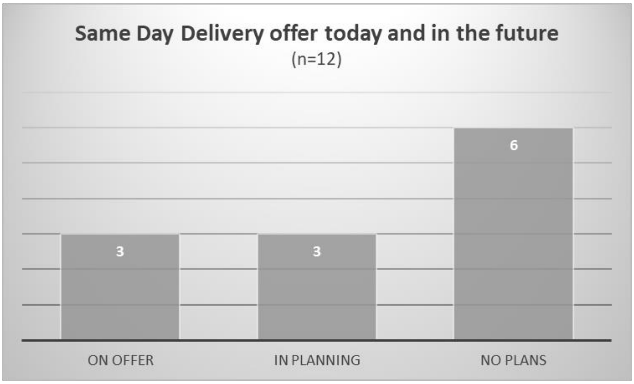

Figure 2: Same day delivery today and in future

In addition, retailers are working on guaranteed delivery on the next working day and on extending cut-off times towards the evening. This means that next-day delivery should be possible even if the customer orders until 6:00 pm. In addition, further services are intended to be offered to end customers, such as the pick-up of returns from home and the expansion of pick-up points, pick-up stations and parcel boxes. The idea is to offer customers a variety of options, and they can then choose the one that suits them best.

All the logistics service providers surveyed stated that they would not deliver faster in the future because other factors are more important in terms of delivery service. These services include flexibility, correct costs (if express, then also payment), sustainability, reliability (if delivery window is guaranteed, the delivery should also arrive in this window), transparency (when will the parcel arrive, delivery window) and control (reschedule, reroute).

3.2 Urban Fulfillment Center

As stated in the introduction, UFC could enable faster delivery to customers and stores in cities. The retailers surveyed see various possibilities for integrating an Urban Fulfillment Center into the supply chain, whereby for some several opportunities are conceivable or combinations would be possible. Only two retailers currently cannot imagine investing in a UFC at all. Half of the retailers interviewed would see the UFC as an additional regional warehouse that mainly serves the urban area, both B2B and B2C. Six retailers can imagine their own stores acting as Urban Fulfillment Centers to fulfill B2C orders. However, one of them thinks that the stores should only be used to cover peak demand (e.g., Black Friday). Four retailers explicitly stated that a UFC would be an additional step in the supply chain.

Another option mentioned was the integration of a UFC into a shopping center, which could then be used by all retailers there. This offers the possibility that customers could shop in several stores and have goods from different stores delivered to their homes in one parcel.

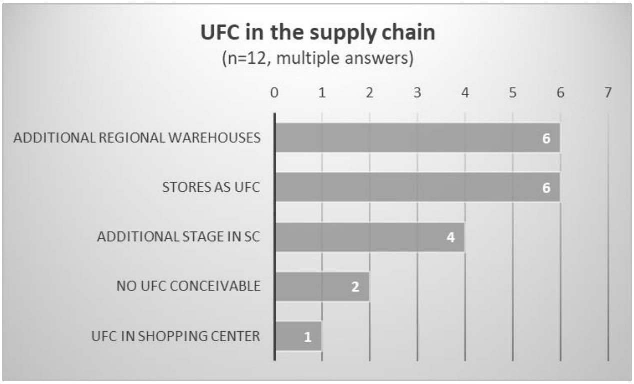

Figure 3: Integration of a UFC into the supply chain

When asked to what extent the supply chain would change because of a UFC, the views are very different. While some retailers would hardly see any changes, others assume that the supply chain would be (significantly) more complex. Two retailers explicitly noted that a UFC would be integrated into the supply chain like another store and would be supplied in this way. Thus, there are hardly any changes in the supply chain. However, if the UFC is seen as an additional warehouse level, it tends to make the supply chain more inefficient. The resulting higher costs would then have to be compensated by higher sales that can be generated due to better service. The issue of inventory levels is also viewed very differently: while some retailers assume that UFCs would increase inventory levels in the supply chain as a whole, other retailers assume exactly the opposite, as less inventory would then be needed in the stores.

Requirements and design options of a UFC

In addition to the integration of a UFC into the supply chain, design options and functions were also discussed with the interviewees. For half of the retailers, fast delivery would be a service that must be enabled by a UFC, with three of them explicitly naming "same day delivery". Two other companies would even require delivery within a few hours (2-4 hours). Six retailers also stated that they expect a pick-up station (24/7) for customers in the UFC.

Three of the twelve companies surveyed said that the UFC should also serve the stores for "Click&Collect," so that end customers would also have the opportunity to pick up the ordered goods at a "favorite store". A quarter of the retailers noted that delivery to any location should always be possible. In general, delivery should not only be fast, but especially reliable (i.e., at the agreed time). In case of urgency, faster delivery, e.g., within one hour, should also be an option.

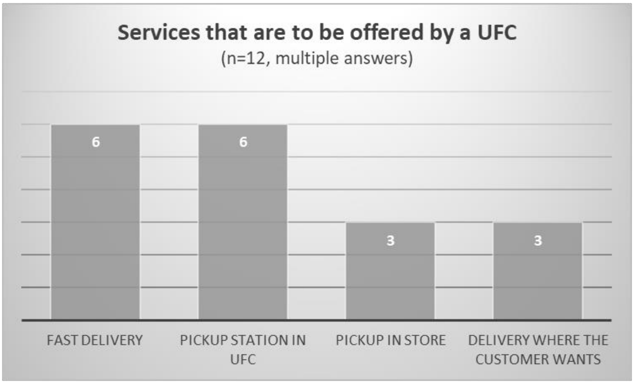

Figure 4: Services that a UFC should provide

In addition to the collection or delivery of goods to the end customer or to the retailer's stores, UFCs should offer additional services. These include, for example, the refinement of products or delivery in a desired packaging (e.g., clothing hanging in a sleeve or gift-wrapped). Overall, it is still noted at this point that automation should enable greater flexibility and an increase in efficiency. The five logistics service providers in the survey named the following services that a UFC should offer:

- Standard: Next day delivery
- Pick up 24/7 and pickup in stores (next or same day)
- Delivery when the customer wants and the option to change delivery times by the customer
- Warehousing and a customer service center
- Wider range of products

- Showroom for specific customers
- Local delivery by bicycle or motorcycle with a local carrier
- Assembly service no matter where, e.g. kitchens
- Flexibility and standardization
- Offer all services nationwide
- Products and services must be available everywhere

In terms of willingness to pay for services, seven retailers indicated that customers are willing to pay for these. Three of the respondents said that the end customers would be willing to pay more if the delivery would be faster. One even mentioned that it should only be a few hours until delivery for the end customers to express a willingness to pay. The urgency would make customers willing to spend a little more money to get their order on time. This was the opinion of two companies. Two retailers see other services that lead to a willingness to pay. These include, for example, attaching importance to sustainability aspects or wrapping the order in gift paper. In addition, customers are already prepared to pay more if large appliances are delivered to their homes and carried directly into the apartment or if help is provided with assembly. Three of the logistics service providers surveyed think that end customers are not willing to pay for additional services.

Possible Usage of a UFC

The next question dealt with whether retailers could imagine sharing the UFC with someone else. In principle, all retailers can imagine using a UFC with other retailers and thus achieving economies of scale. Only one company noted that joint use would only be conceivable if the factor of economic efficiency is given.

Five companies answered "yes" to the question of whether they could imagine sharing a UFC with their direct competitors. Only three retailers could not imagine sharing it with competing companies in any way. Four retailers said that joint use is conceivable in principle, but depends on various preconditions. Accordingly, it is particularly important in the case of joint use with competitors that data theft is ruled out and that no conclusions can be drawn about corporate strategies. A strict separation of the areas used would therefore be advisable. It was also mentioned that the product portfolio might not match. This would then make automation as well as the processes in the UFC more difficult and ultimately not worthwhile.

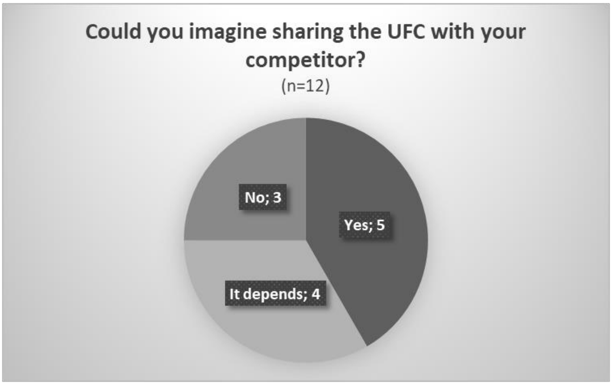

Figure 5: Shared Space with direct competitor

The interviewees who favored sharing mainly attributed this to synergy effects. The companies that cannot image sharing a UFC with a competitor fear, as mentioned above, that data theft would be possible or that strategies of their own company could be derived. Another reason was that the company would like to improve itself, and that would not be possible with a competitor in a UFC. This means that there would have to be appropriate specifications that would be anchored in the contract. Something like access rights should also be clarified. It is also important to ensure the best possible service for retailers. Should a seasonal peak occur, the question is whose order will be processed first. This should also be considered and written into the contract. While one said that they did not have any specific competition clauses in their company, they would still prefer not to be in a UFC with the competition.

Overall, consideration should also be given to which IT systems are used in the UFC. This could be a challenge. However, the best solution would be a jointly used IT system. Care should be taken to ensure that the companies still have the greatest transparency on their data.

All the logistics service providers interviewed can imagine a shared space concept. One service provider mentioned that shared use would have many advantages and bring synergies. In addition, he saw one of the biggest advantages in the fact that retailers sharing a UFC could also share a truck transport to the city. Another one said he had already seen several companies sharing a building, although they were competitors. Service providers clearly see advantages in costs, as these would be split in a sharing model. Another interviewee stated that he could well imagine this, but already mentioned a first prerequisite here and that was physical separation. Data or customer theft was denied, as he did not believe in this. The following other prerequisites were mentioned:

- Uniform IT platform vs. no linked IT system: there were differing views on this and both variants were mentioned
- Reduction of fear of contact
- Clear rules, especially who is served first in peak times and who is the owner.

In addition to the topic of shared space, the question of whether it is conceivable for retailers to open their own stores in the UFC was also discussed: seven of the 12 companies answered this question in the positive. This is due to the fact that some retailers already see or operate their own existing stores as UFC. Four retailers would not see this as an option. One reason for this is, for example, that the UFC would be built in a peripheral location or near an industrial area (real estate prices are more favorable) and would therefore not be attractive for customers.

The question whether a further use of the building, in which an Urban Fulfillment Center is located, is conceivable, was answered by all interviewees with "yes". The prerequisite is that the building also allows such a use, that flexibility is maintained, and the operation of the UFC is not restricted. Other possible uses that have been mentioned are:

Table 3: Possible uses for a UFC building

Usage option	Number of mentions
Office	3
Shopping center	3
Parking space	2
Restaurants	1
Workshops, e.g., for further services for end customers	1
Car rental	1
Short term rental of storage space	1

The logistics service providers were also asked about further possible uses. Four of the respondents agree that it would make sense to use the building 100%, even if this means that others work in the building as well. Two of the interviewees already practice this today. Even if it is partly a supplier-service provider relationship, they can well imagine it. Three noted that this will come sooner or later, as more and more green space is disappearing and buildings near the city are quite expensive. Only one service provider said he could not imagine co-funding at all. The following were additionally mentioned:

- Quality inspection
- Merchandising area
- Warehouse space rental
- Office rental

4 Implications and Outlook

As research groups observe how the retail sector is evolving, retailers examine the need for fulfilment and distribution solutions in metropolitan regions. Being able to serve the consumers in larger urban areas with fast delivery service is a key to improve customer experience, foster brand differentiation and generate revenue for e-commerce and omnichannel retailers. The sooner a paradigm shift occurs in urban logistics, the better. Especially as the pressure on the consumer-driven supply chain continues to increase. What was yesterday's same-day challenge could be tomorrow's same-hour delivery. And that's against a backdrop of rising environmental awareness with significant implications for inner-city motor vehicle traffic.

Widely discussed logistics concepts as UDC or UCC do offer some answers to the service levels demanding customers wish, but will not fulfil the challenges arising by omnichannel concepts. New concepts as the UFC will be able to cover these tasks.

Nevertheless, the concept and term of UFC is rarely discussed in research, the concept is not widely spread in the retail and logistics landscape by now. This is also because the concepts and services of UDC, UCC and UFC are often difficult to distinguish as their concepts and services often merge into one another. However, it is expected that the progressive penetration of omnichannel concepts will create a growing need for solutions UFCs are able to provide and will therefore gather increased awareness within the retail and logistics sector.

5 Limitations and Conclusion

The limitations of the study lie in the size of the sample and the focus on the Central European region. The sample also focuses on the fashion sector. All in all, this made it difficult to identify differences both in terms of region (Northern Europe, Central Europe and Southern Europe) and in terms of the retail sector. The sample for the survey of experts from the logistics sector was also very small, but from the research design point of view it was seen as a supplement to the interviews from the retail sector right from the start of the study.

Retail companies are the key players when it comes to urban fulfillment centers (UFC). They are in direct contact with their customers and are confronted with their expectations and needs. Only those who meet customers' expectations in the long term will be successful on the market. In urban areas in particular, increasing restrictions are to be expected with regard to the supply of stores. Added to this are topics such as sustainability, environmental protection and the protection of local residents from emissions and noise. In this area of conflicting interests - rising customer expectations, official restrictions and environmental protection - the study discusses the extent to which retailers see urban fulfillment centers as viable solutions for the future. Discussions were also held with logistics service providers, as they know the market very well and could provide valuable input for the study as potential operators of UFC's.

The results of the study on the topic of "Urban Fulfillment Centers" show the different opinions of the retailers. This already starts with the importance of even faster deliveries to the end customer: while same day delivery will be of high importance for some of the retailers, others assume that even faster delivery than nowadays will not be necessary in the next five years. However, there is agreement on service quality and transparency: better and more comprehensive service, additional delivery and pickup options are key success factors in the battle for the customer.

The extent to which Urban Fulfillment centers play a role in this cannot be clearly deduced from the study: while some of the retailers believe in this concept, others tend to assume that they will definitely not invest in a UFC in the next few years. Some retailers are also thinking about implementing an Urban Fulfillment Center in their own stores. These retailers assume that the demand for even faster deliveries in urban areas will not be so high that an investment in an (automated) UFC would be profitable in the next few years. A UFC would have to offer clear added value to the end customer, which would also be reflected in increased sales. The extent to which this added value is indeed given is partly questioned by retailers, since even now a great number of orders from the online channel reach the customer on the next working day.

The minimum services that a UFC must offer to end customers are fast delivery (same day, or even better few hours), pick-up options on site or at a preferred store, and delivery to any desired location of the customer.

The integration of UFC into the supply chain of retailers is discussed controversially by the respondents. While some retailers would see little change in the supply chain (supply like a store), others assume that a UFC would represent another warehouse level. These also assume that the integration of a UFC would lead to greater changes in the supply chain.

However, retailers agree that if a UFC is established, it should also be used for other purposes to reduce costs and achieve economies of scale. There are differences, however, as to whether cooperate with direct competitors is also conceivable. Other uses, such as office space, are also imaginable and desirable, provided that clear access rules or separate areas are defined.

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New Opportunities for Smart Urban Logistics - Results of a Field Study

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Purpose: *Sustainability and customer service of urban last mile logistics are lacking behind the expectations of today's society. This paper provides a holistic framework and empirical evidence of a field study ("Kiezbote") on evaluating smart urban logistics concepts with the purpose to increase customer service and improve ecological and economic sustainability of smart urban logistics concepts.*

Methodology: *The smart urban logistics concept "Kiezbote" was tested in a 12-months field study in Berlin-Charlottenburg. We consolidated parcels in a micro-hub and delivered by cargo bike within 2h-time windows. Based on multiple quantitative and qualitative criteria, we developed a holistic framework to study feasibility, profitability, customer-centricity and effects on the environment.*

Findings: *The findings indicate that our smart urban logistics concept outperforms the service-level of conventional parcel delivery by far. C02 emissions could be significantly reduced. The additional costs generated need to be covered by receiver, parcel logistics service provider and online-shops in order to enable economic implementation.*

Originality: *This work closes the gap between many studies available in the literature dealing with smart urban logistics concepts and their missing practical implementation. This is one of the first completed field studies that provides an empirically grounded framework regarding environmental-friendly, economic viable AND customer-centric last mile delivery.*

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1 Introduction

The problems of urban logistics have not been finally solved yet, but are becoming more crucial due to various trends. On the one hand, e-commerce continues to grow, so that the number of parcels increases significantly. The ongoing COVID19 pandemic intensified this trend (BIEK, 2021), but even without this global event, parcel deliveries would have increased (BIEK, 2019). Another trend that has a strong impact on urban logistics is the intended reduction of traffic in city centers to both offer more quality of life in inner cities and to contribute to the reduction of greenhouse gases, which is demanded in all areas of industries and society. Furthermore, parcel recipients are increasingly dissatisfied with the service provided by parcel service providers. Various studies have shown that almost 50 per cent of all deliveries do not reach the recipient, but are left with neighbors, parcel shops, parcel stations or other pick-up businesses. (Seeck and Göhr, 2018; GS1 Germany GmbH, 2019)

There are several reasons for the poor service by parcel service providers: On the one hand, the highly competitive pressure in the industry causes a need for efficiency, on the other hand, parcel service providers do not see the recipients as their customers, as they are mostly paid by the shippers. The shippers are becoming increasingly aware that their customers - the parcel recipients - project the poor service and thus their dissatisfaction with the delivery onto the shipper. Therefore, the pressure to provide a much better service, especially from the large shippers (e-commerce player), will increase on the parcel service providers.

In addition to the dissatisfaction of the recipients, the increasing parcel volumes exacerbate the problem of the highly stressed infrastructure of urban centers. Neither the increasing number of parcel vehicles nor the environmental pollution caused by the diesel-powered vehicles play the decisive role here. This is because parcel vehicles do not drive very much, but stand still for the majority of their operating time, namely about 90 per cent, as various studies on delivery tours in urban areas show (Schäfer, et al., 2017; Seeck and Göhr, 2018). During this time, the parcel vehicles are parking on the lanes in the second row, in violation of traffic regulations. Thus, parcel vehicles are a source of danger and, above all, a source of congestion in inner-city traffic. In order to cope with this problem and to make city centers more attractive for the people living there and the businesses located there, many municipalities - especially in Germany - are planning several restrictions on traffic. This will mainly affect diesel-powered vehicles, but even e-cars will be impaired in the future due to entry and passage restrictions.

Therefore, smart solutions are required for urban logistics that both guarantee deliveries at times and locations when and how the recipients are demanding it and contribute to relieving the urban infrastructure. Technical solutions such as the use of drones or robots have not yet been able to establish themselves, because although the technology is available, both safety aspects and customer acceptance have not been sufficiently clarified. This type of delivery will probably be limited to special cases such as the transport of urgent medical products. Solutions such as the delivery to parcel stations and collection by the recipient relieve the infrastructure, but often do not meet the wishes of the recipient; most of the online-shoppers expect the service of home delivery, as they could otherwise also visit a shop (Seeck and Göhr, 2018; IFH Köln GmbH and Hermes Germany GmbH, 2019).

An interesting alternative for the delivery of parcels in urban areas is the concept of a micro-hub with subsequent delivery by cargo bike. This concept relieves the urban infrastructure, as cargo bikes strain it less than parcel vehicles and, above all, do not cause any traffic jams while they are standing. At the same time, the concept makes it possible to deliver to recipients in desired time windows and thus, guarantee attended deliveries. Additional advantages of the concept are the physical proximity of the micro-hub to the recipients, which allows for easy pick-up, and the bundling of all parcel deliveries from different parcel service providers. Furthermore, by locating the service in the middle of the neighborhood – that is where the name "Kiezbote" comes from - creates a close emotional relationship to the recipients that leads to high identification potential of the recipients with *their* Kiezbote.

The research question arises of how such a concept can be comprehensively evaluated in order to prove its economic implementation, to determine its effects on emissions reduction and to investigate effects on customer satisfaction. A 12-month field trial was conducted for this purpose. In a selected area ("Kiez") in Berlin-Charlottenburg with approx. 15,000 inhabitants, the service described - desired time window delivery of bundled parcels by cargo bike - was offered free of charge.

After a brief outline of the basics of Smart Urban Logistics (SUL) and the prior work in chapter 2, the evaluation criteria for the concept are developed in chapter 3. Then, the data collection methods during the field trial are described and the results are presented and discussed in chapter 4 followed by the conclusion in chapter 5.

2 Prior Work

Smart Urban Logistics (SUL) solutions can be grouped in two categories:

1. *cooperative logistics* (e. g., transshipment and consolidation facilities, home deliveries systems, intelligent transportation systems for freight monitoring and planning/routing, cargo bikes for Business-to-Business (B2B) and Business-to-Consumer (B2C), city lockers) and
2. *administrative & regulatory schemes and incentives* (e. g., access restrictions, (un)loading zones, off-peak deliveries and enforcement and intelligent transportation system adoption for control and traffic management) (NOVELOG, 2016; Karakikes and Nathanail, 2017; Korczak and Kijewska, 2019).

Several pilot studies have been conducted and evaluated containing different SUL solutions in the past few years, an extract of them is presented in the following. Patier and Browne (2010) developed a methodology for the evaluation of urban logistics innovations and applied it on two pilot studies in Paris (mail and small packages) and Bristol (Urban Consolidation Center (UCC) for retailers). The evaluation framework contains a broad range of categories, e. g., logistics data, economic, environmental and social indicators, regulation and also customer satisfaction. However, looking at the application of the framework customer satisfaction as an important aspect of urban logistics was not included anymore. In the EU-project CITYLOG (2010-2012) the SUL solution of provider-opened parcel lockers has been tested in Berlin, Lyon and Turin and evaluated especially regarding traffic impact and CO2 emissions (Rybarczyk, 2019). The system has been further developed and is currently (2020-2022) being tested and evaluated in the German project STADTQUARTIER 4.1 with respect to environmental criteria (Leibniz-Institut für Raumbezogene Sozialforschung, 2020). The EU-project NOVELOG (2015-2018) tested many SUL pilot projects that have been conducted in

Gothenburg (UCC), Athens (intermodal transport), Graz (cargo bike), Mechelen (lockers, UCC, cargo bike), Turin (multi-users lane, (un)loading lots), Reggio Emilia (UCC in parking house, e-vans, cargo bikes), Venice (connect islands to core urban areas), Barcelona (cargo bike), and Pisa (parking slot software) (NOVELOG, 2017). Even if they developed a holistic evaluation framework containing criteria like air quality, greenhouse gas emissions, noise pollution, level of service (i. a. customer satisfaction), safety and security (e. g., accidents), vehicle (e. g., load factor) the pilots were only assessed using a few of the 25 criteria of the framework. Comprehensive data collection seems to be an important challenge in evaluating SUL pilots. In the EU-project CITYLAB (2015-2018) pilot studies have been conducted in London (UCC, electric vehicle), Amsterdam (floating depot, micro hub, cargo bike), Brussels (utilizing spare van capacity), Southampton (joint procurement and consolidation), Oslo (joint logistics for shopping centers), Rome (integration direct and reverse logistics), and Paris (logistics hotels) (CITYLAB, 2018). Environmental and economic effects have been assessed individually for each pilot and not following a standardized approach (e. g., total distance travelled, CO2 emissions, shipments per day), customer satisfaction was not considered. Furthermore, Leonardi, Browne and Allen (2012) conducted a before-after assessment of a logistics trial with micro consolidation center and cargo bikes in London and evaluated the total distance travelled (-14 per cent) and CO2 emissions (- 55 per cent), financially the case was proofed successfully by the company but the financial data is not accessible. Verlinde, et al. (2014) investigated in a Brussels trial as part of the EU-project STRAIGHTSOL, if mobile depots make urban deliveries faster, more sustainable and more economically viable with the result that the savings of diesel-kilometer doubled the costs for the operator. Navarro, et al. (2016) studied economic, operational, energy efficiency, environmental and social perspectives of urban freight transport via cargo bike for smart cities in Barcelona, Bologna, Piraeus, Rijeka and Valencia and concluded that the economic viability is hard to reach. They found out that the total number of shipments is important to become profitable – what we can also see in our pilot study. Table 1 summarizes the results found in prior works.

While both the spectrum of solutions that have been piloted and the developed evaluation methods are versatile, the application of the evaluation methods mostly only focus on single aspects, especially on environmental impact, partly on economic performance and rarely on customer satisfaction. Thus, our work is a first attempt to develop *and* apply a comprehensive approach how SUL pilots can be evaluated. The underlying study is one of the first completed field studies that provides empirical evidence regarding environmental-friendly, economic viable *and* customer-centric SUL solutions.

Table 1: Summary of Prior Work

Project	SUL pilots	Evaluation criteria	Criticism or shortcomings
Patier and Browne (2010)	UCC (Bristol), Mail and small packages (Paris)	Environmental economic, social; regulation; satisfaction; operational	Customer satisfaction not considered in application
Rybarczyk (2019)	Parcel lockers (Berlin, Lyon, Turin)	Environmental	Main focus only on environmental impact or technical aspects
NOVELOG (2017)	UCC, intermodal transport, cargo bike, locker, etc. in 9 EU cities	Environmental and economic; customer satisfaction; safety and security	Pilots were only assessed using a few of the 25 developed criteria

Project	SUL pilots	Evaluation criteria	Criticism or shortcomings
CITYLAB (2018)	UCC, cargo bike, floating depot, micro hub, etc. in 7 EU cities	Environmental and economic	Different evaluation approaches applied; customer satisfaction not considered
Leonardi, Browne and Allen (2012)	micro consolidation center, cargo bikes (London)	Environmental and economic	Financial data is not accessible, customer satisfaction not considered
Verlinde, et al. (2014)	Mobile depots (Brussels)	Environmental and economic	Customer satisfaction not considered
Navarro, et al. (2016)	Cargo bikes in 5 EU cities	Environmental economic, social; operational	Customer satisfaction not considered

3 Evaluation Framework

The purpose of the framework is to provide a foundation for comprehensive evaluation of SUL solutions regarding their impact on customer satisfaction, profitability and environmental impact. After developing criteria, the framework is summarized in 3.2.

3.1 Development of Criteria

3.1.1 Customer Satisfaction

Customer Satisfaction can be understood “as post consumption evaluation of a product/service in terms of positive/neutral/negative attitudes toward the product/service” (Day, 1977). The customer satisfaction approach is theoretical grounded by the *confirmation/disconfirmation paradigm* that defines satisfaction as a reaction on the subjectively perceived discrepancy between expected and experienced performance (Töpfer, 2020). According to Haller (1995) satisfaction is setting in when expectations are met.

Satisfaction can be measured using objective criteria like revenue or market share, but the validity of this approach can be questioned because a purchase does not inevitably imply satisfaction, in addition to that, the indicators occur at a later date (Töpfer, 2020). On the other hand, subjective approaches (e. g., customer surveys) are fitting well for measuring customer satisfaction because only by asking the customer it can be found out, if the product matches the customer needs (Lingenfelder and Schneider, 1991). Subjective approaches can be divided into attribute-oriented and event-oriented approaches. Attribute-oriented approaches consist of indirect measurements that imply customer satisfaction by measuring suitable indicators and direct measurements where customers are asked explicit for their perceived satisfaction (Töpfer, 2020). For SUL solutions the indirect criteria are developed based on the following logistics service performance targets:

- “Delivery reliability” indicates customer satisfaction by stating the ratio of deliveries on time compared to the overall numbers of deliveries.
- “Delivery flexibility” by explaining the ability to change an already arranged delivery order.
- “Information transparency” gives the receiver information about the delivery, e. g., by Track & Trace functions.
- “Shipment quality” states the share of damages of all shipments that also is relevant because the additional handling step in a micro hub is an additional damage risk cause.

The first three criteria are, especially in an urban environment with an increasing share of B2C deliveries, highly relevant for customer satisfaction due to the increasing customer requirements regarding individualized and flexible delivery.

Other logistics performance targets like “lead time” and “delivery capability” are not considered because last mile carriers do not have a significant influence on product availability or speed in the upstream supply chain. As one direct criterion, “satisfaction quantification” is used with the aim to investigate individual perceptions of customers of the SUL solution by conducting quantitative online-surveys asking for the importance and performance of single aspects of the offered service (SERVIMPERF).

In contrast to the attribute-oriented criteria, event-oriented criteria do not survey single attributes, but they deal with experiences of a specific event. One event-oriented criterion is “satisfaction exploration”. The customer is asked to talk about his or her pleasant and unpleasant experiences with the product or service along different touch points (Stauss and Hentschel, 1990). Another event-oriented criterion is „customer complaints“ that deals only with the critical negative moments of truth and is used for problem identification (Stauss, 2000). Quantifying and classifying those points is the starting point to derive action fields (Töpfer, 2020).

3.1.2 Profitability

Profitability can be measured based on “revenues” and “costs”. Only if SUL solutions are profitable, a sustainable implementation is realistic. Therefore, either being profitable or pointing out how to become profitable is crucial for all SUL pilots. For SUL solutions the typical revenue streams can be either the “sender” that benefits through a better delivery service that builds closer customer relationships and increases retention rates, the “receiver” who benefits by saving time while receiving parcels conveniently or a “logistics service provider” that outsources parts of its last mile operations. For each of the players, we chose the “willingness to pay” as the criterion to calculate the revenue potentials as we cannot test real prices on the market. Furthermore, the criterion “amount of freight units” is required to calculate potential revenues of each revenue stream.

On the other hand, in order to describe the costs, they can be divided into “fix costs” (e. g., micro hub rent) and “variable costs” (e. g., delivery staff). The costs for SUL solutions are evaluated on this general level and not further specified because the single cost elements depend on the individual characteristics of each SUL concept, e. g., on the chosen operating model (degree of automation or outsourcing) so that the costs always need to be interpreted with respect to the associated processes and services. In addition, there are some relevant process KPIs that influence the variable costs (especially the delivery costs per parcel) that need to be considered in an overall assessment on profitability because those KPIs provide levers for improvement of the productivity. The KPIs are the following:

- “Consolidation factor” states the amount of freight units that can be delivered to one customer at a time.
- “Service time” is the time the driver is off the vehicle to handover the parcel.
- “Stop density” describes the average distance between two stops.
- “Driving speed” is the average speed a vehicle is driving between the stops.
- “Driving-service ratio” describes the shares of overall driving time, and the overall service time and indicates where to focus to increase productivity and thus, reduce costs per freight unit.

The (re)loading time is not considered as a criterion because it has no relevant impact on productivity (Breitbarth, et al., 2021).

3.1.3 Environmental Impact

The environmental impact can be evaluated based on the produced “CO2 emissions” that can be calculated according to the standard EN 16258 “Methodology for calculation and declaration of energy consumption and greenhouse gas emissions of transport services”. Furthermore, parking of transportation vehicles on the driving lane produces indirect emissions by generating mini-congestions. Thus, the second criterion regarding environmental impact is “parking on driving lane” that describes the share of stops that are made on the driving lane in the second row. For more differentiated analysis of environmental impact, see (Patier and Browne, 2010; NOVELOG, 2017; CITYLAB, 2018).

3.2 Summary of Criteria

Based on the aforementioned criteria *Table 2: Evaluation Framework for Smart Urban Logistics Solutions* presents a holistic evaluation framework for SUL solution pilots. It is divided into the three evaluation areas customer satisfaction, profitability and environmental impact which are further divided into several evaluation sub areas that are again further divided into specific qualitative and quantitative evaluation criteria.

Table 2: Evaluation Framework for Smart Urban Logistics Solutions

Evaluation area	Evaluation sub area	Evaluation criteria
Customer satisfaction	Indirect satisfaction measurement	Delivery reliability
		Delivery flexibility
		Information transparency
		Shipment quality
	Direct satisfaction measurement	Satisfaction quantification
	Event-oriented satisfaction measurement	Satisfaction exploration
		Customer complaints
Profitability	Freight volume	Amount of freight units
	Revenue streams	Willingness-to-pay sender
		Willingness-to-pay receiver

Evaluation area	Evaluation sub area	Evaluation criteria
		Willingness-to-pay logistics service provider
	Cost structure	Fix costs
		Variable costs
	Cost driver	Consolidation factor
		Service time
		Stop density
		Driving speed
		Driving-service ratio
Environmental impact	Emissions	CO_2 emissions
		Parking on driving lane

4 Field Study "Kiezbote": Application of Framework

In the following, the field study "Kiezbote" is described in chapter 4.1 because the developed evaluation framework is applied on this case. Chapter 4.2 explains the data collection approach and chapter 4.3 presents and discusses the results within the three dimensions "customer satisfaction", "profitability", and "environmental impact" of the SUL field trial "Kiezbote".

4.1 Description of the Field Study “Kiezbote”

The SUL solution “Kiezbote” was implemented and tested in a 12-months field study in Berlin-Charlottenburg within the postal codes areas 10585, 10587, 10589, 14059 from 13.07.2020 to 30.06.2021. We consolidated B2C parcels of all senders and parcel logistics providers in a micro-hub and delivered by cargo bike within 2h-time windows between 4 and 10 pm. The parcel volume was not generated by cooperation with parcel logistics providers or online shops. Instead, the recipients decided to use “Kiezbote” by (voluntarily) change their delivery address during online shopping to the address of the “Kiezbote” micro-hub (“c/o Kiezbote”). As soon as the parcel arrives at the “Kiezbote” micro hub, the recipients get notifications via mail and app and can choose their preferred time window for parcel delivery. The technical infrastructure mainly consists of two cargo bikes (“Bullitt”, “Citkar Loadster”), apps for B2C communication and micro-hub management (“Pickshare”) as well as mobile devices for delivery drivers. Feasibility of all processes and resources was proven during the pilot study.

4.2 Data Collection

Within the field trial several internal data was collected regarding customer satisfaction, profitability and environmental impact that was enriched with external data from literature about conventional parcel delivery in order to interpret the results better. Three databases build the basis for data collection: The customer database, the parcel database, and the delivery database. The customer database contains all relevant information regarding customers (name, email, address, registration date, using behavior data). The parcel database tracks meta data (date, time, sender, parcel service provider, receiver, weight, size and volume, comments) and handover data (booked time window, address, date, and time of handover). The delivery database consists of date, transport mode, action (drive, handover), start time, duration, number of parcels, target address.

4.2.1 Customer Satisfaction

Customer satisfaction data is collected in the customer data base (“delivery reliability”, “shipment quality”, “customer complaints”) and by conducting qualitative and quantitative research with “Kiezbote” customers (”satisfaction exploration”, “satisfaction quantification”). “Delivery flexibility” and “information transparency” is qualitatively assessed based on the developed processes and used IT systems (that does not foresee any flexibility or tracking and tracing transparency).

For “satisfaction exploration” two focus groups of 2h each with group sizes of 4-5 participants were conducted in February 2021 in order to gain a deeper understanding of why customers use “Kiezbote”, how satisfied “Kiezbote” customers are, their thoughts of willingness-to-pay and improvement potentials where also additional data regarding the criteria “delivery flexibility” and “information transparency” could have been collected. The focus groups were transcribed using f4 transcript and analyzed using the qualitative content analysis after Mayring with a deductive-inductive approach (Mayring, 2015).

“Satisfaction quantification” was investigated by conducting a quantitative online survey with “Kiezbote” customers in June 2021 to get a broad understanding of how satisfied they are with “Kiezbote” service and conventional delivery using 5-point scales with equidistant verbal anchors after Rohrmann (1978). Furthermore, the customers are asked for their preferred payment model (per delivery or monthly flatrate) and their willingness to pay for the related payment model.

4.2.2 Profitability

To assess profitability data was collected regarding freight volume, revenue streams, cost structure and cost driver. The freight volume was generated out of the parcel database. The willingness-to-pay of customer was gained with help of surveys as described in chapter 4.2.1, whereas the willingness-to-pay of parcel logistics provider was put out of literature. The sender willingness-to-pay could not be collected due to the reasons described in chapter 4.3.2. Overall daily revenue (rev_daily) calculation is shown in (1) and considers the following factors:

- daily amount of parcels (dp = 12.4 parcels per day)
- share of willingness-to-pay of recipients (swtp_r = 0.83)
- willingness to pay of parcel service provider (wtp_p = 0.50 € per parcel)
- share of pay per delivery of recipients (sdel_r = 0.68)

- average pay per delivery of recipient (adel_r = 2.32 € per delivery)
- consolidation factor (cf = 1.97 parcels per delivery per customer)
- share of pay per flatrate of recipients (sflat_r = 0.32)
- average monthly pay per flatrate of recipients (aflat_r = 8.50 €)
- number of working days per month (wd = 21 days).

$$rev_{daily} = dp * swtp_r \left(wtp_p + sdel_r * \frac{adel_r}{cf} \right) + swtp_r * sflat_r * \frac{aflat_r}{wd} \quad (1)$$

The fix cost could be calculated based on real bills (micro hub rent and equipment, cargo bike leasing, marketing, insurance, staff equipment) while micro hub staff was calculated based on the experience that only 1h per day is needed to handle the parcels in the hub. Prerequisite is that the parcel service provider can keyless access the micro depot to deliver the parcels. The variable delivery costs were calculated based on the assumption that 13 parcels can be delivered in one hour at costs of 15.50 € per hour and the variable IT costs were calculated based on the assumption that 10 per cent of the revenues need to be payed to the revenues.

The cost driver data for "consolidation factor", "service time", and "driving-service ratio" was collected in the delivery database. "Stop density" and "driving speed" could not be measured because we only documented the time, not the distances between two stops. The data of conventional parcel deliver companies were collected out of literature as it is stated in Table.

4.2.3 Environmental Impact

Breitbarth, et al. (2021) calculate CO2 emissions for "Kiezbote" compared to conventional parcel delivery based on the standard EN 16258 and vehicle routing models. A well-to-wheel emission calculation consisting of fuel emissions of the transport services (tank-to-wheel) and emissions of fuel production, vehicles manufacturing, streets construction and transport network maintenance (well-to-tank) is used (Schmied and Knörr, 2012). The data of parking on driving lane was collected by the delivery data base for "Kiezbote" and by literature for conventional parcel delivery (Seeck and Göhr, 2018).

4.3 Results and Discussion

4.3.1 Customer Satisfaction

The findings indicate that our SUL solution “Kiezbote” outperforms the service-level of conventional parcel delivery by far. The “satisfaction quantification” shows that “Kiezbote” customer are very satisfied with the “Kiezbote” service (4.7 / 5 points on a 5-point Likert scale) while they are rather not satisfied with the service of conventional parcel companies (2.7 / 5). These findings are supported by the results of the “delivery reliability”, where 99.6 per cent of the parcels have been personally delivered within the customer-defined 2h-time windows. In the rare cases when the parcel could not be delivered, the customers were not at home, even if they chose the time window, but it has never been an operative bottleneck of “Kiezbote”. Compared to a “delivery reliability” of parcel companies of 95.0 per cent incl. handover to neighbors etc. and about 50 per cent when only personal handovers are counted (Seeck and Göhr, 2018), “Kiezbote” does not only offer a greater service, but also gains efficiency because a “second try” is practically not necessary. The “shipment quality” is 100 per cent, parcels have not been damaged by “Kiezbote”, but only 98.8 per cent of the parcels arrived without damage at the “Kiezbote” micro hub, what customers see as failure of the parcel companies. Exploring customer satisfaction further resulted in the findings that customers especially like the reliable personal parcel handover within a time window from a friendly and service-oriented driver. Furthermore, parcel consolidation over parcel companies and time, environmental-friendly delivery by cargo bike and the trouble shooting activities in case of customer complaints have been seen as main drivers for satisfaction. The only few “customer complaints” reached us through different channels (mail, nebenan.de, Facebook, Instagram, phone, in person) and they mostly contained complaints about the registration process and the time window booking via the app at the beginning of the pilot trial, what was also confirmed in the customer interviews. The following improvement potentials could be derived:

- better general functionality
- tracking and tracing of the whole upstream process
- announcements of the expected time of arrival (ETA)

- flexibility in cancelling or rebooking of time windows
- additional value-added services: courier service within the neighborhood (this idea was tested in the pilot but was not demanded in real-world, whereas bulky waste collection as one idea out of the interviews was tested and well demanded)

As mentioned above, “delivery flexibility” plays a crucial role to increase customer satisfaction. In the pilot, this was possible through individual communication by phone or mail, at scale this needs to be implemented in the app. In addition, “information transparency” needs to be integrated into the app to further increase the trust in the service and enable capacity planning for “Kiezbote”. While larger parcel companies do not offer delivery flexibility, information transparency is a strength in terms of tracking & tracing across the whole delivery process and not yet realized at “Kiezbote”.

Table 3 summarizes the quantitative comparison of Kiezbote and conventional parcel service provider regarding customer satisfaction and underlines that “Kiezbote” outperforms the large parcel companies. At this point, the question arises what effect the increasing service performance has on the overall costs of last mile delivery. The following chapter 4.3.2 will address this question.

Table 3: Quantitative Results Customer Satisfaction

Criteria	Field trial "Kiezbote"	Parcel service provider
Delivery reliability	99.6 per cent (only personal handover)	50.0 per cent (only personal handover) (Seeck and Göhr, 2018) to 95,0 per cent (incl. handover to neighbours)
Shipment quality	100.0 per cent	98.8 per cent
Customer satisfaction quantification	4,95 / 5	2,70 / 5

4.3.2 Profitability

The increased service level of consolidated time window deliveries by cargo bike leads to additional costs that needed to be covered by receiver, parcel logistics service provider and online-shops in order to enable economic implementation. The main question is under what circumstances profitability of the mentioned SUL concept can be reached. Therefore, "freight volume" and "willingness to pay" of different revenue streams are used to calculate the revenue potentials. Compared to the fix and variable costs in a break-even analysis the required number of parcels per day to be profitable can be identified. Furthermore, relevant cost drivers are presented and productivity issues are discussed comparing "Kiezbote" with conventional parcel service providers.

The number of parcels account for an average of 7.5 parcels per day over the 12 months trial. While in the first month an average of only 2.1 parcels per day is reached, the last month shows an average of 12.4 parcels per day. The number of parcels is rising steadily from month to month due to high service level and customer satisfaction. At the same time, three factors limit the growth trend. First, during the COVID-19 pandemic a lot of people have had to work from home and could attend parcel deliveries of conventional parcel service providers. For those people, there was no need for the time window delivery. Second, the number of parcels was acquired by convincing parcel receivers to change the delivery address of their online orders to the “Kiezbote” micro hub. Having the first point in mind, this “convincing process” requires much more marketing and communication efforts and expertise as we would have expected. Third, we have had some challenges with the registration process and the app functionality as mentioned in chapter 4.3.1, so that an unknown part of the people in the neighborhood did not even use the service even if they were interested.

The customers that used “Kiezbote” were almost all willing to pay for the experienced service (83 per cent). Thereof, 68 per cent prefer to pay for each delivery (Ø 2.32 €), 32 per cent for a monthly flat rate (Ø 8.50 €). The willingness to pay of online shops cannot be quantified yet because after an initial discussion with a leading online shop it has become clear, that for a cooperation SUL services needed to be rolled out at scale so that the process changes justify the benefits. The willingness to pay of online shops is a topic that should be studied further. The willingness to pay for parcel logistics provider is theoretically set to be about 0.50 € as this is the amount that parcel shops are receiving. In practice, those companies are not willing to cooperate on the last mile with consolidation services for brand strategic reasons because they do not want to lose the “face to the customer”. Nevertheless, we calculate with 0.50 € due to the high efficiency improvements, a parcel company gains when multi-dropping parcels at one place instead of delivering to the front door.

Considering the willingness to pay of receivers and parcel logistics providers and the number of daily parcels that is covered by the willingness to pay of receivers (83 per cent ~ 10 parcels per day) “Kiezbote” could currently generate revenues of 13.50 € per day or 283.50 € per month delivering 210 parcels per month.

On the other hand, there are the fix and variable costs for operating “Kiezbote”. Monthly fix costs consist of micro hub rent and equipment (527 €), micro hub staff (400 €; 1h per day for parcel handling), cargo bike leasing (300 €), marketing (150 €) insurance (89 €), staff equipment (18 €) and total 1,484 € per month. Variable costs contain the driver costs (1.17 € per parcel; delivering 13 parcels per hour at 7 stops at labor costs of 15.50 € per hour) and IT costs (0.09 € per parcel ~ 10 per cent of receiver fee) so that the variable costs total 1.26 € per parcel.

At this point it becomes clear, that a parcel volume of 10 parcels per day and the resulting revenue of 283.50 € per month cannot cover the overall costs of 1,749 € per month. The productivity could be increased from the empirically reached 13 parcels at 7 stops per hour up to 20 parcels at 10 stops per hour – what is realistic according to bike delivery experts – variable costs could be reduced to 0.87 € per parcel. Based on this data a break-even analysis is conducted an presented in Figure 1. Furthermore, there are several opportunities to reduce fix costs regarding the parcel handling process in a micro hub (automation, outsourcing) or on the transport process (purchasing advantages of cargo bikes at scale).

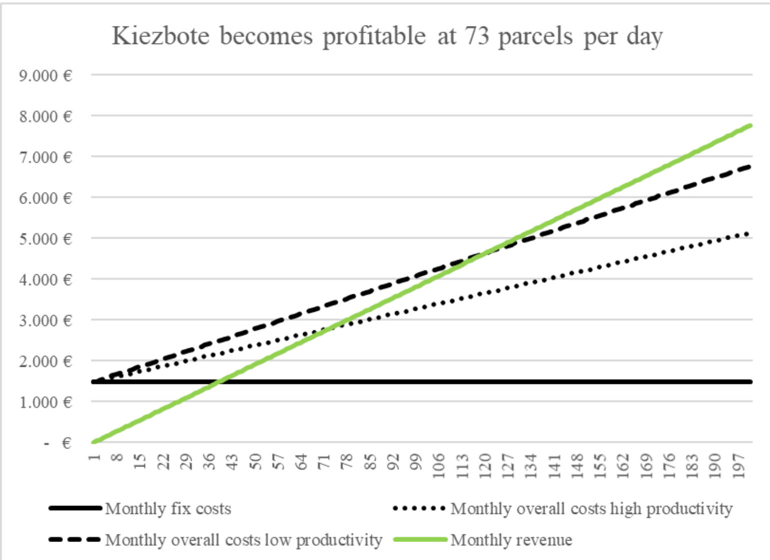

Figure 1: Results Profitability: Break Even Analysis

For further improvement of the delivery productivity, several cost drivers can be analysed. Empirical “Kiezbote” results already show some advantages over parcel logistics companies regarding driving and handover of parcels, see Table 4.

Table 4: Results Profitability: Improvement Levers KPI of Last Mile Productivity

Criteria	Field trial “Kiezbote”	Parcel service provider
consolidation factor	2.08	1.2 (Brabänder, 2020)
service time	02:35 min	02:26 min (Sesam GmbH, 2020)
service time per parcel	01:14 min	02:01 min (calculated based on references above)
driving-service ratio	35:65	10:90 (Seeck and Göhr, 2018)

While the consolidation factor and therefore the service time per parcel is significantly better at “Kiezbote”, driving takes a much higher share on the overall time due to the lower stop density caused by the yet low parcel volume. Thus, “Kiezbote” should reduce the driving time by optimizing their routes using an intelligent route planning software that incorporates the advantages of cargo bikes over conventional transporter.

4.3.3 Environmental Impact

C02 emissions can be significantly reduced of about 60 ex micro depot and of about 12 per cent on the last mile ex depot out of the city (Breitbarth, et al., 2021). The long distance from depot to micro depot cannot be eliminated; therefore, new sustainable solutions for this distance should be further investigated. Parking on driving lane could be reduced to 0 per cent of stops while we see a number of 30 per cent of stops at conventional parcel delivery companies (Seeck and Göhr, 2018).

5 Conclusion

The aim of the report was to show how SUL solutions pilots like "Kiezbote" can be comprehensively evaluated in order to prove its economic implementation, to determine its effects on emissions reduction and to investigate effects on customer satisfaction. Therefore, a holistic evaluation framework was developed containing 20 criteria. The results show that the customer satisfaction can be strongly increased when using "Kiezbote" from 2.7 / 5 (satisfaction rate conventional parcel delivery) up to 4.96 / 5 (satisfaction rate Kiezbote). The increased service – the consolidated parcel delivery within time windows by cargo bikes – produces additional costs that raise the question of how the concept can be implemented profitable as a prerequisite for sustainable and independent operations. However, the break-even analysis has shown that profitability can be reached from 73 parcels per day when the delivery staff reaches productivity of 20 parcels at 10 stops per hour. The CO_2 emissions on the last mile starting from micro depot can be reduced by 60 per cent.

This work provides empirical evidence as one of the first completed field trial on SUL solutions that considers profitability, environmental impact, *and* customer satisfaction. This work provides not only a comprehensive evaluation framework focusing on customer satisfaction, but also delivers some input data for further simulations and optimization of SUL solutions. Practically the results are relevant for last mile startups to inspire and validate their business models in terms of customer satisfaction, profitability, and environmental impact and thus, opens up new opportunities for SUL.

The work underlies the following limitations: First, the empirical data was collected during the COVID-19 pandemic when consumer behavior was changed. It is expected that the results would differ when conducting the trial after the crises due a higher need for time window delivery caused by more out-of-home-time. Second, the comprehensive framework consists of all relevant areas to evaluate SUL solutions pilots. However, when setting the target focus in a specific direction (e. g., environmental impact), the criteria should be individually enriched to get a more differentiated picture (e. g., not only evaluating CO_2 emissions reduction). Third, the evaluation framework was only applied to one pilot. It should be validated with further pilots of a different nature (e. g., lockers, intermodal transportation) and also with SUL trials that include the distance from depot to micro-depot.

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Accepting a crowdsourced delivery - a choice-based conjoint analysis

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Purpose: The increase in parcel quantities on the last mile requires new and innovative concepts to support sustainability efforts in urban areas. Crowdsourced delivery (CSD) represents a promising concept as it allows private couriers to take over the parcels' last mile on trips they would have traveled anyway. Whereas first research on the attributes leading to the acceptance of CSD requests via platforms exists, the attributes' respective importance remains unclear.

Methodology: A choice-based conjoint analysis with 193 respondents willing to participate in CSDs was conducted. Attributes' relative importance and part-worth utilities were calculated using Hierarchical Bayes estimation.

Findings: Results show that differences in deviation of the original travel time and remuneration have the greatest impact on couriers' request selection, while the degree of familiarity with the recipient and parcel weight are less decisive. Additionally, it became apparent that couriers' sentimental traits of environmental concerns and extraversion affect the choice of a CSD request.

Originality: The study contributes to the scarce literature on the promising concept of CSD to reduce logistics-related environmental externalities and strengthens the application of marketing-related methodologies in logistics research. For CSD platform providers, results enable higher competitiveness through a more individualized request for potential couriers.

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1 Introduction

Last-mile logistics is facing unprecedented challenges in the future. Urbanization is leading to an increase of the total worldwide population that is living in cities by more than 60% until 2050 (United Nations, 2019). This is accompanied by a rapid growth in e-commerce volume particularly accelerated by the ongoing COVID-19 pandemic (United Nations, 2021). The global share of e-commerce in all retail sales is projected to increase by more than 60% until 2024 compared to 2019 (eMarketer, 2021). Both developments are leading to an intensification of urban freight, resulting in negative externalities, such as congestion, noise and carbon emissions (Lim, Jin and Srai, 2018). Additionally, changes in customer behavior require adequate solutions by shippers, including the provision of more sustainable ways of transportation as well as shorter and more flexible delivery times (Kafle, Zou and Lin, 2017; Ta, Esper and Hofer, 2018). These conditions led to the emergence of a new business model for last-mile transportation: crowdsourced delivery (CSD).

CSD is described as the transportation of shipments on the last mile through a network of private couriers, carrying parcels on premeditated trip with only small deviations from the original route (Le and Ukkusuri, 2019a). In this way, excess capacities on travel patterns of the couriers are used (Paloheimo, Lettenmeier and Waris, 2016). The fact that the average passenger car in urban travel is occupied by only 1.3 persons (European Environment Agency, 2021) underlines the potential of higher utilization of individual trips for freight delivery. The positive contribution of CSD on last-mile logistics is threefold. Firstly, it increases the delivery capacity in the urban area by individual people, relieving traditional courier, express and parcel services (CEP) providers (Chen and Chankov, 2017). Secondly, CSD allows for an ad-hoc delivery of parcels, independent of routes and the number of transmission runs of CEP providers (Shen and Lin, 2020). Thirdly, if parcels are delivered on premeditated trips with only small deviations from the original route, CSD reduces traffic and CO2 emissions in the urban area (Carbone, Rouquet and Roussat, 2017). Various firms have identified the need for CSD as a new approach to provide shipments to their customers. In a global research study incorporating more than 2,700 retail professionals nearly 90% expected to use CSD to handle requests in daily business by 2028 (Zebra Technologies, 2018).

As with all crowd-based services, CSD platform providers need to have a critical mass of participants to offer the fast and reliable deliveries that are expected by customers (Frehe, Mehmann and Teuteberg, 2017; Behrend and Meisel, 2018). For this reason, it is necessary to find out which attributes of a single CSD request influence the couriers' willingness to accept a CSD request. Only a limited number of empirical-based literature has contributed to this field of research. Predominantly, the present literature is focused on financial attributes for request acceptance for potential couriers, followed by demographic and time-dependent determinants. However, none of the studies examined the interrelation between these attributes and insights regarding which attribute outweighs the others in combination are missing (Le and Ukkusuri, 2019b). Still, as supported by other platform business models, it is essential to consider the attributes as a whole rather than individually to make sufficient predictions about the respective importance for potential couriers (Wang and Lai, 2020). Therefore, this paper addresses the interrelationship of different attributes influencing the willingness of potential couriers to take over a request in the CSD concept. It is guided by the following research question.

- RQ1: How are different attributes of a CSD interrelated in the acceptance of a request by potential couriers?

Serafini, et al. (2018) showed that demographics and sentimental traits determine whether potential couriers are willing to participate in a CSD concept. Therefore, it is concluded that the interrelation between attributes characterizing a CSD request diverges between different participant groups. Based on that, a second research question is conducted:

- RQ2: How do the couriers' characteristics affect the interrelationship of different attributes of a CSD in the request acceptance?

The contribution of the paper is the following. It is the first paper to examine the respective importance of different attributes of a CSD request for potential couriers. Based on the results, CSD platform providers can achieve a higher individualization of CSD requests for couriers, leading to more executions of CSDs. In this way, the results allow to a higher competitiveness of CSD platform providers and the reduction of logistics-related environmental externalities. Moreover, the study contributes to the scarce literature on understanding the promising concept of CSD. Finally, the study strengthens the application of marketing-related methodologies in logistics research.

2 Background

The phenomenon of sharing economy received increasing attention from scholars and is already present in many industries (Kathan, Matzler and Veider, 2016). Driven by digital and technological developments, individuals are enabled to monetize their skills and make use of their underutilized resources (Belk, 2014). These developments contributed to the creation of the neologism “crowdsourcing”, established by Howe (2006). With regards to the delivery of parcels, CSD emerged as “the outsourcing of the last mile delivery to a mass of actors through the coordination of a technical infrastructure” (Mehmann, Frehe and Teuteberg, 2015, p. 123). Technical infrastructure includes innovations, such as mobile communication via smartphones and accurate localization via GPS (Alnaggar, Gzara and Bookbinder, 2021). These enable the exchange of CSD requests via a digital CSD platform (Basik, et al., 2018).

On a CSD platform, shippers and couriers of a parcel delivery are brought together. The shippers are CEP providers having their shipment carried out by a CSD, e-retailers substituting a traditional CEP provider and individual persons (Frehe, Mehmann and Teuteberg, 2017; Alnaggar, Gzara and Bookbinder, 2021). Couriers are individual persons who voluntarily register on the platform. Their motivation to participate in a CSD is mainly the remuneration but also intrinsic motivations, such as new experiences and enjoyment of the task act as further motivators (Huang, et al., 2020). If the shipper wants an item to be delivered to a recipient, the CSD is placed as a request via the platform. Based on the respective information on the CSD, couriers simply select the requests that match their scheduled trip and delivery preferences (Alnaggar, Gzara and Bookbinder, 2021). After a request’s acceptance, the CSD is carried out by the courier’s preferred way of transportation (on foot, bike, car or public transportation) (Seghezzi, et al., 2020). Finally, the courier confirms the successful CSD and receives a pre-defined remuneration from the shipper that is based on a selection of price-determining factors, such as distance, parcel weight or waiting time.

According to Carbone, Rouquet and Roussat (2017), CSD is a relatively new field of research and differentiates from similar crowdsourcing services in logistics, such as crowd storage or crowd freight forwarding. The existing literature on CSD is differentiated the following. Firstly, literature on CSD operations is addressing the underlying decision-making systems to enable the execution of a CSD most efficiently. This includes the matching of potential couriers with a single CSD request based on the couriers' communicated transportation routes and time constraints (e.g., Archetti, Savelsbergh and Speranza, 2016; Dayarian and Savelsbergh, 2017; Guo, et al., 2019), route optimization for a CSD of multiple parcels (e.g., Macrina, et al., 2017; Arslan, et al., 2019; Ulmer and Savelsbergh, 2020) and the ideal level of remuneration for a courier (e.g., Qi, et al., 2018; Dai and Liu, 2020). Secondly, literature refers to the positive contribution of CSD in reducing CO2 emissions and total costs of delivery (Lee, Kang and Prabhu, 2016; Devari, Nikolaev and He, 2017). Thirdly, literature is examining the motivators to participate in the CSD concept itself. It becomes apparent that most literature identified remuneration as the most important motivator for participation, accompanied by trust in the concept and flexibility of working (Feller, et al., 2012; Mladenow, Bauer and Strauss, 2016; Huang, et al., 2020). Moreover, demographic determinants, such as age, ethnicity and income were identified (Serafini, et al., 2018; Le and Ukkusuri, 2019b; Punel, Ermagun and Stathopoulos, 2019). Fourthly, sparse literature is dedicated to the motivational factors to accept a single CSD request when participating in the concept, considering determinants, such as remuneration, parcel size, day of delivery and delivery distance (Ermagun and Stathopoulos, 2018; Le and Ukkusuri, 2019b).

Ultimately, some limitations of the CSD concept need to be mentioned. Whereas a CSD allows for high flexibility for the couriers by completely leaving the decision for the request acceptance by them, CSD platform providers cannot guarantee a delivery in case the request is not accepted by potential couriers (Alnaggar, Gzara and Bookbinder, 2021). Therefore, it is expected that CSD will be a supplement to traditional shipping by CEP providers, rather than a replacement (Punel, Ermagun and Stathopoulos, 2019). Moreover, several issues concerning the trust and liability of couriers during a CSD are still unclear and call for clarification (Rougès and Montreuil, 2014). Finally, potential rebound effects are possible, if the increase in individual deviations from the original trip offsets the benefits from a higher utilization in passenger cars (Paloheimo, Lettenmeier and Waris, 2016).

3 Methodology

3.1 Choice-based conjoint analysis

Whereas the choice-based conjoint analysis (CBC) is rarely used in the supply chain management domain, it is a commonly applied quantitative research methodology in marketing (Maldonado, Montoya and Weber, 2015). The purpose of CBC is to examine customers' preferences towards the features or functions of a product or service. However, it is also applicable for other contexts beyond purchasing decisions (Reutterer and Kotzab, 2000). The following characteristics of CBC emphasize the methodology is particularly well suited to answer the proposed RQs. Firstly, participants consider all attributes of a CSD simultaneously by asking them to choose one of several different CSD requests that randomly diverge by a predefined set of attributes (Anderhofstadt and Spinler, 2020). Thus, a realistic situation is simulated since in practice more than one isolated attribute determines the decision of accepting a CSD (Green and Srinivasan, 1990). Secondly, unlike similar preference methods, CBC is suitable for evaluating preferences for hypothetical products or services (Scherer, Emberger-Klein and Menrad, 2018). Assuming that most respondents are still unfamiliar with CSD, the CBC is preferred as a research methodology in this paper. Figure 1 illustrates the subsequent process outlined by Anderhofstadt and Spinler (2020) for CBC, further described in the following.

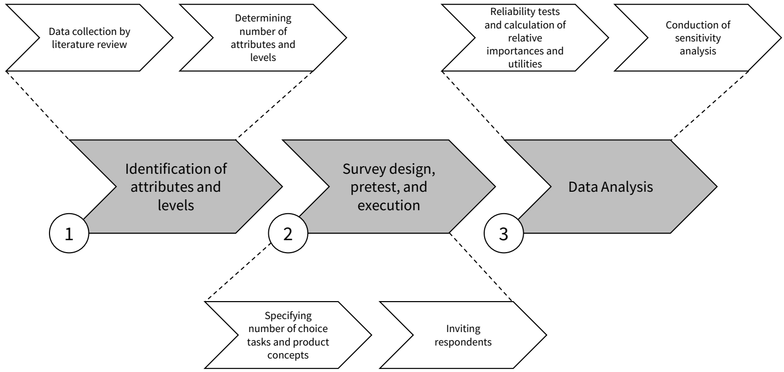

Figure 1: CBC experiment process phases, own representation based on Anderhofstadt and Spinler (2020)

3.2 Identification of attributes and levels

A careful selection of relevant and limited attributes and levels is very important when conducting a CBC to provide simplified, yet realistic alternatives (Lohrke, Holloway and Woolley, 2010). In this context, levels express the different characteristics of an attribute. The attributes and their levels used in this paper are described in Table 1. According to Le and Ukkusuri (2018), delivery time is considered an important influencing factor to the willingness to work as a crowd-shipper. As CSD is characterized by delivery on a commuter route rather than an additional trip, delivery time is specified as the deviation from the travel time that takes place anyway. Following Le and Ukkusuri (2019a), the delivery time range was defined from five up to 30 minutes of extra time. Additionally, remuneration referred to the monetary compensation of a courier when executing a CSD request. The levels of remuneration ranged between one to five EUR per delivery,

Table 1: Attributes used in the CBC analysis

Attribute	Levels
Delivery time	5 minutes, 10 minutes, 20 minutes and 30 minutes
Remuneration	None, 1 €, 2 €, 3 €, 4 EUR and 5 €
Degree of familiarity	Relative, close friend, neighbor, working colleague, acquaintance, unknown person
Parcel weight	2 kg, 5 kg, 10 kg and 15 kg

following the typical range of two to four EUR provided by existing CSD platforms (Paloheimo, Lettenmeier and Waris, 2016; Marcucci, et al., 2017). To address potential altruistic motivation among the respondents, the level of “none” remuneration was added. The degree of familiarity was selected as another attribute, defining the relationship of the potential courier to the recipient of the CSD. Based on the studies of Devari, Nikolaev and He (2017) and Le and Ukkusuri (2019a), a set of six levels was selected, containing relative, close friend, neighbor, acquaintance, working colleague and unknown recipient. Since other means of transportation than a car can be considered for a CSD, the parcel weight was defined as the last attribute. Based on the standard weights of parcels from the CEP service provider DHL (2021), the levels ranged from 2 kg to 15 kg. Although the maximum possible weight of parcels can be higher, the levels were selected to assure that all potential CSD requests could be delivered without auxiliary means of transport.

3.3 Survey Design, Pretest and Execution

The CBC was conducted using the online survey tool Sawtooth Software Lighthouse Studio 9.9.1. Sawtooth is a standard software used in academic literature to generate and analyze CBC and has been used in several previous CBC studies (e.g., Apostolakis, et al., 2018; Scherer, Emberger-Klein and Menrad, 2018; Anderhofstadt and Spinler, 2020). At the beginning of the survey, CSD, as well as the research scope, were briefly explained. Afterward, demographic information of the respondents was requested. Subsequently, the respondents' previous experiences with CSD and their willingness to work as a courier in a CSD concept were asked. Those participants who were willing to take part in a CSD were asked to put themselves in the position of a potential courier by selecting a common route and means of transportation and were presented the choice tasks. After the explanation of the CBC procedure, a total number of twelve choice tasks was presented to each participant. For online-based CBCs, about ten choice tasks per respondent are recommended to avoid a decline in data quality (Sawtooth, 2019b). One choice task included four single CSD requests that were differentiated by the random selection of a level for each of the four attributes. To maximize the efficiency of the survey design in the selection of decision options, both a balanced design and orthogonality were ensured (Hair, J., Black, W., Babin, B. and Anderson, R., 2014). Therefore, the choice tasks were generated using Sawooth's balanced-overlap function that guaranteed no duplication of the same attribute levels within the same task. Each choice task included a "none" option to make the CBC even more realistic in case that none of the decision options was attractive (Sawtooth, 2019b; Souka, et al., 2020). To measure the validity and reliability of the CBC model, two fixed tasks with manually selected attributes' levels were included (Anderhofstadt and Spinler, 2020). Both were identical for all respondents. The fixed tasks comprised one more preferred and three less preferred choices. They were used to test whether participants decided the same for both tasks or if decisions were made randomly. After finishing the twelve choice tasks, further questions regarding the participants' frequency of parcel delivery, individual attitude to sustainability and personality traits were questioned.

Before the official survey launch, a pre-test was conducted with six candidates from academics and practice to test the survey design and their feedback was included in the final study design. The CBC was conducted between November and December 2020 in Germany by inviting potential respondents to participate via mail. Additionally, the survey links were shared on social media platforms (Halassi, Semeijn and Kiratli, 2019).

The survey link was opened 544 times, thereof 329 respondents completed the questionnaire (60.5%). In the analysis of the CBC, only participants willing to participate in a CSD (63.8%) were included, of which another eight “straight liners” and an additional nine participants having a relatively low RLH value below 0.4 (see section 4.1) were excluded. This resulted in a final sample of 193, which is far beyond the necessary 50 respondents for a CBC proposed by Hair et al. (2014).

4 Results

4.1 Data Analysis

The data analysis was conducted using an iterative process by Hierarchical Bayes (HB) estimation (Sawtooth, 2021b). Following Scherer, Emberger-Klein and Menrad (2018), 20,000 iterations were performed, whereas the first 10,000 were necessary to achieve convergence and the following 10,000 were applied for the actual model estimation. To secure the results' validity and reliability, several tests were conducted. Based on the two fixed choice tasks, the test-retest rate was calculated. It showed that 91% of the participants answered both fixed tasks as intended, accounting for a high internal consistency (Apostolakis, et al., 2018). Moreover, the goodness of fit of the HB model was tested by calculating its root likelihood (RLH) value. The closer the RHL is to 1.0 and the further away from the critical value of 1/k, the more likely it can be assumed that respondents did not choose randomly (Sawtooth, 2021a). K is indicating the number of decision options presented in one choice task. The RLH of the present model was 0.69, displaying a much better fit than the 0.25 of a potential chance model with four different choices.

4.2 Demographics

The sample for the CBC included 193 participants that were willing to act as a courier of a potential CSD platform. The sample was mainly female (68.0%) and had an average age of 33 years. Most of the participants had a university degree (43.1%), followed by a high school diploma (27.9%) and a middle school diploma (23.9%). The sample included mainly full-time employees (55.3%) and students (26.4%). The level of income was very diverse with a median income of between 30.000 and 49.999 EUR. 2.5% of the participants had made experiences as a courier in a CSD concept already. With regards to the commuter route, most respondents chose to deliver parcels on their way from work to home (42.1%), followed by going out for shopping (22.8%). On these routes, the majority favored using a car (63.5%) over public transportation (13.7%) and bicycle (13.2%). The sample was predominated by respondents that were willing to participate at least one to two times per week (66.0%), whereas 10.7% outlined participation only once or twice a month.

4.3 Relative importance and part-worth utilities

Relative importance and part-worth utilities were calculated for all attributes. The relative importance represents the individual attributes' contribution to the decision-making process within a CBC (Sawtooth, 2019a). It was calculated by taking the absolute distance between the part-worth values (regression coefficients) of the most and least preferred level (highest and lowest importance) of a particular attribute, divided by the sum of the ranges across all attributes (Tabi and Wüstenhagen, 2017). The part-worth utilities indicate the degree of influence of each attributes' level on the choice of the respondent. Consequently, it serves as a predictor for the respondents' choice task decisions. Part-worth utilities for the four identified attributes were calculated across all 193 participants, using computer-supported HB estimation. The results for the relative importance presented in Figure 2.

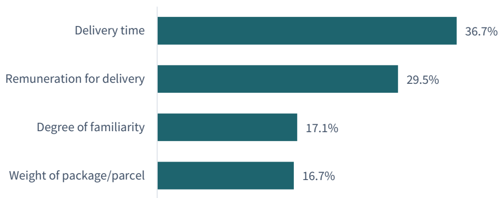

Figure 6: Relative importance of CSD attributes, own representation

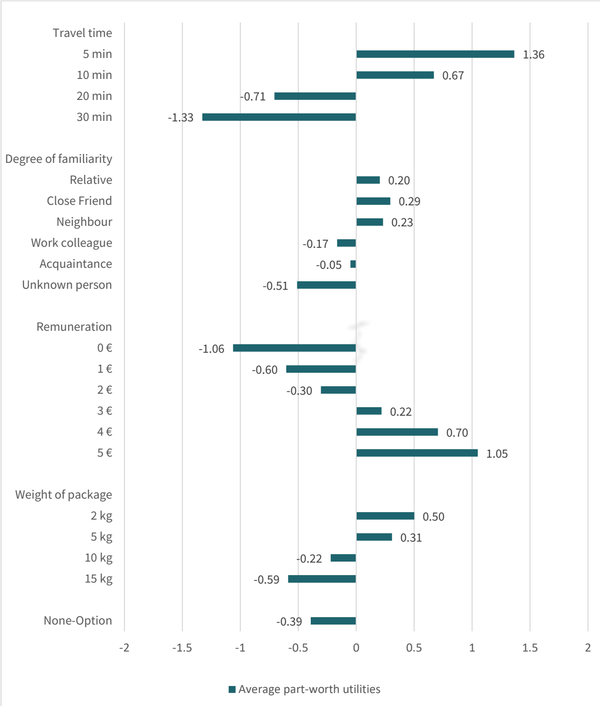

Figure 3: Average part-worth utilities of attributes' levels, own representation

The results of the part-worth utilities analysis are displayed in Figure 3. They are scaled to an arbitrary additive constant within each attribute. Negative utility values indicate that the respective level is less preferred to the other attribute's levels. The results show that CSD couriers prefer shorter delivery times, higher compensation and lower parcel weight. Surprisingly, participants preferred delivering a parcel to close friends and neighbors over their relatives. Moreover, results show that delivering a parcel to an acquaintance is preferred over a working colleague.

4.4 Sensitivity Analysis

To refine the results of the part-worth utilities, a sensitivity analysis was conducted by using Sawtooth Market Simulator. This analysis shows how sensitive participants react

Table 2: Scenarios of the sensitivity analysis, own representation

Scenario	Share of Preferences	Delivery Time	Remuneration	Degree of familiarity	Parcel weight
Best Case (1)	99.0 %	5 min	5 €	Relative	2 kg
2	97.0 %	10 min	5 €	Relative	2 kg
3	78.7 %	20 min	5 €	Relative	2 kg
4	61.6 %	30 min	5 €	Relative	2 kg
5	99.0 %	5 min	4 €	Relative	2 kg
6	96.9 %	5 min	3 €	Relative	2 kg
7	94.8 %	5 min	2 €	Relative	2 kg
8	88.7 %	5 min	1 €	Relative	2 kg
9	80.3 %	5 min	none	Relative	2 kg

Scenario	Share of Preferences	Delivery Time	Remuneration	Degree of familiarity	Parcel weight
10	98.7 %	5 min	5 €	Close Friend	2 kg
11	99.1 %	5 min	5 €	Neighbour	2 kg
12	99.0 %	5 min	5 €	Working colleague	2 kg
13	98.5 %	5 min	5 €	Acquaintance	2 kg
14	96.8 %	5 min	5 €	Unknown person	2 kg
15	98.3 %	5 min	5 €	Relative	5 kg
16	92.9 %	5 min	5 €	Relative	10 kg
17	85.8 %	5 min	5 €	Relative	15 kg

to different changes around a predefined base scenario (Danielis, Marcucci and Rotaris, 2005). The results of the sensitivity analysis can be more easily interpreted than the part-worth utilities and allow for comparison between different potential CSD requests. For conducting the sensitivity analysis, the best-case scenario (shortest delivery time, highest remuneration, delivering to relatives, lowest parcel weight) was selected as the base case scenario. Based on the part-worth utilities, individual shares of preference were calculated. These indicate the probability of choosing a simulated decision option by the respondents over all other possible decision options. For instance, a share of

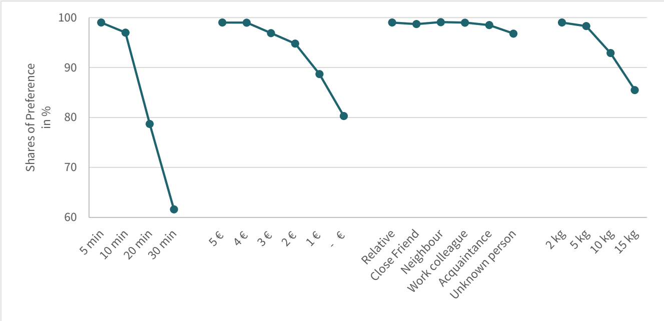

Figure 4: Sensitivity analysis based on the total sample, own representation

preference of 99% for the base case scenario signifies that 99% of the respondents would choose this decision option over the others, whereas 1% would not. By “changing one attribute level while holding all other attributes at base case levels” (Sawtooth, 2019a, p. 81), all levels within the respective attributes were tested. This approach resulted in 17 different scenarios, presented in Table 2.

The results (see Figure 4) show, for instance, that the increase of a delivery time from five to ten minutes only leads to a reduction in preference of two percentage points. Contrary, if delivery time increases from 10 to 20 minutes, the share of preference decreases by 18 percentage points. Sensitivity analysis was repeated for different groups within the sample, to allow further refinement of the respective share of preferences.

Firstly, differences in sensitivity for delivery time and remuneration between male and female potential couriers were noticed (see Figure 5 in appendix). Men were far more sensitive to an increase in delivery time of more than 10 minutes in their share of preference. For instance, whereas women’s share of preference for scenario 4 was 65%, it only reached 53% share of preference among men. Simultaneously, men were slightly more sensitive to the remuneration, if the remuneration was less than two EUR.

Secondly, it became apparent that the age group with the more mature respondents is the most sensitive to changes (see Figure 6 in appendix). This particularly refers to the delivery time and parcel weight. Interestingly, sensitivity for the remuneration was highest among the mature group and lowest among the middle-aged group.

Thirdly, extensive differences were discovered with regards to the four groups of frequency of delivery that potential couriers would be willing to execute a CSD (see Figure 7 in appendix). The respondents with the lowest frequency of delivery were far more sensitive than the other three groups. For instance, whereas respondents willing to deliver one to two times a month preferred scenario 4 (see Table 2) with only 40%, it was 74% among the frequent deliverers (three to five times a week).

Fourthly, attention was paid to the respondents' personal characteristics (Figure 8 in appendix). For assessing the respondents' attitude to environmental protection, their degree of environmental concerns was questioned. The analysis shows that respondents being very worried about the environment were more sensitive to parcel weight than respondents that were worrying less about the environment. Additionally, respondents that were less worried about the environment were more sensitive to remuneration.

With regards to the sentimental traits of the respondents, a shortened version of the widely used OCEAN model was applied (Gosling, Rentfrow and Swann, 2003). This model quantifies the human personality traits into five broad, empirically proven dimensions. Respondents were asked to rate the extent the respective dimension matched their personality on a five-point Likert scale. Based on the rating of all participants, the median was calculated. Those respondents with a rating below the median were assigned to the "negatively" connoted expression of the dimension (e.g., reserved), while others were assigned to the "positive" connoted group (e.g., extraverted) for each of the respective dimensions. Exemplary, the analysis shows a higher sensitivity for the extraverted respondents in delivery time and parcel weight (see Figure 9 in appendix). Contrary, concerning remuneration, reserved respondents were more sensitive.

5 Discussion

The success of a CSD platform is determined by the critical mass of its users working as potential couriers (Buldeo Rai, Verlinde and Macharis, 2019). From all the 329 respondents, a considerable 63.8% said that they were willing to participate in a CSD concept. This is remarkably higher than the 30% discovered by Miller, Nie and Stathopoulos (2017), but still less than the 87% as surveyed by Marcucci, et al. (2017). Considering that these studies' samples were comparable in their panel composition regarding the demographics but different in the country the sample was generated, this study indicates that the willingness to act as a CSD courier may dependent on cultural backgrounds. Therefore, further research is needed on country-specific effects to act as a courier to enable practitioners to adapt their CSD platforms to the national couriers' requirements.

Marcucci, et al. (2017) showed that the willingness of participants to receive a parcel by a CSD is significantly higher (93%) than to deliver a parcel. To secure that this demand can be satisfied, the "supplier side" is of particular interest to scholars and practitioners. If attractive CSD requests are presented to potential couriers, the chance of finding a respective courier increases. Based on that, RQ1 ("How are different attributes of a CSD interrelated in the acceptance of a request by potential couriers?") will be discussed.

In the present study, delivery time turned out to be the most important determinant in selecting a particular CSD request. That is opposed to the existing literature that suggested remuneration being the most important factor for participating in a CSD (e.g., Paloheimo, Lettenmeier and Waris, 2016; Miller, Nie and Stathopoulos, 2017). The relevance of delivery time in this study is further emphasized by the fact that respondents were more sensitive to changes in this attribute than to remuneration. This can be accounted to the fact that the potential courier in the present sample are pursuing more altruistic objectives with taking over a CSD than to profit financially. However, their resources in time dedicated to CSD are limited to a maximum of ten minutes in deviation on their commuter way. Therefore, limiting the deviation of travel distance to 2.4 km for an individual courier as proposed by Marcucci, et al. (2017), is a decisive factor for the success of a CSD platform. Practitioners are recommended to follow this through the algorithms proposed by Giret, et al. (2018) or Wang, et al. (2016). Although remuneration was less decisive as delivery time, this attribute still accounted for nearly a third of the respondents' decisions. Consequently, further research on algorithms to find the best remuneration, whereas reducing the deviation in travel time is proposed.

With regards to the degree of familiarity of the recipient, the results differ from the findings of Devari, Nikolaev and He (2017). Their study showed a large proportion (72%) of respondents that were only willing to participate in a CSD if they would be delivering parcels to (close) friends. Still, in the present sample, respondents merely declined a CSD, if delivering a parcel to acquaintances or even unknown recipients. Further, the degree of familiarity accounted less for respondents' overall share of preference. This could be attributed to country-specific perceptions of security. As the sample only contained German participants, respondents might have fewer concerns regarding their safety compared to the studies conducted in other countries (Mamdooh, 2016). Therefore, this study suggests that the degree of familiarity is less decisive in taking over a CSD in Germany. This is a positive outcome, as when couriers were only delivering to known persons, the crowd effect would often not be feasible. For practitioners, the results highlight that potential couriers can be attracted to their platforms, albeit their social network is not participating in CSD.

Only a few studies have considered parcel weight as a determinant of selecting a CSD request. As existing studies assumed that the CSD is executed by car, parcel weight did not represent a limiting factor. The present study explicitly considered other ways of transportation as well, allowing for a higher influence of this factor. Surprisingly, the analysis revealed that the parcel weight's relevance is much lower than for delivery time and remuneration. This is accounted to the fact that, although all means of transportation were included, most of the respondents would execute the CSD by car. Therefore, parcel weight should not represent a limiting factor, as compared to other ways of transportation. Simultaneously, respondents were more sensitive to changes in parcel weight than to the degree of familiarity. Therefore, it is suggested for CSD platform providers to individualize the requests for potential couriers based on their preferred way of transportation. To refine the relevance of parcel weight for different ways of transportation, further research is needed under the consideration of the modal shift of individual traffic in urban areas.

Studies further show that individual behavior is dependent on surface-level characteristics of an individual as well as its deep-level characteristics (Spickermann, Zimmermann and van der Gracht, 2014). Thus, surface-level characteristics (gender, age, delivery frequency) and deep-level characteristics (environmental concerns, extraversion) of the respondents were accounted for within the sensitivity analysis. Based on that, RQ2 ("How do the couriers' characteristics affect the interrelationship of different attributes of a CSD in the request acceptance?") is examined. It is worth mentioning that the best case was chosen as a base case scenario in the analysis. Therefore, the shares of preferences are relatively high. Selecting another scenario as a base case would lead to lower shares of preference, yet the sensitivities would be the same.

The results show that men are more sensitive to remuneration than women. It is suggested that this is justified by the fact that women are more open to CSD than men (Le and Ukkusuri, 2019a). Consequently, men experience the participation as more effortful, resulting in higher expected remuneration. Moreover, women showed a higher willingness to deliver parcels on an additional trip longer than 10 minutes. Thus, it is recommended to process CSD requests with a higher deviation in travel time by women. Surprisingly, no significant differences concerning the parcel weight were identified. Despite different physical conditions, the results indicate that parcel weight can be neglected when individualizing requests in consideration of gender.

The results of the sensitivity analysis were more diverse when accounting for the couriers' age. The daily routines of older couriers are more established, resulting in a lower acceptance of higher deviations for a CSD from the original trip. In contrast to gender, parcel weight plays a decisive role for couriers of different ages. These results reflect physical constraints due to an increase in age. The provision of easy-to-handle tools for frequent couriers through the CSD platform provider represents a potential solution to this limitation. Interestingly, the sensitivity for remuneration was highest among the middle-aged group. This age group subsumes the highest income earners in Germany (Destatis, 2017). Therefore, an additional income by CSD is perceived as less necessary among this group, resulting in a higher decline of lower-paid CSD requests. For practitioners, these results highlight that offering an attractive remuneration is particularly relevant for the age area (Roberts and Manolis, 2000). Consequently, to reduce the costs for a CSD, particularly younger and older age groups should be addressed as potential couriers.

Moreover, it is assumed that respondents who were willing to frequently participate in CSDs value its positive effects for the environment and themselves higher as the less frequent couriers. This is reflected in the sensitivities, as respondents that were willing to frequently participate in CSDs are characterized by a lower sensitivity along with all attributes. Therefore, it is proposed for CSD platform operators to actively present the most attractive requests to couriers with a lower delivery activity. In this way, their engagement is increased, whereas the frequent CSD couriers are still satisfied with less attractive requests.

With regards to the deep-level characteristics of environmental concerns, it was expected that respondents that paid lower relevance to environmental protection would be more sensitive. Surprisingly, this applies only to remuneration and parcel weight. Consequently, these participants must pursue alternative objectives with their participation that kept their motivation to select a CSD request on a high level. To examine these motives in depth is proposed as a promising field for further research. Interestingly, respondents with higher environmental concerns were more sensitive to changes in parcel weight. This might be accounted by the fact that they use more environmentally friendly ways of transportation, such as a bicycle or public transportation, limiting the parcel weight that they are capable to carry. Finally, the sensitivity in consideration of the respondents' extraversion as an additional sentimental was exemplary examined. The analysis showed minor, yet recognizable differences between the respondents. Summarized, it is emphasized that the deep-level characteristics of environmental concerns and extraversion influence the decision-making process in a CSD. For practitioners, it is recommended to account for these differences by individualization of CSD requests. Therefore, it is recommended to apply surveys to identify their couriers' sentiments beforehand.

6 Conclusion

The last mile logistics faces major upcoming challenges. Increasing parcel quantities are accompanied by higher customer expectations of immediate delivery, yet causing environmental externalities. CSD represents a complementary for traditional last mile logistics. Based on the principle of crowdsourcing, CSD outsources the last mile delivery to a mass of voluntary couriers via digital platforms. Through the delivery of parcels on premeditated trips with only small deviations from the original route, CSD leads to higher utilization of urban transportation capacities. Whereas first literature deals with CSD attributes that result in the acceptance of a respective delivery, the attributes' relative importance towards others remains unclear. Therefore, a choice-based conjoint analysis was conducted, including 193 respondents who were willing to participate in a CSD concept. Respondents were asked to select one of three different potential CSD requests in 12 scenarios. The CSD requests were distinguished by different levels of delivery time, remuneration, degree of familiarity with the recipient and parcel weight.

The analysis of the relative importance displays that deviation of the original travel time and remuneration had the greatest impact on customers' request selection. The results show that the degree of familiarity with the recipient and parcel's weight were less decisive in a request selection. Based on sensitivity analysis, it became apparent that the sensitivity for the delivery time was higher than for remuneration among all groups. Moreover, results of the sensitivity analysis were further refined for various groups, differentiated by surface-level and deep-level characteristics. By considering the results, a higher individualization of CSD requests is enabled for CSD platform providers, leading to a higher acceptance rate among potential couriers.

Eventually, some limitations need to be mentioned. Firstly, most of the sample had no previous experience in working as a courier. Consequently, they might behave differently when choosing a real CSD request. Secondly, the respondents' motivation for participating in a CSD remained unclear. Further research could explicitly examine the motivation's influence on respondents' decisions. Thirdly, CBC was limited to four attributes of a CSD to limit complexity. Thus, further research might consider other attributes, such as platform usability, delivery day or flexibility of pick up/delivery time.

Appendix

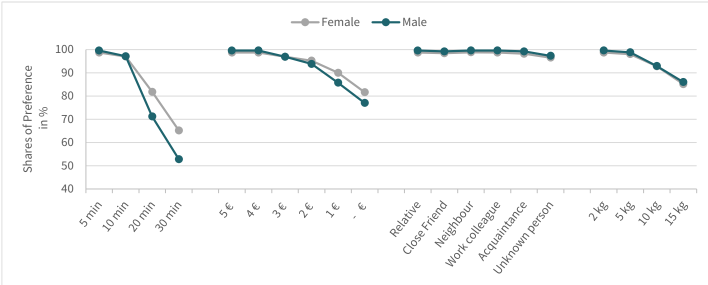

Figure 5: Sensitivity analysis based on gender, own representation

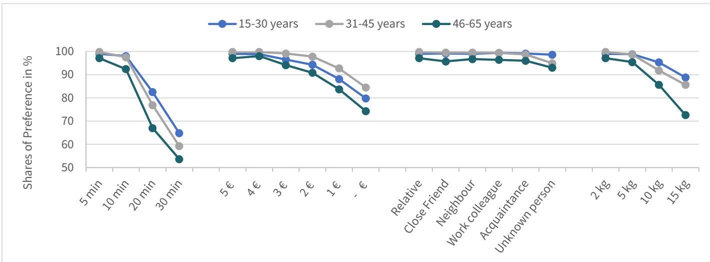

Figure 6: Sensitivity analysis based on age, own representation

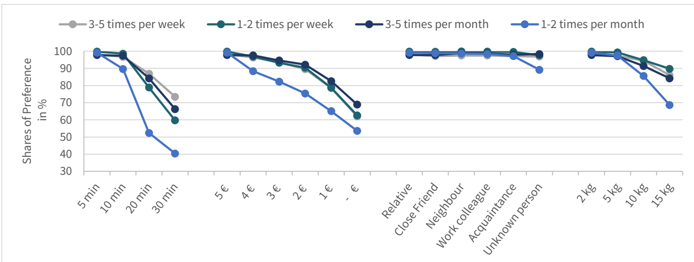

Figure 7: Sensitivity analysis based on the frequency of delivery, own representation

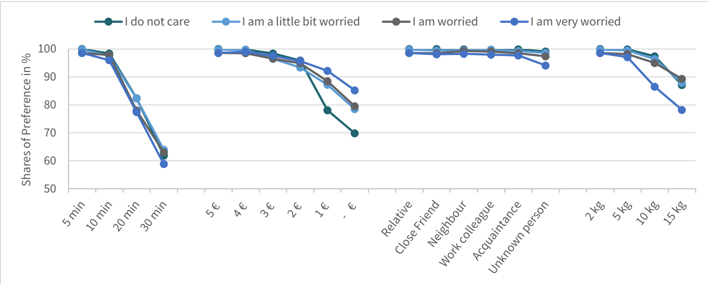

Figure 8: Sensitivity analysis based on environmental concerns, own representation

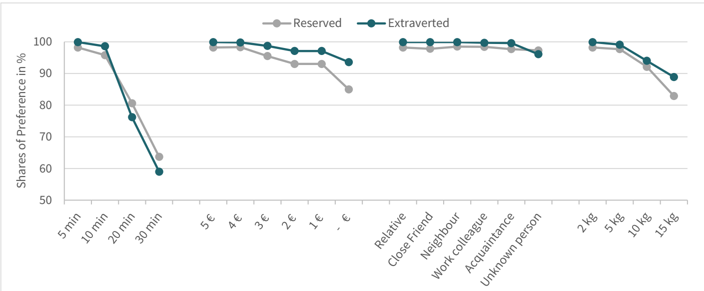

Figure 9: Sensitivity analysis based on extraversion, own representation

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Sustainable Public Transportation using Markov Chains: Case Study Hamburg Public Transportation

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Purpose: *Intelligent public transportation systems have been largely focused on improving the planning, and monitoring the transportation flows during recent years. Advancements in public transportation systems increase service levels and encourage more usage of public transportation. The forecast of buses' arrival time to stations and having a dynamic system to anticipate the real-time possible events for users, significantly increase passenger satisfaction. This paper has studied the literature considering dynamic public transportation systems and also matters of environmental emissions.*

Methodology: *The paper has developed a method to predict bus arrivals at stations by considering the buses' operation parameters and variables with stochastic characteristics by applying Markov Chains. The paper also applied the assignment problem technique and multi-objective planning to enable a framework for public transportation resource assignment considering the perspectives mentioned earlier.*

Findings: *The real data of Hamburg public transportation has been used to verify the capabilities of the platform. The findings show that the model validity of the platform and enabled effective strategic planning for public resource assignment.*

Originality: *This paper has studied the related literature and discussed the considerable gap for proposing a dynamic public transportation system that brings satisfaction from the side of the users and also mutually minimizing environmental emissions.*

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1 Introduction

Public network transportation systems are an indispensable part of each city's composition that the daily lives of many people depend on its structure. Efficient public transport enriches a society for having a dynamic community that could largely impact its inhabitant's quality of life. Many people commute with Public transportation systems and the satisfaction of these people is one of the factors that has been considered always in the planning. However, in addition to the service level of passengers, recently due to the large amount of pollution that produced in this sector, environmental issues have been regarded for implementing a suitable urban transportation planning.

For achieving less CO2 emissions and having a clean environment in the world, all countries in the world must have an integrated program and coordinate fully with each other to implement this program effectively. Germany as one of the pioneer countries in the protection of the environment, discussing and regarding these issues from various aspects, and also, they are working with other countries to fulfill programs for protecting the environment. There is a climate protection plan act 2050 (Klimaschutzplan 2050) that was made by German politicians in 2016 to reduce emissions and greenhouse gases according to a plan by 2050. This plan is also integrated with the Paris Climate Agreement that is agreed on at the international level. According to studies, the transportation sector is one of the main sectors that is not yet reduced its CO2 emissions significantly since the number of cars is getting more on roads, air travel and road freight are increasing.

According to the European Commission studies, 40% of CO2 emissions come directly from urban mobility while up to 70 % of other pollutants also have originality from transportation. This triggers a common challenge to most major cities in Europe, where to intensify movement and increase service level, the congestion, pollution, and environmental criteria should be controlled. Thus, for finding the right responses to this challenge, it is recommended to apply Sustainability Assessment (SA) as a critical tool to analyze the environmental aspects by common SA's criteria (Ribeiro et al., 2020). The importance of sustainability in public transport has got more attention since international laws and domestic regulations are impacting transportation for sustainability concerns. The focus of sustainability is to establish principles on reliably sufficing the requirements of public transportation according to the three pillars: economic, environmental, and social (also known informally as profits, planet, and people). So, SA as an appraisal method can be applied to support long-term and short-term decisions for transportation planning fulfilling the three aforementioned pillars.

In terms of environmental criteria, SA encourages governments to consider main prospects that influence the wellbeing of the environment, such as reducing greenhouse gases and emissions, preserve the ecosystem, and hinder the progress of global warming. In public transportation, the consumption of fuels that produce various air pollutants is the primary concern that effects environmental criteria (Tang et al., 2020). These pollutants mostly incorporate Carbon dioxide, Nitrogen oxides, Methane, and particulates. So, an efficient transport planning system with sustainable considerations must seek to diminish harmful gases. Simultaneously, from the social and economic perspectives, sustainable transportation must consider the preferences of its citizens with the proper transportation service level.

Public transport can be analyzed from two perspectives; in the view of users, the cost of transportation, service level and reliability are among the most favored factors (Mishalan et al., 2006). While from the other perspective, the target is to represent public transport as a viable alternative to self-driving, which both satisfies the logistics requirements of passengers and also will be more successful to fulfill the urban environmental traffic regulations. So, it is a significant challenge that needs a proper solution to fulfill the both citizens' service level and also SA considerations mutually.

The research roadmap is structured as follows. In section 2, the paper has conducted a literature review for studies of Markov Chains in public transportation. In section 3, the problem is formulated. Section 4 discusses the problem based on a case study that considers the Hamburg city center and then reviews the results.

2 Literature Review

The public transportation resource assignment is well-known in literature, see (Guihaire & Hao, 2008) for a comprehensive list of references. (Lin & Bertini, 2002) studied existing algorithm for predicting the bus arrival time to stations at free flow traffic without of congestion consideration. They formulate a Markov Chain to analyze the behavior of a bus in possible scenarios of delays.

(Xiao et al., 2018) obtained the errors state transition probability matrix by employing a Markov Chain model to analyze the error fluctuation of the neural network prediction results. Their results were shown in the rail transit line 6, 7, 13 in Beijing as input data of the model and the volume of passengers are output of the model that verified with rail transit data of line 1 and 2. They also studied its case in Beijing by formulating the spillover effect with Markov Chains. They applied Hidden Markov Chains to identify submarkets as hidden states. Then they obtained the transition probability Matrix and analyze a ranges of spillover type through regression analysis. (Huang et al., 2017) studied the service efficiency in public transportation of China and analyzed the process of delay of buses at bays where they divided delay into two kind of delays as entering delay and exiting delay. Then by forming the queuing model for delay they propose Markov Chains to obtain the steady-state of the equilibrium through calculation of entering delay at bays that are helpful to assess the dwell time distribution and evaluate efficiency of bus bays. (Li, 2014) also combined Markov Chains model with Grey Markov Chain and compare them together, where he also predicted the volume of passengers travel in the bus route.

(Więcek et al., 2019) based on Markov Chain proposed an approach for prediction that were presented based on real-life data in order to optimize energy and cost in the public transport system. They considered the flow of passengers are stochastic to use Markov processes for determining occupancy level of buses and estimating the transition probability Matrix. The Matrix specified according to the historical data set for each bus stop in the heterogeneous Markov Chains. (Rajbhandari et al., 2003) applied Markov Chains in order to determine the propagation of bus delay and propose a model for using these delays of buses in the estimation of bus arrival times. He obtained the transition probability matrix based on Homogeneous and Heterogeneous propagation of delay between time-points for one-way trip bus transport system in New Jersey from Newark Penn's station to Woodbridge center Mall that is last about 1 hour 40 minutes travel time. (Saadi et al., 2016) studied a survey data of Belgian Household daily travel to estimate transport related variable for forecasting travel behavior by Markov Chain. (Şahin, 2017) reviewed the sequence of train departure and arrival times in stochastic process by using Markov Chains, where all the delays at stations were considered as possible states and the fluctuations among them were predict possible scenarios to predict steady state delay probabilities.

(Huang et al., 2017) focused on optimizing the bus standard driving stile based on route conditions and efficient fuel consumption, where predicted driving cycles of specific bus routes. They proposed an estimation model between 27 inter-stations, which four of them were represented the driving cycles features among all stations based on the multiple linear regression model. Iterative Markov Chains was applied for the bus lines assignment. (Delaram & Valilai, 2016) the mutual service level satisfaction of passengers, and environmental emissions in public transportation are considered as a motivational gap for this research. (Sodachi et al., 2020) optimized transportation planning in Hamburg city center regarding efficient of service level and minimizing emissions. They propose the routes that buses can travel while all stations are visited and passengers' satisfaction are adapted. This paper contributed to the (Sodachi et al., 2020) and studied its result from the other point of view to propose new solution to the model and also by employing the Markov Chains properties, analyze and forecast the delay at the assumed stations of the proposed model accordingly.

From the related literature, it is clear that the goal of the most of papers was to predict possible time delay at stations through obtaining the transitions probabilities of the Markov Chains model in various perspectives. They pursued this through the side of the passengers and they main goal was to predict possible delays in order to enhancing customer satisfaction. In this paper as well, we seek to maintain high service level, but also from the model we considering SA criteria as well. Thus, the Markov Chains is applied on the model that both optimizing service level from the side of passengers and environmental emissions from the side of SA.

3 Problem Formulation

In this section, the main goal is to implement a dynamic transportation model on (Sodachi et al., 2020) model by considering Markov Process properties. By this, we can mutually observe sustainability assessment issues in transportation from one side and also the passengers' satisfaction from the other side through predicting delays. According to literature, sustainability in transportation is an important trend that most developed countries are planning and seeking to adapt fully its criteria. So, it is not possible only to optimize the model from the side of the passengers. For this reason, achieving the sustainable transportation model is very crucial and the paper target here is to propose a dynamic transportation system that is mutually suitable for customer satisfaction, and friendly working peace to the environment. Due to this, the paper aims to study the results of the previous paper by (Sodachi et al., 2020). According to upcoming subsections, the paper first analyzes the sustainability assessment criteria in public transportation and review the results of references. Then for having a dynamic model in transportation, the Markov Process is applied to determine bus delay's propagation that is a basis for employing bus delay in the prediction of bus arrival time.

3.1 Sustainable Public Transportation with Service Level Efficiency

Sustainability assessment in public transportation depends on various criteria. The study of sustainability is not limited only to environmental metrics such as CO2 emissions. However, according to the literature, the impact of CO2 emissions is much more significant. For observing the most effective criteria in public transportation, the minimization of CO2 emissions and waiting time of passengers at stations were studied (Sodachi et al., 2020).

They minimized both the emissions of buses and the waiting time of passengers at stations by a Multi-Objective Optimization Problem (MOOP). The objective function of fuel consumption of buses is obtained based on three factors: the vehicle type, the distance traveled, and the load carrier as follows (Molina et al., 2014).

$$\min(F) = min \sum_{i}\sum_{j}\sum_{k}\sum_{t} ef^{CO_2r}.d_{ij}.x_{ijt}^{K}\left(fe^{K} + feu^{K}.L_{ij}^{K}\right) \tag{1}$$

Where the parameter of (1) are as following

ef^{CO_2r}: The amount of CO_2 emitted per unit of fuel consumed as an emission factor

fe^{K}: The amount of fuel consumed while the vehicle is empty

feu^{K}: The amount of fuel consumed based on the additional load in the vehicle

L_{ij}^{K}: The load carried by the vehicle between the considered stations

The mathematical model for minimizing the waiting time of passengers at stations is proposed according to the following equation

$$\min\left(\overline{W_j}\right) = \min \sum_{j=1}^{n} (h_j - \frac{\lambda_j\left(\lambda_j - 1\right)}{2.h_j})$$

$$= \min \sum_{j=1}^{n} (\sum_{K} y_{jt}^{k} - \sum_{K} y_{j(t-1)}^{k} - \frac{\lambda_j\left(\lambda_j - 1\right)}{2\left(\sum_{K} y_{jt}^{k} - \sum_{K} y_{j(t-1)}^{k}\right)}) \tag{2}$$

while (2) constraints are

$$\sum_{j=1}^{n} x_{0jt}^{k} = 1 \qquad \forall t,k \tag{3}$$

$$\sum_{j=1,j\neq i}^{n} x_{ijt}^{k} - \sum_{j=1,j\neq i}^{n} x_{jit}^{k} = 0 \qquad \forall i,t,k \tag{4}$$

$$\sum_{k=1}^{m}\sum_{i=1}^{n} x_{ijt}^{k} = 1 \qquad \forall j,t \tag{5}$$

$$\sum_{i=1,i\neq j}^{n}\sum_{k=1}^{m} x_{ijt}^{k}\left(y_{it}^{k} - y_{jt}^{k}\right) = 0 \tag{6}$$

$$\begin{cases} y_{jt}^{k} \geq x_{0jt}^{k}.t_{0j} & \forall k,t \\ y_{jt}^{k} = \sum_{i=1}^{n} xy_{ijt}^{k} + x_{ijt}^{k} * s_{i}^{k} + x_{ijt}^{k} * t_{ij} & \forall j,t,k \\ xy_{ijt}^{k} \leq M.x_{ijt}^{k} & \forall i,j,t,k \\ M\left(1 - x_{ijt}^{k}\right) + xy_{ijt}^{k} \geq y_{it}^{k} & \forall i,j,t,k \\ xy_{ijt}^{k} \leq y_{it}^{k} & \forall i,j,t,k \end{cases} \tag{7}$$

$$\begin{cases} y_{it}^{k} + s_{j}^{k} + t_{ij} \leq y_{jt}^{k} + T^{k}\left(1 - x_{ijt}^{k}\right) \\ t_{0j} \leq y_{jt}^{k} + T^{k}\left(1 - x_{0jt}^{k}\right) \end{cases} \tag{8}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{n} x_{ijt}^{k}(t_{ij} + s_{j}^{k}) \leq T^{k} \quad \forall t,k \tag{9}$$

$$\begin{cases} xy_{ijt}^{k} \geq 0 & \forall i,j,t,k \\ y_{ijt}^{k} \geq 0 & \forall i,j,t,k \\ x_{ijt}^{k} = (0,1) & \forall i,j,t,k \end{cases} \tag{10}$$

The parameters were defined according to the Vehicle Routing Problem as following

$$G(V,A): \begin{cases} V = (v_0, v_1, \dots, v_n),\ v_0\text{: } depot,\ V' = V\backslash\{v_0\}\text{: } Stations \\ A = \left\{(v_i, v_j) \middle| v_i, v_j \in V, i \neq j\right\} \end{cases}$$

$K = (k_1, k_2, \dots, k_m)$: Vehicles which are assigned individually to each route,

d_{ij}: Distance between station i and j,

t_{ij}: Travel time between different stations,

T^k: Maximum allowing travel time for vehicle k,

S_i^k: Service time at station i.

And also, Decision Variables are:

$x_{ijt}^{k}: \begin{cases} 1, & If\ vehicle\ k\ travel\ from\ station\ i\ to\ j\ at\ period\ t \\ 0, & Otherwise \end{cases}$,

y_{jt}^{k}: Arrival time of vehicle k at station j in period t,

xy_{ijt}^{k}: Dummy variable for linearization, By y_{jt}^{k} definition, the headway at station j could be obtained as

$$h_j = \sum_{K} y_{jt}^{k} - \sum_{K} y_{j(t-1)}^{k} \tag{11}$$

3.2 Transportation Delays with Markov Process

In this section, the dynamic transportation system is considered in order to obtain the propagation of bus delays. For this reason, a Markov process has been applied to predict bus arrival times. Traffic condition situations can be categorized into homogeneous and heterogeneous, which could be predicted with transition probabilities. For the construction of transition probabilities of a Markov Chain, it is required all possible states are defined in transportation based on delays between time points. Hence, the states for the delay in bus transportation could be categorized at each time-points regards to three states as the arrival of bus exactly according to the determined scheduled, early arrival, and late arrival. These states are debriefed with “e” for early arrival, “l” for late arrival, and “o” for on-time arrival.

By knowing the possible states, then the transition probabilities between these states are calculated as follows:

$$P_{ij}^{r} = \frac{n_i}{\sum_{j=1}^{m} n_{ij}}, m \in \{1,2,3\}, r \in \{r_1, r_2, \dots, r_r, \dots, r_R\} \tag{12}$$

Where,

m: Total number of delay states that are classified into three mentioned states,

n_{ij}: number of events that states jump from i to j,

r: number of time-points

So, the matrix of transition probabilities is obtained as follows:

$$P_{ij} = \begin{bmatrix} p_{11} & p_{12} & p_{13} \\ p_{21} & p_{22} & p_{23} \\ p_{31} & p_{32} & p_{33} \end{bmatrix} = \begin{bmatrix} ee & el & eo \\ le & ll & lo \\ oe & ol & oo \end{bmatrix} \tag{13}$$

As shown in (4) each p_{ij} determines the probability of being in a state delay j at downstream time-point, while the upstream time-point has a delay state of i. For example, p_{11} represents the probability where the delay state is “early” at the downstream time-point, while the delay state at the origin time-point is also “early”. So, for obtaining the transition probabilities, it is required to combinate the upstream time-point delay state and downstream time point delay state as shown in the next section.

3.3 Prediction of Transition Probabilities

In transportation, transition probabilities for Markov Chains are calculated to determine the possibility of fluctuation based on all available states with the combinations of time points. In transportation planning, these transition probabilities are computed based on homogeneous and heterogeneous propagation of time delay between time-points, where these transition probabilities of delay states are predicted at time-points regarding time-point originality.

Assume downstream time-point r_R and r_1 based on homogeneous delay propagation are determined as follows:

$$P_{r_1-r_R} = P_{r_1-r_2} \times P_{r_2-r_3} \times \ldots \times P_{r_{R-1}-r_R} \tag{14}$$

Because of the homogeneous delay propagation, all these probabilities are equal as follows:

$$P_{r_1-r_2} = P_{r_2-r_3} = P_{r_3-r_2} = \cdots = P_{r_{R-1}-r_R} \tag{15}$$

$$P_{r_1-r_R} = (P_{r_1-r_2})^R = \begin{bmatrix} ee & el & eo \\ le & ll & lo \\ oe & ol & oo \end{bmatrix}_{r_1-r_2}^R \tag{16}$$

Similarly transition probabilities between downstream time-points $r_{R-1}$and r_1, and also finally $r_{R-2}$and r_1 based on homogeneous delay propagation are determined as follows:

$$P_{r_1-r_{R-1}} = (P_{r_1-r_2})^{R-1} = \begin{bmatrix} ee & el & eo \\ le & ll & lo \\ oe & ol & oo \end{bmatrix}_{r_1-r_2}^{R-1} \tag{17}$$

$$P_{r_1-r_2} = \begin{bmatrix} ee & el & eo \\ le & ll & lo \\ oe & ol & oo \end{bmatrix}_{r_1-r_2} \tag{18}$$

On the other hand, if the propagation of time delays is considered heterogeneous, then the predicted time delay at downstream time point r_R and r_1 are as following:

$$P_{r_1-r_R} = P_{r_1-r_2} * P_{r_2-r_3} * \dots * P_{r_{r-1}-r_r} * P_{r_{r-1}-r_r} * P_{r_r-r_{r+1}} * \dots * P_{r_{R-1}-r_R} \quad (19)$$

$$P_{r_1-r_2} \neq P_{r_2-r_3} \neq P_{r_3-r_2} \neq \cdots \neq P_{r_{R-1}-r_R} \quad (20)$$

$$P_{r_1-r_R} = \begin{bmatrix} ee & el & eo \\ le & ll & lo \\ oe & ol & oo \end{bmatrix}_{r_1-r_2} \times \begin{bmatrix} ee & el & eo \\ le & ll & lo \\ oe & ol & oo \end{bmatrix}_{r_2-r_3} \times \dots \times \begin{bmatrix} ee & el & eo \\ le & ll & lo \\ oe & ol & oo \end{bmatrix}_{r_{R-1}-r_R} \quad (21)$$

Therefore, by using above equations, the $P_{ij}^{r}$for all downstream time-points were determined concerning time-point r_1.

4 Case Study

Efficient public transportation in Hamburg is a very important topic from various aspects. Hamburg is known as a free and Hanseatic city that is the second-largest city in Germany after Berlin and also the 7th largest city in the European Union with a population of over 1.84 million (Wikipedia). Hamburg has a strategic position among German cities and because of its key role in the German economy, it is required to have optimized public transportation since, in large cities as Hamburg, public transportation has an enormous effect on the everyday life of its inhabitants, and it is a significant role for the dynamic face of the city. Accessibility to transportation or easy access, level of service, comfortability, effectiveness, the value of cost, and other aspects are major factors that encourage people to use public transportation in their everyday travels. But from the other side, the change in the structures of the cities and the human manipulation cause a gigantic effect on the environment. Sustainability criteria in general and protection of the environment are issues that are indispensable in future public transportation planning. So, optimization of public transportation without consideration of sustainability is not enough and complete. Certainly, sustainability in general and environmental protection, in particular, is one of the main issues that is a trend for policymaking in most governments.

According to Hamburg municipality divisions, Hamburg is divided into five rings that most of the city covered with rings A and B around the city center. Other rings are covering other parts up to 60 km far from the city. The most strategic and populous part of Hamburg is covered with rings A and B based on Figure 1.

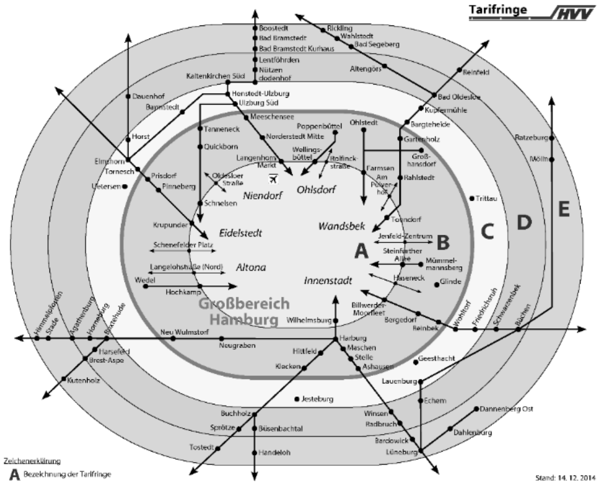

Figure 1: Divisions of Hamburg and its suburbs into Rings, (adapted from www.nimmbus.de)

Based on Figure 2, this paper focused on city center that is part of the city in Ring A since it is crowded with a high demand of a large number of passengers that they use everyday travels around the city. In this region, there are some fixed stations as nodes as shown in Figure 3. All possible direct travel between these stations is also determined in this figure. Table 1 also indicates the available stations by their names and determined numbers.

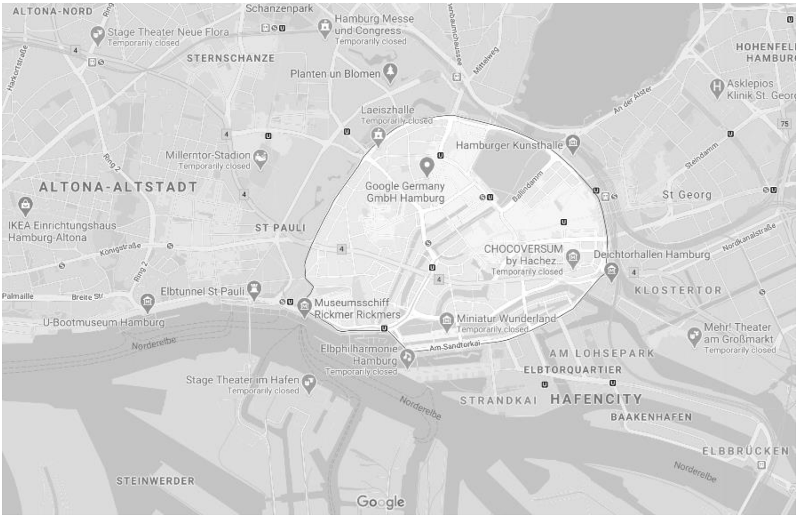

Figure 28: City center of Hamburg that is focused area in this paper obtained from Google© (Date 03/2021)

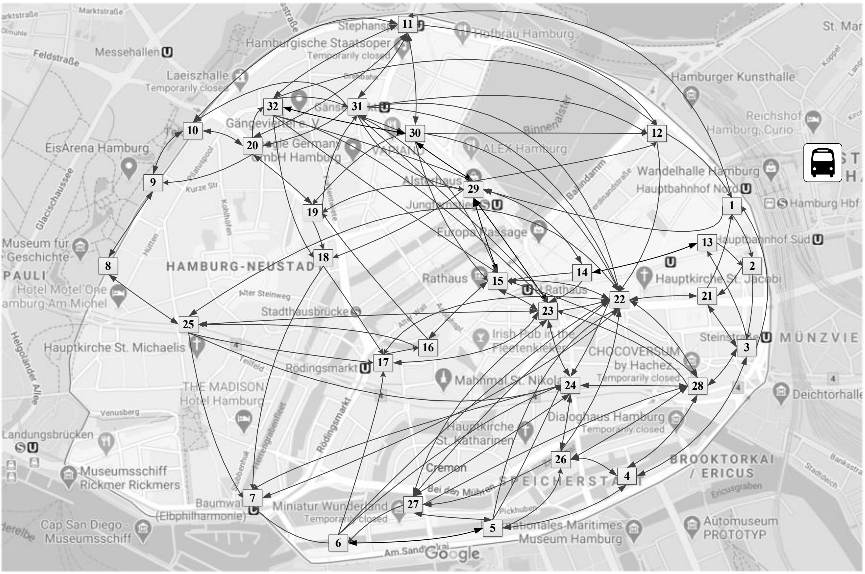

Figure 3: Bus stations in Hamburg city center and related connecting graph obtained from Google© (Date 03/2021)

Table 1: Bus stations in the Hamburg city center

1	HBF/ Spitalerstraße	9	Handwerkskammer	17	U Rödingsmarkt 2	25	Michaeliskirche
2	Hauptbhf./ Steintorwall	10	Johannes-Brahms-Platz 1	18	Axel Springer Square 1	26	Bei St Annen

1	HBF/ Spitalerstraße	9	Handwerkskammer	17	U Rödingsmarkt 2	25	Michaeliskirche
3	U Steinstraße (Deichtorplatz)	11	U Stephansplatz	19	Axel Springer Square 2	27	Auf dem Sande (Speicherstadt)
4	Singapurstraße	12	Kunsthalle	20	Johannes-Brahms-Platz 2	28	Meßberg
5	Am Sandtorkai	13	HBF/Mönckebergstraße	21	U Steinstraße	29	US Jungfernstieg
6	Am Kaiserkai	14	Gerhard Hauptmann Square	22	Jakobikirchof	30	U Gänsemarkt
7	Baumwall	15	Rathausemarkt	23	Rathausemarkt (Petrikirche)	31	Valentinskamp
8	Museum für Hamburgische	16	U Rödingsmarkt 1	24	Brandstwiete	32	Dragonerstall

Sodachi et al. (2020) found the optimum routes which incorporate all stations effectively for minimizing the waiting time of the passengers at these stations and simultaneously minimizing effectively the produced environmental emissions such as CO2 by buses that are traveling around this region. In Figure 4 the optimum assigned routes of buses based on the two objective functions are determined.

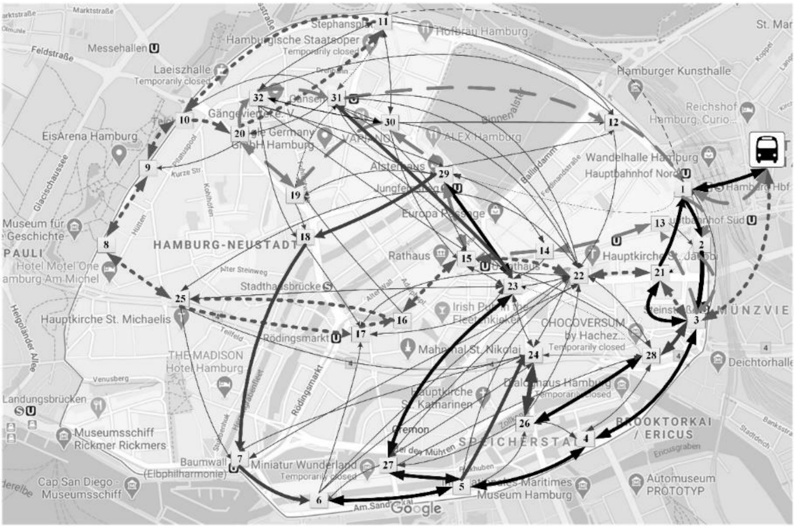

Figure 4: Graph of optimum assigned routes for three buses obtained from Sodachi et al. (2020)

They find three lines of travel for the transportation of buses in the city center. According to Figure 4, by assigning buses to these lines, the service level of passengers would be enhanced. According to the calculations, the waiting time of passengers decreased 20% and also environmental emissions was decreased largely accordingly. So, this model is worked properly both for the protection of the environment and also satisfying passengers. However, this model was not considered the propagation of bus delays in the downstream time points. The model just found the optimum routes for traveling in order to protect the environment and enhance service level in general. But time-delays in traveling specifically in some part-time of the day could differ situation for traveling. So, the proposed model could be remodeled based on dynamic conditions.

Arrival time at stops is developed by using a stochastic approach to predict bus travel time and propagation of bus delays in the determined lines in Figure 4. In each line, buses are traveling in processes that include travel time data correspond to periods. Generally, a bus starts its travel in a specific time-points and then finishes the travel in another specific time-points. The interval between successive time points is standard traveling time. Standard traveling time obtains from the difference between the bus door open time at the following stop and this door close time at the preceding stop. Table 2 demonstrate the standard time-points between stations and also the length of travel between these three lines continuously. In this Table, the depot is considered a place around the central rail station that from where buses are started their travels and then after the service in each line they will back again to this assumed location as the depot.

Table 2: The standard time-points between stations of each line (Blue, Black, and Red lines)

stations numbers (Blue line)	starting time-point	ending time-point	Length
Depot - 1	0	0.5	110
1-2	0.5	1.5	220
2-3	1.5	2.3	180
3-13	2.3	8.5	1600
13-14	8.5	10	400
14-15	10	11	300
15-29	11	12	260

stations numbers (Blue line)	starting time-point	ending time-point	Length
29-30	12	13	450
30-19	13	15	600
19-20	15	16	350
20-32	16	17	300
32-31	17	17.5	150
31-12	17.5	22	1300
12-1	22	24.5	500

stations numbers (Black Line)	starting time-point	ending time-point	Length
Depot - 1	0	0.5	110
1-2	0.5	1.5	220
2-3	1.5	2.3	180
3-4	2.3	5	1000

stations numbers (Blue line)	starting time-point	ending time-point	Length
4-5	5	6	220
5-27	6	7	230
27-23	7	11	1100
23-29	11	14	850
29-18	14	16	700
18-7	16	19	1100
7-6	19	21	550
6-5	21	22	450
5-24	22	24	700
24-26	24	25	180
26-28	25	26	450
28-3	26	27	450
3-21	27	28.5	400

stations numbers (Blue line)	starting time-point	ending time-point	Length
21-1	28.5	30	450
1 - Depot	30	30.5	110

stations numbers (Red line)	starting time-point	ending time-point	Length
Depot - 3	0	1.5	510
3-21	1.5	3	400
21-22	3	4	350
22-15	4	5.5	450
15-16	5.5	7	500
16-25	7	9.5	850
25-8	9.5	11	450
8-9	11	12	300
9-10	12	12.7	150

stations numbers (Red line)	starting time-point	ending time-point	Length
10-20	12.7	13.25	100
20-11	13.25	15	710
11-10	15	17	800
10-9	17	17.7	150
9-8	17.7	18.7	300
8-25	18.7	20	450
25-17	20	23	650
17-16	23	23.5	100
16-15	23.5	25	500
15-22	25	27	500
22-21	27	28	350
21-3	28	29.5	400
3 – Depot	29.5	31	510

For estimation of bus delay propagation in each station with the formulation of the Markov process, it is required to obtain transition probabilities of delay states between time points. As in the previous section mentioned, the number of observed delays is classified as early arrival or "E", late arrival or "L", and on-time arrival or "O". By using the (19) and (20) relationships, the transition probabilities in each line are determined as shown in Table 3, Table 4, and Table 5, respectively. These transition probabilities are obtained based on the Maximum Likelihood Estimation between time points.

Table 3: The standard time-points between stations of line 2 (Black line)

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
E	0.5	0.5	0	0	0.5	Depot – 1
L	0	0.9003	0.0997			
O	0.007	0.112	0.881			
E	0.795	0.004	0.201	0.5	1.5	1-2
L	0.033	0.713	0.254			
O	0.02	0.11	0.87			
E	0.732	0.004	0.264	1.5	2.3	2-3
L	0.008	0.782	0.21			
O	0.025	0.11	0.865			
E	0.48	0.23	0.29	2.3	8.5	3-13
L	0	0.921	0.079			

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
O	0.048	0.42	0.532			
E	0.89	0.053	0.057	8.5	10	13-14
L	0.03	0.66	0.31			
O	0.06	0.21	0.73			
E	0.55	0.03	0.42	10	11	14-15
L	0.036	0.584	0.38			
O	0	0.189	0.811			
E	0.41	0.12	0.47	11	12	15-29
L	0	0.89	0.11			
O	0.04	0.35	0.61			
E	0.84	0.04	0.12	12	13	29-30
L	0.0231	0.6339	0.343			
O	0	0.22	0.78			
E	0.529	0.006	0.465	13	15	30-19
L	0	0.728	0.272			
O	0.11	0.3	0.59			

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
E	0.71	0.002	0.288	15	16	19-20
L	0.011	0.559	0.43			
O	0.026	0.28	0.694			
E	0.81	0	0.19	16	17	20-32
L	0.008	0.502	0.49			
O	0.013	0.267	0.72			
E	0.82	0.0303	0.1497	17	17.5	32-31
L	0.02	0.66	0.32			
O	0.05	0.22	0.73			
E	0.322	0.54	0.138	17.5	22	31-12
L	0	0.89	0.11			
O	0	0.743	0.257			
E	0.586	0.12	0.294	22	24.5	12-1
L	0.07	0.59	0.34			
O	0.13	0.26	0.61			
E	0.48	0.52	0	24.5	25	1 – Depot

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
L	0.05	0.81	0.14			
O	0.002	0.15	0.848			

According to Table 3, transition probabilities between stations of Line 1 show that when a bus starts its route on time, then it would with great possibility arrive on time on next downstream stations 1, 2, and 3, respectively. However, results show that this on-time arrival contradicts travel between stations 3 and 13. It means here the bus may encounter some traffic or route problems that the late arrival has more possibility. This situation repeats between stations 31 and 12. However, among other stations, there are not any critical issues and when a bus starts its travel according to the time plan then it would arrive at the next station with satisfaction planning.

Table 4: The standard time-points between stations of line 3 (Red line color)

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
E	0.5	0.5	0	0	0.5	Depot – 1
L	0	0.9003	0.0997			
O	0.007	0.112	0.881			
E	0.795	0.004	0.201	0.5	1.5	1-2
L	0.033	0.713	0.254			
O	0.02	0.11	0.87			

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
E	0.732	0.004	0.264	1.5	2.3	2-3
L	0.008	0.782	0.21			
O	0.025	0.11	0.865			
E	0.48	0.23	0.29	2.3	8.5	3-13
L	0	0.921	0.079			
O	0.048	0.42	0.532			
E	0.89	0.053	0.057	8.5	10	13-14
L	0.03	0.66	0.31			
O	0.06	0.21	0.73			
E	0.55	0.03	0.42	10	11	14-15
L	0.036	0.584	0.38			
O	0	0.189	0.811			
E	0.41	0.12	0.47	11	12	15-29
L	0	0.89	0.11			
O	0.04	0.35	0.61			
E	0.84	0.04	0.12	12	13	29-30

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
L	0.0231	0.6339	0.343			
O	0	0.22	0.78			
E	0.529	0.006	0.465	13	15	30-19
L	0	0.728	0.272			
O	0.11	0.3	0.59			
E	0.71	0.002	0.288	15	16	19-20
L	0.011	0.559	0.43			
O	0.026	0.28	0.694			
E	0.81	0	0.19	16	17	20-32
L	0.008	0.502	0.49			
O	0.013	0.267	0.72			
E	0.82	0.0303	0.1497	17	17.5	32-31
L	0.02	0.66	0.32			
O	0.05	0.22	0.73			
E	0.322	0.54	0.138	17.5	22	31-12
L	0	0.89	0.11			

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
O	0	0.743	0.257			
E	0.586	0.12	0.294	22	24.5	12-1
L	0.07	0.59	0.34			
O	0.13	0.26	0.61			
E	0.48	0.52	0	24.5	25	1 – Depot
L	0.05	0.81	0.14			
O	0.002	0.15	0.848			

Results of transition probabilities between stations in Table 4 shows that when a bus starts its route on time, then it would with great possibility arrive on time to next downstream stations 1, 2, 3, 4, 5, and also with about 0.6 probability arrive on time from station 5 to station 27. However, results show that this on-time arrival contradicts between stations 27 and 23 that just with 0.22 probability it arrives on time while it was departed on time. Similarly, it means here the bus may encounter some traffic or route problems that the late arrival has more possibility. This situation repeats between stations 18 and 7 and stations 3 and 21. Table 4 also shows late arrival somehow between stations 5 and 24 and stations 26 and 28 has a considerable possibility that could not be ignored. However, among other stations, there are not any critical issues and when a bus starts its travel according to the time plan then it would arrive at the next station with an expected suitable time scheduling.

Table 5:Transition probabilities between time-points of line 1 (Blue line)

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
E	0.562	0.104	0.334	0	1.5	Depot – 3
L	0.005	0.63	0.365			
O	0.025	0.44	0.535			
E	0.74	0.03	0.23	1.5	3	3—21
L	0.04	0.44	0.52			
O	0.08	0.28	0.64			
E	0.75	0.016	0.234	3	4	21—22
L	0.13	0.43	0.44			
O	0.016	0.34	0.644			
E	0.474	0.12	0.406	4	5.5	22—15
L	0	0.872	0.128			
O	0	0.38	0.62			
E	0.495	0.15	0.355	5.5	7	15—16
L	0	0.834	0.166			
O	0.04	0.24	0.72			

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
E	0.354	0.245	0.401	7	9.5	16—25
L	0	0.932	0.068			
O	0	0.634	0.366			
E	0.685	0.13	0.185	9.5	11	25—8
L	0.018	0.422	0.56			
O	0.08	0.3	0.675			
E	0.46	0.07	0.47	11	12	8—9
L	0.04	0.63	0.33			
O	0.013	0.27	0.717			
E	0.53	0.03	0.44	12	12.7	9—10
L	0.008	0.632	0.36			
O	0.007	0.3	0.693			
E	0.43	0.021	0.549	12.7	13.25	10—20
L	0.075	0.68	0.245			
O	0.072	0.2	0.728			
E	0.289	0.26	0.451	13.25	15	20—11

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
L	0	0.81	0.19			
O	0	0.53	0.47			
E	0.485	0.1	0.415	15	17	11—10
L	0.003	0.71	0.287			
O	0.01	0.27	0.72			
E	0.51	0.05	0.44	17	17.7	10—9
L	0.01	0.76	0.23			
O	0.088	0.211	0.701			
E	0.449	0.12	0.431	17.7	18.7	9—8
L	0.008	0.71	0.282			
O	0.029	0.301	0.67			
E	0.73	0.073	0.197	18.7	20	8—25
L	0.1	0.49	0.41			
O	0.025	0.245	0.73			
E	0.32	0.28	0.4	20	23	25—17
L	0	0.86	0.14			

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
O	0	0.66	0.34			
E	0.56	0.03	0.41	23	23.5	17—16
L	0.028	0.77	0.202			
O	0.01	0.3	0.69			
E	0.43	0.089	0.481	23.5	25	16—15
L	0	0.92	0.08			
O	0.03	0.29	0.68			
E	0.44	0.08	0.48	25	27	15—22
L	0.005	0.839	0.156			
O	0.03	0.35	0.62			
E	0.772	0.018	0.21	27	28	22—21
L	0.13	0.41	0.46			
O	0.041	0.319	0.64			
E	0.781	0.02	0.199	28	29.5	21—3
L	0.038	0.47	0.492			
O	0.026	0.374	0.6			

	E	L	O	Upstream Time-Point	Downstream Time-Point	Station
E	0.493	0.127	0.38	29.5	31	3-Depot
L	0.02	0.66	0.32			
O	0.007	0.49	0.503			

Finally, for the third line, the results of Table 5 show that when a bus starts its route planning according to the time plan, due to the route and also the possible traffic around the central rail stations the bus may arrive with substantial delay to the next station, station number 3. But the bus can continue its travel without any significant delay from station 3 to other stations till station 16, where between station 16 and station 25 there is much more possible considerable delay. In addition, between stations 25 and 17, and between stations 20 and 11 are possible delays that are encountering delays that are greater than on-time arrival.

For prediction of transition probabilities for each line of transportation for all mentioned time-points in transportation routes, Markov Chains based on both homogeneous and heterogeneous propagation of time delay between time-points is applied. First assuming homogeneous time delay propagation between time-points of Table 2 stations. Based on (20) the transition probabilities are as following:

$$P^{T2}_{r_{Depot}-r_{Depot}} = P_{r_{Depot}-r_1} \times P_{r_1-r_2} \times \ldots \times P_{r_{12}-r_1} \times P_{r_1-r_{Depot}}$$

Due to the homogeneous assumption all transition probabilities between two successive time-point are equal as follows:

$$P_{r_{Depot}-r_1} = P_{r_1-r_2} = P_{r_2-r_3} = P_{r_3-r_{13}} = \cdots = P_{r_{12}-r_1} = P_{r_1-r_{Depot}}$$

Therefore, the transition probability for this line is as following:

$$P^{T2}_{r_{Depot}-r_{Depot}} = (P_{r_{Depot}-r_1})^{15} = \begin{bmatrix} 0.5 & 0 & 0,5 \\ 0 & 0.9003 & 0.0997 \\ 0.007 & 0.112 & 0.881 \end{bmatrix}^{15}_{r_{Depot}-r_1}$$
$$= \begin{bmatrix} 0.006482 & 0.529496 & 0.464022 \\ 0.006221 & 0.539603 & 0.454176 \\ 0.006907 & 0.510373 & 0.48272 \end{bmatrix}$$

On the other side, if considering the propagation of delay between time-points is heterogenous, then the predicted delay for the line is computed as following:

$$P_{r_{Depot}-r_1} \neq P_{r_1-r_2} \neq P_{r_2-r_3} \neq P_{r_3-r_{13}} \neq \cdots \neq P_{r_{12}-r_1} \neq P_{r_1-r_{Depot}}$$

$$P^{T2}_{r_{Depot}-r_{Depot}} = \begin{bmatrix} 0.5 & 0 & 0,5 \\ 0 & 0.9003 & 0.0997 \\ 0.007 & 0.112 & 0.881 \end{bmatrix}_{r_1-r_2} \times \begin{bmatrix} 0.795 & 0.004 & 0.201 \\ 0.033 & 0.713 & 0.254 \\ 0.02 & 0.11 & 0.87 \end{bmatrix}_{r_2-r_3} \times \ldots$$
$$\times \begin{bmatrix} 0.48 & 0.52 & 0 \\ 0.05 & 0.81 & 0.14 \\ 0.002 & 0.15 & 0.848 \end{bmatrix}_{r_1-r_{Depot}}$$
$$= \begin{bmatrix} 0.073457 & 0.523654 & 0.402889 \\ 0.073121 & 0.523804 & 0.403075 \\ 0.073195 & 0.52377 & 0.403035 \end{bmatrix}$$

Similarly, for the two other lines as in Table 3 and Table 4, the computation of transition probabilities for the homogeneous assumption of propagation of delay between time-points are the same as (18) according to the following matrices.

$$P^{T3}_{r_{Depot}-r_{Depot}} = (P_{r_{Depot}-r_1})^{19} = \begin{bmatrix} 0.5 & 0 & 0,5 \\ 0 & 0.9003 & 0.0997 \\ 0.007 & 0.112 & 0.881 \end{bmatrix}^{19}_{r_{Depot}-r_1}$$
$$= \begin{bmatrix} 0.006516 & 0.527113 & 0.466372 \\ 0.006421 & 0.531071 & 0.462508 \\ 0.00669 & 0.519632 & 0,473678 \end{bmatrix}$$

$$P^{T4}_{r_{Depot}-r_{Depot}} = (P_{r_{Depot}-r_3})^{22} = \begin{bmatrix} 0.562 & 0.104 & 0,334 \\ 0,005 & 0.63 & 0.365 \\ 0,025 & 0.44 & 0.535 \end{bmatrix}^{22}_{r_{Depot}-r_3}$$
$$= \begin{bmatrix} 0.03109 & 0.530312 & 0.438598 \\ 0.031088 & 0.530314 & 0.438598 \\ 0.031088 & 0.530314 & 0.438598 \end{bmatrix}$$

And accordingly, while the propagation of time delay between time-points is heterogeneous, then based on (7) the transition probabilities for the line are as follows, respectively:

$$P^{T3}_{r_{Depot}-r_{Depot}} = \begin{bmatrix} 0.5 & 0 & 0,5 \\ 0 & 0.9003 & 0.0997 \\ 0.007 & 0.112 & 0.881 \end{bmatrix}_{r_{Depot}-r_1} \times \begin{bmatrix} 0.795 & 0.004 & 0.201 \\ 0.033 & 0.713 & 0.254 \\ 0.02 & 0.11 & 0.87 \end{bmatrix}_{r_1-r_2} \times \dots \times \begin{bmatrix} 0.48 & 0.52 & 0 \\ 0.05 & 0.81 & 0.14 \\ 0.002 & 0.15 & 0.848 \end{bmatrix}_{r_1-r_{Depot}} = \begin{bmatrix} 0,083427 & 0,551018 & 0,365554 \\ 083427 & 0,551018 & 0,365554 \\ 083427 & 0,551018 & 0,365554 \end{bmatrix}$$

$$P^{T4}_{r_{Depot}-r_{Depot}} = \begin{bmatrix} 0.562 & 0.104 & 0,334 \\ 0,005 & 0.63 & 0.365 \\ 0.025 & 0.44 & 0.535 \end{bmatrix}_{r_{Depot}-r_3} \times \begin{bmatrix} 0.74 & 0.03 & 0.23 \\ 0.04 & 0.44 & 0.52 \\ 0.08 & 0.28 & 0.64 \end{bmatrix}_{r_3-r_{21}} \times \dots \times \begin{bmatrix} 0.493 & 0.127 & 0,38 \\ 0.02 & 0.66 & 0.32 \\ 0.007 & 0.49 & 0.503 \end{bmatrix}_{r_3-r_{Depot}} = \begin{bmatrix} 0,070961 & 0,515553 & 0,426346 \\ 0,070845 & 0,514709 & 0,425648 \\ 0,070851 & 0,514755 & 0,425686 \end{bmatrix}$$

5 Conclusions

The efficient public transportation system in large cities is significantly contributed to the inhabitants' quality of life. Having a public transportation system that works properly based on dynamic planning, and also have a cost-effective program encourages more and more people to use them for their daily traveling. By having a dynamic public transportation system, not only does the service level of passengers increase, but also most criteria of sustainability assessment as environment, society, and economic perspectives would be observed. From the previous paper, (Sodachi et al., 2020), it is concluded that proper management of public transportation creates paradoxical challenges for fulfilling the mutual service level satisfaction for the passengers and also the environmental perspective considerations. According to the Vehicle Routing Problem technique and also proposing a multi-objective optimization planning model, the best possible routes are obtained that simultaneously regarding service level of users and reduced emissions. This paper has also studied the obtained results and discussed them for predicting possible delays among stations. As the delay in a station propagates itself to other downstream stations, it could bring greater delays to other stations that cause the bus transport system encounter more disorders. So, by considering the Markov Chains, the paper defined three possible states for the arrival of buses in stations. Then the transition probabilities for every two successive stations are achieved through the Maximum Likelihood Estimation. Therefore, with Markov Chains, all possible delays in the available stations of each line of the bus transport system in Hamburg city center can be predicted and a dynamic bus transport system scheduling program can be proposed to satisfy users accordingly.

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Enabling Decentralized Transshipment in Waterborne Container Transportation

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Purpose: *This research aims at developing a comprehensive transshipment solution leading to additional opportunities of transshipment from small inland vessels throughout the West German canal network and, thereby, extending the existing capacities consisting of container bridges and reach stackers.*

Methodology: *The cargo flows between the major western seaports in Belgium and the Netherlands and relevant hinterland destinations in the West German canal network were analyzed and complemented by spatial analyses of potential transshipment points and their respective facilities. Based on this, the design process of a mobile transshipment facility has been initiated in order to realize its integration into the decentralized waterborne container transportation network.*

Findings: *On the basis of the framework conditions, an effective transshipment solution in the form of a mobile onboard crane has been developed. Performance data of both the small inland vessels and the newly developed cranes have been generated so that a comparison of the existing alternatives and a performance evaluation have been made possible.*

Originality: *Equipped with the mobile onboard crane, the small inland vessels operating in the designated area are no longer dependent on the transshipment facilities ashore. Comparable projects have either focused on the transport network or the onboard crane exclusively.*

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1 Introduction

Throughout Europe, including Germany at its heart, traffic has been growing over the past decades so strongly and steadily that capacity limitation hinders further growth at many points now. With the prospect of further economic growth, further aggravation of the problem is expected. Parallelly, the existing infrastructure has begun to show undeniable signs of wear and tear and partly even decay. This is particularly true for road transport but applies to rail transport as well. Less availability of the transport infrastructure and its ever increasing use are conflicting trends leading to a deadlock in the foreseeable future.

Furthermore, the transport sector has seen the freight structure change effect, a deep transformation of the composition of the transport volume in the development process of the national economies. As part of that development process, the production structure is converted from bulk goods into high-quality piece goods. Thereby, different types of shipments are required which again reflects in gradual modal shift from some transport to certain other ones. Along with the freight structure change effect come more demanding service level agreements between consignors and logistics service providers and the need of integration of all participating actors and stakeholders across company or even national boundaries using all opportunities from modern information and communication technologies.

In addition, the macrosocial trend of increased environmental awareness and vivid climate protection affects the transport and logistics domain by a clear and ambitious agenda of adequate measures, including the reduction of greenhouse gas emissions in each transport mode by 2035 and 2050, respectively, the adequate and consistent pricing of CO2 as a means to take external effects into consideration, the promotion of alternative (emission-free or at least low-emission) fuels, and a modal shift towards the more sustainable transport modes. On a political level, the sector pursues the vision of zero-emission transport by 2050.

Inland waterway transportation appears as a possible solution as it offers significant untapped potential in various regions in Europe and around the globe while featuring high reliability, cost efficiency, and energy efficiency (Frémont, Franc and Slack, 2009;

Janjevic and Ndiaye, 2014; van Duin, Kortmann and van den Boogaard, 2014; van Hassel, 2015; Stein, et al., 2016). Today, the share of IWT amounted to mere 6.1 percent of the total inland freight transport in 2019 while road freight transport accounted for 76.3 percent and rail transport for 17.6 percent (Eurostat, 2021). Traditionally, inland waterway transportation predominantly serves bulk and liquid bulk transportation whereas only ten percent of all cargo goods transported by inland barges was containerized in 2019 with 69 percent loaded and 31 percent empty containers (Eurostat, 2020). In combination with the above-mentioned freight structure effect, the barge owners and fleet managers need to watch out for new business segments to serve and, thereby, to secure an income. Hence, expanding efforts in the container transportation business appears obvious.

The huge potential of waterborne transportation offers a remedy to the above-mentioned threat of a traffic deadlock and, thus, deserves particular attention. Due to the low density of inland waterway transport network, various combinations with other transport modes like road and rail in the long-haul routes and cargo-bikes and electric vans in urban distribution concepts appear promising but may require one (or even more) additional transshipment operation. A series of prototypical implementations and use cases of multimodal transport concepts including inland vessels throughout Europe and elsewhere illustrate the technical feasibility of such solution concepts and their economic viability, at least under specific conditions.

This work presents the case of a decentralized waterborne hinterland container transportation service in the West German canal network and its transshipment concept. The precise task was the enhancement of transshipment capacity in the network. Coming from the starting condition in the considered geographic area, several approaches to detect and select appropriate and promising transshipment points on a concept level and integrate them into the overarching logistics concept in a technical perspective are presented. While some transshipment points in the network are already equipped with container handling infrastructure, such as container bridges and reach stackers, others require minor investment into such classical handling equipment or innovative solutions, such a mobile onboard crane.

2 A Decentralized Waterborne Hinterland Container Transportation Service

The goal of the underlying research initiative is to foster modal shift towards IWT by designing and developing a container transportation service in the German federal state of North Rhine-Westphalia (NRW). This service is to operate in the West German canal network, call at numerous inland ports and transshipment points in the considered area, and make use of dedicated small inland vessels. Slightly deviating from the official definition of an inland port, a simple transshipment location deems sufficient for the concept (Rodrigue, 2020, pp. 434–435). Furthermore, it is to exploit various transshipment solutions and feature a full integration into existing transport service concepts and familiar transport planning and monitoring systems. From the perspective of economic geography, the major focus of the service lies in moving import and export containers between the Western North Sea ports of Zeebrugge, Antwerp (both Belgium), Rotterdam, and Amsterdam (both Netherlands) and some of the economic hubs of NRW.

When looking at a typical transport chain in an import case, the first leg between the consignor’s premises and the nearest seaport takes place overseas and is mostly likely carried out via truck. Followingly, the cargo is transshipped onto an ocean carrier and hauled to a seaport in Europe from where the shipment is either directly hauled to the consignee via truck or sent to an inland port via inland waterway transportation. In the latter case, the transshipment ashore marks the begin of the final leg between the inland port in the vicinity of the consignee and his factory, warehouse, or distribution center. Analogously, the export case works vice versa. In the German federal state of NRW, this results in a clear focus on the river Rhine and the adjacent inland ports like Duisburg, Düsseldorf-Neuss, Cologne, and Wesel, some of them the largest of the state, the Federal Republic of Germany, and even entire Europe (Ministerium für Bauen, Wohnen, Stadtentwicklung und Verkehr des Landes Nordrhein-Westfalen, 2016). Typically, these inland ports are served by large CEMT class VI inland vessels, a waterway classification specified by the European Conference of Ministers of Transport, with a carrying capacity of up to 500 Twenty-foot Equivalent Units (TEU) and 5,500 tons, respectively (Lucke, et al., 2012, p. 353). With respect to container transportation, a significant increase is expected on the route between NRW and the Western North Sea ports in the coming decade whereas bulk cargo haulage on the Rhine is expected to decline significantly. The volume of container shipments between the considered geographic region and the Western seaports accounted for approximately 400,000 TEU in 2010 and is expected to increase by approximately 300,000 TEU by 2030, of which the half is expected to be transported on inland waterways in the main leg (Ministerium für Bauen, Wohnen, Stadtentwicklung und Verkehr des Landes Nordrhein-Westfalen, 2014). As a contrast to that, the West German canal network has remained underutilized so far with a less optimistic outlook until 2030 (Information und Technik Nordrhein-Westfalen, Statistisches Landesamt, 2020).

A decentralized waterborne container service could be an economically sound and environmentally friendly alternative to existing transport services for the task of container shipping between NRW and the Western seaports. The entire concept of the decentralized waterborne hinterland container transportation service consists of four sub-concepts, i.e., a logistics concept, an integration concept, a vehicle concept with a series of dedicated small inland vessels, and a transshipment concept. All four sub-concepts are presented briefly. Conceptual details of the designed decentralized waterborne hinterland container transportation service can be found in a dedicated research article from which some major content elements are used for illustration hereafter (Alias, et al., 2021).

2.1 Logistics Concept

The logistics concept consists of a supply and a demand side. The supply side represents the service offer to be designed in terms of shipping locations, transport capacities, service frequency, and attainable service level whereas the demand side refers to the eligible cargo volumes.

The logistics concept of the decentralized waterborne hinterland container transportation service includes the waterways of the West German canal network and a multitude of transshipment points in the geographic area form its backbone (see Figure 1). The frequented waterways include the Datteln-Hamm Canal, the Dortmund-Ems Canal, the Mittelland Canal, the Rhine-Herne Canal, the Wesel-Datteln Canal, the navigable part of the river Ruhr, and a small portion of the river Weser – and feature a total length of approximately 400 kilometers on the waterway. The covered geographic area extends from Duisburg and Wesel on the Rhine in the west, the Mittelland Canal with its direct vicinity in the north, the river Weser in the east, and – loosely – the river Ruhr in the south. Large cities like Dortmund, Essen, Duisburg, Bochum, Bielefeld, Münster and Osnabrück belong to the covered area as well as the Ruhr area, Münster region, Eastern Westphalia, and the adjoining Lower Saxony (Osnabrück region). Larger inland ports, such as Dortmund, Osnabrück, Hamm, Lünen, and Minden, are situated in the covered area. Further appropriate transshipment points have been sought when appearing promising (Alias, et al., 2020a). Details and results of this work are presented in a subsequent chapter of this article.

An optimal logistics system is characterized by high service level, low cost, high efficiency, low stock levels, best availability, and high transparency. Opening up all potential ports may lead to maximal service levels – but deteriorate the pertaining costs possibly and ultimately result in unprofitability. Thus, a thorough selection of the ports and transshipment locations from the pool of possible locations is a goal of the scientific examination. In the later stages of the research work, the number of transshipment points will be modified in both directions - in reaction to the results of each configuration.

As to the demand side, the existing cargo generated in each municipality of the considered area has been examined and checked for eligibility for westbound haulage. The eligible cargo volumes need to be assigned to the potential inland ports and transshipment locations in order to design the resulting transport chains. Details of the assignment of the cargo volumes to each of the municipalities can be found in a separate research article (Alias, et al., 2020b). In the end, precise values for the cargo volumes at each considered inland port and transshipment location are ready for further processing.

With respect to the related transportation costs, three design variants of the transport chain need to be compared with each other (Alias, et al., 2021). The cost analysis encompasses the direct truck haulage between the seaport and the consignee (and the consignor and the seaport, respectively), the intermodal transport with an IWT leg from the seaport to the inland port followed by a truck transport to the consignee, and the new variant which replaces large parts of the truck leg with a combination of a new IWT leg between the large inland port and the small transshipment location in the vicinity of the consignee and a much shorter truck leg from that transshipment location to the final destination at the consignee's premises. So, the new variant exhibits an additional transshipment with related costs and an elevated journey time due to its higher share of waterway transport with a speed ranging between nine and fifteen kilometers per hour.

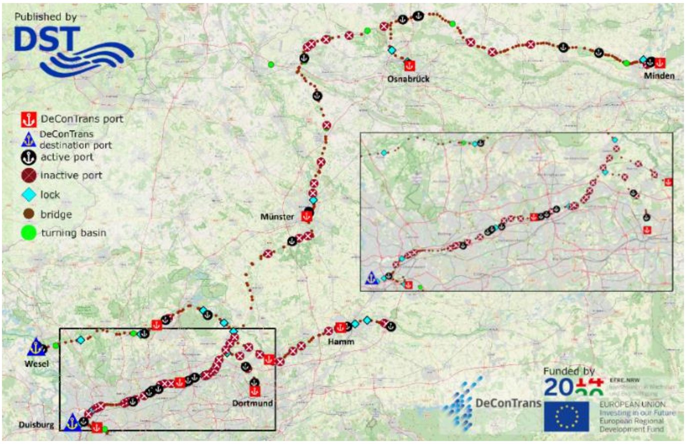

Figure 1: Map of the hinterland container transportation service network

2.2 Integration Concept

The integration concept refers to the integration of the new service concept into existing transport service concepts and the exploitation of the opportunities offered by today's information and communication (ICT) landscape in transportation management.

As to the integration into existing transport chains, the new service around the small inland vessels may cover different legs. In an import use case example of goods being hauled from Rotterdam, the Netherlands, to Bielefeld, Germany, the base case of a IWT leg to Duisburg, Germany, and a truck leg to Bielefeld, three different integration scenarios have been defined: in the first scenario, a small inland vessel as part of the new decentralized waterborne hinterland container transportation service would take over the containers in Duisburg and haul them through the waterways of the West German canal network to Minden, Germany. From there, a much shorter on-carriage is carried out by truck or rail. In the second scenario, several small inland vessels from the new service receive their respective cargo in the western North Sea ports. Subsequently, the vessels are coupled as a pushed convoy, and pushed to Duisburg by a push boat. There, the convoy is decomposed, and each vessel starts the journey to its respective regional destination port, i.e., Minden. From there, the containers are then transported to Bielefeld. The third scenario omits the intermediate stops and allows a direct trip from Rotterdam to Minden with the small inland vessel before the final leg is taken over by rail or truck. All three scenarios will be examined in detail with respect to service level, cost level, profitability, and ecological effects at a later stage of the research.

For the integration into the existing ICT system landscape, an exemplary use case based on the first integration scenario, i.e., with a new IWT leg between Duisburg and a port in the West German canal network, has been translated into a diagram of the planning and execution processes with multiple parties involved (Alias, et al., 2021). The interactions between the different parties have then been showcased by means of classic booking and planning tools and routines in a typical use case example.

During the planning and booking processes, the usual sequence of request for information (RFI), request for proposal (RFP), and request for quotation (RFQ) is pursued for each transport leg. After completion of the booking, the related transport details including the conditions and requirements to take into account during execution of the respective transport leg are passed on to the logistics service provider. On arriving at the destination address, both the shipment and documents are handed over to the subsequent party, possibly with the help of intermediaries. After finishing each leg, the party responsible for the transport planning and execution, especially vis-à-vis the consignor, is informed and kept up to date. By this, the ease and comfort of using the new service can be proved. In the execution process, the various steps, especially during cargo transfer, can be monitored with solutions already existing and available on the market. In essence, there is hardly any additional ICT system needed to make the decentralized waterborne hinterland container transportation service work and go live (Blic, et al., 2018). Thereby, IWT can be perceived as a ‘normal’ transport mode without any elevated background or specialist knowledge required. It can be expected that the ease of operation promotes the acceptance and prevalence of IWT in large transport chains of global value-creation networks.

2.3 Vessel Concept

The vessel concept mainly focuses on small inland vessels appropriate for the predominant use in the West German canal network, i.e., several vessels of CEMT class II to IV with a length of 50 to 80 meters and a width of 6.8 to 9.5 meters as well as one larger vessel of CEMT class V with 95 meters length and 9.5 meters width (Alias, et al., 2021). In order to take the expected variances in freight volumes into account, a series of different vessel sizes have been determined before conceptualizing, designing, and examining the respective inland vessels computationally - and testing them in a towing tank from a hydrodynamic perspective. In total, seven different types of vessels have been determined with a load capacity between eight and 30 TEU, and 36 TEU, respectively. Due to restrictions related to the clearance gauge, the dimensions of the vessel are limited: the width and the length of the vessel are supposed to be suitable for the lock chambers of the considered geographic area, the height is confined to the clearance height of the bridges, and the draft of the vessel is limited by the depth of the waterways (Lucke, et al., 2012, p. 338). Consequently, the vessels are designed as one-layer container transportation services – with two exceptions for the analysis of a potential future scenario of bridges lifted by several decimeters and, thereby, allowing two-layer container transportation in the long run.

As to the model tests in the towing tank in Duisburg, Germany, the different small inland vessel models have been tested for an operation on the Rhine (with a rectangular profile of the waterway) as well as on the canal network (with rectangular trapezoid profile). Precisely, drag and propulsion tests with model ships belonged to the portfolio as much as propulsion tests in the canal and the collection of rope forces and ramp forces measured during the scenario of conventional inland vessels passing. The tested models of inland vessels have changed in size and draft, respectively. The shaft power required to operate the inland vessels on the Rhine accounts for 72 to 189 kW with an average speed of 13 kilometers per hour. In the canal network, the shaft power for inland vessels operating at an average speed of 12 kilometers per hour amount to 43 to 196 kW.

Regarding the operation modes, typical modes applicable to the Rhine and to the West German canal network are to be applied. On the Rhine, the modes A1 (max. 14 hours with two persons), A2 (max. 16 hours with three persons), and B (max. 24 hours with four persons) are allowed (CESNI, 2017). On the contrary, the operation modes on the canal network include A (max. 16 hours with two persons), B (max. 18 hours with three persons), C (max. 20 hours with three to four persons), and D (max. 24 hours with four to five persons) (Wasserstraßen- und Schifffahrtsverwaltung des Bundes, 2018). However, the operation modes applicable to the Rhine can also be applied on the canal network – not vice versa. When looking into the future, several potential operation modes like reduced crew with only one person being operative 24 hours and the cases of remotely operated inland vessels as well as fully unmanned autonomous inland vessels are of interest for the remaining research as well.

3 Transshipment Concept

The transshipment concept foots on two threads: on the one hand, the eligible inland ports and transshipment locations need to be detected in order to select the most promising ones among them. On the other hand, additional solutions are sought as existing container handling infrastructure is assumed to be a precondition for the well-functioning of the entire decentralized waterborne hinterland container transportation service . That means in effect that each transshipment location with container bridges, slewing cranes, and mobile reach stackers is eligible to become part of the network and, thus, be served by the new service. The pertinent literature gives a good overview of existing options of transshipment equipment at different ports (Studiengesellschaft für den kombinierten Verkehr e.V., 2002; 2017; POM Oost-Vlaanderen, 2019).

However, such investment in port superstructure, i.e., mobile equipment such as cranes and reach stackers, fixed equipment, and surface arrangements located in a port in order to provide transport-related port services, can be huge and lead to a too long amortization time (ATF savjetovanje d.o.o., 2017). This again may result in a reluctance among many smaller ports and municipalities to participate in the new service. Since the new service is designed to be decentralized in nature and to avoid large influx to an inland hub on the congested road, smaller transshipment locations with lower container volumes are to be included. The (possibly only initially) low container volumes at such locations, however, will impede a quick amortization of huge capital expenditures which can amount to up to several million euros (POM Oost-Vlaanderen, 2019). Consequently, innovative solutions with lower capital intensity with respect to capital expenditures and operating expenditures are called upon to step forward. Such a solution needs to connect smaller, more remote inland ports to the new service and be cost-efficient in order to remain attractive for them.

The following sub-chapters describe the process of gradually extending the operation area of the decentralized waterborne container transport service by adding further inland ports and transshipment locations to the network and, thus, carefully expanding the solution space. In addition, the new transshipment concept, a mobile onboard crane resting on the sideboards of the new small inland vessel and being used after the berthing of the vessel at the respective port, is presented. Such a stand-alone solution helps to connect remote locations with little freight volumes to the new service without significant initial investment costs.

3.1 Starting Condition: Major Container Terminals

The starting point of our investigation was the map of existing inland ports in the state, esp. those of larger size and offering container handling services. Such larger container terminals feature the advantage of sufficient provision of transport connections, existing infrastructure and superstructure, and a solid customer base. When looking at the considered geographic area, the major inland ports with container terminals are situated in the cities of Dortmund and Minden (see Figure2). When lifting the prerequisite of existing container handling business, a few additional locations like Hamm, Lünen, Gelsenkirchen, and Osnabrück come into play.

In the initial stage, the two container terminals in Minden and Dortmund have been used as transshipment locations in the hinterland. When defining the catchment area of both locations, a sufficiently large share of the total route from the respective origin port to either destination port should be covered by IWT. As an example, the so-called relevant periphery of each transshipment location can be defined on the basis of half of its waterway distance to the nearest destination port at the Rhine, i.e., Duisburg and Wesel. Thereby, lengthy detours can be avoided, and the attractiveness of the new service safeguarded. On applying the rule, only two regions scattered across the federal state and not even connected to each other represent the catchment area of the two selected transshipment locations and, thus, the operation area of the decentralized waterborne container transportation network.

Adding the major inland ports and transshipment locations of the considered geographic area helps to expand the operation area of the new service. In total, nine transshipment locations for the decentralized waterborne hinterland container transportation service have been selected based on their size, their existing container handling business and devices, and their regional balance (Alias, et al., 2020a). The latter encompasses the inclusion of all waterways served by the new service, a balance between the various regions in the designated operation area, and a connection to the economic hubs in the considered area. However, white spots on the map remain a challenge leading to partly isolated operation areas as an interim result.

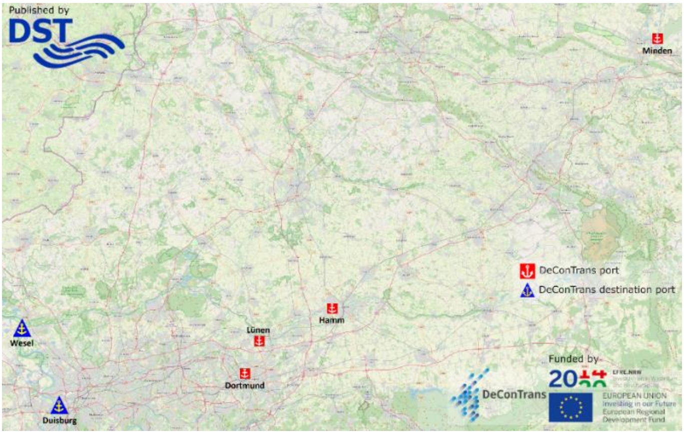

Figure 2: Map of the major inland ports and transshipment areas

As part of the search for further eligible transshipment locations, the geographic area of interest needs to be scanned for potential locations. Apart from using existing literature, reference projects, maps, and databases, external experts with profound knowledge have been consulted as part of this task in order to conduct semi-structured expert interviews. The experts have selected from shipping lines, third-party logistics service providers, consignors and port authorities but also state ministries, chambers of industry and commerce, and local municipalities. Derived from the expert interviews as well as the analysis of other publicly available information is a list of initial criteria to be considered when looking for additional transshipment locations. After a careful check whether any of the collected locations can be omitted with good reason, the residual set of criteria is the used as the final set and applied on the considered geographic area in the West German canal network with its three rivers and five canals (Alias, et al., 2021).

3.2 Enhancement: Active Ports

The first enhancement level was the consideration of all active ports in the considered geographic area, regardless of their current business focus. The reason behind this decision was the comparatively easy transformation of inland ports from dry bulk to containerized cargo. The required spaces and infrastructure need to be repurposed and processed accordingly, and the required superstructure needs to be acquired and prepared for operation. Parallelly, the ongoing transition from the fossil fuels and nuclear energy age to the solar and efficient energy age strongly affects inland waterway transportation and inland ports as the transportation and transshipment of dry bulk cargo is expected to shrink significantly over the next two decades, leaving the players in desperate search for new activity areas. Engaging more in container transportation and handling appears logical in this respect.

In total, the considered area features 44 active inland ports have been marked as eligible transshipment locations of the new service (Alias, et al., 2020a). Thereby, the effort of developing and setting up new locations is omitted. Among those 44 active inland ports, the largest part neither offers any container handling service nor features any related superstructure. So, adding these ports as transshipment locations requires additional effort of providing them with container handling equipment.

Despite the considerable increase in eligible transshipment locations, their geographical clustering still leaves some white spots on the map.

3.3 Reactivation: Inactive but Reactivatable Ports

The second enhancement level is the identification of additional transshipment locations. As the considered geographic area, the Rhine-Ruhr area, has a long heritage of coal mining, ore smelting, and iron and steel production with many former production sites. These host currently inactive transshipment locations that can potentially be reactivated in case of need and have also been taken into consideration. As 61 of such inactive loading bays are deemed eligible, a total of 105 potential transshipment locations of the decentralized waterborne transportation service have been identified (Alias, et al., 2020a). Figure3 shows the network of all potential transshipment locations.

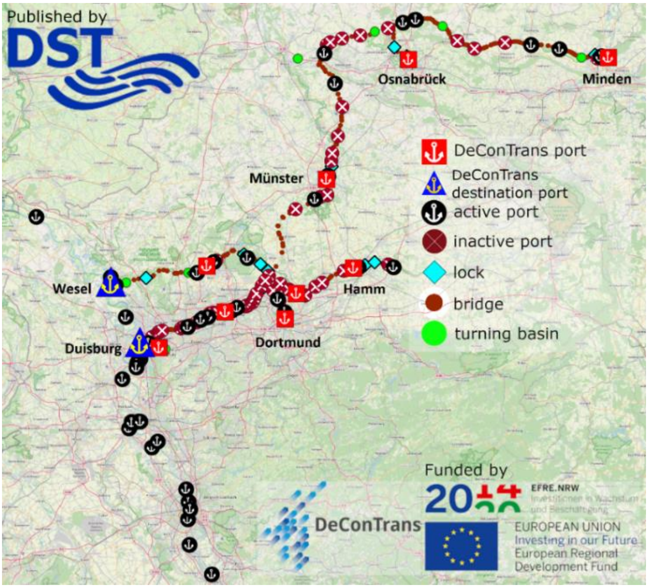

Figure 3: Map of the transshipment locations (Alias, et al., 2021)

From a technical point of view, preparatory aspects like enquiries about the permissible floor load and the surface stabilization are already completed and require minimal care, if at all. As these locations have been used for the very same purpose in the past, the prerequisites for a resumption of the operation appear advantageous.

From a political point of view, this approach finds support as the concept provides a new role for the formerly active transshipment locations that nowadays find themselves under pressure to become transformed into residential or recreational areas. Once completed, a re-purpose to commercial activities, let alone transshipment and port operations, appears highly improbable. In order to keep as many locations reserved for current and future use, this approach has an essential part in this political endeavor.

After identifying the eligible transshipment locations and selecting the ones to serve with the decentralized waterborne hinterland container transportation service , those transshipment locations that do not exhibit any existing container handling infrastructure need to be equipped with appropriate devices.

3.4 Upgrade: Equipment with Handling Infrastructure

The options range from gantry cranes (container bridges), hydraulic slewing cranes for material handling, mobile harbor cranes, mobile reach stackers, and crane ships (POM Oost-Vlaanderen, 2019). While gantry cranes promise throughput levels between 25 and 45 container moves in an hour, their acquisition costs account for seven to twelve million euros. Transshipment locations without a bright and shining future in container handling business ahead might be deterred from investing in such costly equipment without the clear prospect of adequate container volumes to handle.

Hydraulic slewing cranes can be acquired for 600,000 euros in smaller size and between two and three million euros in larger size. With 40 to 60 container moves per hour, their performance level is even higher than the one of gantry cranes. Their quick interchangeability with other tools allows a swift and flexible use of such cranes as multi-purpose devices. However, the cost level might still be too high for transshipment locations that still need to develop a steady consistent handling volume.

Mobile harbor cranes cost approximately 2.5 million euros and feature a performance level of 30 moves per hour. Clearly, the cost-to-benefit is significantly less favorable for these devices than for others.

Whereas new reach stackers may cost between half a million euros and 650,000 euros, used reach stackers promise equal service at considerably lower costs, i.e., between 50,000 and 250,000 euros. With twenty container moves per hour, the performance level is sufficient for a low-volume port. Moreover, it can reach inside the inland vessel and take up containers even in the fourth row. Likewise, it is able to stack container up to five container levels high on the quay and allows a negative lift of up to 2.5 meters below quay. The only major prerequisite regarding the infrastructure is the existence of a heavy duty quay wall.

As to container handling in inland terminals, the use of reach stackers amounts to costs between twenty and fifty euros per container move. The costs of the alternative devices are assumed to be higher despite a lack of publicly available information.

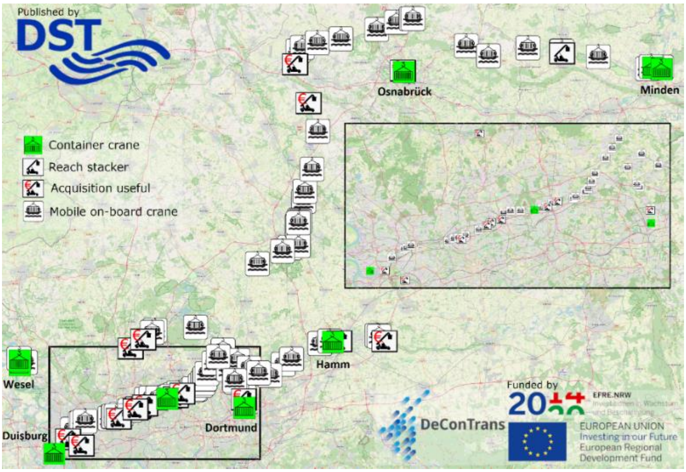

Figure 4: Container handling equipment at each location (Alias, et al., 2021)

For the decentralized waterborne hinterland container transportation service , mobile reach stackers are thus recommended as the container handling device to be acquired for those transshipment locations whose container handling volumes at a threshold value. Generally, the reach stacker serves the goal at low investment cost and decent performance level for low volumes. In the case of substantial growth of volumes, the option of upgrading the container handling superstructure still remains open.

Figure4 illustrates the respective situation at each inland port and transshipment location. While some locations feature container cranes and mobile reach stacker, respectively, others do not exhibit any operational equipment for container handling. While some of them are recommended an acquisition of a reach stacker due a sufficient container volume expected, others are eligible for a stand-alone solution with no investment effort ashore. A mobile onboard crane on the small inland vessels operating in the considered geographic area represents such a stand-alone solution.

4 Mobile Onboard Crane

A stand-alone solution like the mobile onboard crane on the inland vessels exempts the operators of the transshipment location of their duty to provide superstructural equipment on their respective premises. Thereby, the transshipment task, along with the transportation task, is to be taken over by the vessel operator. Parallelly, the investment cost for the handling device remains with the vessel operator, not with the port or terminal operator. The mobile onboard crane complements the decentralized nature of the waterborne container transportation service as potential new locations can participate easily and without too challenging and costly preconditions. Even network expansions limited in time or for selective times are conceivable. In this way, the entire concept becomes easily scalable as the entry barriers are remarkably low. The only preconditions are a sufficient soil bearing capacity and enough maneuvering space for the mobile onboard crane ashore. For the operators of the individual locations, the risk attained to a large investment is avoided in this way. On the contrary, when the business gains momentum, they are able to upgrade their handling equipment by acquiring a reach stacker or even a container bridge.

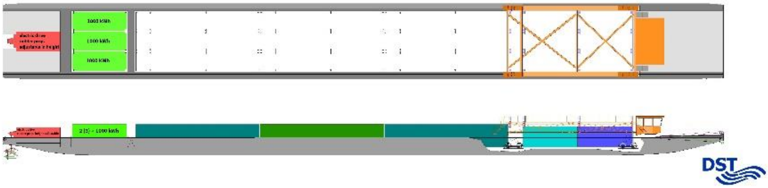

Figure 5: Plan of the mobile onboard crane (own illustration)

The mobile onboard crane is designed to work on nearly all small inland vessels of the current program except for the smallest one with only 50 meters length, 6.8 meters width, and a capacity of eight TEU. All other small inland vessels can be equipped with the mobile onboard crane. For instance, the vessel type 4 (80 meters length, 9.5 meters width, and a capacity of 24 TEU) exhibits an air draft of 4.50 meters with a draft of 0.45 meters in the unladen case and a maximum draught of one meter with 3.95 meters of air draught, respectively. Similar values apply to all eligible types of small inland vessels of the current program. Figure5 shows a plan of the mobile onboard crane.

With respect to its operation mode, the mobile onboard crane sits on the side passage of the inland vessel and is able to run along its length on wheels with rubber tires. The home position of the crane is next to the ship's bow. The crane operator's cabin is co-located with the control stand of the vessel so that no valuable space is wasted aboard.

On arriving at the transshipment location, the vessel docks to the quay wall semi-automatedly, and the control stand along with the container lift truck is hydraulically lifted to deck's level (see Figure6). After safely berthing in the port, the skipper switches the operation mode to crane operation and uses the mobile onboard crane henceforth. In order to retrieve the respective container, the skipper moves the crane to the desired position. Once the container is lifted, the crane starts moving to the bow and leaves the vessel in order to place the container at the right position in the container storage area ashore. The right position can be a storage position on the ground, container supports resembling stilts, or even a truck trailer available at the destination (see Figure6). Apart from the cargo containers, the battery boxes can be exchanged with the same technique.

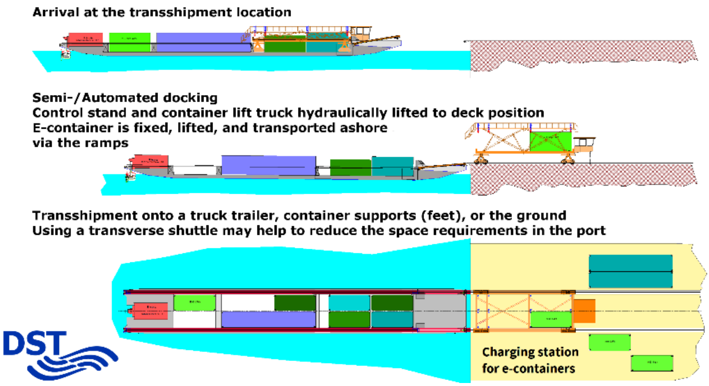

Figure 6: Transshipment with the mobile onboard crane (own illustration)

Then, the mobile onboard crane returns back to the inland vessel and retrieves the subsequent containers according to the loading and unloading list. Ultimately, after finishing all unloading and loading tasks, the crane returns to its home position so that the skipper can take over the control stand again and resume the journey on the waterways. Table1 shows the cycle times and energy consumption for several exemplary use cases. While low volumes of containers to loaded or unloaded appear realistically feasible, larger transshipment demand causes severe delay. This complements the starting argumentation that the mobile onboard crane is supposed to act as a first entry ticket to the decentralized waterborne hinterland container transportation service which can be upgraded when the volumes grow.

Figure7 shows the system components of the vessel, , that is composed of a steel body and features an adjustable hydraulic or mechanic rudder propeller with a shaft power of 70 to 200 kW, with the mobile onboard crane. The energy supply comes from up to three battery boxes with 1,000 kW each. In addition, the vessels have a bow thruster of approx. 100 kW and a Ro-Ro ramp with a coupling point safeguarding a holding force of approx. 200 kN. The container lift truck, which is co-located with the control stand, has a lifting capacity of nearly 42 tons and, thus, is able to deal with overload containers. Four scissor lifts are active for the container lift truck, exhibiting a lifting capacity of nine tons each.

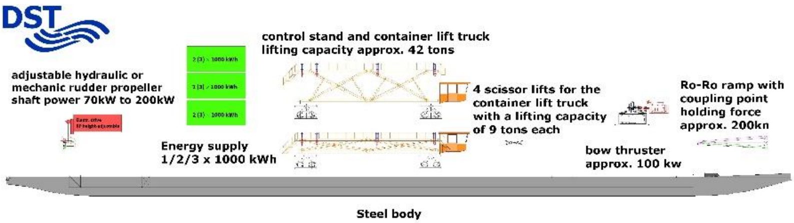

Figure 7: Components of the vessel with the onboard crane (own illustration)

The container lift truck is capable of adjusting the respective space requirements in different situations and can be raised and lowered according to the specific need. Figure8 shows the various positions of the container lift truck. During the vessel journey, the lift remains retracted and on deck's level. During the loading processes, the crane needs to run above the empty or filled loading bay of the inland vessel and, thus, is elevated. The truck is even able to adjust to different container heights and raise itself appropriately. When the container lift truck runs above deck to store or retrieve a container, it needs to run with sufficient room with the transported container and the residual ones onboard. Therefore, the scissor lifts are extended, and the required height achieved.

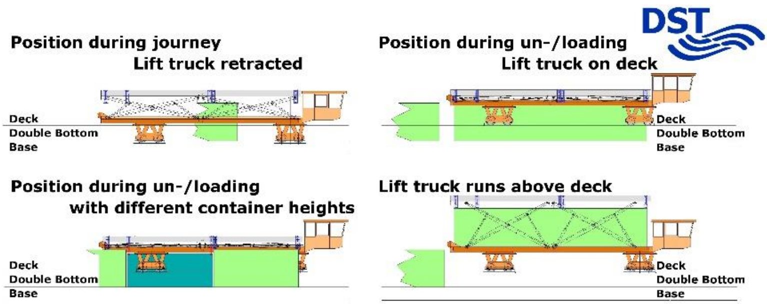

Figure 8: Positions of the container lift truck (own illustration)

The mobile onboard crane allows the participation of many potential transshipment locations in the decentralized waterborne hinterland container transportation service at low investment risk and reasonable performance level. Further examination and development tasks cover the feasibility check and impact assessment of rail guides on the terminal ground, the increase in flexibility by adding steerability to the container lift truck, and the energy supply and signal transmission of the container lift truck while ashore.

5 Related Work

Related work can be found in manifold areas. On the one hand, several waterborne transportation service including such of containers can be found in scientific and grey literature. On the other one, dedicated transshipment solutions are occasionally researched, and pertaining results presented.

The probably most relevant article in terms of an overview of use cases of urban freight transportation on the water is the work of Janjevic and Ndiaye (2014). The authors looked into various prototypical and commercial application examples and reviewed them with scientific criteria. However, the transshipment process did not play a central role in the review.

With respect to waterborne transportation services, van Hassel (2015) has looked into opportunities of reviving the small Flemish inland waterways. His approach included introducing new vessel types for this purpose and designing an intelligent logistics network (van Hassel, 2011). Transshipment facilities and capacities has not been an integral part of the work but has been assumed as given at the respective locations.

The potential of a network of hubs for waterborne distribution of goods in the city of Amsterdam, The Netherlands, has been at the center of a work of van Duin, Kortmann and van den Boogaard (2014). The authors examined the performance of the system and determined the number of required urban hubs and the required size of the optimized vessel fleet by means of discrete-event simulation (van Duin, Kortmann and van de Kamp, 2018).

In the research project RUHRCARGO, a transportation service between the inland ports of Duisburg and Dortmund based on nonmotorized barges has been developed and examined (DST - Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V., 2013). Whereas the number of barges, push boats and staff members has been examined thoroughly, the transshipment points were fixed from the beginning.

In the German-Dutch research project tRHEINco, the goal was to promote intermodal transportation chains by better utilizing existing waterway and terminal infrastructure in the Rhine-Waal Euregio on both sides of the border (DST - Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V., 2015). With the new push convoy service, (containerized) continental cargo between Germany and The Netherlands was supposed to be hauled via IWT. As the availability of a sufficient number of efficient terminals was the prerequisite for the development and implementation of such transportation services, a longlist of potential destinations has been worked out. However, the transshipment facilities themselves were not in the focus of the research work.

In the research project MEGAHUB, a potential new inland port on the Rhine with hub function was to be examined (DST - Entwicklungszentrum für Schiffstechnik und Transportsysteme e.V., 2014). With the opening of the new hub and re-assigning the incoming containers according to the final destinations, existing seaports and inland ports should be relieved, and transports on the waterways optimized.

Good overviews of existing transshipment technologies in the ports can be found in different sources, dating back to early 2000s and more recent ones (Studiengesellschaft für den kombinierten Verkehr e.V., 2002; 2017). Even crane ships are mentioned in some of them, indicating handling costs of 50 to 60 euros per container move and the requirement of well-functioning bollards and a quay with asphalt or granting access to trucks in some other way (POM Oost-Vlaanderen, 2019).

Concerning mobile transshipment solutions, various crane barges can be used as reference. Malchow (2019) presented the so-called Port Feeder Barge which was designed for the use in seaports like Hamburg, Germany. With a storage capacity of 168 TEU, it was designed as a mobile floating terminal that could serve inland barges for mooring, loading, and unloading.

In the German project Watertruck, an innovative lightweight container barge with an onboard gantry crane has been designed and developed (ISE – Institut für

Strukturleichtbau und Energieeffizienz gGmbH; Kaufmann, et al., 2018). With the container crane aboard, various commercial zones adjacent to the waterways can be served. By using modern lightweight materials, the onboard crane can be applied without increasing the maximum draught of the inland vessel. The gantry crane uses telescopic arms along the vessel length and an internal stabilization system based on a ballast water tank and pumps allowing the movement of the water according to the specific need. Thereby, static and dynamic loads on the ship's hull can be controlled, and the hydro-stability guaranteed.

Further examples of mobile onboard cranes as part of the inland vessel and the entire logistics concept are the beer boat project in Utrecht, the Netherlands, and the AMSbarge in Amsterdam, the Netherlands (Journée; Jong, 2013; Post, 2015). In general, crane barges mainly encompass slewing cranes with an extended reach towards onshore storage areas whereas gantry cranes are a minority.

6 Conclusion and Outlook

Setting up a decentralized waterborne container transportation network requires the detection of sufficient demand and the set-up of an attractive service offer that should encompass adequate inland vessels and sufficiently dense network of transshipment locations.

Creating such a dense network of ports participating in the new service is not an easy task – particularly when considering the lack of adequate cargo handling equipment like for containers in this case.

The present article has shown the cascade of steps to enhance the transshipment capacity in the new network – from adding more transshipment locations to the network over reactivating old disused ports and loading bays to developing a stand-alone solution and, thereby, disburdening the new locations from any major investment. In addition, design parameters and performance indicators of the mobile onboard crane have been presented and explained.

Detailed analyses of the configuration of the transportation network are to follow. The selection of the routes and ports to be served, the composition of the fleet, and the service concept to be pursued need to be determined. With the help of discrete-event simulation, various parameters like the operation mode of the vessels, the fleet mix, and the application of different transshipment concepts can be examined and compared with each other. Ultimately, the service levels and utilization indicators, the estimated transportation and transshipment costs, the ecological impact of the decentralized waterborne hinterland container transportation service will be derived from such analyses. From a technical point of view, a solution is still required for seamless container swaps onshore. More precisely, containers placed onshore by the mobile onboard crane must be able to be collected by truck without extra handling equipment, e.g., with the help of four legs on which the container would rest.

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Appendix

Table 1: Cycle times and energy consumption of the mobile onboard crane

#	Step	cycle time (min)	energy consumption (kWh)	cycle time (min)	energy consumption (kWh)	cycle time (min)	energy consumption (kWh)	Comment
	Length (in m):	**95**		**80**		**66**		
	Width (in m):	**9.5**		**9.5**		**9.5**		
1	Lifting the container lift truck of the mobile onboard crane to deck's level	**0.7**	**0.189**	**0.7**	**0.189**	**0.7**	**0.189**	applicable for each loading/unloading process
2	Lowering the container lift truck of the mobile onboard crane from deck's level	**0.7**	**0.189**	**0.7**	**0.189**	**0.7**	**0.189**	applicable for each loading/unloading process
3	Mobile onboard crane unloads one container from the inland vessel and returns empty back on board	**6.2**	**5.745**	**5.9**	**5.344**	**5.7**	**4.970**	– 1
4	Mobile onboard crane goes empty ashore and loads one container onto the inland vessel	**7.1**	**6.242**	**6.7**	**5.800**	**6.4**	**5.388**	+ 1
5	Mobile onboard crane unloads one container from the inland vessel and loads another container onto it	**11.5**	**10.928**	**10.7**	**9.998**	**10.0**	**9.129**	– 1 and + 1
	EXAMPLES							
A	*unloading 1 TEU (steps: 1+2+1*3)*	**00:07:35**	**6.1**	**00:07:18**	**5.7**	**00:07:02**	**5.3**	
B	*loading 1 TEU (steps: 1+2+1*4)*	**00:08:29**	**6.6**	**00:08:06**	**6.2**	**00:07:44**	**5.8**	
C	*unloading 10 TEU (steps: 1+2+10*3)*	**01:03:43**	**57.8**	**01:00:50**	**53.8**	**00:58:09**	**50.1**	
D	*unloading 12 TEU and loading 7 TEU (steps: 1+2+7*5+5*3)*	**01:53:04**	**105.6**	**01:46:20**	**97.1**	**01:40:03**	**89.1**	
E	*unloading 18 TEU and loading 18 TEU (steps: 1+2+18*5)*	**03:28:26**	**197.1**	**03:14:50**	**180.3**	**03:02:08**	**164.7**	

Investigating the Return Cost for B2C e-commerce

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Purpose: *Online sales have significantly increased, especially in the realm of the COVID emergency. For B2C e-commerce, reverse logistics is critical: it strongly impacts the willingness of customers to buy online, but it is very expensive for online players, who are striving to find ways to reduce the associated costs. This work aims to define a measure of the return cost and to investigate the main factors affecting it.*

Methodology: *This work combines analytical modelling and simulation. The model allows to represent the reverse logistics process and to define the associated cost; simulation is used in testing the model and analysing different scenarios. The used data were collected from both primary and secondary sources.*

Findings: *The return cost includes three main components (usage of the van, time spent by the driver to travel and to perform collection activities). The application of the model to Milan (Italy) resulted in an average unitary return cost of 2.78€. The variables impacting the most on this cost are the collection density and the travel speed.*

Originality: *This research is a first attempt to propose a measure for the cost of B2C e-commerce returns, and to analytically investigate the variables having the greatest impact in determining such cost.*

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1 Introduction

B2C e-commerce is on the rise: online sales have been increasing in many industries and different countries, and this trend is expected to continue also in the future. According to the B2C e-commerce observatory (2021), Italian online sales in 2020 were worth €32.4 billion, with €25.9 billion generated by products. Also due to the effects of the COVID sanitary emergency, those values will be boosted in 2021, when e-commerce sales should increase up to €38.6 billion. On a global scale, Statista (2020) forecasted a continuous and significant e-commerce diffusion, with US$3,299.5 billion revenues for 2024, signing a +71% growth rate if compared to 2019.

Despite this increasing trend, different barriers still make some customers favour offline traditional brick and mortar retailing to the online one. Among them, the main element is the lack of "physical interaction" with the product, which may result in customers' dissatisfaction in case of the wrong fit of ordered items, unmatching features with the description provided online or lower quality than expected (Zhenleong & Zaiqiu, 2010). In this direction, one of the main solutions that increase the customers' willingness to buy online is the possibility to easily (and typically for free) return products they are not satisfied with. Accordingly, most of the players operating online are trying to optimise return processes.

As a result, the product return rate (i.e., the percentage of products returned over the total number of items bought) is very high in the online channel. Focussing on the Italian scenario, product return rates in e-commerce account for 5% in the case of general goods, 15% for electronics and over 40% for fashion. Since e-commerce sales are growing, online returns are expected to increase as well. Hence reverse logistics, intended as the set of processes that move physical products from the final customer back to the retailer, is no longer to be considered an afterthought. It should not be managed as an additional service offered by retailers to clients but as the "New Normal".

These being the premises, reverse logistics is very critical for online players, as it strongly impacts the willingness of customers to buy online. Nonetheless, it may be very expensive, and operators are striving to find ways to reduce the associated costs. Despite its significance, there seems to be a shortage of academic contributions aimed to measure the cost of reverse logistics. As a result, this work defines a measure of the return cost and investigate the main factors affecting it.

The remainder of this paper is organised as follows: Section 2 presents the results of the literature review, section 3 defines the research objective and the methodology, section 4 displays the developed model, section 5 illustrates the model application and the deriving results, and section 6 summarises the main conclusions stemming from the work.

2 Literature review

In line with the overall goal of the paper, the objective of the literature review is to systematise extant academic knowledge dealing with reverse logistics for B2C e-commerce. The searching process performed on Scopus led to 44 articles, which have been examined to identify relevant patterns in the reverse logistics field, if any. In this regard, in line with the approach followed by Perego et al. (2011), the 44 papers were first classified according to their descriptive characteristics (i.e., source, country of the main author, and addressed sector); second, the research method used by authors was identified, alongside with a content-based analysis.

Concerning the source, they are quite broad, with journals belonging to domains ranging from marketing to computer science; this result allows to state that the field of reverse logistics for e-commerce is interesting for scholars from different disciplines. From a country perspective, China and the USA are the main contributors in the field of online reverse logistics: the presence of e-commerce giants as Alibaba and Amazon, as well as the penetration of internet retailing in those countries, have a key role in determining this pattern (Wang et al., 2007). Concerning the industry, scholars do usually not focus on a specific sector, probably due to their willingness to provide a generalisable contribution to current academic knowledge. While it could be expected to find a higher number of papers addressing the most return-inclined sector – namely the fashion one, where return rates are above the average (Velazquez and Chankov, 2019)– this was not confirmed by the literature analysis.

Switching to the content-based analysis, the reverse logistics process for B2C e-commerce is usually debated as a side topic of more general works addressing forward logistics. It might be assumed that academia is willing to provide an overall picture of the e-commerce sector which encompasses reverse but also forward logistics. Arguably, scholars consider forward logistics in B2C e-commerce at least partially similar to reverse one, accordingly assuming forward logistics studies as good proxies of reverse logistics ones (Hübner et al., 2016).

In most of the cases, analysed papers have the aim of understanding which variables have an impact on the number of returned products. In this sense, surveys play a relevant role, since these allow to better understand the behaviour of customers concerning e-commerce and returns management (e.g. Lin et al. (2020), Wang et al. (2020), Li et al. (2021), Rintamäki et. al. (2021), Stöcker et al. (2021)).

A further step was performed aimed to systematise the papers by considering the analysed phases of the process of reverse logistics. Following the approach proposed by De Araùjo et al. (2017), the B2C reverse logistics process can be synthesised based on the following phases: (i) pre-receipt, (ii) collection, (iii) transport, (iv) processing of returns and (v) shipment to the final destination. The role of the different actors involved in a typical e-customer journey - i.e., customers, logistics service providers and merchants (Vakulenko et al., 2019) – may vary, based on the peculiar activities they carry out. By considering these units of analysis, the literature proves to be quite scarce in insightful contributions: in most of the cases, the collection and the transport are the only phases described in detail by scholars, whereas very little attention is devoted to both the return processing and the shipment to the final destination.

The content-based analysis also allowed to identify the different ways that are implemented to allow customers to return products in B2C e-commerce. The literature displays three different options from a consumer perspective, namely the traditional return – based on the home pick-up made by the courier – (Röllecke et al., 2018), the collection points option – both attended and unattended – (Kedia et al., 2017) and the cross-channel option – which encompasses the possibility to buy goods online and return them to the merchants' physical store – (Hjort et al., 2019). Referring to the last-mentioned option, it has recently received particular attention by Huang et al. (2020) and

Jin et al. (2021), investigating competing e-tailers' BORS adoption strategies. Crowdsourcing logistics is another interesting discussed way to return products, with an example provided by Upadhyay et al. (2020).

Among the papers having the returns as a core topic, it is worth mentioning the innovative mathematical model approach followed by Chen et al., (2017). The author proposes an innovative model to collect e-commerce reverse flows utilising a network of taxis and CDPs (i.e. collection and delivery points), leveraging on the crowdsourcing paradigm. The proposed model moves returned items and passengers in an integrated way, relying on the constant flows of taxis in the city and their extra capacity. Negative social, environmental and economic impacts could thus be reduced if compared to traditional return management. Considering instead the work by Chang and Zheng (2014), it presents an effective strategy of non-defective reverse logistics. The authors develop a model according to which online players can choose another consumer's delivery address as the client's return address to reduce the distance of non-defective return transportation. In such a case, the integrity checking process is delegated to a third-party logistics service provider.

As shown by these two works, logistics service providers (LSPs) play a fundamental role in managing reverse logistic flows, since online players are not used to managing internally last mile and reverse logistics. Such behaviour is expected: in most of the case, it would not be cost-efficient for an online player to manage transport internally, mainly for a matter of missing economies of scale and experience effects. In Wang et al. (2021), the importance of choosing the right LSP is underlined, and a decision support system is developed.

By the way, the lack of papers on reverse logistics cost assessment should be underlined: despite some articles addressing the theme of prices customers have to pay given the different cost components (Difrancesco et al. (2020), Nageswaran et al. (2020)), sources address this aspect with conceptual frameworks (Nel et al. (2020)) or choosing the preferable channel considering variations in costs (Mandal et al. 2020). Shah et al. (2021) developed a model including cost components, validating it with real case studies. However, the paper focus stays on proposing collaborative buffering between LSP and e-retailer, to reduce the storage and distribution efforts. In this sense, no instances on how much is the reverse logistics process have been found in the existing body of literature, as well as an up-to-date description on the different ways to return products with peculiarities, differences and flaws.

Nevertheless, the low incidence of “core” papers dealing with the return methods in e-commerce B2C is in line with the statement by Hjort et al. (2019), who have been recently claiming that “literature on return management (i.e. reverse logistics) is still underdeveloped”. So far, scholars have widely discussed optimisation methods and models in the last-mile delivery trying to study and propose solutions to improve efficiency and lessen the negative externalities of e-commerce (i.e. pollution and congestions): fewer sources quantify and suggest new frameworks which consider forward and reverse logistics at the same time, or solely the latter one.

Based on the analysis of the literature and the emerging findings, the following three main research gaps were uncovered.

- Despite different scholars recognise how reverse logistics for e-commerce is very critical in terms of efficiency, there is a lack of models aimed to assess the cost of returning products in a B2C e-commerce environment
- The state-of-art description of the different options e-commerce clients might use to return products is incomplete (as additional innovative options could be exploited, e.g., relying on parcel lockers).
- While different works target specific phases of the return process, an holistic description of the overall return management process, concerning both the various return methods and the role of the actors in the different phases, is not present in academic literature.

Among the gaps identified, this paper focusses on the first one, addressing the following research questions:

- RQ1: What is the average cost for returning an item?
- RQ2: What are the elements impacting the return costs most?

3 Objectives and methodology

To answer the research questions, this work adopts an analytical approach, combining mathematical modelling and simulation. The model allows to depict the reverse logistics process, and to define the formulas needed to estimate the associated cost; simulation is instead used to get numerical insights, in applying and testing the model, and analysing different scenarios. The data used in the application phase have been collected from both primary (i.e., interviews and direct observation) and secondary sources (reports and logistics practitioners' journals), following the approach of Latte et al. (2020).

As far as the approach embedded into modelling and simulation is concerned, this can be described as follows. Following the scheme proposed by Seghezzi et al. (2020), firstly, great emphasis has been placed on the problem setting phase, where relationships among variables have been investigated and introduced, and a basic scheme of the model has been built. Later on, data to be plugged into the algorithm have been collected. Afterwards, the problem-solving phase has taken place, and two different approaches have been tested for the definition of the delivery tours (further details are presented in the following section): a clustering algorithm based on the k-means approach and a "constrained" methodology. Similar approaches have been used by Ahmed et al. (2017), to determine optimal resources required (vehicles, field executives) to operate a city-logistics network with a given distribution of sellers and customers. Both of them hold pros and cons, therefore the final decision has been to merge the two approaches in a sort of "time-constrained k-means clustering" algorithm, which makes use of k-means clustering as a baseline with time correction/constraint. Once the final model has been defined, it has been applied to a representative case in Milan (Italy), to gain numerical results and accordingly derive managerial considerations.

4 Model

Figure 1 represents the architecture of the model, which was developed in R.

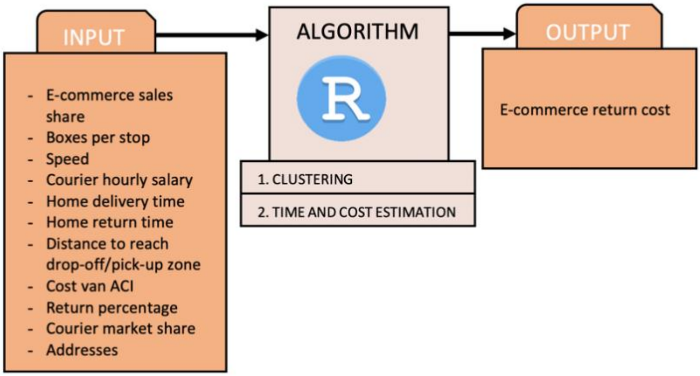

Figure 1: Model architecture

The "**Input**" variables describe the implementation context. Some concern the deliveries (e.g., Home delivery time) because in the tested scenario, both deliveries and returns are managed in the same tour, meaning that the express courier van travels each day to the different customers' homes either to drop-off or pick-up packages. They are defined as follows:

- E-commerce sales share: ratio between the number of locations to be visited daily on the total number of eligible locations in the considered geographical area.
- Boxes per stop: number of boxes to be delivered at/returned from a single address.
- Speed: average travelling speed of the van.
- Courier hourly salary: hourly salary of an express courier driving a van.
- Home delivery time: time needed to deliver a parcel once the home location has been reached (e.g., ring the doorbell).
- Home return time: time needed to collect a parcel to be returned once the home location has been reached.

- Distance to reach drop-off/pick-up zone: distance between the departure point (i.e, the hub of the courier) and the delivery area.
- Cost van ACI: cost per travelled kilometre for the usage of the van (including fuel).
- Return percentage: ratio of returns on the total number of boxes managed per tour (deliveries + returns).
- Courier market share: percentage of orders managed by a specific courier over the total number of orders to be managed daily in the same area.
- Addresses: set of candidate addresses for customers' delivery/pick-up locations in terms of geographical coordinates.

The "**Output**" is expressed in terms of "return unitary cost"; it represents a sort of summary variable which encompasses the costs of all the elements needed to handle return requests in B2C e-commerce, from the customer's location to the first hub of the courier.

The "**Algorithm**" is the set of processes and computations needed to estimate the return unitary cost based on the considered input values. It works according to two main steps: (i) clustering and (ii) time and cost estimation.

In the (i) clustering step, the considered delivery/pick-up locations are grouped, via a time-constrained clustering method, in clusters, where each cluster is associated with a tour performed by a single van. The k-means clustering approach is applied to a set of addresses within the considered area (in the case of this research the municipality of Milan), which are net of the daily e-commerce requests, courier market shares and the average number of orders (boxes per stop) each address might account for. Different input variables are plugged into the algorithm to let R generate the optimal number of clusters to satisfy the demand (namely the average speed of the van, the unitary operation time and the distance to be travelled outside the delivery area, from the drop-off/pick-up area to first couriers' hub). It should also be noted that the model is dynamic, meaning that depending on the customers' requests (e.g. e-commerce sales) and the relative market share of the express courier, a different number of clusters is activated.

In the (ii) time and cost estimation step, the time spent by the van driver and the associated cost are estimated for each delivery tour, and the return unitary cost is subsequently derived as follows.

$$Return\ Unitary\ Cost = Cost\ Van\ Unitary + Cost\ Driver\ Unitary + Cost\ Driver\ Return\ Unitary$$

The Return Unitary cost is found – as shown in the previous formula – by summing three cost voices (please note that “unitary” indicates that the cost refers to one single returned box):

Cost Van Unitary: the cost for the van is computed as the cost per kilometre related to a specific typology of a van – which includes fuel, maintenance, taxes, insurance and other indirect costs (ACI, 2017) – multiplied by the total distance travelled by the van within and outside the delivery area. The cost of the van is then split on the total number of boxes managed in a specific tour regardless of the percentage of deliveries and returns (since such cost does not depend on the type of service to be performed).

$$Cost\ Van\ Unitary = \frac{(Din + Dout) \cdot Cfi}{Boxes\ per\ tour}$$

Cost Driver Travel Unitary: this value accounts for the cost related to the time spent by the courier travelling. It is obtained by multiplying the travel time by the hourly salary of the courier, and – also in this case – dividing it by the total number of managed boxes.

$$Cost\ Van\ Unitary = \frac{Travel\ time \cdot SC}{Boxes\ per\ tour}$$

Cost Driver Return Unitary: it is the cost related to the time spent by the courier performing pick-up and delivery activities. In this case, it only considers returns (since the time spent to perform deliveries does not contribute to the return cost). It is obtained by multiplying the time spent to perform the activities related to one return, by the courier hourly salary

$$Cost\ Driver\ Return\ Unitary = truh \cdot SC$$

For sake of simplicity, some assumptions were made concerning the model development. First, the courier delivers/picks up only one box from one customer. If a customer orders different products in the same online order, these items are included in the same box (1 box = 1 customer). Second, time windows are not taken into considerations when scheduling the tours. This is in line with most of the “generic” last-mile deliveries, which are not managed by appointment. Third, there are not tours dedicated to deliveries only and returns only: in each tour, there is a certain percentage of deliveries and a complementary percentage of returns. This reasonable assumption has been justified by the interviewed express-courier. According to what emerged during the interview, managing returns with dedicated tours is not an option due to the low volumes at stake. Fourth, the input database with the candidate delivery/pick-up destinations does not only include residential addresses, but also other locations like commercial activities or offices. The assumption is that customers can schedule deliveries and pick-ups also in these alternative locations, as it happens in real life.

5 Model application and results

This section of the work is devoted to presenting the application of the model to a realistic case in an Italian city, Milan. The considered base scenario is described in Table 1, which reports the values assigned to all the different input variables and parameters previously presented in Figure 1. These input data, retrieved from both primary and secondary sources, were validated by an express courier senior manager interviewed in October 2020.

Table 1: List of input variables with values

Input variable	Value
E-commerce sales share	27 %
Boxes per stop	1.23 boxes/stop
Speed	10.21 km/h
Courier hourly salary	20 €/h
Home delivery time	1.5 minutes
Home return time	2 minutes

Input variable	Value
Distance to reach drop-off/pick up zone	15 km (one way)
Cost van ACI	1.6 €/km
Return percentage	10 %
Courier market share	12.5 %
Geolocated addresses	Longitude and latitude

This scenario was used to answer both the proposed research questions.

As far as RQ1 is concerned, the model was applied to such values, to obtain an average return cost for the presented scenario. As anticipated in section 4, after the identification of the delivery/pick-up customer destinations to be reached, the solving algorithm groups such locations in clusters, and assigns each of them to one van. Figure 2 shows the result of the k-means clustering (a different colour is assigned to different tours).

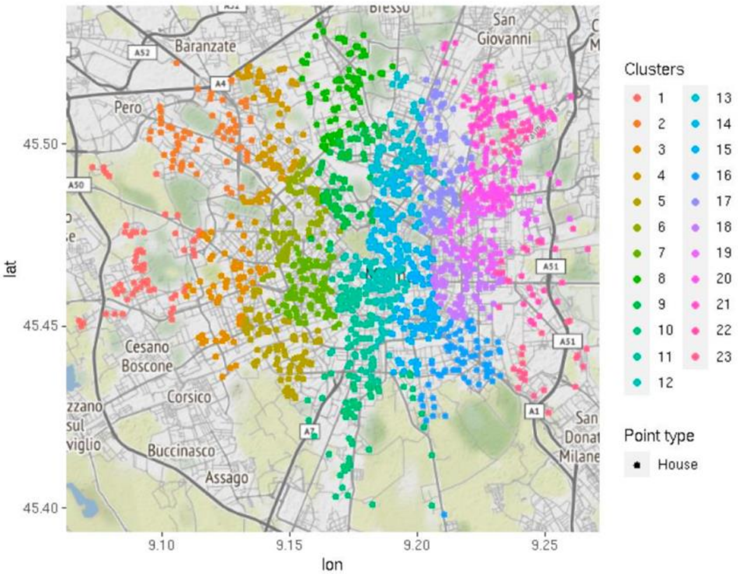

Figure 2: Result of the clustering – Delivery tours

The return unitary cost was then derived according to the formulas presented in section 4, resulting in the outcome shown in Figure 3. The average return unitary cost accounts for 2.78 €/box returned. The highest incidence in the final cost among the three illustrated cost components is represented by the "cost driver travel unitary" (42%), followed by the "cost van unitary" (34%) and finally, the "cost driver return unitary (24%). Considering instead the time components, the incidence of the travel time on the total is more than double if compared to the operation time (69% vs. 31%). It should be noted that the travel time might also be affected by a higher degree of uncertainty: urban congestions, for instance, could decrease the vehicle speed, thus requiring couriers to reschedule delivery/pick-up missions and/or to activate the overtime with a consequent cost increase.

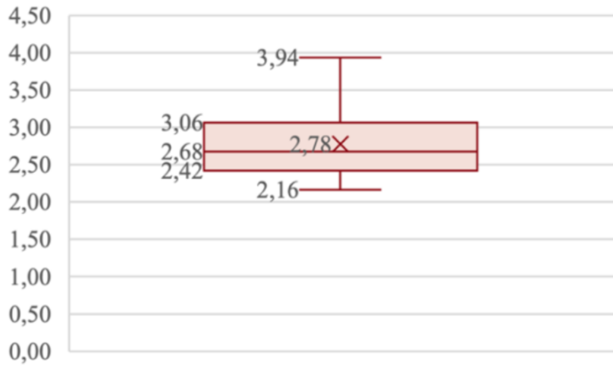

Figure 3: Return unitary cost

Switching to RQ2, which aims at identifying the elements affecting the most return cost, it has been addressed employing some sensitivity analyses run on the different input variables. More specifically, the effects on the return unitary cost caused by the same variations for the different inputs (considering their benchmark value as a reference starting point) have been investigated. The results of this analysis are displayed in Table 2.

Table 2: Impact of input variables variations on the return unitary cost

	Variables							
	1	2	3	4	5	6	7	8
	Speed	Courier market share	E-commerce sales share	Return percentage	Cost van ACI	Home boxes per stop	Home return unitary time	Home delivery unitary time
Delta % Variables	Delta % Return Unitary Cost	Delta % Return Unitary Cost	Delta % Return Unitary Cost	Delta % Return Unitary Cost	Delta % Return Unitary Cost	Delta % Return Unitary Cost	Delta % Return Unitary Cost	Delta % Return Unitary Cost
-75%		63%	63%	0%	-26%		-21%	-12%
-50%		28%	28%	-1%	-17%		-15%	-10%
-25%	39%	9%	9%	-1%	-9%		-7%	-4%
0%	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
25%	-16%	-6%	-6%	0%	9%	-6%	5%	2%
50%	-26%	-11%		-1%	17%	-11%	13%	9%
75%	-32%	-14%		0%	26%	-11%	19%	13%
100%	-36%	-17%		-1%	34%	-15%	25%	19%

These outcomes allow deriving different considerations.

First, the variables that show the greatest impact – whether positive or negative – on the “return unitary cost” are the market share courier and e-commerce sales share (+63% in return unitary cost for a 75% drop in the input variables). The determinant of this pattern may be found in the relationship between these two inputs and the drop density, which is defined as the number of packages to be managed in a drop-off/pick-up zone divided by the covered surface. The higher the e-commerce sales share (and/or the higher the market share of the courier), the higher the number of customers’ houses to be visited in the same area (as represented in Figure 4).

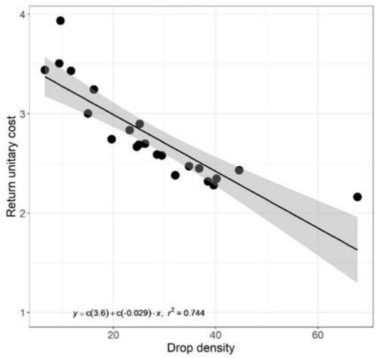

Figure 4: Drop density VS Return unitary cost

The drop density is statistically significant in predicting the return unitary cost, as it may be noticed from the results of the test shown in Figure 5. Above all, economies of scale and scope phenomena play a pivotal role in explaining the abovementioned figures.

TRADITIONAL regression analysis: Return unitary cost VS Drop density	
	Dependent variable:
	Return unitary cost
Drop density	-0.029***
	(0.004)
Constant	3.561***
	(0.115)
Observations	22
R2	0.744
Adjusted R2	0.731
Residual Std. Error	0.243 (df = 20)
F Statistic	58.118*** (df = 1; 20)
Note:	*p<0.1; **p<0.05; ***p<0.01

Figure 5: Output of the regression analysis for Drop density vs. Return unitary cost

The third variable in terms of the highest impact on the return cost is the **speed**: if the speed decreases by 25%, a 39% increase in the return unitary cost is expected. The determinants of this strong interaction can be found in the way the speed relates to both the "travel time" and the number of "boxes per tour". More in detail, the speed affects the travel time negatively, and thus the higher the average speed the lower the incidence of the travel time over the operation time (on the total time-constrained to 8 hours) and so the ability to handle more packages within one single tour (and vice versa). Also, in this case, a test has been made to support the statement that the number of boxes per tour is inversely proportional to the cost of a returned box and that such an effect is statistically significant. Therefore, the joint effect of the "speed-boxes per tour" and "speed-travel time" relationships attribute the speed of the van to a key role in modifying "return unitary cost". Considering the effect of speed on the return unitary cost, it is worth noticing that it is not constant, but it assumes the pattern shown in Figure 6. The decreasing tendency is due to the relationships between the speed and the number of boxes per tour, which implies that for high numbers of boxes per tour a lower number of tours needs to be activated by the single express courier to fulfil the demand. Considering instead the horizontal asymptote, this is caused by fixed components (i.e. fixed distance to reach the drop-off/pick-up area) which have to be beared in any case.

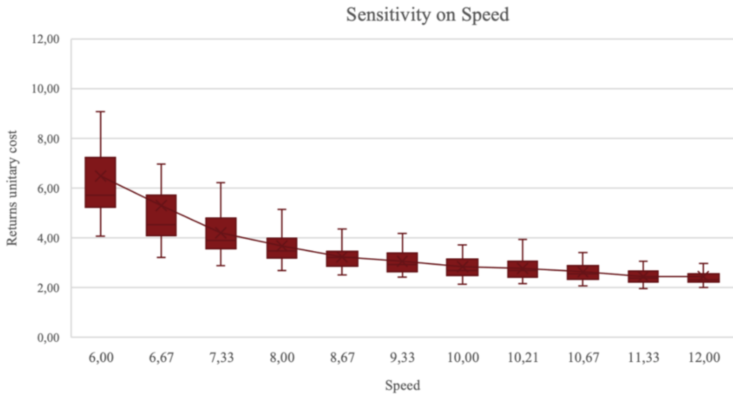

Figure 6: Output of the regression analysis for Drop density vs. Return unitary cost

The variable **Cost van ACI**, expressing the cost per km ascribed to the use of the vehicle to perform deliveries-pick-ups, causes slight variations in the return unitary cost: this variable is present in the formula to compute the cost as a multiplicative coefficient, with no links to other variables. Its direct relationship with the travelled kilometres implies that the effects caused by variations in the cost of the van on the return unitary cost have the same entity in both negative and positive cases (meaning that a 25% decrease in the cost causes a 9 % decrease in the return unitary cost, as well as a 25% increase causes a 9% increase). As noticeable, a drop/rise in the cost per van does not causes the same percentage variation in the return unitary cost, because this latter does not only include vehicle operations costs, but also labor ones (and the effect is thus mediated).

Coming to the number of **boxes per stop**, differently from what could be expected, by doubling the number of boxes to be managed in a single location, the return unitary cost decreases by just 16%. The reason behind this result can be find in the way the analysis is set: in order to be able to analyse the impact of each variable, one variable at a time is modified in the what-if analysis. As a result, changing the number of boxes per stop without changing the overall demand implies that – since the driver spends more time at each customer's home to perform delivery/pick-up activities – a lower number of addresses will be visited in a single tour (since less time will be left to travel). As a result, the drop density – being defined as the ratio between the number of boxes and the surface of the tour itself – is not strongly affected because both the numerator and the denominator increase. In other words, while both the market share of the courier and the e-commerce sales have a pivotal role in changing the drop density (and thus reducing cost), the number of boxes per drop by itself does not.

As far as both the **home return unitary time** and the **home delivery unitary time** are concerned, the impact that variations in their values have on the “return unitary cost” is even lower than the previous ones. These two elements solely affect the operation time, which accounts for one-third of the total time of 8 hours.

Finally, the input variable having the lowest impact on the return unitary cost is the **return percentage**. The reason behind this result is that the considered tours manage both returns and deliveries. As a result, in case the percentage of returns decreases, the number of managed boxes does not change, and the mix simply shifts towards a predominance of deliveries.

The presented results have been discussed with the interviewed manager, who has confirmed their reliability and agreed with the derived considerations.

6 Conclusions

B2C e-commerce has been increasing in the last years, especially in the realm of the COVID emergency, which has boosted the online sales of products. For e-commerce, reverse logistics is critical in a twofold direction. On the one hand, it strongly impacts the willingness of customers to buy online; on the other hand, it is very expensive for online players, who are striving to find ways to reduce the associated costs. This work is a first attempt to propose a measure for the cost of B2C e-commerce returns and to analytically investigate the variables having the greatest impact in determining such cost.

This research answers the defined research questions identifying the main components of the return cost (usage of the van, time spent by the driver to travel and to perform collection activities). Thanks to the application of the model to Milan (Italy), it provides an estimation of such cost, which resulted in an average unitary return cost of 2.78€. Moreover, it identifies the variables impacting the most on the return cost, i.e., the collection density and the travel speed.

This work has both academic and managerial implications. From an academic perspective, this work is a first attempt to propose a measure for the cost of B2C e-commerce returns and to analytically investigate the variables having the greatest impact in determining such cost. From a managerial perspective, the dynamic, scalable and modular model developed could help practitioners, especially express couriers, to gain a deeper understanding of the variables driving the return cost. More specifically, some remarks can be drawn stemming from the mentioned analyses, and potential managerial implications and suggestions may be derived about all the studied variables if considering the perspective of the courier service.

- Courier market share – Couriers might invest more in trying to gain higher market shares if compared to competitors. They could increase the service level considering the perspective of both customers (e.g., offering the possibility to reschedule deliveries/returns, providing on-time services, warranties and tracking services ...) and online players (i.e. offering frequent load batches, tracking services, flexibility ...).
- Speed – Regulators play a fundamental role in this regard: the more the area under investigation is developed from an infrastructural point of view, the higher the expected value of the speed (assuming no congestions). The active role couriers may have in this direction is including in the tour definition the analysis of aspects linked to the congestions (which should be real-time modelled).
- Cost Van – Different vehicles may entail different costs per km travelled, depending on their features. Additional considerations could also be made concerning electrical or green vehicles, which in some countries could allow benefiting from national incentives.
- Home delivery time – Different delivery policies could be defined by both couriers and merchants aimed to reduce the home delivery time (e.g., proof of delivery not required, delivery in the garden/courtyard…).
- Number of boxes per stop – The number of boxes per stop is more related to demand issues. Nonetheless, some initiatives could be implemented aimed at increasing the delivery/return density, such as relying on dynamic pricing policies.

- Return percentage – There will always be a certain percentage of returns to be managed, even if new technologies (AI, VR) might decrease their likelihood.

Despite its contribution, this research has some limitations, which offer sparks for future research efforts. First, the data validation. Despite data from primary and secondary sources have been confirmed by an express courier senior manager, validation by more than one sources could be included. Second, the context of application. The model has been applied to the municipality of Milan. Future works could enlarge the scenario, applying the model also to additional areas, with different characteristics. Third, the return mode. The model focusses on the traditional return mode, in which the parcel is collected at the customer's home. Nonetheless, it could be interesting to evaluate how the cost would change if considering alternative return modes (e.g., returns at collection points, in parcel lockers). Fourth, the focus on the economic aspect. This research addresses the economic aspect estimating the return cost. It would be interesting to consider also the environmental perspective, addressing the emissions associated with reverse logistics processes.

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Requirements for robots in combined passenger/freight transport

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Purpose: *Delivery robots promise to provide gains in logistics in many ways especially on short distances. However, there is a lack of orderly overview of requirements for their successful implementation. The aim of this paper is to generate a better understanding of how to implement delivery robots in public infrastructure.*

Methodology: *This paper follows an explorative, applied and interdisciplinary research approach based on the pilot project "TaBuLa-LOG". The results of a literature review were used as the foundation for thematically targeted expert workshops, interviews and desktop research. The individual approaches and outlined requirements are then combined and structured on the basis of a dependency model.*

Findings: *We discuss not only the independent solo autonomous use of delivery robots, but also the combined use, where the main run takes place in an automated passenger shuttle. The result of this paper is a comprehensive overview of the identified requirements structured along the developed dependency model.*

Originality: *When it comes to delivery robots there is limited uniform information about the implementation in real environments so far. This paper closes the gap by identifying requirements for implementing a delivery robot into a combined passenger and freight transport.*

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1 Introduction

Delivery robots promise to solve various problems in logistics, especially on the last mile. Their use serves, for example, to reduce traffic, counteract environmental pollution and enable request delivery as well as contactless delivery (e.g. Figliozzi and Jennings 2020, University of Toronto Robotics Institute 2020). When the term delivery robot is used, it usually refers to small or micro vehicles that automatically transport only a small volume of goods, such as individual packages or small food deliveries. A classification option named in the literature relates to the transportation infrastructure used. On the one hand, there are road autonomous delivery robots (RADR) which travel roadways together with conventional motorized vehicles (Figliozzi and Jennings 2020). On the other hand, the more frequently discussed delivery robots are pedestrian-sized and use only sidewalks and pedestrian paths, the known as sidewalk autonomous delivery robots (SADR) (Figliozzi and Jennings 2020). This seems an appropriate classification when talking about delivery robots, since the implementation differs significantly from each other in many characteristics (e.g. grade of technology, complexity of automated control, moving between pedestrians or cars).

Limitations of sidewalk autonomous delivery robots are the low transport capacity and a small radius of action. But solutions to these limitations have already been discussed, for example, combining the robots with other means of transportation (e.g. Hoffmann and Prause 2018, Figliozzi and Jennings 2020). In comparison to road autonomous delivery robots, sidewalk autonomous delivery robots can be integrated in other transport modes for longer distances, like commercial vans or busses, we call this scenario combined transport. In the same way, however, the SADR can then also cover shorter distances independently, which we refer to as solo transport. The solo autonomous use is the independent operation of the robot on the first and last mile, while the main run takes place in an automated passenger shuttle. In this respect, the combination enables a more flexible use of the delivery robots. Therefore, the sidewalk autonomous delivery robots are the subject of this paper, in line with numerous pilot projects (e.g. Brandt et al. 2019, Jennings and Figliozzi 2019).

But when it comes to delivery robots there is limited uniform information about the implementation in the real environment so far. Therefore, the aim of this paper is to generate a better understanding of how to implement delivery robots in public infrastructure. The question to answer is what are the requirements for implementing a delivery robot and how can they be assigned into a distribution process. In this paper the term “requirements” refers to software and hardware features as well as characteristics of development and logistics processes that are necessary to successfully implement a delivery robot in distribution.

For this purpose, a literature review will first be conducted to identify the areas from which requirements arise in the context of a delivery robot. The findings from the literature analysis are then used for our own methodological design. It is structured in several approaches focusing on operational, legal and technical issues. The identified requirements consist of an explorative mixed method approach in the sense of combining data from qualitative and technical sources by using a variety of different methods like expert workshops and interviews, desktop research as well as of a use case based on the pilot project “TaBuLa-LOG”. The individual results are then combined and the requirements systematized on the basis of a dependency model. Based on this the requirements for the implementation of a delivery robot are examined in more detail. The special characteristic of the consideration is that the delivery robot covers longer distances in an automated shuttle in a kind of "piggyback transport" and drives only the last mile to the end customer autonomously. This way, the range of the delivery robot can be extended. The shuttle is originally used for public passenger transport, but by taking the delivery robot with it, it then combines passenger transport with freight transport. The paper closes with a discussion and recommendations for actions to facilitate the integration of delivery robots into public infrastructure.

2 Delivery robots in literature

The literature was examined using the scoping approach, as according to Arksey and O´Malley (2005) this is appropriate, if fields of study are to be mapped and research gaps identified.

From a technical perspective in particular, there is of course a great amount of specific research on basic functionality such as mapping, localization and navigation. Since the adoption of these techniques is required for a wide range of autonomous robots and not limited to delivery robots, they are not considered in this literature review. Despite that, the literature shows different areas in which requirements are important with regard to the delivery robot.

Rubio et al. (2019) give a broad overview on the topic of mobile robots, not exclusively covering unmanned ground vehicles. They present and discuss the key technologies and methods in the areas of locomotion, perception, cognition and navigation.

Sindi and Woodman (2020) examine impacts and barriers for the use of autonomous vehicles for last-mile delivery on the basis of semi-structured interviews. The interviewed experts generally endorse the use of autonomous vehicles but also saw barriers, e. g. missing information regarding required infrastructural modifications.

Hoffmann and Prause (2018) concentrate on the regulatory framework of autonomous delivery robots for packages. They based their research on expert interviews, data analysis, and a case study. They have worked out that the two main challenges in the use of delivery robots will be liability and acceptance issues.

Pani et al. (2020) deal with the acceptance of autonomous delivery robots by the users to provide guidelines and recommendations for action to make delivery robots suitable for mass use over the last mile. They are focusing on decarbonizing the last mile, as this is where large savings can be expected according to Pani et al. (2020). Abrams et al. (2021) address the applicability of existing acceptance models to delivery robots. They introduce the idea of an "Existance Acceptance", which explicitly considers spontaneous or passive interactions. Kapser, Abdelrahman and Bernecker (2021) investigate the acceptance of delivery robots in last-mile delivery in Germany. They also study the influence of gender as a moderator. The results of their study point to a correlation of the gender of the participants and certain aspects of their acceptance of the robots. Furthermore, Baum et. al (2019) focused on the status of development, vehicle concept and the field of application. In line with Hoffmann and Prause (2018) they came to the point, that public acceptance is one key factor for successful implementation of autonomous delivery robots.

Also, Brandt et al. (2019) identified a need for regulatory action, in particular by examining what legal framework conditions are required. They examined the use of delivery robots in CEP delivery for a case study in the city of Hamburg, Germany.

Figliozzi and Jennings (2020) also examined sidewalk autonomous delivery robots which operate from a mothership van and identified them to be a feasible alternative to standard delivery vehicles in terms of reducing road miles travelled. In other sources as Hoffmann and Prause (2018) this kind of solution is called RoboVan and autonomous delivery robots that launch from trucks deliver shipments to customers. However, these savings then come at the expense of the sidewalk, which in turn can lead to new challenges such as pedestrian safety. In addition, Figliozzi and Jennings (2019, 2020) raise the issue that the additional mothership van needed might park longer and take up larger parking slots. Furthermore, Figliozzi and Jennings (2020) examined on the one hand the current capabilities of autonomous delivery robots and on the other hand the potential energy and emission reductions which they could bring. However, the analysis also shows that especially when it comes to energy consumption, emissions and parking space utilization, the use of road based autonomous delivery robots can be beneficial. Additionally, Figliozzi (2020) points out that the analysis, at least from an emission reduction perspective, has to take into account some requirements or factors such as the distance to be covered or the product size.

Simoni et al. (2020) focus on the possibility of implementing an integrated truck-robot system for the last mile delivery. Based on a scheduling problem they show that robot-assisted last-mile delivery systems are quite efficient, when robots are employed in heavily congested areas. However, according to Simoni et al. (2020), one requirement for this would be the robot having several individual compartments. Boysen et al. (2018) studied this concept from an operations research perspective by addressing scheduling and routing issues.

Yu, Puchinger, and Sun (in press) also discuss the routing of van-robot systems and present an algorithm to solve these tasks. A case study modeling a realistic scenario is used to verify their findings.

Deng et al. (2020) model vehicle routing problems and also consider sidewalk delivery robots in the context of cooperative delivery schemes through movement synchronization between different delivery resources. Sidewalk delivery robots can bring cost savings compared to truck deliveries (Deng et al. 2020). Chen et al. (2021b) also investigate how to schedule vehicles and delivery robots as assistance for city logistics with the aim of minimizing total route time.

Marsden et al. (2018) present the BUGA:log project, in which they test the use of an automated transport system in a new living quarter as well as the BUGA 2019 (Bundesgartenschau – National Garden Festival) in Germany as part of a real-world laboratory.

Literature study shows that the development in the field of delivery robots is highly dynamic. But when it comes to the requirements that delivery robots should meet for proper implementation there is little information in the literature to date. Nevertheless, the questions addressed in the literature can be ordered into technical, legal and operational issues.

3 Research approach and methodology

This paper follows an explorative, applied and interdisciplinary research approach. Basis of our findings is a prototype study conducted as part of the research project “TaBuLa-LOG”. The aim of the project is to investigate and test the combined transport of passengers and goods in automated shuttles, with delivery robots performing the goods transport aspect. The interdisciplinary nature of our research requires knowledge of engineering, law, logistics, and transportation planning. For this reason, we decided to use an explorative mixed methods approach, which allows us to identify the diversified requirements for the development and implementation of delivery robots.

At the time of publication, the “TaBuLa-LOG” project is still ongoing. Hence our findings may change or expand as our research progresses. To address this limitation, we conducted a literature review in the form of a scoping study as mentioned above, both as a first starting point, as well as to complement our own findings. As shown in the previous section, the literature to date can be categorized into three areas: technical, legal and operational issues. As these appear to be the three most important areas in the implementation of delivery robots, it is necessary to identify requirements in each category. For this purpose, individual analyses are carried out in each area.

To identify operational requirements in distribution, an expert workshop was held to capture different experiences. The method of an expert workshop is a qualitative approach, which is used in an early state of research to find possible solutions for a given problem by integrating expert knowledge or the interested public (Häder 2015). The workshop incorporated knowledge of six participants, four from research with regard to engineering, transport and logistics and two from industry with an expertise in transport and logistics. In our workshop, operational requirements were identified by using an iterative process based on the World Café. The method was developed by Brown and Isaacs in 1995 with the aim of integrating different perspectives and views of all group members on a topic (Brown and Isaacs 2007).

Legal requirements were determined on the one hand by desk research and on the other hand by expert interviews. The desk research consisted of studying laws, regulations and standards in the development of delivery robots. Unanswered questions from the desk research and generic specifications were addressed in the interviews. The interview partner was an experienced auditor from TÜV Nord, an independent technical inspection and certification organization. As the approval and testing of the "TaBuLa-LOG" delivery robots takes place in Lauenburg/Elbe (Germany), the legal requirements refer to German law. However, since national law in many cases implement international legal provisions, transferability, at least in certain areas, is plausible.

Since the research and development of delivery robots is still at an early stage, it is difficult to obtain openly accessible information on technical requirements. For this reason, we held an expert workshop with five researchers from the fields of computer science, mechatronics, mechanical engineering and technical logistics. To provide a framework for this workshop, the operation of the delivery robot was modelled as a generalized transport process. The top level of abstraction is shown in Figure 1.

In addition to solo transport, optional combined transport, and (un)loading, the process model also includes multi-stage tours and passive waiting states. Any additional handling of goods is implicitly covered by the (un)loading step. This model was then used to identify, discuss, and group requirements along the transport process, providing a simple and intuitive workflow.

Finally, to structure the requirements identified, we introduce a dependency model that clusters the requirements based on their interdependencies.

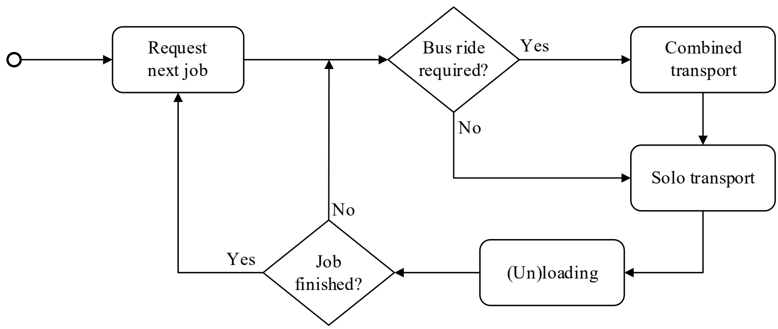

Figure 1: Flowchart of the generalized delivery robot transport process (own figure)

In summary, our approach consists of three main steps: the identification of requirement areas, the identification of requirements themselves, and the description along identified dependencies. The following Figure 2 summarizes our methodical approach.

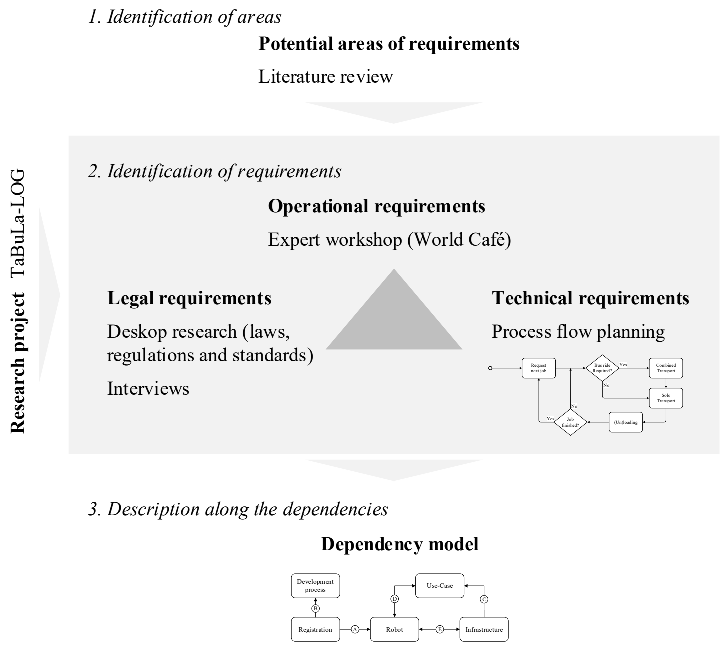

Figure 2: Illustration of the methodical approach (own figure)

4 Requirements along the dependency model

Our research showed that the requirements to be fulfilled when developing an autonomous delivery robot and implementing it into an (existing) supply chain can be assigned to one of the following aspects: registration, development process, robot, use case, infrastructure. For every identified requirement, one of these aspects can be considered the source. It imposes requirements upon another aspect, the target. Figure shows what hereafter we will refer to as the dependency model. It illustrates the aspects of development along the directions in which requirements are imposed depicted as arrows.

In the following, we will present the results of our research along the dependency model in that we will go through all aspects of development pairwise and list the requirements that arise in this relation. The order we will use is indicated by the letters on the arrows in Figure 3.

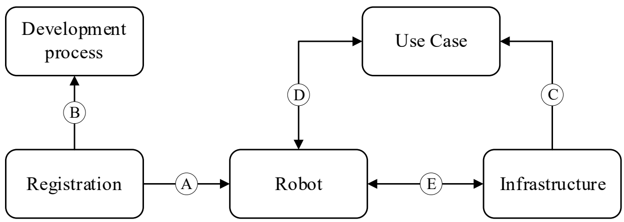

Figure 3: Dependency model with direction of imposed requirements (own figure)

4.1 Registration and Robot

Since the operational environment of the delivery robots are sidewalks, bike paths and streets in public space, it must first be determined which country-specific regulations such vehicles are subject to. This applies both to the use and behavior in road traffic as well as to the technical equipment of the robots. In Germany, small mobile robots are not explicitly covered by traffic law. Nevertheless, they are classified as motor vehicles under the German Vehicle Registration Ordinance (§ 2 FZV). Depending on the intended maximum speed, motor vehicles must undergo an official registration procedure. Vehicles with a maximum design speed of not more than 6 km/h are exempt from registration (§ 1 FZV). However, an additional permit might be required.

A further consequence of a classification as motor vehicles is the technical equipment and design of the robots within the framework of the German Road Traffic Licensing Ordinance (§ 16 StVZO). Here, specific requirements are placed on the technical equipment and design of the robots, e.g. with regard to lighting, braking systems, design of protruding outer edges but also electromagnetic compatibility. The regulation also refers to the respective international legislation that must be implemented.

Despite a vehicle's ability to perform an entire journey fully automatically, the German Road Traffic Act requires the presence of a driver. This driver must be able to override systems or switch off automated driving functions at all times (§ 1a StVG). With delivery robots, these cannot be drivers in the conventional sense, who monitor the movement from a position within the vehicle. It is therefore necessary to check whether country-specific legislation permits monitoring from the robot's immediate surroundings, or also from a remote control center.

Before delivery robots can be deployed, preparatory assessments and permits need to be obtained. As far as approval for operation is concerned, the country-specific regulations and processes must be taken into account. In Germany the exact steps and requirements depend on whether the robots are series production vehicles or prototypes. Importantly, even for research prototypes such as those being developed in the "TaBuLa-LOG" project, a technical expert assessment must confirm conformity with road traffic regulations. Only then can an operating permit be applied from the licensing authority. Furthermore, proof from an insurer is required. To operate robots on sidewalks, an additional exemption permit is required. If the delivery robots are to use public transport vehicles for part of their journey, expert assessments must also be obtained to confirm the safety of the robots and of the passengers during the journey.

4.2 Registration and Development Process

As outlined in the previous section, national laws reference international law, including UN/ECE regulations. These not only set out requirements for the technical design of vehicles, but also for the documentation and validation of the development and safety concept. The latter two are described in particular by two standards: ISO 26262 Road Vehicles Functional Safety and ISO 21448 Safety of the Intended Functionality. An important aspect of these standards is a structured, iterative approach to the development of safety-critical systems, including risk assessment, rigorous testing and validation.

4.3 Use case and Infrastructure

In order to allow customers to request deliveries, a server system needs to supply an application programming interface (API) with this functionality. A graphical user interface (GUI) is required that uses this API and allows users to specify the desired delivery. The server needs to keep track of incoming delivery requests and assign them to available robots.

For the combined transport to take place without the need of manual interventions, the shuttle needs to supply an API that allows the robot to query various information such as the shuttles current location as well as to instruct the shuttle to perform tasks such as halting at a specific bus stop, opening a door or extending a ramp. This kind of communication is referred to as vehicle to vehicle communication (V2V). It typically requires a network connection of both systems.

During solo transport, depending on the selected routes, the infrastructure may have to be equipped with a vehicle to X communication (V2X) system that allows, for example, traffic lights to broadcast signal changes. This, of course can be circumvented by choosing routes that do not require the robot to cross any roads.

4.4 Use Case and Robot

Due to their design, delivery robots have a limited transport capacity, both in terms of volume and payload. This has to be considered when designing the use case. Conversely, with a given geometry or weight of goods to be transported, the robots' cargo compartment and weight distribution needs to be chosen accordingly. Especially since the characteristics of the cargo can have a significant impact on the robots' driving stability. The robots may have to be equipped with further hardware components such as insulation, climate control or shock absorbers to preserve the cargo's integrity.

Depending on the size and characteristics of the chosen delivery area, a combined transport may be required in order for the robot to reach its destination. This requires the delivery robot to be able to enter and exit a bus or shuttle, safely navigate inside, as well as securely dock during the trip.

In order for the robot to autonomously enter and exit the shuttle it needs to be able to use the above-mentioned Shuttle API to initiate the opening of a shuttle door or the extension of a ramp.

As the robot moves in close proximity to other passengers, distinct human-machine interaction is a major consideration. The sensors installed on the robot should be configured in such a way that the immediate vicinity of the robot can be monitored right down to the ground. Furthermore, it must be verified whether the selected sensors and localization method allow for localization in such geometrically confined and changing environments. The environment is changing as the number of passengers, the presence of luggage or pets is not known in advance and varies from trip to trip.

If the delivery robot is used in a regular public transport system, priority of passengers for transportation may have to be respected. This depends on the local conditions of carriage.

While riding the shuttle, the robot covers large distances in a short amount of time without being responsible for the motion. This has to be considered in the mapping process. Some parts of the recorded map may not have to be of the same level of detail as others. The robot may even have the ability to switch from one map to another.

Access to the cargo compartment should allow for easy and ergonomic (un)loading of the transported goods. The doors or flaps should open wide enough to accommodate larger items and the robot must be designed in such a way that partially removed load carriers or parcels do not cause the robots to tip over.

The robot must also ensure that only authorized customers get access to the cargo compartment. This may require an input device to be mounted on the robot.

4.5 Robot and Infrastructure

To enable regular operation of the delivery robots, it is necessary to set up a charging infrastructure on site. On the one hand, this concerns the charging stations themselves. On the other hand, this concerns the grid-side installations. The physical energy transmission interface of the charging station and robot have to be designed in such a way that it does not pose a risk to each other or people in close proximity. Depending on the location of the charging station, different weather conditions may have to be considered. In addition, the charging station needs features that render it recognizable by the robot for automated docking. The grid-side infrastructure must be capable of providing the necessary charging currents. A service station with tools, materials and spare parts is required to perform maintenance and repairs directly on site. This also includes a trolley for transporting the robot if inoperable.

In order for the robot to request its next job, it must be equipped with a network connection to be able to consume the above-mentioned server API. Subsequently, the robot must be able to deduce from a given job whether or not a combined transport is required.

Delivery robots are a classic example of mobile robots in outdoor environments and thus during solo transport are subject to typical challenges: Localization, typically with respect to a given map, path finding within predefined operating areas, and obstacle avoidance. As stated earlier, since these aspects not solely apply to delivery robots, this is why they were not considered in our research.

Depending on the robots' physical configuration it may require the infrastructure to be barrier-free. This includes entering and leaving the shuttle, accessing buildings, and traveling on public infrastructure. For a robot deployment, these infrastructural adjustments must be made in advance. However, the selection of certain robot configurations such as a legged robot that provide it with specific locomotion capabilities that render these requirements unnecessary.

Depending on the robots’ routes, it may be required to engage in the above-mentioned V2X-communication in order to, for example, receive the status of traffic lights and cross roads safely.

During the combined transport, the robot must not roll, slide or tip over. This applies to regular travel as well as during emergency maneuvers of the shuttle. To secure the robot, structural modifications to the shuttle may be necessary.

When it reaches its destination, to start the (un)loading process, the robot has to notify the recipient of the transported goods. This may require the server system to send notifications to customers.

Figure 4 gives an overview of all identified requirements.

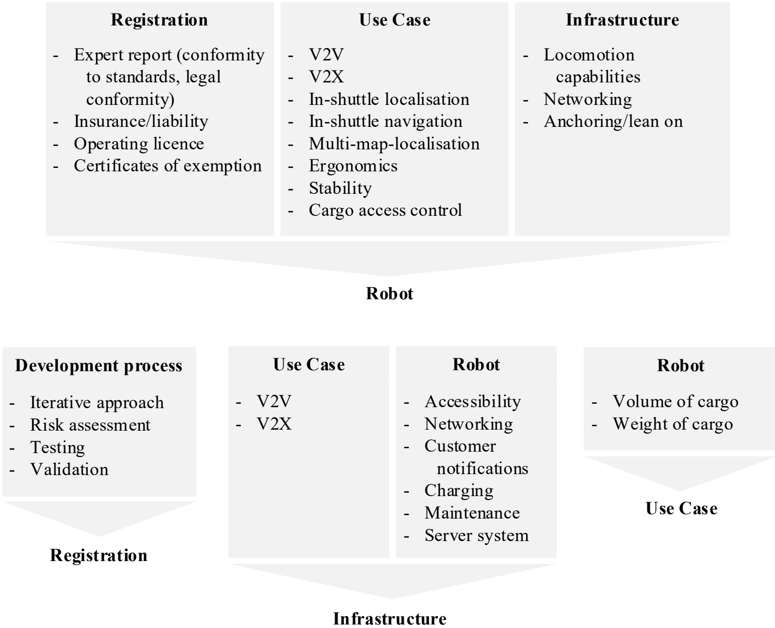

Figure 4: Overview of the identified requirements (own figure)

5 Conclusion

The aim of the paper was to generate a better understanding of the development of delivery robots and their implementation into public infrastructure and transport. To achieve this, we conducted a literature review to identify areas in which requirements arise using a scoping approach. The results were used as the foundation for thematically targeted expert workshops, interviews and desktop research.

Using this explorative mixed methods approach, legal, technical and operational requirements were identified and augmented with the help of the pilot project “TaBuLa-LOG”. In this project, an autonomous delivery robot is implemented into an existing shuttle operation in order to achieve a combined passenger and freight transport system. Afterwards, the requirements were structured on the basis of a dependency model developed specifically for this purpose. This model is integral for obtaining a deeper understanding of the wide range of requirements and their interconnectedness. A structure of this kind has not been proposed in literature yet.

Our research yielded numerous requirements for the development and implementation of delivery robots. We close this paper by giving a comprehensive overview of the requirements identified along the structure introduced with the dependency model.

Recommendations for action can be derived from the findings. Currently, German traffic law does not explicitly cover delivery robots. General requirements can be inferred from the Road Traffic Licensing Regulations, but specific standards are not yet included. In the past, extensions have been made for new vehicle categories, such as electric scooters. This should also be pursued with a focus on delivery robots.

In general, a delivery robot can be used for various applications, e.g. delivery of mail, food or pharmaceuticals, which presupposes that the transport containers are adaptable and modular. Also, standardization of packaging sizes and shapes is important for better capacity planning as well as easier handling. For these two reasons, we encourage the adoption of standardized, modular norm containers.

For widespread use of delivery robots, it is necessary to consider their use in future transport and urban planning and thus the needed infrastructure (V2X-communication, barrier-free accesses). However, in line with Hoffmann and Prause (2018), it is also important to strengthen the acceptance among the population.

As the development and operation of delivery robots in public infrastructure and transport is a very young field of research, this paper is not free of limitations. Due to the limited amount of information, we resorted to qualitative methods like expert workshops and interviews, which are common practice at early research stages. These methods are based on individual experiences and estimates, which is why the results may not be exhaustive.

In addition, our analysis is based on a prototype consideration, which means that some requirements, most notably the ones addressing and originating in the registration process, might still have to be adjusted in the case of series production. The same applies when fleets of delivery robots are used.

Moreover, the analysis was almost exclusively based on German law and standardization, which must be taken into account when using the identified requirements.

It is noteworthy that the literature almost exclusively considers use cases in the parcel or food delivery sector. Further research is therefore needed to identify other areas of application. It might also be beneficial to expand the currently used terminology of “delivery robots” in literature to “transport robots” to open up the field of research.

All in all, it can be stated that future research will increasingly focus on digitalization and automation. In this context, policymakers should focus their attention on a holistic view of the transport system to better exploit the individual advantages of different modes of transport.

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II.
HICL and Practice - Excellence in Logistics and Supply Chain Management

Robotic Process Automation in Logistics: Implementation Model and Factors of Success

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Purpose: *Robotic process automation (RPA) refers to software robots (bots) that automate repetitive, rule-based tasks in a business process. In this study, the research questions regarding logistics applications are as follows: (1) What are suitable use cases for RPA in logistics? (2) Which criteria support the selection of appropriate processes? (3) How should a procedure model for implementation be designed to systematically support the introduction while considering critical success factors?*

Methodology: *This study follows the design science research process by Peffers et al. (2006). The research gap was identified through an extensive literature analysis, reflecting the state of research. Insights gained were compared with empirical data from the use of RPA at a case company.*

Findings: *A procedure model was designed to systematically consider success factors for an implementation, comprising (1) initiation; (2) piloting; (3) deployment; and (4) ongoing governance, maintenance, and continuous improvement.*

Originality: *RPA can contribute to solving challenges such as increased service demands from customers, combined with cost pressures and a shortage of skilled labor. The procedure model closes a research gap, both from a scientific perspective and from the practitioners' viewpoint, supporting an efficient and effective implementation. The consideration of knowledge from both theory and practice ensures practical relevance and significantly expands the state of research.*

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1 Introduction

Robotic process automation (RPA) refers to software robots (bots) that emulate humans in executing repetitive, rule-based tasks in a business process (Cernat et al., 2020; Willcocks et al., 2015a). In comparison to other modes of automation, RPA bots act at the front-end level of applications (Lacity et al., 2016a). Logistics is one of the many domains of interest for RPA implementation. Logistics is characterized not only by physical processes but also by digital processes such as interactions between application systems that can potentially be automated with RPA. The benefits of RPA in logistics are manifold. First, the automation of routine tasks enables employees to conduct more value-adding work and coincides with cost reductions achieved by workforce salary savings (Mullakara and Asokan, 2020; Murdoch, 2018). Second, organizations profit from a fast and reliably predictable return on investment (ROI; Alberth and Mattern, 2017). Further benefits are the increasing process execution speed and 24/7 availability of bots as well as higher process execution accuracy and improved compliance due to log data transparency (Murdoch, 2018). In addition, the implementation effort is relatively low compared to invasive automation solutions. This is because neither complex adjustments to application systems nor extensive coding knowledge are required, as programmed modules can be reused (Czarnecki and Auth, 2018; Lacity et al., 2016a; Langmann and Turi, 2020).

The main challenge in exploiting these benefits is the development of a holistic framework for RPA implementation. The ensuing research questions are as follows: RQ1: What are suitable use cases for RPA implementation in logistics? RQ2: What criteria support the selection of processes suitable for the implementation of RPA? RQ3: How should a procedure model for implementation be designed to systematically support the introduction while taking critical success factors into account? Chapter 2 provides an overview of the state of research to deduce the research agenda, and the research methodology is outlined in Chapter 3. Following the phases of the design science research process, the procedure model is developed and validated in Chapters 4 to 6. In the concluding chapter, the main findings are summarized, and implications for further research and practice are derived.

2 State of the Field and Research Gap

To obtain an overview of the state of research, a comprehensive literature review was conducted utilizing the approach by Vom Brocke et al. (2009). Relevance was gained by refraining from investigating what is known already (Baker, 2000). Rigor results from effectively applying the existing body of knowledge base (Hevner et al., 2004). As part of the keyword-based literature research, 1,120 publications were initially identified in eight databases. Based on an analysis of article titles and abstracts as well as forward and backward searches, this number was decreased to a sample of 57 publications by applying the criteria of relevance, timeliness, and validity (see Figure 1). To provide high quality sources, the focus was on articles in scientific journals and conference proceedings. For the literature review presented next, the authors used the concept matrix presented in Appendix A, which breaks down topic-related concepts into different units of analysis.

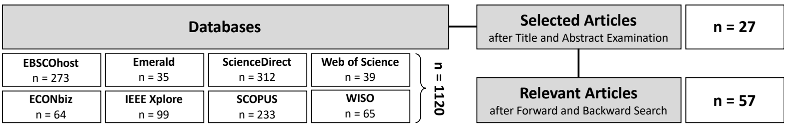

Figure 1: Databases and statistics from the literature search process

Many of the examined articles focus on general success factors for subsections of RPA implementation, often lacking a holistic and coherent view. However, in 17 papers, a structured phase model for implementation is presented (Alberth and Mattern, 2017; Hallikainen et al., 2018; Herm et al., 2020; Ilo, 2018; Jimenez-Ramirez et al., 2019; Kanakov and Prokhorov, 2020; Koch and Fedtke, 2020; Kyheröinen, 2018; Langmann and Turi, 2020; Masó, 2018; Myllymäki, 2019; Rutschi and Dibbern, 2020a; Sig-urðardóttir, 2018; Smeets et al., 2019; Willcocks et al., 2015a; Willcocks et al., 2019; Zaharia-Radulesu et al., 2017). Nonetheless, an in-depth analysis of these papers revealed substantial differences regarding the implementation approach and the focus of consideration. Furthermore, only four articles provide a profound practical validation of the theoretically derived procedure model (Ilo, 2018; Kyheröinen, 2018; Masó, 2018; Rutschi and Dibbern, 2020a).

Apart from these limitations, a major portion of the examined articles are confined to a general-level analysis. Of the few domain-specific papers that exist, a large proportion focuses on finance and accounting, followed by auditing, human resources, controlling, and manufacturing. However, none of those articles related to RPA implementation addresses logistics-specific aspects. Therefore, the literature research was extended to identify logistics use cases for RPA, resulting in an analysis of seven further articles (Agaton and Swedberg, 2018; Czarnecki and Auth, 2018; Feld et al., 2017; Kaya et al., 2019; Madakam et al., 2019; NTT DATA, 2018; Scheer, 2018), although these articles do not derive any logistics-specific characteristics and success factors for implementation.

Hence, the state of the field can be summarized as follows: Procedure models for RPA implementation are rarely domain-specific, but are often limited to general-level analysis. No logistics-specific procedure model exists. Moreover, most procedure models lack practical validation. It is therefore difficult for practitioners to understand how the outlined benefits of RPA can be achieved in logistics.

3 Research Methodology

For the design and evaluation of the procedure model, design science was chosen, as it offers a proven methodological context for construction-oriented research projects. Specifically, the research logic is based on Peffers et al. (2006), incorporating the guidelines by Hevner et al. (2004). The design science research process outlined by Peffers et al. (2006) essentially consists of six steps: problem identification and motivation, objectives for a solution, design and development, demonstration, evaluation, and communication. Following this approach, Hevner et al.'s (2004) guidelines ensure the scientific relevance and rigor of research as well as sufficient validation and effective communication of the outcome to both researchers and practitioners (see Figure 2).

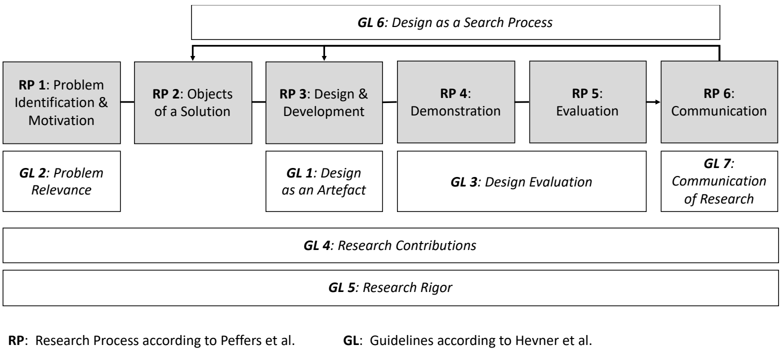

Figure 2: Design science research process and guidelines, cf. Zellner (2015)

Problem identification, objective formulation, and design and development were carried out based on a systematic and comprehensive literature review, following Vom Brocke et al. (2009); see Chapter 2. With regard to the design phase, the aforementioned 17 existing phase models for RPA implementation were mapped to identify commonalities and deviations. Building upon this mapping, insights from a case study at a leading German coating manufacturer were obtained, validating the theoretical findings and enhancing the quality of the artefact.

4 Problem Identification and Objectives for a Solution

Based on the literature review outcomes, the research gap identified is the lack of a holistic procedure model for systematically guiding practitioners in implementing RPA in logistics processes. To illustrate the complexity, the research problem can be further atomized. First, substantial knowledge about logistics use cases and suitable logistics processes is lacking. Moreover, practitioners risk making poor decisions when implementing RPA, leading to an unnecessarily long implementation duration. As a result, the costs incurred may increase, especially if external consultants are hired for implementation assistance.

The problem specification indicates that practitioners require a structured approach for implementing RPA in logistics, comprising transparent information about the objectives, input, procedure, output, methods, and success factors at every stage. A procedure model is a mapping of the activities to be performed within the context of an overall task (Schütte, 1998; Feldmann et al, 2020): A standardized process structures the fulfillment of the implementation task so that progress can be tracked and documented during the RPA project. A procedure model encourages a common understanding of the process and cooperation between the parties involved.

With regard to the research questions outlined in the introductory chapter and the problem specification delineated in the previous chapter, three main objectives for a solution are pursued. First, suitable logistics use cases for RPA implementation are to be identified. Second, criteria supporting the selection of suitable logistics processes are to be depicted in a structured way. Third, a procedure model for systematic implementation is to be designed, consisting of critical success factors derived from a literature analysis and practical implementation.

5 Design and Development

5.1 Overview

The artifactual solution to be designed is a procedure model for the implementation of

RPA in logistics processes. In Section 5.2, the fundamental design principles are outlined. Then, in the subsequent sections, an overview of the procedure model is provided, and its individual phases are described in detail.

5.2 Design Principles

According to Vom Brocke (2007), modeling is a design process intended to create a model that meets users' requirements. In terms of RPA implementation, the procedure model should provide a useful reference guideline for practitioners such as project managers and team members of RPA implementation projects as well as logistics process owners. To ensure high model quality and practicability, various design principles are applied. Following Becker et al. (1995), these design principles are accuracy, relevance, cost-effectiveness, clarity, comparability, and systematics.

5.3 Procedure Model

5.3.1 Overview

Seventeen phase models for RPA implementation were identified during the literature research. These phase models were mapped to detect commonalities as well as deviations and to derive an appropriate procedure model framework (see Appendix B). The resulting model encompasses four main phases (see Figure 3):

3. Initiation, which entails (1.1) project setup, (1.2) logistics use cases and processes identification, (1.3) business case calculation, and (1.4) software provider selection;
4. Piloting, comprising (2.1) process documentation and optimization, (2.2) pilot bot development, and (2.3) pilot validation;
5. Deployment, which involves (3.1) operating model setup, (3.2) center of excellence creation, and (3.3) deployment at a large scale;
6. Ongoing governance, maintenance, and continuous improvement.

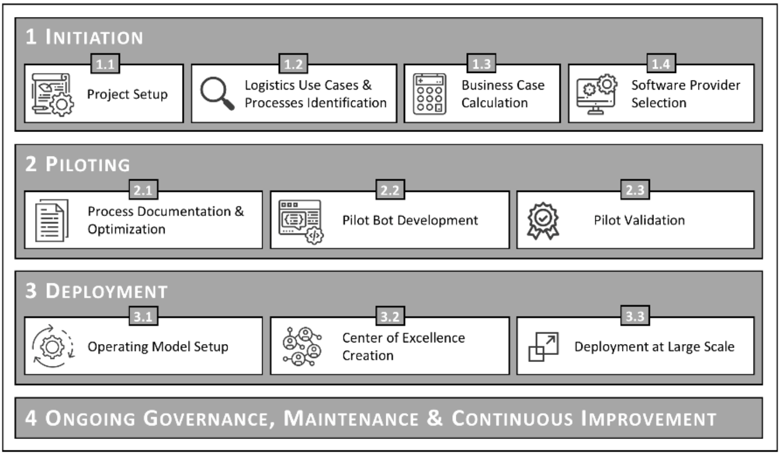

Figure 3: RPA implementation phases

To ensure consistency and practicability, each sub-phase is structured into objectives, required input, procedure, generated output, supporting methods and tools, and success factors. The following sections focus on particularly relevant aspects of the procedure model, and a comprehensive description can be found in Appendix C.

5.3.2 Phase 1: Initiation

The first step of the procedure model is to plan the project and assemble the team (1.1 Project Setup). Project planning should be based on proven project management standards, such as those of the Project Management Institute (PMI), to plan the scope, time, cost, quality, risk, resources, communication, and change management, among other topics. Apart from an early involvement of the IT department, it is important to ensure stakeholder support, especially management's tolerance for making mistakes and experimenting with RPA (Koch and Fedtke, 2020; Lacity and Willcocks, 2016; PMI, 2017).

The next step is to identify generally suitable logistics use cases and concrete processes for the pilot implementation of RPA (1.2 Logistics Use Cases & Processes Identification).

Proven use cases found in literature can be used as stimuli for a transfer to the own company, such as the entry, processing, and adjustment of master and transaction data, or the execution of functions in ERP systems (Kaya et al., 2019; Madakam et al., 2019). Appendix D provides a detailed compilation of logistics use cases.

The underlying processes must be evaluated based on qualitative and quantitative criteria. Qualitative process characteristics that should apply are a high degree of rule-based, standardization, repetitiveness and digitalization, low complexity and cognitive requirements, high process maturity, high error-proneness during manual execution, high stability of the system environment, and high re-deployability of personnel (Herm et al., 2020; Murdoch, 2018). To obtain a more comprehensive overview, the meta-analyses conducted by Agaton and Swedberg (2018) and Eggert and Moulen (2020) can be utilized. In terms of quantitative process characteristics, the monthly cost savings can be calculated by multiplying the number of process runs per month by the usual duration of a process run in hours and the involved employee costs per hour (Smeets et al., 2019). For the combined evaluation of qualitative and quantitative process characteristics, a two-dimensional heatmap can be used. Regarding the success factors within this sub-phase, it is important to analyze whether there are better-suited automation technologies than RPA for specific processes such as ERP automation or artificial intelligence (Ilo, 2018).

Next, a business case calculation for the previously selected processes must be conducted and evaluated (1.3 Business Case Calculation). Here, the quantitative and qualitative benefits as well as the costs for RPA implementation must be taken into account (Agaton and Swedberg, 2018; Alberth and Mattern, 2017; Murdoch, 2018). Based on an ROI calculation, a decision must then be made regarding whether to proceed with the implementation project or stop it. In the case of a positive decision, a suitable RPA software provider is to be selected (1.4 Software Provider Selection). The selection can be facilitated by using a scoring model with the following criteria: software costs; skill requirements; vendor reputation and support; software maturity and security; scope of functions; user friendliness; and next-generation capabilities (Herm et al., 2020; Murdoch, 2018; Taulli, 2020; Willcocks et al., 2019). Apart from using trial versions of different providers, it is recommended not to invest too much effort in the provider selection, because the major providers are on a similar capability level at the current time of technology development. Moreover, adjustments to the solution can be made after a successful pilot implementation (Koch and Fedtke, 2020; Taulli, 2020).

5.3.3 Phase 2: Piloting

In the second phase, the processes selected for RPA piloting must be comprehensively documented, standardized, and optimized (2.1 Process Documentation & Optimization). Regarding documentation, a process definition document (PDD) must be composed, providing a detailed process description as well as information on in- and out-of-scope activities, involved systems, required access rights, and responsibilities (Koch and Fedtke, 2020). The PDD draft creation can be supported by using proven process mapping methods such as BPMN 2.0, and it may be enriched by step-wise desktop screenshots and videos with voice-over (Murdoch, 2020). Regarding standardization, the process-related data must be available in a structured format (Moffitt et al., 2018). Furthermore, a re-sequencing of process steps can be useful to better separate human and robot work (Asatiani et al., 2019). Before moving to bot development, a solution design document (SDD) is to be created, consisting of technical details that are necessary for the development and maintenance of the RPA solution (Koch and Fedtke 2020). Moreover, it is recommended to document best practices and lessons learned during the entire piloting stage to facilitate future deployment activities.

The next step is to develop the robot script for the automation of the selected processes based on the PDD and SDD (2.2 Pilot Bot Development). Following an agile approach, a minimum viable product (MVP) must be built and iteratively refined by continuously conducting tests (Smeets et al., 2019). Aside from close collaboration with the respective process experts and frequent consultation with the IT department, a pragmatic approach should be adopted, allowing workarounds if necessary (Koch and Fedtke, 2020; Langmann and Turi, 2020; Wibbenmeyer, 2018).

The piloting stage concludes with the technical and economic validation and approval of the developed bots (2.3 Pilot Validation). During the technical validation, functional tests, integration tests, and finally user acceptance tests are designed and executed (Cernat et al., 2020; Ilo, 2018; Smeets et al., 2019). As soon as the bots are technically approved, the business case calculated in Phase 1.3 must be validated. Prior to final pilot approval and migration to production, the following are vital: ensuring staff acceptance and providing training to process experts in case their attendance is required.

5.3.4 Phase 3: Deployment

The deployment phase starts with defining a standardized framework for the effective, cost-efficient, and secure implementation and operation of new RPA solutions (3.1 Operating Model Setup). The operating model should include RPA demand pipeline creation; implementation project approval; implementation; go-live in production environment; and ongoing governance, maintenance, and continuous improvement. Furthermore, guidelines regarding, for example, bot access rights, the architectural anchoring of bots, and automation restrictions must be defined, and compliance with data privacy and security regulations must be ensured (Alberth and Mattern, 2017; Langmann and Turi, 2020; Smeets et al., 2019). Moreover, a change management plan must be created, following, for example, Kotter's eight-stage change model (Kotter, 2013).

The next step is to build a center of excellence (CoE) that is responsible for RPA governance, design, development, operation, and maintenance during the RPA rollout (3.2 Center of Excellence Creation). The number of personnel resources within the CoE team depends on the intended scope of deployment as well as the company size. Recommended roles are a CoE lead, a business analyst, a developer, and a tester for process selection and RPA solution development; an IT architect, support, and a controller for continuous monitoring and support; a trainer for knowledge transfer; and a distributor for communication of RPA benefits. Following Hallikainen et al. (2018), the creation of new RPA solutions and the maintenance of existing RPA solutions should be distinctly separated within the CoE from an organizational point of view.

Having set up an operating model and assembled a CoE team, the deployment of RPA at a large scale can be ensued (3.3 Deployment at a Large Scale). With regard to the demand pipeline creation, it must be ensured that process specialists comprehensively understand the capabilities of RPA (Cooper et al., 2019). The ideation process can be enhanced by incentivization and by showcasing successful RPA implementations

(Balasundaram and Venkatagiri, 2020; Murdoch, 2018). In terms of bot development, it is recommended to create and utilize a centralized component library with common RPA modules to decrease the solution design effort (Hallikainen et al., 2018).

5.3.5 Phase 4: Ongoing Governance, Maintenance, and Continuous Improvement

In addition to RPA piloting and deployment, RPA governance, maintenance, and improvement must be continuously ensured for long-term functionality and error prevention. Aside from the provision of a service desk for RPA issues, change requests and application system releases should be analyzed and managed (Anagnoste, 2018; Koch and Fedtke, 2020). Moreover, the bots' performance must be monitored, the standardized implementation procedure must be reviewed, and business continuity plans for cases of bot unavailability must be delineated (Ilo, 2018; Smeets et al., 2019; Taulli, 2020). Along with log data storage for transparency, it is further recommended to continuously examine whether an extension of RPA with next-generation technologies, such as natural language processing or optical character recognition, is beneficial (Anagnoste, 2018; Langmann and Turi, 2020).

6 Demonstration and Evaluation

Two examples of RPA implementations in the logistics processes of a German coating manufacturer were used to validate the applicability of the procedure model. The first example is a bot that replaces repetitive human input to IT systems in the context of transport processes. The second use case is the application of an RPA bot instead of developing a conventional interface between two IT systems.

6.1 Use Case One: Transportation Management

The first RPA project began as a trial-and-error approach (Phase 1), as RPA was a new phenomenon to the team involved. The first objective was to get to know the technology and collect first experiences to evaluate the benefits and constraints of utilizing RPA in logistics. In contrast to the model presented, the case company has a CoE for RPA processing, which offered services to the logistics operations team. As described by Herm et al. (2020) and Murdoch (2018), the team started with identifying simple, digital, administrative processes as potential use cases. Therefore, here, the business case calculation was done after the roll-out. The first use case chosen was the input of shipping documents into the ERP system. Transport lists, checklists, loading pictures, and other transport-related documents are collected and manually attached to the transport documentation in the ERP system.

To understand the manual process, a process analysis was conducted and documented (Phase 2). In this case, the information collected included all relevant data as described by Koch and Fedtke (2020): procedure description, involved systems, access rights, handled documents, and transactions of the process. To support the programmers in the CoE, live videos were recorded in addition to the process documentation, showing all relevant process steps performed by the employee in a repeatable manner. Following the video, the scripting was done by the CoE, and after functional and integrational testing by the CoE, the local project team tested user acceptance, taking all eventualities into account.

After successful testing, the migration to production commenced. The bot's email address required for the process was created, its access rights were requested, the bot was activated, and the process went “live.” Change management was then documented, the teams were onboarded, and management was informed. After implementation, Phase 4 was launched. The process was maintained regularly, performance was checked, statistics were compiled, and the process itself has been optimized continuously according to the LEAN principles of plan, do, check, act (PDCA).

6.2 Use Case Two: Digital Outbound Checklist

The second use case is the application of an RPA bot instead of developing a conventional interface between two IT systems. Interfaces for automated data exchange with other IT systems are not available with every IT system. For process automation, they must often be programmed and implemented in a time-consuming and cost-intensive manner. For simple standard processes, the use of bots is an alternative to data transfer between IT systems as a so-called non-invasive solution without major programming effort or deeper intervention in the respective IT systems. Standardized workflows, the comparison of use cases, and the adaptation of existing bots for further implementations are part of the deployment phase (Phase 3). The second use case demonstrates the applicability of this approach.

The physical logistics department handles the dispatch of outgoing trucks. Here, the picked and packed pallets are loaded onto the trailers. Loading security is ensured by warehouse workers using a paper-based checklist to document the correct condition of the truck and loaded cargo leaving the coating manufacturer's yard. Since this process was digitized using a digital checklist, a transfer method was needed to digitally store the checklist data, picklists, loading image, personal data of the trucker, and other shipping documents for further processing. Time-consuming and costly custom-programmed interfaces were traditionally used to transfer the data to the system, which would hinder rapid process implementation. Instead, the above-mentioned existing transportation management bot was modified to fill the gap of a missing data transfer interface between the plug-and-play checklist and the company's ERP system. The process was designed as visualized in Figure 4.

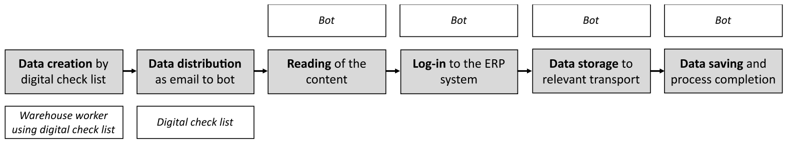

Figure 4: Process for robotic process automation (RPA) implementation in case company

The bot receives the aforementioned data as an e-mail attachment, reads the content, logs on to the transport management system with its personalized access rights, files the document under the corresponding shipment number, saves the status, and completes the process at the end. A detailed overview of success factors derived from the delineated RPA implementation approaches at the coating manufacturer can be found in Appendix C.

6.3 Evaluation

From the company's point of view, the bots offer flexibility because they can work independently 24/7, thereby enabling improved productivity. The bots also work in a standardized and error-free manner, meaning that the high process performance remains constant and measurable. Both the productivity boost and the consistent high performance increase compliance and safety, especially in companies that are strongly quality driven, such as the automotive industry. Employees can focus on more value-added work rather than dealing with strenuous or low-value work, thus increasing employee satisfaction. In addition, RPA can be implemented quickly and cost-effectively, and the benefits could be measured both qualitatively and quantitatively. In summary, RPA has the potential to increase quality and efficiency, and the lessons learned that have been incorporated into the procedure model are transferable to other use cases. RPA is suitable not only for taking over human activities on IT systems, but also for data transfer between two systems as an alternative to a complex programmed interface.

7 Communication

The objective of this paper was to provide support to logistics practitioners in implementing RPA efficiently and sustainably. To achieve this objective, three research questions were answered. RQ1: What are suitable use cases for RPA implementation in logistics? Based on a comprehensive literature review, numerous use cases were identified. RQ2: What criteria support the selection of processes suitable for the implementation of RPA? Qualitative and quantitative criteria were provided for the selection of suitable processes. In particular, a high degree of rule-based tasks, standardization, repeatability and digitization, low complexity and cognitive requirements, high process maturity, high error-proneness in manual execution, and a high stability of the system environment indicate suitability for RPA. RQ3: How should a procedure model for implementation be designed to systematically support the introduction while taking critical success factors into account? Previously available process models were not specifically geared to the requirements of logistics or were not sufficiently validated. This gap was closed by the domain-specific process model. The logistics-specific procedure model presented in this paper significantly expands the state of research. On the one hand, a comprehensive literature review and a phase model synopsis were conducted to derive an appropriate framework based on commonalities and deviations. On the other hand, the results of a case study validation comprising two logistics use cases were considered.

Nonetheless, limitations remain. First, apart from the necessity of further validation, a distinction between small and large companies would be useful regarding, for example, the number of employees in the CoE. Moreover, further research could focus on a more holistic approach to process automation, including a criteria-based selection between different tools and technologies such as artificial intelligence (AI) or intelligent business process management suites (iBPMS).

RPA has various benefits for practitioners. Aside from cost reductions, 24/7 bot availability, and a higher process execution accuracy, the automation of routine tasks enables employees to conduct more value-adding work. Moreover, neither complex adjustment to application systems nor extensive programming knowledge are required for RPA implementation. The presented procedure model supports practitioners with the implementation process, providing step-by-step guidance including objectives, input, procedure, output, methods and tools, and success factors for each phase. It must be emphasized that continuous change management is essential to run RPA successfully.

Appendix A: Concept Matrix for Literature Analysis

Source	Implementation			Procedure Model					Domains						Peer-reviewed
	Success Factors	Methods	Project Management Focus	Structured Phase Model	Project Initiation Phase	Process Selection Phase	Pilot Phase	Roll-out Phase	Audit	Controlling	Finance/ Accounting	Human Resources	Logistics/ SCM	Manufacturing	
Alberth and Mattern 2017				X		X	X								X
Anagnoste 2017							X	X			X	X			X
Anagnoste 2018	X	X													X
Asatiani and Penttinen 2016						X									X
Asatiani et al. 2019	X														X
Asatiani et al. 2020	X				X						X				
Balasundaram and Venkatagiri 2020					X	X	X	X				X			X
Bourgouin et al. 2018						X									X
Camin 2018	X					X	X	X							
Carden et al. 2019	X		X		X		X				X				X
Cernat et al. 2020	X	X													X
Cooper et al. 2019	X										X				X
Eggert and Moulen 2020						X									
Fernandez and Aman 2018	X										X				X
Fung 2014	X					X									X
Gotthardt et al. 2020	X								X		X				X
Hallikainen et al. 2018	X			X	X		X	X							X
Heponiemi 2019	X					X									X
Herm et al. 2020	X		X	X	X	X	X	X							
Ilo 2018	X			X	X	X	X				X				X
Jalonen 2017						X									X
Jimenez-Ramirez et al. 2019				X		X	X								
Kanakov and Prokhorov 2020				X		X	X	X							X
Knauer et al. 2020	X									X					
Koch and Fedtke 2020	X	X	X	X	X	X	X	X							
Kokina and Blanchette 2019	X				X	X					X				X
Kyheröinen 2018	X		X	X	X		X								X
Lacity and Willcocks 2016	X														X
Lacity et al. 2016a	X					X	X	X							
Lacity et al. 2016b	X						X	X							
Lacurezeanu et al. 2020	X					X			X		X				X
Langmann and Turi 2020	X	X		X	X	X	X	X		X	X				
Leopold et al. 2018						X									
Masó 2018	X			X		X	X								X
Moffitt et al. 2018						X	X		X						X
Murdoch 2018	X		X			X					X				
Myllymäki 2019	X			X		X	X								X
Penttinen et al. 2018						X									X
Plattfaut et al. 2020						X									X
Radke et al. 2020						X		X						X	X
Rutschi and Dibbern 2020a				X			X								X
Rutschi and Dibbern 2020b								X							
Santos et al. 2020	X				X	X									X
Schmitz et al. 2019	X					X									
Seasongood 2016	X					X					X				
Sigurðardóttir 2018	X			X		X	X	X							X
Šimek and Šperka 2019						X	X					X			X
Smeets et al. 2019	X	X	X	X	X	X	X	X							
Syed et al. 2020	X														X
Taulli 2020	X	X	X		X	X	X								
Wanner et al. 2019		X				X									X
Wewerka et al. 2020	X														X
Wibbenmeyer 2018	X				X		X								
Willcocks et al. 2015a	X			X		X	X	X							
Willcocks et al. 2015b	X														
Willcocks et al. 2019	X		X	X	X										
Zaharia-Radulesu et al. 2017				X		X	X	X							X

Appendix B: Synopsis of Phase Models

<table>
<tr><th>Source</th><th>Project Setup</th><th>Process Selection</th><th>Business Case Calculation</th><th>Software Provider Selection</th><th>Process Documentation/ Optimization</th><th>Pilot Bot Development</th><th>Pilot Validation</th><th>Rollout/Deployment</th><th>Ongoing Governance & Support</th></tr>
<tr><td>Alberth and Mattern 2017</td><td colspan="4">1) Proof of Concept Phase</td><td colspan="3">2) Pilot Phase</td><td>3) Leverage Phase</td><td></td></tr>
<tr><td>Hallikainen et al. 2018</td><td colspan="2">1) Pre-Implementation Stage</td><td></td><td></td><td colspan="3">2) Pilot Implementation Stage</td><td colspan="2">3) Expansion Stage</td></tr>
<tr><td>Herm et al. 2020</td><td>1) Initialization</td><td colspan="6">2) Implementation</td><td>3) Scaling</td><td>(Continuously)</td></tr>
<tr><td>Ilo 2018</td><td></td><td colspan="2">1) RPA Opportunities
2) Business Case Assessment</td><td></td><td>3) Process Assessment</td><td colspan="2">4) Development
5) Production Go-Live / Intensive Support</td><td></td><td>5) Production Go-Live / Intensive Support</td></tr>
<tr><td>Jimenez-Ramirez et al. 2019</td><td></td><td>1) Process Selection</td><td></td><td></td><td>2) Process Design
3) Process Development</td><td>4) Bot Deployment</td><td>5) Bot Testing</td><td></td><td>6) Maintenance</td></tr>
<tr><td>Kanakov and Prokhorov 2020</td><td></td><td></td><td colspan="2">2) Assessment of the Impact on the Operating Model</td><td colspan="3">1) Pilot Implementation</td><td>3) Implementation / Scaling</td><td></td></tr>
<tr><td>Koch and Fedtke 2020</td><td>1) RPA Knowledge Building
2) Basic Setup</td><td colspan="3">2) Basic Setup</td><td colspan="3">3) Pilot Implementation</td><td>4) Rollout</td><td></td></tr>
<tr><td>Kyheröinen 2018</td><td colspan="2">1) Preceding the Project
2) Conceptualization</td><td></td><td></td><td colspan="3">3) Execution</td><td></td><td>4) Termination
5) Following the Project</td></tr>
<tr><td>Langmann and Turi 2020</td><td colspan="7">1) Proof-of-Concept</td><td>2) Ramp-up
3) Scale & Institutionalize</td><td>3) Scale & Institutionalize
4) Mature & Innovate</td></tr>
<tr><td>Masó 2018</td><td></td><td colspan="4">1) Requirement & Analysis Phase</td><td>2) Development Phase</td><td>3) Testing Phase</td><td></td><td>4) Deployment & Governance Phase</td></tr>
<tr><td>Myllymäki 2019</td><td></td><td>1) Target Process Identification & Description</td><td></td><td></td><td>1) Target Process Identification & Description</td><td>2) Minimum Viable Product Development</td><td>3) Quality Assurance
4) Implementation to Production</td><td></td><td></td></tr>
<tr><td>Rutschi and Dibbern 2020a</td><td></td><td>1) Identify Suitable Routines</td><td></td><td></td><td>2) Routine Translation</td><td colspan="2">3) Routine Inscription</td><td></td><td></td></tr>
<tr><td>Sigurðardóttir 2018</td><td></td><td>1) Process Assessment</td><td>2) Business Case</td><td></td><td colspan="3">3) Proof of Concept</td><td>5) RPA Lifecycle</td><td>4) Project Design & Build</td></tr>
<tr><td>Smeets et al. 2019</td><td>1) Project Setup</td><td>2) Process Selection</td><td></td><td>3) Provider Selection
4) Proof of Technique</td><td>5) Preliminary Process Optimization</td><td>6) Agile Artifact Development</td><td>7) Testing</td><td colspan="2">8) Rollout</td></tr>
<tr><td>Willcocks et al. 2015a</td><td colspan="4">1) Product & Process Evaluation
2) Project Mobilization</td><td colspan="3">3) Project Design & Build
4) Initial Launch</td><td>5) Ramp up</td><td>6) Improvement</td></tr>
<tr><td>Willcocks et al. 2019</td><td colspan="4">1) Generating the Context for RPA</td><td colspan="3">2) RPA Design and Development</td><td colspan="2">3) Putting RPA into Practice</td></tr>
<tr><td>Zaharia-Radulescu et al. 2017</td><td></td><td colspan="6">1) Proof of Concept</td><td>2) RPA Assessment
3) RPA Implementation
4) Production Rollout</td><td>5) Maintenance</td></tr>
</table>

Appendix C: Procedure Model for RPA Implementation

	1 Initiation	
	1.1 Project Setup	**1.2 Logistics Use Cases & Processes Identification**
Objectives	– Definition of basic project guidelines (Koch and Fedtke 2020) – Project planning – Project team assembly and division of responsibility	– Use case identification and process selection for RPA pilot implementation based on combination of qualitative and quantitative criteria
Input	– Support by management (Willcocks et al. 2019) – Statement of Work (SOW) – Personnel resources – Budget approval	– Assembled project team – Project plan – Purpose of RPA implementation
Procedure	– Determine the purpose/objectives of RPA implementation (Alberth and Mattern 2017, Kyheröinen 2018) – Ensure alignment with business strategy (Herm et al. 2020) – Define project scope (Carden et al. 2019) – Prepare timeline (Koch and Fedtke 2020) – Assess risks, calculate project effort, define quality requirements, develop communication and change management plan – Assemble a cross-functional team for RPA implementation (Balasundaram and Venkatagiri 2020, Koch and Fedtke 2020, Smeets et al. 2019): RPA facilitator (experienced project manager), RPA expert (IT-savvy employee with RPA development expertise) and IT infrastructure expert (employee with a broad network within the IT departments) – Define guidelines for cooperation in the project (Koch and Fedtke 2020) – Develop basic RPA capabilities (Willcocks et al. 2019) – Prepare project charter (Carden et al. 2019)	Identify general logistics use cases and get overview of process landscape (cf. appendix for detailed overview of proven logistics use cases found in literature) (Alberth and Mattern 2017) Evaluate use cases based on qualitative process characteristics in scoring model (Herm et al. 2020, Murdoch 2018) – Degree of rule-based (high --> easy decomposition into clear sub-processes) – Process complexity (low) / cognitive requirements (low) – Process maturity (high) – Degree of digitalization (high) – Number of involved systems (high) – Excerption rate (low) / standardization degree (high) – Degree of repetitiveness (high) – Stability of environment (high --> no/few changes in underlying systems) – Re-deployability of personnel (high) Evaluate use cases based on quantitative process characteristics (Smeets et al. 2019) – Calculation of monthly cost savings by multiplication of: – Number of process runs per month – Usual duration of process run in hours – Involved employee costs per hour Combine qualitative and quantative characteristics evaluation in matrix/heatmap to select use cases / processes for RPA pilot implementation

	1 Initiation	
	1.1 Project Setup	**1.2 Logistics Use Cases & Processes Identification**
Output	– Purpose/objectives of RPA implementation (Alberth and Mattern 2017) – Project plan, scope, timeline, risks, effort, quality requirements, communication, change management – Assembled project team with clear roles and capabilities – Guidelines for cooperation (Koch and Fedtke 2020) – Project charter (Carden et al. 2019)	– Use cases / processes for RPA pilot implementation (Hallikainen et al. 2018)
Methods	– Proven methods for project planning (e. g. stakeholder analysis matrix, work breakdown structure analysis, responsibility assignment matrix, risk probability and impact matrix)	– Workshops, surveys, discussions for basic process identification (Herm et al. 2020) – Scoring model for qualitative process characteristics evaluation (Langmann and Turi 2020) – Matrix/heatmap for combination of qualitative and quantitative process characteristics
Success Factors	– Develop stakeholder support and organizational commitment (management, employees) by communicating vision and benefits, ensuring clarity about what is going to happen and ensuring active stakeholder participation (Willcocks et al. 2019) – Consider hiring an external resource specialized in RPA implementation to acquire RPA skill-set (Taulli 2020) – Approach RPA project with a lean team (Murdoch 2018) – Management tolerance for making mistakes and experimenting with RPA (Koch and Fedtke 2020) – RPA has to be regarded as a strategic innovation (not only operational) by management (Willcocks et al. 2019) – Early IT involvement to ensure compliance with IT security and configure infrastructure (Lacity and Willcocks 2016) – Use a central expert unit for internal development (Case Study) – Ensure an open mindset to try and test a new technology (Case Study)	Highly relevant process characteristics for RPA pilot implementation: – Simplicity of process (rule-based) to ensure successful implementation (Hallikainen et al. 2018) – High motivation of process expert/owner and willingness to communicate experiences to other departments (Koch and Fedtke 2020) – Clear visibility of improved process efficiency after RPA implementation (high volume) to ensure management support (Hallikainen et al. 2018) – High degree of repetitiveness and error-proneness during manual execution to ensure employee support and strengthen interest in RPA technology (Willcocks et al. 2019) – Scan logistics process landscape systematically (Alberth and Mattern 2017) – Analyze if there are better-suited automation technologies for specific processes than RPA (Ilo 2018) – Organize general RPA training for personnel at pilot site (process specialists) (Hallikainen et al. 2018) – Consider use cases in administrative logistics (e. g. transport management) or the bridging between two application systems as starting points for RPA implementation (Case Study)

<table>
<tr><th></th><th colspan="2">1 Initiation</th></tr>
<tr><th></th><th>1.3 Business Case Calculation</th><th>1.4 Software Provider Selection</th></tr>
<tr><td>Objectives</td><td>– Calculation and evaluation of business case for selected use cases / processes (Langmann and Turi 2020)
– Decision whether RPA implementation project should be proceeded or stopped</td><td>– Selection of a suitable RPA software provider (Alberth and Mattern 2017)</td></tr>
<tr><td>Input</td><td>– Selected processes for pilot implementation
– Current business strategy</td><td>– Decision that RPA implementation project should be proceeded based on business case calculation
– Knowledge of basic RPA software requirements (Murdoch 2018)
– Selected processes for pilot implementation</td></tr>
<tr><td>Procedure</td><td><u>Calculate / estimate quantitative and qualitative benefits</u> (Agaton and Swedberg 2018, Alberth and Mattern 2017, Murdoch 2018)
– Reduced processing workforce (in euros per year)
– Reduced office space (in euros per year)
– Reduced costs due to defective processing (in euros per year)
– Reduced FTE overhang costs (in euros per year)
– New revenue sources because of new products (near real-time; in euros per year) --> e.g. offer better service level agreements due to 24/7 availability
– Improved employee satisfaction / engagement
– Improved compliance due to log data transparency

<u>Calculate costs / expenses</u> (Alberth and Mattern 2017, Murdoch 2018)
– Investment costs upfront for framework (in euros)
– Investment costs upfront per use case (in euros)
– License costs (in euros per year)
– New workforce costs to implement, control, govern, maintain RPA (in euros per year)
– Office space costs for those people (in euros per year)

<u>Compare benefits and costs</u> (Alberth and Mattern 2017)</td><td>– Define requirements and selection criteria (Murdoch 2018)
– Get market overview (Smeets et al. 2019)
– Pre-select generally suitable providers (Czarnecki and Auth 2018)
– Decide on one provider based on selection criteria (Masó 2018)

<u>Selection criteria:</u> (Herm et al. 2020, Murdoch 2018, Taulli 2020, Willcocks et al. 2019)
– Software costs
– Skill requirements
– Vendor support
– Vendor reputation
– Software maturity and security
– Scope of functions (e.g. functions for exception handling or testing, process discovery tool)
– Ease of use / user-friendliness
– Next-generation capabilities (e.g. artificial intelligence)</td></tr>
</table>

	1 Initiation	
	1.3 Business Case Calculation	**1.4 Software Provider Selection**
Output	– Calculated and evaluated business case for selected processes (Balasundaram and Venkatagiri 2020) – Decision whether RPA implementation project should be proceeded or stopped	– Offers of various RPA software providers – Selected RPA software provider (Alberth and Mattern 2017)
Methods	– Return on investment calculation (Herm et al. 2020)	– Scoring model
Success Factors	– Broad perspective on quantitative and qualitative dimensions of benefits – Robust data as input or valid assumptions in case of predicted data – Be aware that RPA is not a "universal remedy" (one bot can provide time savings, but there are many bots necessary to provide FTE savings) – Consider all kinds of process steps (e. g. walking distances) (Case Study) – Take "soft" factors like compliance or user satisfaction into account (Case Study)	– Fast selection of a suitable provider (do not invest too much effort in provider evaluation for pilot implementation) because all major providers are on a similar level and more comprehensive evaluation can be conducted after successful RPA pilot implementation (Koch and Fedtke 2020) – Use trial versions of providers to get a feeling for the capabilities of the software (Taulli 2020)

	2 Piloting	
	2.1 Process Documentation & Optimization	**2.2 Pilot Bot Development**
Objectives	– Documentation, standardization and optimization of selected processes (Alberth and Mattern 2017)	– Iterative development of robot script for automation of selected processes (Koch and Fedtke 2020)
Input	– Selected processes for pilot implementation	– Process Definition Document (Koch and Fedtke 2020) – Solution Design Document (Koch and Fedtke 2020)
Procedure	<u>Process documentation</u> – Comprehensively understand the activities in the selected processes (interview key users, record manual tasks including all variations, capture the "unwritten rules" of processes) (Hallikainen et al. 2018, Murdoch 2018) – Depict entire process as well as individual pages per sub-process with screenshots (Smeets et al. 2019) – Create desktop screenshots/video of each step (+ voiceover) (Murdoch 2018) – Provide a list of typical bugs and errors to enable a quick error detection and elimination – Compose draft of Process Definition Document (PDD) with detailed process description, in-scope, out-of-scope, involved systems, required access rights, responsibilities (Koch and Fedtke 2020) <u>Process standardization</u> – Data cleansing/standardization (Alberth and Mattern 2017) – Data should be in a structured format so that software program can successfully interpret inputs (Moffitt et al. 2018) <u>Process optimization</u> (Alberth and Mattern 2017, Smeets et al. 2019) – Alignment of process with process requirements – Transform paper into electronic data – Create flawless dataflows – Implement electronic process trigger to initiate RPA transaction – Adjust PDD <u>Draw up Solution Design Document</u> (SDD) with description of all technical details that are necessary for development and maintenance of RPA solution (Koch and Fedtke 2020)	– Iteratively develop robot script based on PDD and SDD (Koch and Fedtke 2020) – Successively increase functional scope (starting with a minimum viable product) (Smeets et al. 2019) – Conduct tests and tune/debug robot script according to test results (Kanakov and Prokhorov 2020) – Update PDD and SDD if necessary (Koch and Fedtke 2020)

	2 Piloting	
	2.1 Process Documentation & Optimization	**2.2 Pilot Bot Development**
Output	– Process Definition Document (Koch and Fedtke 2020) – Solution Design Document (Koch and Fedtke 2020) – Documented lessons learned	– Robot script (Koch and Fedtke 2020) – Documented lessons learned
Methods	– Flowchart (Murdoch 2018) – Process map (Murdoch 2018) – Lean, Kanban, Six Sigma (for process optimization) (Taulli 2020) – Process mining	– Scrum for agile development of automation solutions (Anagnoste 2018)
Success Factors	– Detailed and high-quality process documentation essential to ensure seamless and thorough development of RPA solution and because nature of supply chain operations is complex with high data volumes, tending to cause many process variations (Carden et al. 2019, Willcocks et al. 2019) – Re-sequence processes to better separate processes into human work (mindful components) and robot work (mindless components) and clearly define the interfaces (Lacity et al. 2016b, Asatiani et al. 2019, Hallikainen et al. 2018) – Utilize proven mapping method such as BPMN 2.0 for process map for easing collaboration with involved (external) parties – Utilize process mining to support documentation – Check whether automation of individual process steps is possible through existing system applications (e.g. SAP workflow) (Langmann and Turi 2020) – Document lessons learned for future rollout/scaling (Case Study) – Standardize/stabilize/simplify processes before automation (Case Study)	– Comprehensively document/comment all development steps (Ilo 2018, Taulli 2020) – Use support services of RPA providers (Koch and Fedtke 2020) – Take a pragmatic approach, allow workarounds, but always in consultation with the IT department (Koch and Fedtke 2020) – Use development/sandbox environment, not directly develop in production environment to prevent disruption of operations (Smeets et al. 2019, Carden et al. 2019) – Close collaboration with process experts/owners (Langmann and Turi 2020, Cooper et al. 2019) – Ensure IT involvement to comply with regulatory and cybersecurity requirements (Wibbenmeyer 2018) – Document lessons learned for future rollout/scaling (Case Study) – Document testing steps and results (Case Study) – Conduct testing together with key users (Case Study)

	2 Piloting	3 Deployment
	2.3 Pilot Validation	**3.1 Operating Model Setup**
Objectives	– Technical and economic pilot validation – Approval of developed bots (Masó 2018)	– Definition of guidelines and standardized framework for effective, cost-efficient and secure implementation and operation of new RPA solutions without stakeholder resistance (Langmann and Turi 2020)
Input	– Robot script – Business case calculation	– Documented lessons learned of pilot implementation
Procedure	Technical validation – Test design: define testing scope / responsibility and create scenarios / test cases (e.g. in Excel file, comprising pre-conditions, post-conditions, the expected result, and the actual result) (Cernat et al. 2020, Smeets et al. 2019) – Test execution: functional tests, integration test, user acceptance test (real data test, precondition for migration to production environment) (Ilo 2018, Koch and Fedtke 2020, Masó 2018) – Further development or technical approval Economic validation – Validate the business case respectively the profitability – Compile KPI list (e.g. cycle time, error frequency) to visualize the improvements achieved by RPA implementation Survey staff acceptance and provide training in case of attended RPA Pilot approval and migration to production (Masó 2018)	Define standardized operating model comprising: (Anagnoste 2018, Willcocks et al. 2019) – Demand pipeline creation – RPA implementation project approval – RPA implementation – Go-live in production environment – Ongoing governance, maintenance and continuous improvement Decide on basic RPA governance/guidelines: (Alberth and Mattern 2017, Langmann and Turi 2020) – Access rights for bots and application process – Restrictions which processes must not be automated by RPA – Architectural anchoring/locating of bots Create change management plan based on Kotter's 8-step change model: (Kotter 2013) – Create sense of urgency around need for change – Form powerful coalition by ensuring relevant stakeholder support – Create clear vision and strategy for change – Communicate vision and address employees' concerns and fears early and honestly – Remove obstacles by reviewing organizational structure and incentivizing change-oriented behaviour – Create short-term wins by starting with "sure-fire" projects – Continuous improvement during change process – Anchor changes in corporate culture by continuously communicating success stories

	2 Piloting	3 Deployment
	2.3 Pilot Validation	**3.1 Operating Model Setup**
Output	– Test protocols (Ilo 2018) – Approved robot script (functioning bot) – Validated business case – KPI list (before and after automation) – Documented lessons learned	– Standardized operating model for ongoing implementation of RPA solutions (Langmann and Turi 2020) – Guidelines for cooperation and governance (Koch and Fedtke 2020) – Change management plan (Taulli 2020)
Methods	– Prototypical testing in representative process activities: functional test, integration test, and user acceptance test	– Management of Change (MOC)
Success Factors	– Check if RPA provider offers test case templates to allow testing in different scenarios (automated test execution, test design still manual) (Cernat et al. 2020) – Involve users (Kyheröinen 2018) – Document lessons learned for future rollout/scaling (Case Study) – Ensure robust business case data (Case Study) – Ensure acceptance by staff prior to final approval (Case Study) – Prepare set of KPIs according to business targets/strategy to visualize the success of RPA implementation (Case Study)	– Design RPA governance early (Willcocks et al. 2019, Smeets et al. 2019) – Ensure compliance with data privacy and security regulations (Smeets et al. 2019, Gotthardt et al. 2020) – Communicate the operating model (Koch and Fedtke 2020)

	3 Deployment		4 Ongoing Governance, Maintenance & Continuous Improvement
	3.2 CoE Creation	**3.3 Deployment at Large Scale**	
Objectives	– Creation of Center of Excellence (CoE) with responsibility for RPA governance, design, development, operating and maintaining to ensure effective RPA deployment (Willcocks et al. 2019)	– Standardized deployment of RPA at large scale based on defined guidelines and operating model	– Ongoing governance, maintenance, support and continuous improvement of implemented RPA solutions to ensure long-term functionality (Koch and Fedtke 2020) – Failure and error prevention (Smeets et al. 2019)
Input	– Standardized operating model and guidelines for cooperation and governance (Willcocks et al. 2019) – Documented lessons learned of pilot implementation – Pilot implementation team – Personnel resources (Herm et al. 2020)	– Standardized operating model for ongoing implementation of RPA solutions (Willcocks et al. 2019) – Change management plan (Taulli 2020) – Documented lessons learned of pilot implementation – CoE team roles	– Developed and validated bots in operation – CoE team roles
Procedure	<u>Assemble CoE team:</u> (Willcocks et al. 2019, Anagnoste 2018, Langmann and Turi 2020, Koch and Fedtke 2020) – RPA facilitator (CoE lead) – RPA business analyst (process selection, documentation and optimization) – RPA developer (design and development of RPA solutions) – RPA tester (development of test cases, execution of tests) – RPA scrum master (agile development) – RPA architect (holistic support of the RPA solutions and platform, coordination with IT department, IT governance compliance) – RPA support/service (first line support for RPA production process, regular testing of the functionality of RPA solutions) – RPA controller/operator (performance measurement, continuous improvement) – RPA trainer (RPA knowledge transfer) – RPA distributor (communication of RPA opportunities and benefits to employees)	<u>Implement new RPA solutions according to operating model:</u> (Anagnoste 2018, Willcocks et al. 2019) – Review requests for RPA implementation from business units based on process selection criteria and create demand pipeline (cf. phase 1.2) – Conduct business case calculation and approve RPA implementation project (cf. phase 1.3) – Implement RPA by conducting process documentation and optimization, solution development and testing, as well as technical and economic validation) (cf. phases 2.1, 2.2, 2.3) – Go-live of RPA solution in production environment – Ongoing governance, maintenance and continuous improvement (cf. phase 4) – Manage change according to change management plan (Taulli 2020)	– Manage change requests (Koch and Fedtke 2020) – Manage application system releases by analyzing impacts on production after 3rd party software updates (e.g. SAP update) (Anagnoste 2018) – Provide service desk for RPA issues and errors – Create business continuity plans for cases of bot unavailability (especially for critical processes) (Ilo 2018, Smeets et al. 2019) – Measure and monitor bot performance (Taulli 2020) – Identify and execute improvement measures (Koch and Fedtke 2020) – Continuously develop and review standards/templates – Check extension of RPA with next-generation technologies (e.g. natural language processing, optical character recognition) (Langmann and Turi 2020)

	3 Deployment		4 Ongoing Governance, Maintenance & Continuous Improvement
	3.2 CoE Creation	**3.3 Deployment at Large Scale**	
Output	– CoE team – Accounting processes for internal cost allocation	– Demand pipeline with potential RPA use cases (Balasundaram and Venkatagiri 2020) – Developed and validated bots in operation – Success stories regarding RPA implementation (Balasundaram and Venkatagiri 2020)	– Service desk for RPA issues and errors – Business continuity plans (Ilo 2018) – New/updated standards/templates for RPA implementation (Lacity et al. 2016b)
Methods	– Work breakdown structure analysis – Responsibility assignment matrix		– PDCA cycle for continuous improvement
Success Factors	– Ensure organizational separation between creating new RPA solutions and maintaining existing RPA solutions (Hallikainen et al. 2018) – Organizationally, anchor CoE on business side, not on IT side (Herm et al. 2020) – Use pilot implementation team to train new team members (Balasundaram and Venkatagiri 2020) – Ensure connections to IT department for exchange of information about future application system releases (Koch and Fedtke 2020) – Management support (Lacity and Willcocks 2016) – Based on scope of rollout and company size, roles in CoE team can be filled with various resources or one resource can fill various roles (Case Study)	– Ensure that process specialists/owners understand RPA capabilities because they have the required domain expertise (Cooper et al. 2019) – Motivate process specialists/owners to identify new opportunities for RPA implementation by showcasing successful RPA implementations and incentivizing the ideation process (Balasundaram and Venkatagiri 2020, Murdoch 2018) – Successively increase complexity of selected processes (Herm et al. 2020) – Document and communicate success stories regarding RPA implementation to strengthen interest in RPA within company (Balasundaram and Venkatagiri 2020) – Create and use a centralized component library with common RPA modules to reduce solution design effort in development phase (Case Study) – Insource RPA knowledge (Case Study)	– Constant monitoring of bot performance by process specialists/owners in the first time after implementation (Knauer et al. 2020, Murdoch 2018) – Make an agreement that process owners commit to performing automated processes manually in case of bot unavailability (Kokina and Blanchette 2019) – Save log data of bots for transparency (Anagnoste 2018) – Define process owners and maintenance cycles (Case Study) – Ensure early communication of change requests and application system releases (Case Study) – Continuously document changes/adjustments (Case Study)

Appendix D: Logistics Use Cases for RPA Implementation

Operations in application systems

- Acquisition, processing and adjustment of master data and transaction data, e. g. creation of new material masters, adjustment/ generation of bills of materials (Agaton and Swedberg 2018, Feld et al. 2017, Madakam et al. 2019)
- Logging into application systems, filling out input masks, extracting data, executing functions in ERP systems (Czarnecki and Auth 2018, Kaya et al. 2019)
- Transfer of data between administrative and operational systems that are not already interconnected, e. g. transfer of shipping data to warehouse management system (Madakam et al. 2019, NTT DATA 2018)
- Creation and updating of customer profiles (Koch and Fedtke 2020)

Order processing

- Identification of anomalies in order processing, e. g. employee forgets to issue invoice (Feld et al. 2017, NTT DATA 2018)

Procurement

- Support in supplier evaluation and selection through preliminary analysis of supplier documents (Feld et al. 2017)
- Generation of forecasting reports in procurement (Heponiemi 2019)
- Initiation of complaint processes by opening and processing e-mails (Czarnecki and Auth 2018, NTT DATA 2018)
- Acceptance of delivery quantity deviations (Feld et al. 2017)

Inventory management

- Comparison of stock levels with customer orders, automatic notification when stock levels fall below a certain limit, adjustment of safety stock levels in ERP system based on data from other systems or emails (Madakam et al 2019)
- Automated demand recognition, availability check of suppliers and order triggering in purchasing system (Scheer 2018)
- Projections creation for demand planning (Koch and Fedtke 2020, Taulli 2020)

Distribution and transport logistics

- Creation of loading lists (NTT DATA 2018)
- Updating and communicating the shipping status to customers (Heponiemi 2019)
- Identification of anomalies in the transport processing, e. g. temperature fluctuations (NTT DATA 2018)

Returns processing

- Identification of customer via customer number and order via order number, display of order history, checking of individual items of the return order for completeness, creation of return order and linking with the items of the original order, completion of standard entries in the return order, completion of return order and accounting initiation (Czarnecki and Auth 2018)

Logistics controlling

- Creation of reports and key figures for decision-making (Koch and Fedkte 2020, Madakam et al. 2019)

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An Approach to Analyzing Shippers' Transportation Management

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Purpose: *The purpose of this article is to present an approach to analyzing the organizational design of shippers' transportation management from a process perspective.*

Methodology: *The proposed analysis approach is based on a comprehensive literature review on transportation management. The literature is categorized by horizontal, vertical, and internal organizational design strategies as well as process levels.*

Findings: *The literature review reveals organizational design strategies and processes of transportation management. Furthermore, by transferring the results into an approach to analyzing the organizational design of a transportation management, it is shown that processes are shaped by organizational design strategies, which can lead to a variety of process variants. Each of these process variants, in turn, influences the performance of a transportation management organization.*

Originality: *The revealed organizational design strategies and processes contribute to explanation-oriented and design-oriented research in the context of transportation management. The proposed analysis approach further provides a methodological contribution for shippers dealing with the optimization of their transportation management.*

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1 Introduction

Transportation Management (TM) is considered an essential function to ensure seamless supply chain operations (Stank and Goldsby, 2000). From a shipper's perspective, TM can be defined as the combination of processes, organization and IT to plan and control transportation execution (Seiler, 2012). A shipper is a company that needs to move goods (Caplice, 2007). While in the past, many shippers owned a fleet to satisfy their transportation demand, today, physical transportation is often outsourced to carriers (Seiler, 2012). Carriers are logistics service providers (LSPs) that own transportation assets and whose main business is the transportation of freight (Caplice, 2007).

The study is inspired by the preparations for a project to analyze and optimize the TM organization of a globally operating automotive supplier, in which one of the authors was involved. From discussions with the practitioners, the question arose about how to analyze the TM systematically. This paper aims to answer this question by developing an approach to analyzing the organizational design of shippers' TM from a process perspective, based on a literature review on organizational design strategies and processes of TM. The focus here is on shippers who do not have a fleet and satisfy their transportation demand via the transportation market. The analysis approach supports shippers in identifying areas for process improvement and organizational redesign. Additionally, the literature reviewed to develop the analysis approach provides a comprehensive overview of the TM knowledge base and can be used as a foundation for future explanation-oriented and design-oriented TM research.

The remainder of this paper is structured as follows. The review methodology is described in Section 2. In Section 3, the review results are presented, and in Section 4, the analysis approach is developed. Finally, the paper concludes with a discussion on the research results and further research opportunities in Section 5.

2 Methodology

To achieve the aim of this paper, first, a systematic literature review was conducted to identify organizational design strategies and basic processes of TM as a basis for developing the analysis approach. For systematization, the guidelines for systematic literature reviews by Durach, Kembro and Wieland (2017) were followed. At first, the research topic was conceptualized, and the scope of the literature review was defined.

In the second step, inclusion and exclusion criteria for paper selection were created. Accordingly, only papers that contribute to processes or organizational design strategies in the TM of shippers without a fleet were considered for paper selection. Furthermore, all papers not written in English, which is regarded as the dominant language of supply chain and logistics research (Pan, et al., 2019), were excluded. To ensure a high quality of publications, the authors included only publications from journals ranked in the top quartile in at least one category in the Scientific Journal Ranking 2020 of SCImago Journal & Country Rank. An exception to this is the monographic publication by Seiler (2012). The monography was used to conceptualize the research topic as it provides a comprehensive overview of TM. Despite the violation of the defined quality criterion, the publication was included in the literature review not to neglect its contributions to TM processes and the design of TM organizations. However, the example shows that the selection criterion used carries the risk that some high-quality publications in other journals or specialized media were not included.

The next step was the literature search. For a broad search, papers in the Web of Science and the Business Source Premier database were searched for the keyword "transportation* management" in title, abstract, and keywords.

The inclusion and exclusion criteria were applied in the fourth step to reduce the sample of identified papers by irrelevant publications. First, all non-English language papers, papers that were not published in Q1-ranked journals, and all papers that violated thematic requirement criteria in the title or abstract were excluded. Subsequently, the remaining articles were subjected to a full-text analysis. For all articles that met the inclusion criteria, an additional forward and backward search was conducted. The procedure for eliminating irrelevant publications was retained. Figure 1 shows the results of the paper selection process.

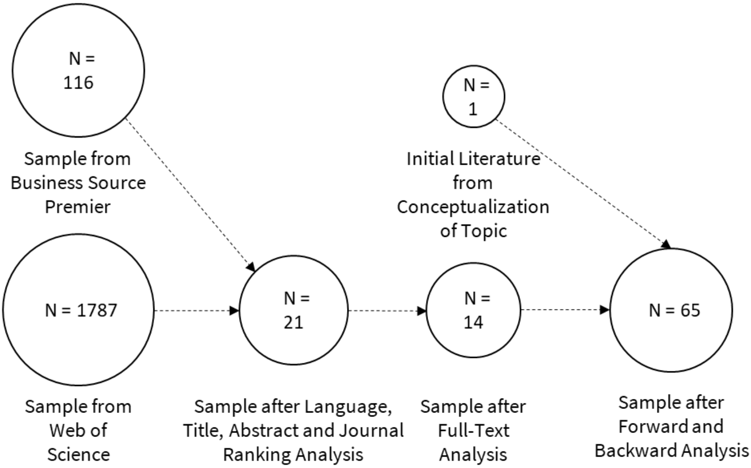

Figure 1: Paper selection process

Finally, the relevant literature was synthesized and used as a basis to develop the analysis approach. A coding scheme was used to extract data for synthesis. Literature was coded by author, year of publication, title, journal, contributions to organizational design strategies, and contributions to processes. Organizational design strategies were further divided into vertical, horizontal, and internal organizational design strategies based on the design dimensions introduced by Mason, Lalwani and Boughton (2007). Processes were differentiated according to strategic/ tactical and operational processes. The review results are presented in the following section.

3 Review Results

The literature review reveals three vertical, three horizontal, and three internal organizational design strategies. In addition, four processes were found in the strategic/ tactical area, and seven processes were found in the operational area of TM. In the following, we present the review findings on the different organizational design strategies and processes.

3.1 Vertical Design Strategies

Vertical design strategies are business decisions about how the production of goods and services is organized. A basic distinction can be made between a "do" and a "buy" strategy (Mason, Lalwani and Boughton, 2007; Selviaridis and Spring, 2007).

3.1.1 Carrier Contract Strategy

Shippers without a fleet inevitably pursue a “buy” strategy to execute transportation. The “buy” strategy for transportation services can be further divided into sub-strategies depending on the form of contract used to govern carrier relationships. The literature distinguishes between contract relationships based on longer-term (annual or longer) contracts and transactional relationships based on contracts agreed on the spot market (Krapfel and Mentzer, 1982; Caplice and Sheffi, 2003; Caplice, 2007; Günther and Seiler, 2009; Seiler, 2012; Jothi Basu, Subramanian and Cheikhrouhou, 2015; Scott, 2015; Lafkihi, Pan and Ballot, 2019). According to Caplice (2007), the main difference between the two forms of contract is the type of carrier assignment and the type of carrier price. With spot contracts, carriers are selected on a load-by-load basis, and the price is agreed upon at the time of demand. In contrast, with longer-term contracts, carrier assignment and pricing are governed by standing contracts. Additionally, the author points out that a contract relationship strategy does not exclude spot contracting, as it is always possible that there is no contract rate for a transportation demand, or all contracted carriers have rejected a load.

While in the past, a transactional relationship strategy prevailed among shippers, today, the contract relationship strategy dominates (Caplice and Sheffi, 2003). The importance of contractual relationships is underlined by literature, which reports several benefits that shows that longer-term contracts with carriers have become an essential tool for cost and service management in TM (Krapfel and Mentzer, 1982; Kleinsorge, et al., 1991; Walter, Allen and Rouviere, 1991; Lambert, Emmelhainz and Gardner, 1996; 1999; Caplice and Sheffi, 2003; Tyan, Wang and Du, 2003; Caplice, 2007; Fugate, Davis-Sramek and Goldsby, 2009; Günther and Seiler, 2009; Bø and Hammervoll, 2010; Chen, Yeh and Chen, 2010; Chan and Zhang, 2011; Li and Chan, 2012; Seiler, 2012; Monios and Bergqvist, 2015). However, the literature also shows various impediments and risks in implementing a contract relationship strategy (Caplice and Sheffi, 2003; Caplice, 2007; Jothi Basu, Subramanian and Cheikhrouhou, 2015; Scott, 2015).

3.1.2 Transportation Management Outsourcing Strategy

The TM outsourcing strategy primarily refers to the extent to which TM activities are outsourced. In the literature, however, there is no uniform understanding of the extent of TM outsourcing. While some papers indicate that TM activities are either fully outsourced or entirely performed in-house (Sheffi, 1990; Hsiao, et al., 2010), other studies provide a more differentiated view. These studies show that outsourcing is not an all-or-nothing decision and can involve individual activities or a bundle of activities ranging from more strategic activities such as rate negotiations to operational activities such as freight auditing (Dapiran, et al., 1996; Razzaque, 1998; Wilding and Juriado, 2004; Hung Lau and Zhang, 2006; Win, 2008; Seiler, 2012; Soinio, Tanskanen and Finne, 2012; Mehmann and Teuteberg, 2016; Hwang and Kim, 2019; Premkumar, Gopinath and Mateen, 2020).

Besides the decision on the outsourcing extent, another decision of the outsourcing strategy concerns the type of the outsourcing partner. Typically TM activities are outsourced to a nontransportation-asset-owning or an asset-owning LSP (Sheffi, 1990). In papers discussing different types of LSPs, LSPs that do not own transportation assets and provide a bundle of services to organize transportation are today often referred to as fourth-party logistics provider (4PL), while LSPs that do not meet these criteria are referred to as third-party logistics provider (3PL) (Selviaridis and Spring, 2007; Win, 2008;

Hingley, et al., 2011; Seiler, 2012; Soinio, Tanskanen and Finne, 2012; Hingley, Lindgreen and Grant, 2015). Furthermore, some contributions indicate that TM activities can be outsourced to a joint venture formed by a shipper and LSP (Lambert, Emmelhainz and Gardner, 1996; 1999; Hingley, et al., 2011; Hingley, Lindgreen and Grant, 2015). Additionally, Potter, Mason and Lalwani (2007) note that a shipper's suppliers may also perform TM activities on behalf of the shipper.

3.1.3 Inbound Control Strategy

Traditionally, the responsibility for transporting goods in a buyer-supplier relationship lies with the supplier. In some industries such as automotive and retail, however, there is an increasing tendency to vertically integrate the organization of inbound transportation. This strategy is referred to as factory gate pricing (FGP). (Mason and Lalwani, 2006; Mason, Lalwani and Boughton, 2007; Potter, Mason and Lalwani, 2007) Many studies on FGP show the benefits of this strategy. Potential benefits include more possibilities for shipment consolidation, improvements in freight rates and transportation service, rising transportation costs for competitors with the same suppliers and without FGP, and increased transparency in price negotiations with suppliers, as transportation prices no longer bias the purchasing price (Mason and Lalwani, 2006; Mason, Lalwani and Boughton, 2007; Potter, Mason and Lalwani, 2007).

3.2 Horizontal Design Strategies

Horizontal design strategies address business decisions regarding the extent to which shippers collaborate in TM. A fundamental decision in this context is, first of all, whether or not to collaborate with other shippers (Mason, Lalwani and Boughton, 2007). If collaboration is pursued, the scope of collaboration can be determined by the following strategies.

3.2.1 Shared Processes Strategy

One of the most important decisions concerns the assets to be shared in a shipper collaboration. These can be data, information, infrastructure (e.g., warehouses or hubs), carriers, market power, expertise, knowledge, and processes (Caplice and Sheffi, 2003;

Ergun, Kuyzu and Savelsbergh, 2007; Audy, D'Amours and Rousseau, 2011; Audy, et al., 2012; Audy, D'Amours and Rönnqvist, 2012; Jothi Basu, Subramanian and Cheikhrouhou, 2015; Pomponi, Fratocchi and Rossi Tafuri, 2015; Sanchez Rodrigues, Harris and Mason, 2015; Palhazi Cuervo, Vanovermeire and Sörensen, 2016; Allaoui, Guo and Sarkis, 2019; Basso, et al., 2019; Pan, et al., 2019; Ferrell, et al., 2020).

As the literature shows, shared processes often form the basis for sharing other assets. For example, a collaborative freight procurement process is used to increase market power and build a shared carrier base (Ergun, Kuyzu and Savelsbergh, 2007). Likewise, a collaborative network design process is executed to set up shared logistics locations, and transportation demand information is shared in a collaborative transportation planning process (Audy, D'Amours and Rousseau, 2011; Audy, D'Amours and Rönnqvist, 2012; Palhazi Cuervo, Vanovermeire and Sörensen, 2016).

3.2.2 Leadership Strategy

The leadership strategy is about deciding who performs collaborative activities on behalf of others (Basso, et al., 2019). Different forms of leadership are described and studied in the literature (Audy, D'Amours and Rousseau, 2011; Hingley, et al., 2011; Audy, D'Amours and Rönnqvist, 2012; Hingley, Lindgreen and Grant, 2015; Sanchez Rodrigues, Harris and Mason, 2015; Basso, et al., 2019; Pan, et al., 2019) A summary of the different leadership forms are presented by Audy, et al. (2012). The authors show that a collaboration can be led by one or a group of shipper(s), by one or a group of carrier(s)/ 3PL(s), by a group of shipper(s) and carrier(s)/ 3PL(s) or by a 4PL.

3.2.3 Collaboration Size Strategy

The collaboration size strategy deals with the decision on the number of collaborating shippers. A higher number of parties involved increases the chance of consolidating shipments and saving transportation costs by better utilizing the carriers' transportation assets (Mason, Lalwani and Boughton, 2007; Sanchez Rodrigues, Harris and Mason, 2015). However, recent studies show that the collaboration size must not become too large, as larger shipper collaborations are likely to fail due to coordination issues (Audy, D'Amours and Rousseau, 2011; Audy, et al., 2012; Basso, et al., 2019).

3.3 Internal Design Strategies

Following Mason, Lalwani and Boughton (2007) internal design strategies address the extent of internal integration in TM.

3.3.1 Strategy of Transportation Concept Planning

Transportation concepts can be described as rules for (de)consolidation and transportation between supply and demand points, considering the bundling effects of distinct locations and products and the available equipment types (Seiler, 2012; Martins, Amorim and Almada-Lobo, 2018). The planning of transportation concepts for inbound and outbound transportation flows can be either integrated or disintegrated. Martins, Amorim and Almada-Lobo (2018) illustrate that consolidation opportunities are limited by predefined replenishment or delivery frequencies in disintegrated transportation concept planning. This limitation, in turn, can reduce the potential for savings from shipment consolidation. In contrast to integrated concept planning, conflicting functional objectives between replenishment planning and transportation planning and delivery planning and transportation planning are not balanced. Relevant trade-offs to consider in integrated concept planning are transportation costs, inventory carrying costs, and delivery service (Ballou, 2007). The study of these trade-offs is the subject of many publications on transportation consolidation. Some of these publications show how consolidation planning affects transportation costs, inventory carrying costs, and delivery service (Jackson, 1980; Cooper, 1983). Furthermore, other publications present approaches to balancing these trade-offs (Hall, 1987; Martins, Amorim and Almada-Lobo, 2018).

3.3.2 Inbound-Outbound Organization Strategy

Another strategic design decision relates exclusively to shippers pursuing an FGP strategy and concerns the extent to which planning, and control of inbound and outbound transportation are integrated. However, there is little literature on this subject. Seiler (2012) states that some organizations have a strict organizational separation of inbound and outbound TM. The disadvantage of this separation is that it prevents the consolidation of inbound shipments with outbound shipments (Stank and Goldsby, 2000). To counteract this, a joint point of control for inbound and outbound shipments is proposed (Mason, Lalwani and Boughton, 2007; Potter, Mason and Lalwani, 2007).

3.3.3 Centralization Strategy

Besides the decision to integrate inbound and outbound TM processes, shippers must decide on the degree of centralization of TM processes and thus on their geographical scope. Caputo and Mininno's (1998) survey findings on organizational logistics structures in the Italian grocery sector indicate that TM activities can be organized centrally or locally. However, there is little literature addressing the centralization decision. Walter, Allen and Rouviere (1991) provide one of a few insights into this topic. The authors use a case study to show that centralization in freight procurement is suitable for leveraging some of the opportunities arising from a contract relationship strategy and an FGP strategy. Potter, Mason and Lalwani (2007), as well as Mason, Lalwani and Boughton (2007), even suggest, in terms of an FGP Strategy, that it is not just the centralization of freight procurement, but a single centralized point of control that is most suitable to plan and control transportation. Concerning transportation planning, this assessment is also shared by Günther and Seiler (2009) and Seiler (2012), who emphasize that a central TM approach is generally needed to increase consolidation potential. However, to make central planning and control possible in the first place, enabling information and communications technology is required (Sheffi, 1990; Potter, Mason and Lalwani, 2007; Seiler, 2012).

3.4 Strategic and Tactical Processes

Based on Seiler (2012), strategic and tactical TM processes can be described as processes not directly involved in fulfilling a transportation demand.

3.4.1 Strategic Transportation Planning

According to Günther and Seiler (2009) and Seiler (2012), strategic transportation planning comprises all decisions that define the network structure, general transportation processes and desired service levels. However, it can be concluded from the explanations of Seiler (2012) that the determination of the network structure is not a purely transportation-related task but an overarching strategic logistics task. Other authors refer to this process as network design rather than strategic transportation planning (Martins, Amorim and Almada-Lobo, 2018; Allaoui, Guo and Sarkis, 2019; Pan, et al., 2019). Caputo and Mininno (1998) separate this process into activities of choosing the number, location and type of warehouses and activities of selecting the mode of transportation. Following Stank and Goldsby (2000), strategic transportation planning can be described as part of network design that includes deciding on the modes of transportation that are appropriate for each material flow by location and product, considering consolidation opportunities, volume, frequency, seasonality, transportation requirements, and handling requirements. In this regard, particular importance is attributed to the planning of consolidation concepts, as several studies on strategic consolidation planning suggest (Jackson, 1980; Cooper, 1983; Hall, 1987). Stank and Goldsby (2000) further show that mode decisions in a transactional relationship strategy can also be made at the operational level, while in a contract relationship strategy, it is a prerequisite for selecting contract carriers in each relevant mode.

3.4.2 Strategic Freight Procurement

Shippers use the strategic procurement process to establish contractual relationships with carriers for the selected modes (Stank and Goldsby, 2000; Caplice and Sheffi, 2003; Caplice, 2007; Ergun, Kuyzu and Savelsbergh, 2007; Günther and Seiler, 2009; Seiler, 2012; Jothi Basu, Bai and Palaniappan, 2015; Jothi Basu, Subramanian and Cheikhrouhou, 2015). Accordingly, the strategic procurement process is only relevant to those shippers who want to pursue or are already pursuing a contract relationship strategy. The overall objective of strategic procurement in TM is to find the "best" assignment of carriers to traffic lanes within one's network (Caplice and Sheffi, 2003; Caplice, 2007; Jothi Basu, Bai and Palaniappan, 2015; Jothi Basu, Subramanian and Cheikhrouhou, 2015). For this purpose, reverse auctions are usually used and are typically conducted annually (Caplice, 2007; Seiler, 2012). Several studies address the freight procurement process with particular emphasis on auction design and methods of bid analysis and carrier assignment (Kleinsorge, et al., 1991; Caplice and Sheffi, 2003;

Caplice, 2007; Ergun, Kuyzu and Savelsbergh, 2007; Meixell and Norbis, 2008; Jothi Basu, Bai and Palaniappan, 2015; Jothi Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019).

3.4.3 Tactical Transportation Planning

Tactical transportation planning is an essential link between strategic and operational planning. According to Seiler (2012), tactical transportation planning is performed regularly within a mid-term planning horizon of approximately 2-12 months. However, the author points out that tactical transportation planning is not common practice among all shippers. A review on solution methods for tactical planning is conducted by Martins, Amorim and Almada-Lobo (2018) in relation to retail distribution, highlighting current planning capabilities and limitations. In the planning process, material flows are assigned to corresponding transportation concepts, and transportation frequencies are determined for continuous material flows (Potter, Mason and Lalwani, 2007; Seiler, 2012; Allaoui, Guo and Sarkis, 2019). Consequently, consolidation rules set in strategic planning (Stank and Goldsby, 2000) are adjusted by tactical transportation planning based on more accurate material demand forecasts (Seiler, 2012). Results of the tactical planning process, in turn, provide a medium-term shipment forecast. In a contract relationship strategy, shipment forecasts are used at the tactical level to inform carriers of medium-term changes in planned shipment volumes so that they can adjust their equipment requirements (Tyan, Wang and Du, 2003; Chen, Yeh and Chen, 2010).

3.4.4 Transportation Controlling

The literature about transportation controlling is sparse. References to the process of transportation controlling can be found, especially in publications that describe the functional scope of IT systems for TM. Most authors, however, do not go into transportation controlling in detail (Sheffi, 1990; Helo and Szekely, 2005; Hisano Barbosa and Andreotti Musetti, 2010; Mehmann and Teuteberg, 2016). An exception is Seiler (2012). The author's description shows that transportation controlling includes freight cost controlling, carrier and location performance measurement and network controlling. From this list of controlling activities, most of the literature contributes to carrier performance measurement (Kleinsorge, et al., 1991; Bhatnagar and Viswanathan, 2000; Caplice and Sheffi, 2003; Tyan, Wang and Du, 2003; Wilding and Juriado, 2004; Helo and Szekely, 2005; Chen, Yeh and Chen, 2010; Jothi Basu, Subramanian and Cheikhrouhou, 2015).

3.5 Operational Processes

Operational processes are the counterpart of strategic and tactical TM processes. They include all processes to fulfill a transportation demand (Seiler, 2012).

3.5.1 Transportation Order Generation

Transportation orders (Günther and Seiler, 2009; Seiler, 2012; Mehmann and Teuteberg, 2016), which are also referred to as shipments (Cooper, 1983; Stank and Goldsby, 2000; Martins, Amorim and Almada-Lobo, 2018), are a group of items that have the same origin and destination and can be transported as a single unit (Hall, 1987). Transportation orders are generated based on a triggered material movement (e.g., in an enterprise resource planning system) and serve as the input of operational transportation planning. (Günther and Seiler, 2009; Seiler, 2012; Mehmann and Teuteberg, 2016). Transportation orders can be generated by a transportation manager or directly by a supplier, plant, or distribution center (Seiler, 2012).

3.5.2 Operational Transportation Planning

Operational transportation planning includes order consolidation, mode and carrier selection with a horizon from a few hours to a couple of days (Seiler, 2012). Jackson (1985) was the first to provide insights into practices of order consolidation. Stank and Goldsby (2000) introduce different consolidation types and present a sequential and an integrated model for mode and carrier selection. The authors also show that contract relationships and adequate IT are required for integrated mode and carrier selection because service and cost information must be known in advance. Insights into IT-based carrier selection with contract carriers are provided by Caplice (2007). Günther and Seiler (2009) review different approaches to order consolidation and find that their cost functions often lack practical applicability because they do not work with shipper-specific freight rates. Based on these findings, the authors present a planning approach to close this gap. Seiler (2012) takes up this approach and describes how the approach can be embedded in an operational planning process using a Transportation Management System (TMS). A TMS is a decision support and transaction processing system that covers various functions to support TM processes (Mason, et al., 2003; Helo and Szekely, 2005; Caplice, 2007; Potter, Mason and Lalwani, 2007; Günther and Seiler, 2009; Hisano Barbosa and Andreotti Musetti, 2010; Seiler, 2012; Mehmann and Teuteberg, 2016; Demir, et al., 2019) Using IT for transportation planning improves efficiency and effectiveness (McLaughlin, et al., 2003). However, most TMSs still have various limitations in planning, as Demir, et al. (2019) point out.

3.5.3 Load Tendering

A load is a group of transportation orders traveling in the same vehicle (Hall, 1987). After the operational transportation planning, all transportation orders that form a load are tendered to carriers for execution (Tyan, Wang and Du, 2003; Chen, Yeh and Chen, 2010; Seiler, 2012; Jothi Basu, Subramanian and Cheikhrouhou, 2015; Mehmann and Teuteberg, 2016). Caplice (2007), who provides a comprehensive description of load tendering, distinguishes between a sequential or "waterfall" tendering for lanes served by a contract carrier and a simultaneous tendering for lanes served by carriers from the spot market. In a sequential tendering process, a load is iteratively tendered to the next best alternate carrier until either a carrier accepts the load or the shipper escalates the search to a private or public exchange, which is used to access the spot market. At the spot market, tendering is simultaneous, as the shipper sends out an "offer" to multiple carriers at the same time. Depending on the shipper's preferred assignment rule, the first response or the best bid wins the load. Based on data from a large shipper, Scott (2015) found for the truckload spot market that the earlier an "offer" is sent before pick-up, the better the pricing.

3.5.4 Transportation Documents Generation

For loads to be processed, transportation-related documents and labels are created and issued (Helo and Szekely, 2005; Seiler, 2012). Documents generated by the shipper in this process are, e.g., the delivery note (Mehmann and Teuteberg, 2016), the shipping manifest, the packaging list, the commercial invoice, the airway bill (Tyan, Wang and Du, 2003), and the advance shipping notice (Mason, et al., 2003).

3.5.5 Dock Scheduling

Dock scheduling is mentioned in the selected literature only by Seiler (2012), who describes dock scheduling as a process for planning the arrival times of vehicles at a location to avoid long waiting times before loading and unloading. However, as Fugate, Davis-Sramek and Goldsby (2009) show, every shipper does not perform this process.

3.5.6 Transportation Event Management

Transportation event management (TEM) can be roughly described as a process of identifying and resolving exceptions of a transportation plan (Tyan, Wang and Du, 2003; Chen, Yeh and Chen, 2010; Seiler, 2012). It can be divided into two subprocesses: management of changes in a tendered load and management of transportation exceptions.

Load changes can occur for various reasons, e.g., due to supply shortages affecting transportation volumes (Seiler, 2012). Several authors describe the subprocess of identifying and resolving changes in a load. Tyan, Wang and Du (2003) and Chen, Yeh and Chen (2010) focus on carrier involvement, while Seiler (2012) considers the impact on operational transportation planning.

Management of transportation exceptions addresses any critical disruptions that occur during transportation execution (Seiler, 2012). One essential task of the management of transportation exceptions is the tracking of transportation statuses. As shown in literature, tracking can be done either manually with extensive use of the phone or through a milestone or real-time based tracking system (Bhatnagar and Viswanathan, 2000; Mason, et al., 2003; Tyan, Wang and Du, 2003; Kärkkäinen, et al., 2007; Mason, Lalwani and Boughton, 2007; Seiler, 2012; Harris, Wang and Wang, 2015; Mehmann and Teuteberg, 2016). The second essential task of the management of transportation exceptions is to respond to an event that has been assessed as a critical deviation during monitoring. If a critical event occurs, a rule-based escalation process is usually triggered (Seiler, 2012).

3.5.7 Freight Settlement

After the physical transportation is completed, freight settlement takes place. Two standard process variants exist, freight auditing and self-billing (Seiler, 2012). Freight auditing activities are addressed in several studies and include invoice collection, invoice check, resolving invoice discrepancies and transmitting payment information to accounting (Sheffi, 1990; Walter, Allen and Rouviere, 1991; Mason, et al., 2003; Tyan, Wang and Du, 2003; Kärkkäinen, et al., 2007; Chen, Yeh and Chen, 2010; Seiler, 2012; Mehmann and Teuteberg, 2016).

However, literature on the self-billing process is scarce. The only contribution in the selected literature that describes this process in more detail can be found in a case study by Mehmann and Teuteberg (2016) on transportation processing in the agricultural sector. In the case study, the self-billing process includes checking the successful completion of the transportation, creating the credit note based on the agreed terms and conditions and sent it to the carrier for usage.

Furthermore, the literature suggests that freight settlement may also include the billing of transportation costs to the customer (Mehmann and Teuteberg, 2016) and the sharing of transportation and leadership costs of a collaborative planning process (Audy, D’Amours and Rousseau, 2011; Audy, et al., 2012; Audy, D’Amours and Rönnqvist, 2012; Pan, et al., 2019; Ferrell, et al., 2020).

4 Analysis Approach

To analyze the identified processes, taking into account the organizational design strategies identified and underlying the processes, we propose a two-step approach. Figure 2 outlines the individual steps of the approach within a phase model for TM optimization. The phase model is adapted from the phase model introduced by Klasen (2019) for business transformation. In the first step, the as-is design of the current TM organization from a process perspective is determined together with process experts involved in the shipper's TM, using established data collection methods such as interviews or workshops (Bach, et al., 2017).

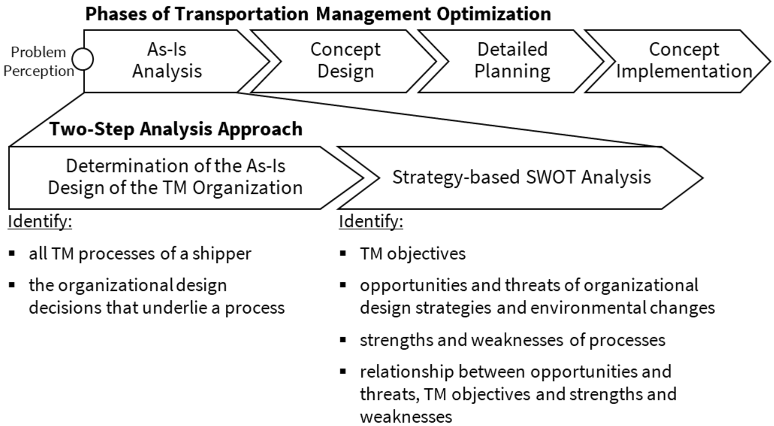

Figure 2: Steps of the analysis approach embedded into a phase model for TM optimization

This step involves identifying the different processes in a TM organization and relating them to the various organizational design strategies to identify the strategic decisions that underlie a process. For process identification and distinction, the processes and process variants found in the literature review can serve as a frame of reference. If necessary, processes must also be divided into sub-processes if there are changing responsibilities within the process. This is the case, for example, when individual activities of a process are outsourced.

For identifying the strategic decisions that underlie a process, a record form has been developed. Figure 3 presents this record form using the load tendering process of a fictitious shipper as an example. In the record form, the following process characteristics are collected for each identified process: name and type of the responsible organizational unit, the assigned inbound and outbound transportation flows, the flow owner, and flow specifics. An explanation of what information is to be recorded under the individual characteristics can be found in Table 1.

(Sub-) Process ID	(Sub-) Process Name	Responsible Organizational Unit		Assigned Transportation Flows		Flow Owner	Flow Specifics	Flow-specific Carrier Contract Strategy	Strategy of Transportation Concept Planning*
		Name	Type	Inbound (Location Name)	Outbound (Location Name)				
7.1	Waterfall Tendering	Central Dispatching	Internal Department	L1, L2, L3	L1, L2, L3	Fictitious Shipper	Sea, Air Flows	Contract Relation-ship	./.
				./.	L4	External Shipper 1	All flows		
7.2	Simultaneous Tendering	Central Dispatching	Internal Department	L1, L2, L3	L1, L2, L3	Fictitious Shipper	Road Flows	Spot Relation-ship	./,

*Only applies to tactical and strategic transportation planning

Strategic Transportation Planning	Strategic Freight Procurement	Tactical Transportation Planning	Transportation Controlling	Transportation Order Generation	Operational Transportation Planning	**Load Tendering**	Transportation Documents Generation	Dock Scheduling	Transportation Event Management	Freight Settlement

Figure 3: Completed record form using the example of a load tendering process

Table 1: Explanation of process characteristics

Process Characteristic	Explanation
Name of the responsible organizational unit	Indicate who is responsible for a process
Type of the responsible organizational unit	Indicate whether the responsible unit is an internal, external, or joint department and, in the case of non-internal departments, further specify the players (e.g., 4PL or external shipper department).
Assigned inbound transportation flows	Indicate for which inbound transportation flows of which locations a process is performed.
Assigned outbound transportation flows	Indicate for which outbound transportation flows of which locations a process is performed.
Flow owner	Indicate the shipper (analyzed shipper, external shippers) on whose behalf a process is performed for a transportation flow.
Flow specifics	Specify the transportation flows in the process scope (e.g., mode-related)

Figure 4 shows how organizational design strategies are reflected in the process characteristics and thus underlie the various processes as strategic design decisions. In addition, in the record form, each process is related, via its assigned flows, to a carrier contract strategy that is followed to execute transportation for the assigned transportation flows. The assignment helps in the subsequent analysis to determine the opportunities and threats of the carrier contract strategy on a process-specific basis. Since carrier contracts govern the execution of transportation and consequently must be taken into account in the planning and control of transportation, it is to be expected that the respective carrier contract strategy shapes the processes of TM. Processes such as strategic freight procurement and variants of carrier selection and load tendering, which are dependent on carrier contract strategy, reinforce this expectation. Furthermore, the record form is used to determine directly and flow-specifically the strategy for transportation concept planning. According to the strategy scope, this is done for the processes of tactical and strategic transportation planning.

1	Outsourcing Strategy (Extent of TM outsourcing)	**reflected in** →	the type of the responsible organizational unit assigned to the respective process IDs, which have no external shipper as flow owner.
2	Shared Processes Strategy (Processes shared in a shipper collaboration)	→	the respective process IDs with at least one external shipper as flow owner.
3	Leadership Strategy (Leader(s) of shared processes)	→	the type of the responsible organizational unit assigned to the respective process IDs with at least one external shipper as flow owner.
4	Collaboration Size Strategy (Number of shippers in a collaboration)	→	the number of different flow owners assigned to the respective process IDs.
5	Inbound Control Strategy (Extent of integration of inbound transportation flows)	→	the specific inbound transportation flows of the locations assigned to the respective process IDs.
6	Centralization Strategy (Geographical scope of TM processes)	→	the specific inbound and outbound transportation flows of the locations assigned to the respective process IDs.
7	Inbound-Outbound Organization Strategy (Extent of integrated inbound and outbound TM)	→	the specific inbound and outbound transportation flows of a location that are or are not assigned to the same process ID.

Figure 4: Relationship between organizational design strategies and process characteristics

The next step is to analyze the current TM organization. The analysis principle is based on the SWOT analysis, in which the strengths and weaknesses of a company are contrasted with opportunities and threats (Gathen, 2014). Unlike the original SWOT analysis, however, the opportunities and threats are not only considered from environmental developments (Gathen, 2014) but also from strategic design decisions.

For an objective-oriented analysis of the opportunities and threats, the objectives of the TM are defined first. Subsequently, the strategic decisions underlying the respective processes or sub-processes and TM relevant environmental developments (e.g., changes in the transportation volume of a location or the expiry of maintenance contracts for a TM software) are analyzed on a process-by-process basis for opportunities and threats to the identified objectives.

This is followed by an analysis of the recognized processes and subprocesses. The strengths that promote the exploitation of opportunities and the elimination of threats are analyzed, and the weaknesses that inhibit the exploitation of opportunities and the elimination of threats are analyzed. The strengths and weaknesses do not necessarily need to relate to the opportunities and threats of the underlying design strategies. Strengths and weaknesses can also relate to opportunities and threats that arise from the strategic design decisions in other TM processes (e.g., weaknesses in the operational planning system that inhibit consolidation opportunities arising from design strategies in tactical planning).

In addition, there may be opportunities and threats to which no strengths and weaknesses from the basic TM processes can be assigned so that the scope of the analysis must be expanded (e.g., contractual strengths and weaknesses to mitigate opportunism in outsourcing). Furthermore, there may be process strengths and weaknesses that are unrelated to identified opportunities and threats but also impact the defined objectives. These strengths and weaknesses must also be identified and presented. As a result of this second step, a shipper has visibility into opportunities and threats, strengths to be maintained or enhanced, and weaknesses to be reduced. For supporting the analysis of processes, Bach, et al. (2017) present several suitable and proven methods that can be used.

5 Discussion and Future Research Opportunities

Inspired by a practical problem, this paper proposes a two-step approach to analyzing shippers' TM organization. The basis of the method design was a systematic literature review. A total of 65 peer-reviewed journal articles from 1980-2020 were systematically selected and analyzed based on their contributions to organizational design strategies and processes of TM. The literature review reveals nine organizational design strategies and eleven TM processes (Figure 5).

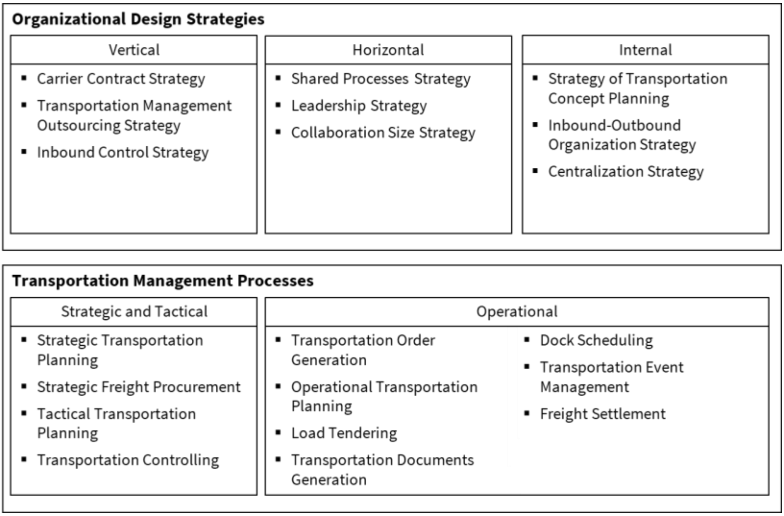

Figure 5: Organizational design strategies and processes of TM

In addition, the literature review shows that there is little research on some processes and organizational design strategies. Furthermore, the analysis of the papers reveals that only a few articles contribute to a holistic view of TM by addressing several processes or organizational design strategies or both.

However, a holistic TM view in research is especially valuable for practitioners to help them increase excellence in TM more systematically. This paper contributes to this need by identifying organizational design strategies and processes of TM and integrating them into an approach with which shippers can record and analyze the as-is design of their TM organization. Furthermore, the approach shows how organizational design strategies shape processes and how the linkage between design strategies and processes affects the performance of a TM organization.

Future research opportunities arise both from addressing the identified shortcomings in the study of TM processes and organizational design strategies and the limitations of this work. At first, the literature review neglects all papers from non-Q1-ranked journals in the Scientific Journal Ranking 2020. In addition, forward and backward searches reveal that a literature search using only the keyword "transportation* management" excludes many relevant papers. Expanding the search space to include more sources or adding more keywords provides the opportunity to confirm, correct, or expand the literature review results. A second limitation is that the utility and quality of the presented analysis approach have not yet been demonstrated. Accordingly, additional research is needed to confirm its practicality. When applying the model, a particular challenge may be identifying the opportunities and threats of a design strategy at the process level and the strengths and weaknesses in the processes in relation to these opportunities and threats. Future research could help to recognize these opportunities and threats, as well as strengths and weaknesses, more easily.

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Barriers to the implementation of 4PL in developing countries

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Purpose: *Fourth-Party Logistics (4PL) involves sharing non-core activities with an external service provider, which can bring about a variety of benefits for the outsourcer. However, there can be a variety of constraints identified from the mini-cases e.g., stagnant management, resistance to change, and a lack of knowledge. These barriers may have a greater weighting if the 4PL concept is implemented in an emerging economy. Therefore, it is crucial to identify which barriers are present for adopting 4PL in developing countries, and then to consider initiatives to overcome these.*

Methodology: *First, a literature review containing best practices of 4PL in countries across Asia and Europe is presented. Qualitative findings through a series of interviews with specialists were analysed, discussed, and compared with recommendations/existing practices from other developing countries, and then were cross-checked by a specialist using 4PL in Europe.*

Findings: *As a result of our interviews, we identified several managerial barriers in the implementation of the 4PL concept.*

Originality: *The literature review has shown that there is a lack of qualitative research regarding the use of 4PL in developing countries. Therefore, the impact of the results of this paper can be vital for academic knowledge.*

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1 Introduction

The last decade has demonstrated a growing tendency to use outsourcing logistics (Lieb and Bentz, 2005; Deepen et al., 2008; de Grahl, 2012) for a variety of reasons including: cost optimisation, adaptability and to improve profit margins (Aertsen, 1993; Langley et al., 2005). On the flow of the goods, services and data, the role of the Logistics Service Providers (LSP) is vital to connect the buyer and supplier in terms of fulfilling and delivering orders On Time and In Full (OTIF) (de Grahl, 2012).

However, the COVID pandemic has changed the way businesses operate, and may require a revision of concepts related to business optimization to allow organisations to focus on their core competencies. For example, Amazon tripled its profits employed 250,000 people in the third quarter of 2020 (Guardian, 2020). Sahin, et al., (2016) highlight that Third-Party Logistics (3PL) may not fulfil the technological and strategical needs of the supply chain network. Similarly, there are now many advanced, non-asset-based concepts such as Fourth-Party Logistics (4PL) providers available. Coined by Accenture, 4PL includes four main elements, architecture, intelligence, supply chain infomediary and resources (Christopher, 2016). Each element contains aspects and factors which play an essential role in the development of the integrated supply chain network, of how goods and services flow (Win, 2008; Fulconis et al., 2006). One of the 4PL success stories is Shell's collaboration with Accenture (2015). They reduced asset downtime caused by material constraints; optimised logistics costs around 25% through improved planning and use of facilities; lessen the safety coverage by reducing the routes of movements; and visualised processes to improve overall performance.

However, a variety of studies suggest that implementing 4PL in developing countries still faces comprehensive problems (Boyko et al, 2018; OECD, 2015; Guo, 2010; Qiuping, 2011; Guo-chen and Hai-peng, 2014; Kao et al., 2019; Xu, Wang and Long, 2019).

To help better understand these challenges, the authors looked to examples and cases in the available literature about existing economies currently using 4PL. These broad themes were then compared with actual responses from potential implementors of 4PL in an emerging economy, followed by a final validation interview with a 4PL specialist to help determine the applicability of the findings.

2 Research Methodology & Methods

The order in which the research activities were conducted, have also been replicated in this paper (Fig. 1). An adapted interpretive approach was used to guide the research. It uses qualitative data analysis to identify/define patterns that may be identified or reproduced in a variety of alternative settings (Collis and Hussey, 2003).

Figure 1: Research Process

First a thematic literature review was conducted in order to help guide and define the research and the authors guiding questions. Following the literature review, we proceeded to determine if the broad themes identified in the literature were applicable and/or relevant via by conducting semi-structured interviews with experienced managers and procurement/logistics specialists in potential users of 4PL in an emerging country.

A mixed analysis was carried on responses to further understand the nature of the opinions of the specialist (Vaismoradi, et al., 2013). The data was analysed by qualifying and quantifying, then triangulated with the patterns from the mini-cases in the literature review.

3 Review of thematic literature

Outsourcing logistics is the strategic utilisation of third-party services to accomplish and control the non-core activities of a company (Rushton and Walker, 2007). Rinsler (2010) describes outsourcing as an intentional sharing of the business processes with an external party that manages these activities on behalf of a company. Godsmark and Richards (2020) explain it as identifying the duty which is not a core activity and using an efficient and cost-effective specialist. Generally, these functions regard IT (Bourlakis and Bourlakis, 2005), warehouse, supply chain network (Zailani et al., 2017) and services of a parent company and by no means a renunciation of their responsibilities.

3.1 The definitions and differences

As shown in Fig. 2, providers are divided into different categories such as 3PL, 4PL, etc., (Godsmark and Richards, 2020). The main difference between the 3PL and 4PL is that the latter is the virtual provider of services which can unite several organisations, even 3PLs.

In 1996, Accenture (2020) had coined the 4PL term to meet the need of the US clients of LSPs, with the definition:

‘A supply chain integrator that assembles and manages the resources, capabilities and technology of its organisation with those of complementary service providers to deliver a comprehensive supply chain solution’ (Accenture, 2020).

It was updated by Saglietto (2013) as sovereign firms which aimed ‘to design, organise and coordinate the client’s entire logistics, documentary and regulatory chains’—also known as a Supply-Chain-as-a-Service (SCaaS) (Leukel et al, 2011).

Existing LSPs identify 4PL as a non-asset-based provider. Gattorna (2003) argues that the ownership of assets does not matter; productivity does. They pointed out that 3PL can be part of a 4PL network or vice versa. Large 3PL companies can set up a 4PL itself for enhancing opportunities. Gattorna (2003) highlights that ‘technology’ is the crucial difference between the 3PL and 4PL, regarding the capabilities of the latter. Hosie, et al. (2012) contradicts Gattorna (2003), suggesting ‘non-assets' are a fundamental aspect of 4PL and adding that neutrality in a selection of shippers is also a crucial feature.

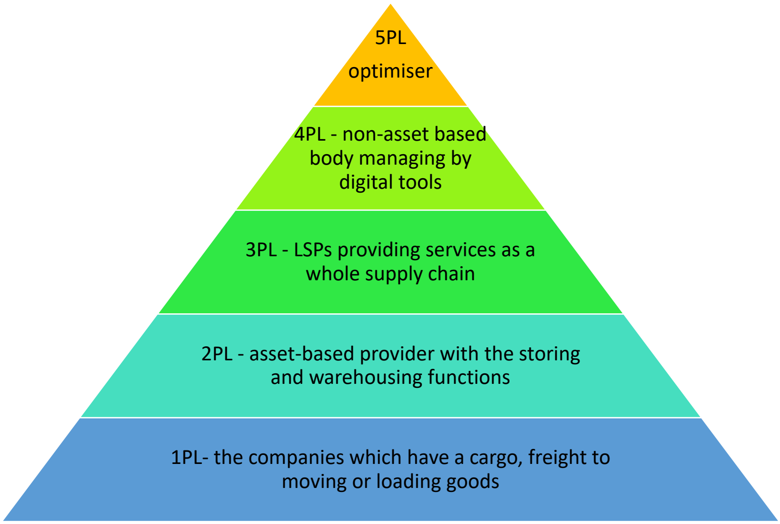

Figure 2: The hierarchy of LSPs. Sources: (GEFCO, 2020; John Good Logistics, 2020; Chetak Logistics, 2015)

The 4PLs can integrate a wide range of participants providing IT solutions and platforms for developing business in a win-win situation. For example, one of the successful firms in Europe, 4PL Central Station, provides sustainable optimisation of logistics operations by consulting, analysing, and coaching. They are promising up to 23% savings on planning, 8-10% on transparent e-procurement process and around 22% on operating transportation and cost management and 10% on the data control (4PL Central Station, 2020).

3.2 Reasons and barriers

There are a variety of reasons for outsourcing logistics in terms of warehousing, procurement, and vehicle costs, etc. Developing countries can have an advantage from using LSPs, through their vast investment and infrastructural influences on purchasing and delivering. For example, Romanian small and medium-sized enterprises (SME) are working on these aspects to become more profitable and efficient (Fulconis and Paché, 2018). However, they can also be affected negatively by the risks of control and private variable incomes (Kherbach and Mocan, 2016).

In terms of outsourcing IT-based platforms, despite the time differences of about a decade, studies show that there might be a hidden cost that can lessen the gains from outsourcing (Reitzig and Wagner, 2010; Barthélemy, 2001). Some studies show that pricing of LSPs has become a vital aspect of the selection of the 3PL provider (Langley et al., 2005). In contrast to previous users which may have been chosen by value-adding activities and reductions of lead times (Fernie, 1999).

The barriers of outsourcing logistics can be a lack of trust and perceived delivery delays due to overlapping management. It can be a corporate view that unique goods and services should not be shared with external services. Kremic, et al., (2006) highlight unrealised savings, low supplier sourcing, environmental and uncertain external factors and workforce issues are some of the barriers. Some studies emphasise the risks of outsourcing logistics for the buyer-supplier relationship (Tsai et al., 2012). The authors conclude that the threat from the unsuccessful relationship can deteriorate both asset and capability risk.

Conversely, risks are associated with assets, when a company is worried about priceless specific assets such as strategic personnel and IT capabilities. Most of these risks are summarised as the 'seven deadly sins of outsourcing' by Barthélemy and Adsit (2003): (1) outsourcing actions what you need to do in-house; (2) choose a wrong partner; (3) do not work out the terms of the contract; (4) overlooking staff issues; (5) lose control over subcontracted actions; (6) underestimate the full cost of outsourcing; (7) do not prepare an "exit strategy". Such failures often do not occur, as companies are reluctant to report such results.

To mitigate risks on the outsourcing logistics Wang et al., (2003) propose measures in which the results of outsourced logistics work eliminate asymmetric data exchange, introduce appropriate performance tactics and develop customer relationship management. Rinsler (2010) highlighted that before deciding on outsourcing, the board should have a SWOT analysis or any other examination to identify any weaknesses and strengths. There should be comparisons on the competitors' capability and the LSPs distribution network on agility, profitability, and opportunity to strengthen the business. There are risks of dependability on the LSP and responsibility on the top management of a company.

However, a company can work from any place in the world, thus identifying the challenges by countries seems more appropriate. Our three mini-cases were chosen from three countries that have vital routes on the international logistics network and are trying to develop the distribution of goods and services.

4 Mini cases

4.1 Country A

Boyko, et al., (2018) state that the logistics outsourcing share in Country A is around 20% due to a lack of infrastructure and trust in external providers. Similarly, Kim (2019) found that the need to share trade secrets is a major barrier and emphasises that increased electronic sales and transnational trade play an essential role. Karhova (2019) suggests that Country A's companies prefer the current economy, using direct storage and transportation costs. This view is supported by the ex-CEO of Itella, preferring local logistics, and perhaps not being aware of the costs of having a warehouse and fleet (Grinberg, 2015). It has been argued even small companies use mini-trucks and drivers instead of outsourcing logistics. This kind of small organization is often without any warehouse management system and often do not worry about storage conditions. In Country A, the majority of active 3PLs and 4PLs are joint ventures with international LSPs. They operate in terms of high competition, sensitivity to logistics efficiency and cost optimisation.

Despite the high cost of conversion (Khalyn, 2018) and the reluctance to delegate core functions to third parties; There are prerequisites for the development of 4PL in Country A, such as a fast-growing warehouse and distribution network; sales and investments from foreign LSPs; access to a highly qualified employee in local companies (Boyko et al., 2018). Kim (2019) adds due to the import of goods and following the labelling requirements of the Eurasian Economic Union (EAEU); it is actually more effective to use

LSPs services due to additional administrative processes. Other essential aspects include seasonality and lack of traffic transmission to and from the European Union (EU) according to bilateral and multilateral treaties. Due to the annual reduction of cargo traffic quotas for non-EU countries, the throughput of 4PLs from the EU may be the solution to this problem (Blogactiv, 2019). Kim (2019) recognize the importance of the 4PL in the optimisation of logistics in Country A, but it requires time to build trust between the buyer and the 4PL operator. The development of logistics in Country A depends on the geographical length of the territory, which can be solved by delivering goods to regional Distribution Centres (DC) (Khalyn, 2018). According to Khalyn (2018), the effectiveness of the supply chain is related to the innovative components of storing, handling and transporting services. However, new logistics solutions are not fully adapted to Country A's realities in the regions.

4.2 Country B

In 2005, Aktas and Ulengin published a paper in which they described that the firms underestimated outsourcing logistics and the 3PL services were classified under transportation (Aktas and Ulengin, 2005) There are a variety of factors such as delivering damage-free items, distribution security, OTIF delivery, reputation, quick response, etc., that affect the choice of the 3PL provider. Aktas and Ulengin (2005) concluded that despite understanding the factors for outsourcing logistics in Country B, development is still in its initial stages.

Investment Support and Promotion Agency (ISPAT, 2013) states that Country B is building logistics villages that can assist in lower-cost transportation. Though the quality of highways can vary in comparison to other countries, thus affecting the price of logistics (Gencer, 2019). The Government is investing heavily in creating logistics corridors for international logistics, and it is expected that by 2023, $500 billion worth of cargo will be transported in these centres (ISPAT, 2013). To decrease the logistics costs and dependence on road transportation, investments in the railways is being encouraged and the Government has liberalised the rail transport system (OECD, 2015). Consequently, it can be attractive for international LSPs to invest in infrastructure and create effective 4PL services.

On the other hand, leading foreign LSPs are concerned about cargo safety due to growing political issues such as sanctions (Gencer, 2019). Therefore, according to an Agency in the early 2010s, there were just a few 4PL companies and no 5PL companies, and it did not change in 2018 (Kalkan and Aydin, 2018).

4.3 Country C

Almost all of the studies considered in this case mention that the development of 4PL in Country C is related to e-commerce. Demand for timely deliveries and cross-border operations have challenged asset-based LSPs to enhance their ability with IT solutions (Kao et al., 2019). Local 3PL companies often cannot afford to have an air fleet; therefore, they must outsource these kinds of cross-border express deliveries.

Guo (2010) lists the obstacles and risks that challenged the development of 4PL in Country C such the essence of trust and checking contracts . Kao, et al., (2019) state that the 3PL is comparatively more established than 4PL, which still is not popular among numerous LSPs. Thus, a transition strategy from 3PL to 4PL is vital for these enterprises. Most of the shortcomings in the 4PL formation process are similar to the problems identified earlier.

Tan (2009) illustrates the global logistics problem in Country C with several factors. First, it is the simple and non-value-adding services and logistics capabilities of local enterprises and their supply chain network. Thus, they cannot satisfy the need of the manufacturers and transnational companies. In Country C, there are few alliances between supply chains, which leads to a limited selection of international LSPs with a full range of services. As a relatively new phenomenon, there is a shortage of specialists with a background in outsourcing logistics by IT solutions.

Kao, et al., (2019) offer several steps to identify Country C's 3PL capabilities for 4PL conversion, such as classifying the skills, determining beneficial and deteriorating aspects, seeking advanced principles, and making strategies based on previous actions.

4.4 Focal Economy

Raimbekov, et al., (2016b) documents the increase of freight flow through Kazakhstan, though there is no rise in the use of LSPs services. Transport companies are still operating on their own due to high tariffs and a lack of capacity. In 2012, the Union of Kazakhstan transport workers “KAZLOGISTICS”, predicted it would jump from 86th to 40th amongst the Custom Unions. However, in 2018 it is ranked at 77th providing plenty of scope for improvement (Arvis et al., 2018). Only a few subsidiaries of the foreign LSPs can provide comprehensive logistics services.

One of the main reasons for this might be due to the low density of the population and irregular DCs in the country. Warehouse and logistics hubs are located near big cities such as Nur-Sultan and Almaty. Also, the length of destinations between the regions is can be more than 3,000 kilometres, and the routes are often not directly connected between areas. Raimbekov, et al. (2016a) divide the possible development of logistics hubs by regions because of the specific scope of the regional economies.

There is some evidence to suggest that despite more businesses interests using platforms like ERP, WMS, etc., the Kazakhstani logistics sphere is far from understanding the benefits of logistics novelties. For example, the subsidiary of DPD in Kazakhstan provides a full range of 3PL services and aims to cover demand from e-commerce distribution. DPD's aim is to keep a balance between cost and speed, as well as to encourage e-commerce, and to reduce the reliance of in-house delivery departments by replacing them with outsourcing logistics (Forbes Kazakhstan, 2013). Surveys have shown that 34% of respondents highlight the high cost of LSP services (Syzdykbayeva et al., 2019). About 19% of respondents want to understand the nature of these costs, and 16% indicated the absence of a cargo control system. As for the improvement, 25% of specialists see it in building infrastructure, and only 5% of respondents emphasized the quality of logistics services (Syzdykbayeva et al., 2019).

Raimbekov, et al. (2016a) suggest that the Government should treat infrastructural development as the primary driver of the economy. Later in 2018, Raimbekov et al. (2018) add that for the development of logistics, the country should use an integrated approach to enhance international trade as the bridge between China and Europe.

Syzdykbayeva, et al. (2019) list some activities which can advance logistics hubs such as, creating regional freight handling and storing logistics centres; the integration transportation capabilities of the freight forwarding companies; ‘creating a unified organizational, legal, informational, technical and technological base for relations between transport infrastructure services and market structures involved in the transport process. By reducing logistics costs and customs fees, regulating the legal framework in industry and training employees to use high-effective technologies, the country can increase the effectiveness of the logistics and consequently it may attract the implementation of 4PL companies.

Table 1. The comparison of the implementation of 4PL in different countries. Sources: (Khalyn, 2018; Aktas and Ulengin, 2005; Grinberg, 2015; Boyko et al., 2018; Kalkan and Aydin, 2018; ISPAT, 2013; Karhova, 2019; Xu et al., 2019; Guo-chen and Hai-peng, 2014; Kao et al., 2019; Guo, 2010)

	Country A	**Country B**	**Country C**
Prerequisites	- Development - E-commerce - Traffic	- Incentives - Workforce	- E-commerce - Infrastructure - Traffic
Barriers	- Trust - Infrastructure - Cost	- Underestimation	- Trust - Infrastructure
Recommendations	- Training - Investment	- Investment - Transparency	- Integration. - Investment - Training

5 Empirical Research: Description, Analysis and Synthesis

5.1 Structured Interviews: Findings and analyses

Data obtained from semi-structured interviews was then compared with the findings from literature and mini-cases to identify/confirm 4PL barriers. It was also important to understand the pre-requisites in the Kazakhstani market for the implementation of 4PL. The respondents provided qualified data on their experiences which can help to understand the absence of the 4PL concept in Kazakhstan. The results of the interview with a 4PL specialist are also provided.

5.1.1 Barriers to making managerial and business decisions in Kazakhstan

One of the significant, obstacles to the introduction of 4PL in Kazakhstan is the lack of knowledge amongst managers, specialists, and businesses about the 4PL concept. Even skilful participants of the interviews found it difficult to answer about the presence of 4PL.

One of the problems is that companies with established managers are unlikely to be willing to change their approach for innovation and tend to rely on middle management to make decisions. In this case, middle managers who are unfamiliar with the 4PL concept are unlikely to help advise and apply this tool in the company. In a broader meaning, it can relate to the shortage of specialists and lack of experience of local LSPs. The need for supply chain managers was apparent in some of the interviews (GM2, PM2, LM1). PM2 states that it may be due to a lack of supply chain management programmes in universities, and perhaps, be solved by the valuable graduates.

From this point, another barrier appears which is the lack of experience available and limited time to develop it. In turn, it is about the background of the local companies which cannot easily sign a long-term contract with the big companies in Kazakhstan, which usually are joint ventures with foreign investors. In such conditions, on the freight forwarder selection process, they will prefer to have an agreement with the supplier with high expertise.

- *'To do 4PL activities, Kazakh companies… Still do not have a proper relationship, and accordingly, they did not have experience. But to work it out, you need enough time.' [GM1]*

PM2 assumes that if the first company implements 4PL in Kazakhstan, it will most likely be significant oil and gas companies; and GM1 stated that such large subsoil users value reputation and experience. The scale and reputation are a matter.

- *'In such large projects, the risk should be relatively minimal, precisely in terms of the delivery risks. Reputation for companies is quite a challenging thing'. [GM1]*

It is possible to hypothesise that these conditions are less likely to occur in local companies in such a short period. The tender procedures often include the requirement of about 10-15 years of experience as said by GM1. Hence, another issue related to experience is trust and reputation. Trust as a barrier appeared in conversations regarding the data security of the businesses. Consequently, it is also associated with technological barriers such as IT integrations and the use of ERP systems.

5.1.2 Validation Interview with 4PL Specialist

As emphasised by a qualified 4PL specialist (GSM1), if a company wants to outsource its logistics and other functions, it should trust the LSP. It is a critical process, and trust is the basis of the 4PL concept, and without it, nothing can be done.

- *'You need to trust; you are part of the dependency, and that's a risk. Right? So, if you are not ready to take that, even though gain other benefits, so, you are not going there'. [GSM1]*

It is a clear view of the GSM1, and the opinions of Kazakh employees shows some of the contrast in the approaches between the two.

- *'Such purchases are usually not given, it is, a trade secret'. [PM1]*

A possible explanation for these results may be due to the lack of good collaboration of expertise and essential requirements of the company regarding data protection. Despite this, some companies can select suppliers through comprehensive processes and logically, these suppliers have a trustworthy reputation.

Transparency, which is another barrier, is one of the critical aspects of the 4PL concept. As stated in GSM1, it is the most crucial issue, showing the whole buying and supplying procedures transparently and crystal clear for the stakeholders. It is a foundation of the trust and buyer-supplier relationship.

- *'So, don't hide any margins or something, anywhere and try to, and this is what a 4PL is doing. Right. You bring transparency to the supply chain. And with that* *transparency, we can have open discussions on issues, improvement, which helps to stabilise the global business partnership'. [GSM1]*

That is transparency. According to GSM1, it can be higher if the companies outsource their functions to 4PL companies; however, not all participants agree with it. For example, GM2 thinks that transparency from outsourcing can be a double-edged sword that can harm the quality of the services or goods, due to the price. The large-scaled LSP can take a massive discount from the original manufacturers and bring the customer the best prices. It does not seem a natural barrier to implement the 4PL concept in Kazakhstan; however, just started local LSPs might not offer such kind of benefits. PM2 adds that there are no large LSPs that can provide a full type of services and big-scale players who would be the primary customer in Kazakhstan. Thus, the volume and scale of customers and suppliers are likely to become barriers.

GSM1 also emphasises that neutrality is a keystone of the 4PL concept.

- *'We have a concept of being a complete neutral 4PL, which means we don't have any financial or physical relations to any 3PL or carrier. In our commercial model, as we get to get a service fee for what we are doing, we don't put any margins on transport, which enables us to be transparent to a client'. [GSM1]*

5.2 Empirical Research: Discussion

5.2.1 Triangulation with literature, cases, and interviews.

First and foremost, the lack of trust and data-sharing process was highlighted as the main barrier for Country A and Country C (Guo, 2010). The result of a survey piloted by Syzdykbayeva, et al. (2019) also shows the worries of Kazakh manufacturing specialists about the unclear pricing policy of the LSPs which does not add further trust in the relationship. The respondents also agree that the lack of trust between partners is one of the most difficult barriers in using 4PL. Surprisingly, there is no information about trust as a barrier in Country B. Unethical supplier selection process and lobbying is also a challenge in some territories around the globe (Guo, 2010). It is consistent with the interviewees' opinion that a biased choice of the customers cannot guarantee the transparency of the purchases.

Second, the studies highlighted the outdated infrastructure and the shortage of capabilities to fulfil the flow of international freight. Boyko, et al., (2018) suggest that the small share of the outsourcing logistics explains the lack of infrastructure. Khalyn (2018) adds that there is an issue about the length of the country which can play a significant role in the implementation of 4PL in Country A. Gencer (2019) believes that the condition of the roads in Country B can impact the pricing of logistics. Despite the massive investments in the economy in Country C, Tan (2009) claims that the basic local LSPs and shortage of facilities lead businesses to choose international LSPs. These factors also exist in Kazakhstan, visible through the intermodal and multifunctional transport systems and outdated techniques (Syzdykbayeva et al., 2019)

Another important finding was the willingness of companies to apply IT solutions. As has been proved by analyses of findings the IT integration level of SMEs is far away from ideal in Kazakhstan; there are only big companies correctly utilising Enterprise Resource Planning (ERP).

The shortage of qualified specialists is an important barrier preventing the development of outsourcing logistics. Like Country A (Karhova, 2019), companies in developing economies may be reluctant to invest in IT solutions.

5.2.2 Recommendations

The barriers at the managerial level can be addressed by activities within the company. The obstacles in the application of the 4PL concept such as unfamiliarity and shortage of specific specialists show the lack of knowledge present (see Table I). Thus, one solution is to hire well-trained and competent people (GSM1). However, due to the lack of such specialists in the country, there are also proposals to invest in the knowledge of employees, their training and popularisation (GM2). Moreover, Tan (2009) suggests developing talent management by creating collaborations between manufacturers and universities.

Most barriers to implement 4PL are cross-linked and have mutual dependence; thus, enhancing the trust and transparency of the local companies depends on each other (see Table I). Without trust, experience is hard to attain, which is vital for the tender procedures. To trust each other supplier selection process should be thoroughly and with the in-depth market, analyses to understand the capabilities of the stakeholders (GSM1). As stated by Baily et al., (2008) supplier selection process is not just choosing the right supplier; it is about the collaboration with existing and potential suppliers in the market. The advancement of mutual dependence and trust allows for further optimisation of logistics cost and expertise (Tan, 2009).

Furthermore, the managers should be better informed by detailed guidelines and be made aware of the effectiveness of the 4PL concept. Transparency of the procurement process is vital and will require considerable work in some territories around the world. Ineffective management is also a significant obstacle on all levels of governance and management as stated by the specialists. It can be mitigated by minimising the tender procedures with the one-source supplier selections procedure.

There is always a risk of meeting an unscrupulous supplier who is trying to mislead the buyer through non-compliance with deadlines and lower quality of services and goods (GSM1). However, creating a strategic document as a Code of Conduct and standards for both suppliers and the staff may mitigate the unethical consequences of the sourcing. The transparency of the shipment should be followed by the tracking technologies (GSM1) and allow customers to see the process holistically.

In terms of barriers related to technology, which is an important element of the 4PL concept, can be caused by a lack of IT solutions and database integration. The implementation of business processes optimisation software as ERP is dependent on the willingness of the managers to invest in such tools. Thus, one recommendation is to apply IT solutions such as ERP, SAP, and TMS (GSM1). Managers can be trained about the need to invest in a comprehensive tool instead of using limited software such as 1C. While the cost of technologies can be another barrier, the trade-off is with improved future optimisations and benefits in warehouse management and transport fleet (Grinberg, 2015). There is a connection with the training scheme above as there will be a need for specialists with IT backgrounds (Tan, 2009); thus, it might be beneficial to hire or train more versatile specialists (GSM1). The findings can help researchers to set up a baseline regarding the prerequisites and barriers of outsourcing logistics.

5.2.3 Research limitations

This study only examined responses from the oil and gas sector. Though, the first probably users of 4PL will most likely be subsoil users. The recommendations above are intended to help to prepare businesses and authorities to be aware of the relevant decision-making processes needed to be to make effective decisions to help outsource activities.

6 Conclusion

This paper aimed to identify possible barriers to introducing 4PL in developing economies and to establish a set of recommendations on first using 4PL. Due to the vast scope of the work, we have listed points directed to managers in business.

First, organisations need to maintain or increase employee training and knowledge attainment (also at managerial levels), which can be a good start in preparing the foundation for 4PL implementation. Training and acquiring further knowledge through collaborations between manufacturers and universities is also recommended. Certification by professional bodies is widely welcomed.

Second, companies should be encouraged to increase the transparency in their procurement processes via ethical supplier selection. For this purpose, they can create strategic documents such as the Code of Conduct and Corporate Social Responsibility, plan of actions and processes for the whole supply chain network.

Thirdly, investing in the technologies and solutions such as ERP and TMS. Using IT specialists who can integrate and digitalise a system will be hugely beneficial. Especially when applying traceable technologies to the logistics functions in supply chains.

These recommendations do not have clear-cut boundaries and may not be fully addressed by the management of a company alone. Government initiatives can also help to accelerate the implementation of 4PL in emerging economies. One of our aims in this research was to encourage further consultation of the items we have raised, potentially as a checklist for analysing the readiness of the business to outsource their activities in emerging economies.

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Efficiency measurement of grocery retail warehouses with DEA

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Purpose: *To enable reliable food supply and to remain competitive, grocery retailers need to operate efficient distribution networks. Therefore, the purpose of this paper is to develop and apply a multi-criteria evaluation framework considering the complexity of grocery retail warehouses while maintaining the highest possible efficiency.*

Methodology: *We propose data envelopment analysis (DEA) as a non-parametric method of efficiency measurement and use an empirical seven-year dataset of 12 grocery retail warehouses. Four inputs and six outputs are included. We examine the efficiency development with DEA window analysis for longitudinal efficiency evaluation. By adding super efficiency, the model gains discriminatory power for efficient warehouses. We provide concrete improvement targets for all non-efficient warehouses through slack-based measurement.*

Findings: *As a method for multi-criteria efficiency evaluation, DEA models provide interesting results for efficiency measurement in food supply chains. Through the non-parametric multi-criteria approach, it enables an objective and holistic analysis perspective. By choosing inputs and outputs independently of their measurement unit, flexible application possibilities appear, giving non-monetary elements the necessary importance in optimization.*

Originality: *Although there are several studies dealing with the efficiency measurement of warehouses using DEA, our approach is the first to explore its application in food retail warehouse logistics over several periods.*

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1 Introduction

Warehouses play a decisive role in every retail supply chain. Their main tasks are to receive and store items from industry partners for subsequent order picking, as well as shipment to the customers (Richards, 2018). In stationary grocery retailing, also referred to as brick-and-mortar grocery retailing (Wollenburg, et al., 2018), these customers are grocery stores ordering items in regular order-delivery cycles manually or automated. In this study, we focus on warehouses processing high-volume-low-mix orders which are typical for distribution centers serving brick-and-mortar grocery structures (Boysen, Koster and Füßler, 2021). Within these warehouses, cooled and non-cooled perishable items, as well as non-perishable items, are processed and delivered on fixed delivery days known in advance (Hübner, Wollenburg and Holzapfel, 2016). Because the competition levels in retail are generally considered to be high in the grocery section, especially in the oligopolistic Germany retailing segment, empirical efficiency measurement methods are in high demand as a basis for informed management decisions in the sector. As in many cases, the details of such an endeavor are not so perfectly clear as theory might suggest. The theoretical knowledge is therefore of relevance in this area in order to be able to make objective decisions and to gain advantages in the competition for displacement. In this context, the classical controlling approaches to multi-criteria evaluation always provide a strong subjectivity due to strong human influences of the weighting. A comparison by Chlupsa from 2017 illustrates the explosive nature of this situation (Chlupsa, 2017). He questions whether management, whose private decisions are emotionally influenced, can meet the strict rational requirements when it comes to professional decisions. What is needed, therefore, is an instrument that helps management to be able to make decisions in whose alternatives, on the one hand, all important factors are taken into account and, on the other hand, no subjective weighting of these factors is necessary.

We aspire to answer the following research questions: (1) What are the components of an efficiency analysis aiming to evaluate the performance of warehouses in brick-and-mortar retailing, and (2) what are the main potentials for the examined warehouses when aspiring to increase their performance? Therefore, we formulate and conduct a long-term non-parametric Data Envelopment Analysis (DEA) model for seven historical years and with ten input and output types for the efficiency of grocery retailing is, therefore, an interesting objective of this research.

The use of Data Envelopment Analysis (DEA), as a multi-criteria, non-parametric method for measuring efficiency, is intended to help answer the question of the efficiency of distribution centers within a homogeneous logistics landscape. Previous approaches in classical logistics controlling can be differentiated from the DEA method with regard to the different methods of efficiency measurement. As a non-parametric method, DEA represents a completely different approach. DEA as a method with a model-generic weighting of input and output factors contributes to an objective benchmark. In addition, DEA always provides a relative efficiency of the investigated units. This means that for each unit under investigation, it can be determined whether it can be counted among the efficient units or how much it is below them.

In order to motivate and legitimate the application of this specific method, a method analysis is first conducted in Section 2. In addition, Section 3 presents the basic characteristics and extensions of the DEA method family. Section 4 provides the model formulation and results, and Section 5 outlines discussion points for retail and warehouse management.

2 Theoretical Background

2.1 Efficiency measurement methods

The permanent development within the logistics systems also requires a continuous drive for optimization of the participants of these systems. Since not all market participants are pioneers within the supply chain or are able to do so. In many places, an orientation towards the best-practice solution offers itself. The instrument of benchmarking is one variant through which this best practice solution can be found (Berens, 1997). Figure 1 provides an overview of the various methods for measuring efficiency (Hammerschmidt, 2006). The classification is basically made into first- and second-generation processes. The first-generation methods can be divided into classes

I-III. Class I methods are purely output-related key indicators. These include, for example, sales, packages, or transport units. Class II key indicators are exclusively input-related, for example, personnel costs or the number of orders. In the case of class III key indicators, the input- and output-related factors of classes I and II are set in relation to each other. This results, for example, in key indicators such as personnel costs per package. To evaluate efficiency, these absolute or relative key indicators of the decision-making units under consideration can be compared with each other in the form of a ranking. As a result of the single-input/single-output case, it is not possible to make an overall statement about the efficiency of the decision-making units under consideration. The change of the considered ratio can completely dissolve the consistency of the benchmark. The second block consists of 2nd generation methods. These are not simple ratios but production functions that establish a mathematical relationship between input and output. In addition, all relevant inputs and outputs are considered simultaneously. The production function makes it possible to determine a technology set and, as a result, to make a statement about the overall efficiency of a decision unit under consideration. Basically, two methods can be classified. Class IV contains the parametric methods. In these methods, the weights of the individual inputs and outputs are defined a priori. Class V contains the non-parametric methods. In this method, the weighting is carried out model-endogenously by the model itself during the efficiency calculation.

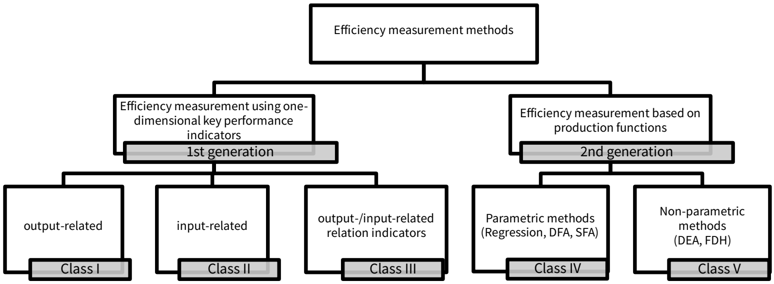

Figure 1: Efficiency measurement methods, adapted from (Hammerschmidt, 2006)

2.2 Technology quantity

The technology quantity T refers to all possible input-output combinations (Scheel, 2000). Figure 2 shows an example of a technology set as a shaded area. It results from the production function y = f(x), which is shown in the form of a straight line. Efficiency measurements that make use of a production function are to be assigned to class IV or class V. The input is defined by x and the output by y. Point A with the input quantity x_1 and the output quantity y_1 lies directly on the upper boundary of the production function and is therefore still part of the technology quantity as well as a possible input-output combination. Point C, with its input quantity x_3 and output quantity y_3, is also part of the technology quantity but is not on the upper boundary of the production function. Point B, with its input quantity x_2 and output quantity y_2, lies outside the shaded area and is therefore not part of the technology quantity. Point C is not a possible input-output combination. The production function y=f(x) shows which maximum output quantity can be achieved for a given input quantity. Similarly, for an expected output quantity, the minimum necessary input quantity can be identified. The linear course of the production function is freely chosen here and could also have a different course.

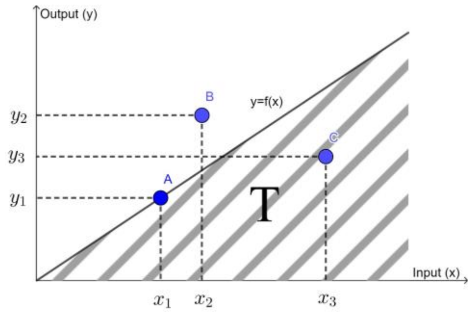

Figure 2: Technology quantity, adapted from (Scheel, 2000)

The technology quantity (T) in Figure shows the case of a single-input/single-output production system. A technology quantity is required for the 2nd generation processes based on production functions. A technology quantity is based on the assumptions of (1) empirical completeness, (2) economies of scale, (3) free wastability, (4) convexity (Scheel, 2000; Bogenstahl, 2012).

2.3 Parametric and non-parametric methods

In the following, the parametric methods are compared with the non-parametric methods in a short description. The decisive difference between the methods lies in the construction of the technology quantity. In parametric methods, a functional relationship between the inputs and outputs under consideration is specified a priori (Scheel, 2000). It should also be noted that in the case of multiple outputs, these must be combined into one output via prices. However, when constructing a production function of a parametric approach, in contrast to non-parametric approaches, stochastic data fluctuations can be considered. The result of a production function in a parametric approach reflects, therefore, the average of the examined units. Here, the non-parametric approaches distinguish themselves from the parametric approaches since they construct a best-practice line with their model-endogenous production function. Data quality is therefore of particular importance for non-parametric methods due to their high sensitivity with respect to data outliers. Table 1 summarizes the results of a bibliometric analysis for research applying non-parametric efficiency measurement, especially DEA, to warehouse setting, prepared by the authors as part of this study. The results indicate that research uses different inputs and outputs for various purposes and analytical objectives.

Furthermore, with regard to the status of knowledge, it can be seen that DEA is already being used in some areas of logistics. So far, however, no application can be found in food retail warehouse logistics over several periods. The factors for inputs and outputs are transferred from the existing research for the application in food retail warehouse logistics.

Table 1: Bibliographic analysis on DEA in warehouse logistics

no	author	Year	purpose	inputs	outputs
1	Dixit, A.; Routroy, S.; Dubey, S. K.	2020	measuring performance of government-supported drug warehouses	warehouse storage capacity, temperature-controlled storage capacity, number of skilled employees, operational cost	order fill rate, number of generic drugs, volume of drugs, consumption points, inventory turns ratio, time efficiency
2	Průša, P.; Jovčić, S.; Samson, J.; Kozubíková, Z.; Kozubík, A.	2020	performance of a logistic company with twelve warehouses is evaluated	number of pickers, average time of picking	annual income
3	Karande, A.; Krishna, A.; Jayasurya, R.; Gopan, G.; Gopinath, M. V.; Kumar, S.; Anoop, K. P.; Panicker, V. V.; Varaprasad, G.	2019	calculate the relative efficiency of warehouses owned by an Indian food grain procurement organisation	storage capacity, number of workers, number of wagons, working hours	monthly labour utilisation, monthly capacity utilisation

no	author	Year	purpose	inputs	outputs
4	Zeng, R.; Zhang, X.; Wang, P.; Deng, B.	2019	designs the performance evaluation system of warehouse operators in e-commerce enterprises	effective working rate	working quantity, working accuracy, working timeliness, working normalization
5	Raut, R.; Kharat, M.; Kamble, S.; Kumar, C. S.	2018	evaluating and selecting the most appropriate third-party logistics (3pl)	transportation charge per ton per km, fleet capacity/strength, vehicle type, and quality, driver rejection rate	percentage of target met by the 3pl, flexibility of a 3pl in providing vehicles, average time it takes for a 3pl to send his vehicles
6	Liu, J.; Gong, Y. Y.; Zhu, J.; Zhang, J.	2018	propose a new approach to conduct competitive environment analysis for a global operations strategy in retailing	the number of outlets; number of warehouses, number of suppliers	sales, market shares, ROI
7	Faber, N.; Koster, R.B.M. de; Smidts, A.	2017	explores fit among warehouse management structure and the context in which the warehouse operates	labour, size (scale 1-7), automation (scale 1-6), number of SKUs picked	production effective order lines, production special operations, flexibility (3-9 scale)
8	Lien, N.T.K.; Day, J.-D.	2017	evaluating 3pl companies specialize in integrated operation, warehousing and transportation services	assets, equity	net income, revenue

no	author	Year	purpose	inputs	outputs
9	Petridis, K.; Dey, P. K.; Emrouznejad, A.	2017	selection of a facility based on service level maximization and not just cost minimization	outgoing connections, total quantity sent	installation cost, fixed transportation cost from plant to warehouse, fixed transportation cost from warehouse to customer, variable transportation cost from plant to warehouse, variable transportation cost from warehouse to customer
10	Yang, C.; Taudes, A.; Dong, G.	2017	freight villages	total area, intermodal area, warehouse area, amount of investment	number of employees, amount of goods handled, no. companies attracted
11	Tang, L.; Huang, X.; Peng, Y.; Xiao, Z.; Li Y., Song H., Ren P.	2015	the paper constructed a "dea-tobit evaluation model" and introduced the mixed dea model	storage area, construction cost, facility cost, work hour, external cost	cargo throughout, pickup and delivery, effective use of the storage, order fulfillment
12	Li, H.; Ru, Y.; Han, J.	2013	an evaluation and identification approach examining a big soft drink company.	cost of sold goods, number of SKU sold, average inventory level, ratio for forecast orders/ real orders, delivery returns, forecast demand	number of customers served, revenue, product cases filled

no	author	Year	purpose	inputs	outputs
13	Andrejić, M.; Bojović, N.; Kilibarda, M.	2013	in order to improve discriminatory power of classical DEA models, PCA-–DEA approach is used	forklifts, employees in the warehouse, warehouse area, pallet places, electricity consumption, other energy costs (water, gas), utility costs, invoices (demands), warehouse overtime	deliveries, order picking transactions, order picking trans./order picker, turnover, warehouse space utilization, failures in the warehouse, write off expired goods, total failures
14	Pjevčević, D.; Radonjić, A.; Hrle, Z.; Čolić, V.	2012	efficiency measurement of ports over 4 years with the help of the DEA window analysis	the total area of warehouses, quay length, number of cranes	port throughput
15	Chakraborty, P. S.; Majumder, G.; Sarkar, B.	2011	operational, financial, quality	number of employees, general expenses, space, inventory	fill rate, sale, service time
16	Johnson, A.; McGinnis, L.	2010	to evaluated individual warehouses and groups of warehouses with regard to technical efficiency and to identify the operational policies, design characteristics, and attributes of warehouses that are correlated with greater technical efficiency	labor, space, investment	broken case lines, full case lines, pallet lines

no	author	Year	purpose	inputs	outputs
17	Mannino, M.; Hong, S. N.; Choi, I. J.	2008	evaluate an efficiency model for data warehouse operations using data from usa and non-usa-based (mostly korean) organizations	labor budget, computing budget	data age, change data, availability, queries, flexibility ratio, number of users
18	Jha, D. K.; Yorino, N.; Zoka, Y.	2008	analyze the performance of the distribution system in nepal by investigating the operational efficiencies of the distribution centers	distribution transformer capacity, feeder length, annual o&m cost, number of employees, distribution loss	annual energy sales, number of consumers
19	Hamdan, A.; Rogers, K. J.	2008	evaluate the efficiency of 3pl warehouses with unrestricted and restricted dea	labor hours, warehouse space, technology investment, material handling equipment	throughput (boxes shipped), order fill (boxes filled (for complete orders)), space utilization (cubic feet utilized)
20	Koster, M. B. M. de; Balk, Bert M.	2008	operational, quality	number of direct full-time equivalents, size of the warehouse, degree of automation, number of different skus	number of daily order lines picked, the level of value-added logistics (val) activities carried out, number of special processes, percentage of failure-free orders

no	author	Year	purpose	inputs	outputs
21	Korpela, J.; Lehmusvaara, A.; Nisonen, J.	2007	quality, financial	direct costs, indirect costs	reliability (time, quality, quantity), flexibility (urgent deliveries, frequency, special request, capacity (ability to respond to changes in warehousing capacity needs of a customer)
22	Min, H.; Jong Joo, S.	2006	financial	account receivables, salaries, and wages, expenses other than salaries and wages.	operating income
23	Ross, A.; Droge, C.	2002	equipment (capacity), operational	average labor experience, fleet size, equipment, mean order throughput time (mot)	product sales volume
24	Hackman, S. T.; Frazelle, E. H.; Griffin, P. M.; Griffin, S. O.; Vlasta, D. A.	2001	analysis of the operating efficiencies in 3 perspectives: the size of the warehouse, level of automation, and unionization	investment, total labor hour, square footage	accumulation, storage, broken case lines shipped, full case lines shipped, pallet lines shipped
25	Schefczyk, M.	1993	review two techniques (1. productivity rations 2. dea) to analyze the performance of industrial entities. performance analysis can be applied to a benchmark of facilities	labor hours, investment in material handling equipment	total number of correct transactions

3 Methodology

3.1 DEA and application requirements

DEA is a method for measuring relative efficiencies of decision-making units (DMUs) (Charnes, Cooper and Rhodes, 1978). DMUs can be very different depending on the application area of DEA. Individuals or teams, as well as entire companies or even national economies, can represent a DMU (Bogenstahl, 2012). In 1978, Charnes, Cooper, and Rhodes published their DEA model (Charnes, Cooper and Rhodes, 1978). This model was named the CCR model after its authors. Decisive for their work were the works of Debreu (Debreu, 1951), Farrell (Farrell, 1957), which dealt with the radial efficiency measurement and Koopmans (Koopmans, 1951), who did research on activity analysis. The first application requirement states that at least two decision units must be included in the analysis. Since the DEA is in the result about the evaluation of the relative efficiency of the decision units, it is necessary that at least two decision units are examined to be able to regard these to each other in relation. In addition, the quantitative relationship between decision units and inputs and outputs is of high importance for applicability (Dyckhoff and Gilles, 2014). The number of decision units must always exceed the sum of inputs and outputs. The reason for this lies in the endogenous weighting of the individual inputs and outputs. Therefore, despite multi-criteria consideration in an input-output combination, it is enough to show the highest efficiency. If the number of decision units is lower than the sum of all inputs and outputs, there is a risk that all decision units are efficient.

Comparability of decision-making units must exist (Dyckhoff and Allen, 1999; Scheel, 2000). Accordingly, only decision-making units whose transformation is comparable may be included in the efficiency analysis. The individual decision-making units must therefore have the same goals and use the same resources to achieve them. In addition to the decision-making units, the inputs and outputs must also be comparable. The literature points out that even if the inputs are apparently the same, it is essential to take a close look at them (Dyson, et al., 2001). The costs of a laboratory facility were apparently the same between the decision-making units. However, a look at the research, which was divided between the natural sciences and the humanities, made it clear that decision-making units in natural science research would always be less efficient as a result of the lower costs of laboratory equipment. The reference of the used data to the same period is also an important factor to be able to establish the comparability of the decision units. The last, but no less important, application requirement is the fulfillment of free wastability. This can be demonstrated by showing that there is no correlation between inputs and outputs. For this reason, a correlation analysis is created based on the determined data to make possible correlations recognizable.

In order to achieve a high informative value of the study and a sufficient amount of data, we use the data of one of the three largest German brick-and-mortar grocery chains operating more than 10.000 stores at the time of our data collection in 2021. Most data warehouse systems store inventory and sales data logs captured at a very detailed level. We use this data and aggregate it on a yearly level per the warehouse. Thus, our dataset contains all inputs and outputs used in the DEA model. Twelve warehouses for non-cooled perishable items were examined and used as the decision-making units of the efficiency analysis. The data was collected for the years from 2014 to 2020. The data used as inputs and outputs are listed in detail in Section 4.1.

3.2 BCC model

The BCC model is named after its originators, Banker, Charnes, and Cooper (Banker, Charnes and Cooper, 1984). They published their model in 1984, which, starting from the CCR model, is extended by one variable (Allen, 2002). These are δ_0. In the following, we note the BCC model with its corresponding constraints.

Mathematical notation of the BCC model:

$$\max E_0^{BCC-I} = \sum_{j=1}^{J} \mu_j y_{0.j} - \delta_0 \qquad (2)$$

Constraints:

$$\sum_{k=1}^{K} w_k x_{0.k} = 1 \quad (3)$$

$$\sum_{j=1}^{J} \mu_j y_{i.j} - \sum_{k=1}^{K} w_k x_{i.k} - \delta_0 \leq 0 \qquad \forall i = 1, \dots, I \quad (4)$$

$$\mu_j \geq 0 \qquad \forall j = 1, \dots, J \quad (5)$$

$$w_k \geq 0 \qquad \forall k = 1, \dots, K \quad (6)$$

Figure 3 shows the comparison between the CCR model and the BCC model. The exemplary decision units represent the points A, B, C, and D. The CCR model with constant returns to scale forms the efficient margin with the dashed line through the origin and point B. Only point B is located on this edge and is, therefore, the only efficient point. The inefficiency of the remaining points can be measured by their respective distance to the efficient edge.

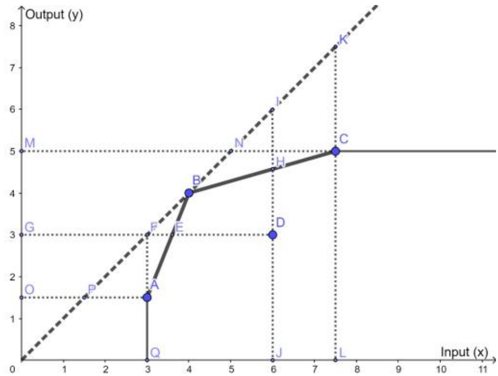

Figure 3: CCR and BCC model in the single-input/single-output case

3.3 Window analysis

In the DEA notation described so far, the decision unit data are each compared within the same period (Charnes, et al., 1985; Cooper, Seiford and Tone, 2007 ff.). Window analysis can nevertheless be used to compare decision units over several periods. A possible need for this tool may exist if no comparable decision units are available for a decision unit that can be included in efficiency analysis. To use Window Analysis, data over several periods must be available for the decision unit under consideration. The relative efficiency of the same decision unit over several periods can thus be determined, and positive or negative development can be shown. Window analysis can also be used when data is available for a large number of decision units over a large number of periods (Jia and Yuan, 2017). As part of the model formulation, the number of periods included in the analysis is defined. In the maximum form, an efficiency comparison of the decision unit with all other decision units is carried out over all periods. The minimum value would be the pure consideration within one period and would make the use of window analysis obsolete.

3.4 Super efficiency

Decision-making units that are efficient have a relative efficiency of 1.00 and are located on the efficient frontier. As already explained, many effective decision-making units can be found on this edge. The instrument of super efficiency makes it possible to differentiate these effective decision-making units (Andersen and Petersen, 1993).

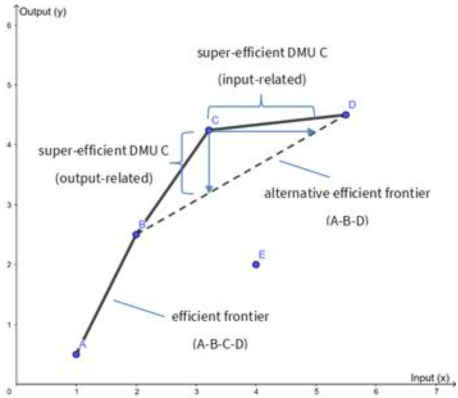

Figure 4: Super-efficiency in the single-input/single-output case

The decision-making units A to E are shown in Figure 4. Only decision unit E is not on the efficient margin determined by the BCC method and is therefore inefficient. To rank the efficient decision units based on super efficiency, an alternative efficient frontier (A-B-D) without C is formed. The distance from C to the alternative efficient frontier can be measured by input or output orientation. Accordingly, by the measured distance, the decision-making unit could increase its input quantity or reduce its output quantity and still be effective. For example, if a 15% reduction in output quantity were possible, the result would be a super efficiency value of 1.15 (Bogenstahl, 2012). All calculated super efficiency values can then be sorted in descending order, and a ranking of the efficient decision-making units is created. The assumption of an alternative efficient frontier is only used to calculate the respective super efficiency. If the removal of an efficient decision-making unit results in an alternative efficient frontier analogous to the original efficient frontier, the value remains at 1.00. The relative efficiencies of all inefficient decision-making units remain unchanged, as do all efficient decision-making units, which are still to be regarded as efficient despite the ranking by super efficiency.

3.5 Model selection method

The two models CCR and BCC differ fundamentally about their returns to scale. Depending on the use case, the result according to the CCR method with constant returns to scale is close to the BCC model with variable returns to scale. The question arises in which case the CCR model is sufficient and in which case a gain in knowledge is achieved by using the BCC model. This question can be answered, along with other methods, with the help of the Bankers test (Banker, 1996). A hypothesis test is used to determine whether the results differ significantly. The threshold value here is a 95% confidence interval. If the result of the calculation is above this value, the use of the BCC model is profitable about the information content and is, therefore, to be used.

4 Empirical Findings

4.1 Model formulation

The factors considered are divided into inputs and outputs. The results of the bibliographic analysis, which are shown in Table 1, were used to determine which factors have already been used as inputs and outputs. Derived from this are the parameters used in this study. It is important to note the different scaling of the factors and the consideration of non-monetary variables. In order to increase validity, 25 sources were used in the bibliographic analysis over a period of 7 years. Based on this analysis, the factors for the present research were chosen. The factors warehouse space, personnel costs, fixed material costs, and variable material costs are included in the analysis as inputs. Outputs included in the analysis are the number of orders processed, orders delivered too late, stores supplied, and incorrectly picked units, as well as inventory difference and average stock. The following assumptions have been made in advance of the calculation. The model is input-oriented, as all input factors are within the sphere of influence of management. The calculation is first performed with constant returns to scale and then again with variable returns to scale. The calculation is performed about the periods in one variant in isolation and therefore only in comparison to decision units of the same period. In another variant, the relative efficiency is calculated using window analysis over all seven periods. There is no exogenous restriction on the importance of weights. Finally, super efficiency is applied as a supplementary calculation method.

As inputs, we use the following parameters: (I_1) warehouse space (square meters), (I_2) personnel costs (euro), (I_3) fixed material costs (euro), (I_4) variable material costs (euro). As outputs, we use the following parameters: (O_1) number of orders processed (piece), (O_2) average warehouse load (euro), (O_3) inventory difference (euro), (O_4) number of orders processed too late (piece), (O_5) number of stores supplied (piece), (O_6) number of incorrectly picked units (piece). The inputs and outputs were validated using a bibliographic analysis of the DEA in warehouse logistics. This answers research question (1) about the components of an efficiency analysis for evaluating the performance of warehouses in brick-and-mortar retailing.

4.2 BCC model with window analysis and super efficiency

The final version of the model is the BCC model with the use of window analysis and super efficiency. The goal is to develop a model with high discriminatory power to create the highest possible informative value and optimization support for logistics. Starting from the basic models CCR model and BCC model, the BCC model was chosen. In the first step, it was extended by the Window Analysis. By adding super efficiency, the model could be further improved.

In Table 2, the changes to the model because of the use of super efficiency have been highlighted by bold formatting. A total of eleven values were changed. This means that 45 of 84 values have a relative efficiency of 1.00. This corresponds to a proportion of 54%. In this way, the application of super efficiency further improves the discriminatory power of the model. The eleven adjusted values are found in a range from 1.038 to 1.784. The mean value is 1.18. The value of "DMU 9" in the period 2018 was assessed with a super efficiency of 1.784. This is a very high value compared to the mean value of super efficiency. Another possibility for model adjustment would be to perform the calculation based on this outlier again without this decision-making unit. Since the relative efficiencies of the remaining decision-making units do not show a significant reduction in the calculation without window analysis in the 2018 period, it can be assumed that the new model would not differ significantly from the current model. In period 2014, only

"DMU 3" shows a changed value. In the period 2015, three changed values can be observed. In the periods 2016-2018, again, only two adjustments, and in period 2019, one adjustment can be seen. In period 2020, no change can be seen in the calculation of the super efficiency.

Table 2: Comparison of relative efficiency according to the BCC model with window analysis over all periods with super efficiency

	2014	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Avg.**
DMU 1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	**1.000**
DMU 5	1.000	1.000	**1.075**	1.000	1.000	1.000	1.000	**1.000**
DMU 7	1.000	**1.273**	1.000	**1.038**	**1.040**	1.000	1.000	**1.000**
DMU 3	**1.051**	**1.252**	1.000	1.000	1.000	1.000	0.970	**0.996**
DMU 4	0.966	0.982	1.000	1.000	1.000	1.000	1.000	**0.993**
DMU 6	1.000	1.000	1.000	1.000	0.882	1.000	1.000	**0.983**
DMU 9	1.000	1.000	1.000	1.000	**1.784**	**1.137**	0.805	**0.972**
DMU 10	1.000	1.000	**1.102**	**1.178**	1.000	0.638	0.873	**0.930**
DMU 8	1.000	1.000	0.940	0.826	1.000	0.739	0.729	**0.891**
DMU 11	1.000	0.914	1.000	0.825	0.843	0.885	0.758	**0.889**
DMU 2	0.972	0.950	0.857	0.815	0.730	0.634	0.604	**0.795**
DMU 12	1.000	**1.099**	0.891	0.797	0.632	0.651	0.586	**0.794**
Avg.	0.995	0.987	0.974	0.939	0.924	0.879	0.860	

Two particularly important findings emerge. The first finding is that, in the analysis to date, the decision-making units that exhibited a relative efficiency of 1.000 in all periods formed the efficient cluster. About the question of which units should serve as best practice examples and as models in practice, it has so far been possible to identify this efficient cluster clearly. Looking at the ranking structure, there is a widespread across the periods and decision-making units. Likewise, there is no dominant location within the ranks. The "DMU 7" site is most frequently represented with three ranks. The "DMU 1" decision unit, despite being consistently efficient, is not represented in the super-efficiency ranks. Accordingly, orientation in practice must be targeted to the best practice decision units, which are differentiated by super-efficiency.

The second important finding can be explained using the decision-making unit "DMU 12" as an example. In the consideration without super efficiency, this location is in the last group because of the low relative efficiency over all periods. Nevertheless, "DMU 12" reaches the seventh rank of super efficiency by the data in the period 2015. From period 2014 to period 2015, this decision-making unit was able to improve and then, after another five periods, only reached a relative efficiency of 0.586 and, therefore, the lowest value of the entire model. Although in this model for "DMU 12" in period 2015 the value is 1.099, the gap from period 2020 to periods 2014 and 2015 is still 0.414 in both cases. This reading accounts for the situation that all values above 1.000 were calculated by alternative efficient frontiers, but the efficient frontier of the model was not changed. In a similar form to "DMU 12", this can be seen in the decision-making units "DMU 3", "DMU 9" and "DMU 10". Looking at the 2020 period, no decision-making unit was able to transfer the special situation caused by the COVID 19 pandemic into an efficiency gain. If we look at the values, we can rather confirm the opposite. Of the decision-making units, which dominated in super-efficiency, sometimes significantly, in previous periods, only "DMU 5" and "DMU 7" can show a relative efficiency of 1.000. Increasing quantities lead to higher order sizes. This results in better conditions for higher picking performance. However, the rapid increase resulted in a strong short-term increase in the number of employees and adjustments to the working hours. The results of the analysis suggest that the resulting negative effects outweighed the positive volume effects.

4.3 Analysis of inefficiency by input factors

In addition to the relative efficiencies for each decision-making unit and input factor, the DEA provides a value by which the input factor would have to be reduced to be on the efficient frontier. The input factors of the inefficient decision-making units are projected to the efficient frontier. The resulting distance is used to calculate the necessary input factor reduction. In the model used, seven periods are considered for each of the decision-making units. At this point, the period 2020 is taken as an example. To be able to apply the findings directly in practice, the most recent period was chosen. In Table 3, the first column lists the decision-making units. The second column lists the relative efficiencies, which are sorted in decreasing order. In the following columns, the values for the corresponding input factors are entered. For a better reading, the input factors are shown in Table according to storage area "(I1) AREA", personnel costs "(I2) PC", fixed material costs "(I3) FIX MC" and variable material costs "(I4) VAR MC" shortened.

Table 3: Distances to the efficient frontier by input factor with window analysis in period 2020

DMU	rel. efficiency	(I1) Area	(I2) PC	(I3) fix MC	(I4) var. MC
DMU 1	0.1000	0 m^2	0T €	0T €	0T €
DMU 4	0.1000	0 m^2	0T €	0T €	0T €
DMU 5	0.1000	0 m^2	0T €	0T €	0T €
DMU 6	0.1000	0 m^2	0T €	0T €	0T €
DMU 7	0.1000	0 m^2	0T €	0T €	0T €
DMU 3	0.970	0 m^2	-1.306T €	-98T €	-34T €
DMU 10	0.873	0 m^2	-3.194T €	-38T €	-185T €
DMU 9	0.805	0 m^2	-2.405T €	-18T €	-293T €
DMU 11	0.758	0 m^2	-4.547T €	-69T €	-322T €
DMU 8	0.729	0 m^2	-3.276T €	-173T €	-353T €
DMU 2	0.604	0 m^2	-3.632T €	-227T €	-609T €
DMU 12	0.586	0 m^2	-4.929T €	-188T €	-1.236T €

The first five decision-making units in Table 3 are not to be considered for this analysis, as there are no input factor improvements to be made for these because they are efficient. For the remaining decision-making units, one similarity can be immediately identified. No reduction is allocated to the input factor storage space. This assessment arises because the input factor was assigned a fixed value in the model because warehouse space cannot be adjusted in the short term.

Furthermore, the input factor personnel costs are assigned the highest savings values. The high absolute values of personnel costs in the input data compared to fixed and variable material costs can be attributed to this. The decision-making unit "DMU 3" with a relative efficiency of 0.970 would have had to save personnel costs of 1,306T€, fixed material costs of 98T€, and variable material costs of a further 38T€ in period 2020 to be efficient. The decision-making unit "DMU 12" with a relative efficiency of 0.586 would have had to save personnel costs of €4,929T, fixed material costs of €188T, and variable material costs of a further €1,326T in period 2020 to be efficient. In total, this amounts to 6,353T €. These values can be used in practice for adjustments in the areas. This could result in adjustments to the warehouse layout, the picking method, the staffing of incoming and outgoing goods, the performance specification for picking, or the conditions of service providers, to name just a fraction of possible approaches for improvement. By quantifying the reduction to be aimed for according to input factors, the target definition is already available as probably the most important part of a measure to increase efficiency. Based on the individual input factors and their calculated values by the DEA, target values are defined for all inefficient decision-making units. Another way to use the results of DEA is the following approach. “DMU 12” has been selected as an example here because the most significant change in relative efficiency can be observed in this DMU.

Table 4: Distances to the efficient frontier by input factor with window analysis of the DMU 12

Year	rel. efficiency	(I1) Area	(I2) PC	(I3) fix MC	(I4) var. MC
2014	1.000	0 m^2	0T €	0T €	0T €
2015	1.099	0 m^2	0T €	0T €	0T €
2016	0.891	0 m^2	-885T €	-119T €	-168T €
2017	0.797	0 m^2	-1.783T €	-166T €	-329T €

Year	rel. efficiency	(I1) Area	(I2) PC	(I3) fix MC	(I4) var. MC
2018	0.632	0 m²	-3.612T €	-212T €	-661T €
2019	0.651	0 m²	-3.761T €	-180T €	-784T €
2020	0.586	0 m²	-4.929T €	-188T €	-1.236T €

The manager responsible for only one of the eleven decision units can use this form of results over the course of the period for decision-making. The decision-making unit "DMU 12" is listed as an example of this. In addition to the possible measures already mentioned in the area of personnel costs, some starting points for influencing the two input factors in the area of material costs should be mentioned here. The implementation of investment measures leads to depreciation costs and, therefore, to fixed material costs. Each measure must be evaluated in light of the operational necessity and the economic benefit. For example, higher depreciation costs can make sense if this results in a more than the proportional reduction in maintenance costs. Maintenance costs are one of the components of variable material costs that can be influenced the most. Especially in variable material costs, a regular review of the classic make-or-buy decision can always be part of the measures. By using DEA, the comparison succeeds beyond monetary limits and still brings clear target values around monetary influenceability. These two approaches answer the research question (2) about the main potentials for the examined warehouses when aspiring to increase their performance.

5 Discussion

5.1 Implications for practice

Our empirical examination on warehouse efficiency for a large German brick-and-mortar chain pointed out that DEA is suitable to assess the efficiency of warehouses for non-cooled and perishable items. For logistics managers, this spawns a way forward to reach multi-criterial efficiency measurement aggregated to one efficiency score. Compared to traditional one- or two-dimensional benchmarking, our methodology enables the integration of several perspectives. Furthermore, our methodology can spawn interesting insights for logistics managers of all levels as the selection of DMUs is highly flexible in DEA. While choosing warehouses as DMUs has a more strategic character on a high aggregation level, the evaluation of trucks in one depot may be used as a benchmarking approach on a more operational level. In summary, while the model formulation has to be adjusted to the purpose of the analysis, our non-parametric DEA model is in general suitable to address management questions of several hierarchy levels from middle to top management.

For further research, logistics managers should consider adjusting the periods to monthly observation. It is recommended to develop a model that is designed with input and output factors only by controllable variables. This change of perspective from the perspective of total costs to a construct of monetary and qualitative factors that can be influenced would run against a behavioral model that is typical in practice. This is shown by pointing out the negative developments of factors that cannot be influenced by managers.

5.2 Implications for theory

From a systems theory perspective, our examination shows that DEA is suitable to measure the efficiency of complex systems operating with various inputs and outputs. For these systems, the degree of internal understanding for the throughput process is limited, often leading to black box assumptions. Because simple or advances parametric methods use various assumptions when evaluating these black box scenarios, the non-parametric DEA with model-endogenous factor weighting is suitable to deal with complex systems. For panel data, the combination with the window analysis, an instrument would be created that makes it possible to visualize the success of the implemented activities over the monthly course of the periods under review. Even with this application option, nevertheless, there are points of attention. Because the monthly presentation of results is used for internal reporting, it does not have to satisfy the legal requirements of external reporting. This results in the risk that not all costs are accounted in the correct period. The use of DEA would therefore require a high level of period-by-period accounting to ensure that the validity of relative efficiency as an aggregation of all factors is not questionable.

Further research avenues may include the integration of shareholder and stakeholder perspectives through an AHP-based pre-factor weighting of the inputs or outputs used in the DEA model. While the model-endogenous factor weighting is a major advantage of DEA, the output of, e.g., on-time delivered transport units, may be 0.00001. Because this may not be in the interest of stakeholders, e.g., the grocery stores, AHP-based pre-factor weighting can avoid this shortcoming of traditional DEA models. Last, the traditional and deterministic DEA models explained above require the availability of exactly known values for the specified input and output measures. Hatami-Marbini et al. (Hatami-Marbini, et al., 2017) argue that this kind of model is susceptible to changes or errors in data values. As the data in real-world problems tend to be imprecise or vague, researchers have been working on DEA models that aspire to deal with uncertain input and output data. Therefore, an interesting further research avenue may include the efficiency measurement of warehouses through fuzzy DEA.

6 Conclusion

Based on data from 12 logistics centers, a multi-criteria efficiency analysis was performed over a period of 7 years. The weighting of the factors was done model endogenously by DEA. The BCC model with variable returns to scale was used as the base model. It was extended to include Window Analyses to provide a cross-period efficiency comparison. In addition, the super efficiency was included to increase the discriminatory power of the model. As a result, an exact value was presented in the input-orientated model for all input factors. This value must be saved to make logistics efficient in relation to the others. A further consideration is the creation of an output-oriented model, as well as a model with factors that can be completely influenced by the responsible managers.

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Evaluation of an Integrated Planning and Simulation Tool

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Purpose: *For new planning or redesigning of existing logistical nodes it is important to use areas and technical equipment for handling, transport and storage as efficiently as possible. Layout planning and logistic simulation are used separately in the development and planning of logistic nodes. In the field of combined transport facilities, planning is in most cases limited to the static layout according to common parameters by classical planning instruments.*

Methodology: *By applying the ISI-Plan tool the layout and configuration of an existing inland terminal is parameterized and implemented via the surface visTABLE®. Consequently, the arrangement of infrastructure modules such as storage blocks, lanes and tracks are modelled. The same applies to the superstructure used.*

Findings: *The functionality of combining both methods via one interface could be demonstrated. Due to the complexity of the terminal which was reflected in high computing times, it was necessary to work with a downscaled model in order to obtain performance statements.*

Originality: *The innovative ISI-Plan application makes it possible for the first time for a wider spectrum of operators of logistics nodes to analyze, evaluate and modify the prevailing situation in an uncomplicated manner. Compared to conventional procedures, it is possible in a significantly reduced scope of time.*

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1 Introduction

In response of growing challenges regarding an increased throughput in less time and higher quality there is a need for continuous evaluation and adaptation of internal operational processes at logistic nodes in ports and the hinterland. Due to the increasing complexity and rising handling figures container terminals (Stahlbock and Voß, 2008) and inland terminals (Khaslavskaya and Roso, 2020) are a prime example of this. When it comes to new planning or redesigning of existing logistic nodes it is therefore fundamental to use the available space and the technical systems used for handling, transport and storage as efficiently as possible. In particular for assuring and optimizing solutions for commonly planning logistic processes and in specific for container terminals, for seaports as well as inland terminals simulation is the key. By combining static layout modelling and its simulation via an interface, modifications in the terminal configuration can be analyzed with little effort in contrast to conventional methods. Up to now, the consideration of an integrated layout planning for logistic nodes has not been done from an academic point of view. The term “terminal” covers not only seaport terminals but also locations for multimodal transshipment in the hinterland of the ports (Notteboom et. al, 2021). Especially for operators of inland terminals there is the chance to reduce the planning and modeling effort for adaptations and new planning. Therefore, this work refers to inland terminals. This leads to the underlying questions in this thesis: How can the two tools be efficiently linked to analyze inland terminals? In the following part, first more theoretical background knowledge about terminal design and simulation software is given. In section 3, the methodology is elaborated. This is followed by the presentation of the results in Section 4 and their discussion in Section 5. Finally, conclusions are drawn in Section 6.

2 Theoretical Background

So far, planning and optimization by means of terminal simulation (Dragovic et al., 2017; Angeloudis and Bell, 2011) has taken place separately from each other. Static terminal layouts (Böse, 2020; Brinkmann, 2005), which are based on standard layouts, empirical values or calculations, serve as the basis of a simulation study. The simulation study then offers possibilities for evaluation and further adaptation of the terminal design to be tested. However, the creation of the simulation models in particular requires extensive software knowledge and time. Subsequently, one or more further adaptation steps would be required for the static terminal layout under investigation, which in turn would result in high workloads and personnel costs.

Object-oriented modelling enables the representation of real systems. For this purpose, an element of a real system is provided with certain changeable attributes. The more complex and realistic the environment, the higher the number of attributes to be adjusted must be. In particular, the modelling of large systems with a large number of attribute states is time-consuming and accordingly complex. They are nevertheless useful for providing answers to specific questions in terminal layouts. Common modelling tools offer predefined functions, but they must be adapted to the models created by reprogramming objects or programming individual scripts and therefore require trained users.

There are simulation models created specifically for container terminals that focus on medium to large overseas ports as a unit. However, they do not meet the requirement of versatile usability as it would be necessary for inland terminals and intermodal terminals, because multiple decision variables, static and dynamic constraints and risks come into play especially in the planning of the mentioned logistic nodes. Therefore, specifically in the simulation of container terminals in seaports, the focus is on selected areas as shown by Nourmohammadzadeh and Voß, 2021; Tan et al., 2021; He et al., 2015; for container gantry cranes or Yu et al., 2021; Kastner, 2021; Gharehgozli et al., 2017 and Kemme, 2012; for automated storage blocks.

Furthermore, software solutions exist that combine planning and its simulation in approaches. In material flow planning (Wurdig and Wacker, 2008) and production planning (Toth et al., 2008) this approach is considered. Only Schwientek et al. (2018) address how the conceptual framework for developing an integrated layout planning and its simulation can look like. The approach consists of the development of an integrated modelling and simulation environment for terminals, which is based on the planning software visTABLE® and the simulation software Enterprise Dynamics®.

Despite many possibilities of innovative layout planning software, this analytical or static approach cannot consider the container handling processes of the terminal. Thus, it not possible to check the defined functional areas and the equipment for adequate capacity, e.g. to cover possible peak loads or to identify bottlenecks. If this is to be investigated in advance and as accurately as possible, simulation software can be used to dynamically model the terminal.

Up to now, the actual planning of the layouts and the corresponding simulation have mostly been decoupled from each other and carried one after the other. As a result, adjustments to the layout based on the simulation results lead to several optimization iterations, which is both time-consuming and causes high personal costs in the planning process. This paper describes with the development of an integrated software tool which allows the user an intuitive and simple layout planning adapted to individual conditions. At the same time, an automatic simulation of the created terminal layout is carried out and provides the basis for a performance analysis.

3 Methodology

To answer the research question of how a static planning tool and a dynamic simulation tool can efficiently be linked, the approach of an integrated solution was chosen in this paper. By implementing the terminal, statements can be made about the KPI of the terminal.

The methodological procedure is as outlined in the following. At first the interface is examined in more detail with regard to its mode of operation, which represents the basis for communication between the frontend and the backend. This is followed by an explanation of the data generation and parameterization by the frontend and the transfer and implementation in a simulation model to the backend.

Based on terminal visits and interviews with various domestic terminals, as well as extensive literature studies, the requirements for the integrated software solution were defined. A concept was then developed for integrating the two applications of the software houses, which had already existed independently for several years, in order to meet the previously defined requirements.

The case study approach is particularly useful when it comes to taking an in-depth look at a problem, event or phenomenon of interest in its real-world context. Therefore, a very classic structured inland terminal, hereinafter called terminal, is used to validate the software application. For this purpose, the terminal layout is created via the visTABLE® graphical interface, in which all relevant data are entered. An executable model is then generated in the Enterprise Dynamics® simulation software via the XML interface. Since simulation models always represent an abstraction of the real prevailing conditions, the integrated planning of terminals and their simulation does not claim to be optimal. Rather, it represents a basis for comparison of further simulation runs. In order to obtain information about the performance of a terminal, variations of a layout are always necessary.

This publication concentrates on the evaluation of the performance indicators handling units, loading units on the terminal, utilization of the terminal areas and utilization of the terminal areas.

3.1 Program Interface

The integrated software tools principle of operation can be seen in the following

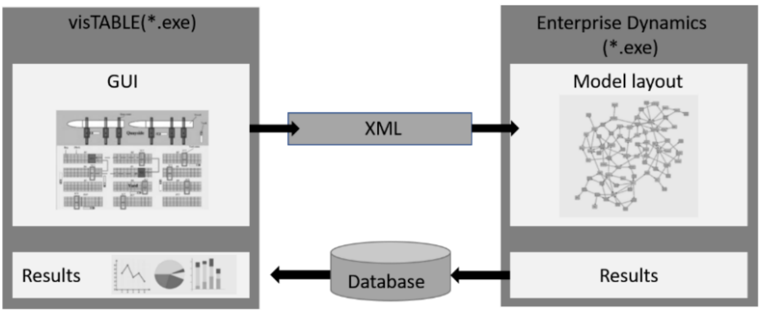

Figure1.

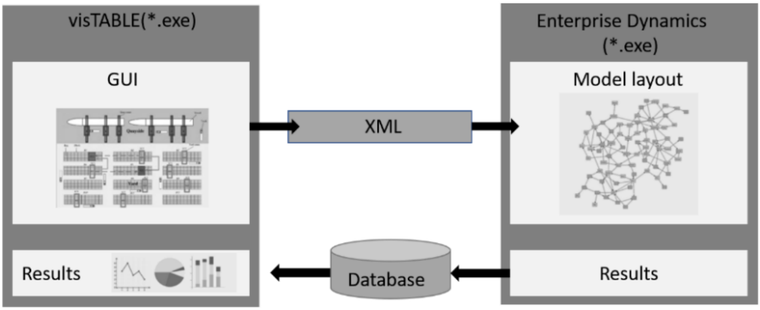

Figure 1: Interface concept

The interface forms the communication basis for both software applications. It is used to transfer all layout and user data, in particular the parameterized components of the layout plus general model parameters and the selection of target variables to be measured. At the same time, it is used for fine control of the simulation. Another interface is used to transfer the raw data generated by the running simulation and also the accumulated result data for presentation in the graphical user interface. Interposing a database for the recording of simulation data has the advantage that the frontend and the backend can act independently of each other. Another advantage is the dynamic determination of the quality of target variables, because as a rule, stochastic parameters become more accurate as the runtime of a simulation increases.

3.2 Frontend

With the help of visTABLE®, terminal layouts are created, designed and parameterized for the realization of the dynamic simulation. To simplify handling, satellite images can be uploaded as a basis for planning in order to place true-to-scale elements. A model library is available for the design and determination of the spatial structure of the terminal, which contains the most important arrangement objects. These include roads, tracks, storage areas, but also crane systems. Furthermore, there are also objects that change location, which are not defined by placement in the layout, as they change their location dynamically during the runtime of the simulation.

3.2.1 Basic Features of the Terminal

The determining properties and performance parameters necessary for planning the terminal must be defined in advance of the simulation.

The loading unit mix indicates which shares of the handled loading units are to be assigned to a specific loading unit type. The specification of these parameters defines for which loading units (types) handling orders are dynamically generated at runtime of the simulation There are five defined loading unit types (20-foot, 40-foot or 45-foot container, swap bodies and trailers).

The cycle time determines the cycles in which the schedules are regularly applied. In this way, planned closing days of the terminals can be considered.

The modal split results from the transshipment volumes for each combination of transport modes.

The value of the global transshipment serves as a validation parameter after the simulation runs. This parameter is used to describe the target global throughput (in TEU) per year. By comparing this parameter with the value achieved in a simulation run(in the respective time slice), it can be determined whether the required performance of the terminal has been achieved.

Furthermore, the parameter Gateway defines the loading units in the terminal that are handled and transported directly between the mass transport means of inland waterways and rail. The share of direct loading describes the parameter that includes all directly handled loading units from one mode of transport to another mode of transport, which means no intermediate storage.

3.2.2 Timetables and generation of order data

The simulation generates handling orders during run time. For this purpose, the simulation generates order data based on fixed timetables as well as on parameters from the modal split and load unit mix, which should simulate a typical operation of the planned terminal as realistically as possible.

Timetables for the rail mode are defined by specifying specific arrival and departure times. They are therefore not generated randomly by the simulation, but are generated repeatedly on the basis of fixed timetable data according to the defined cycle.

A timetable entry is to be defined for each planned transshipment of the mode of transport ship if this transshipment is planned and takes place regularly. Arrival and departure are to be defined analogous to the railway timetables.

In contrast to the schedules of the rail and ship modes of transport, no fixed schedules are defined for trucks. The order data of the transshipment orders are determined by the simulation at runtime from various parameters. The terminal parameters global modal split, share of gateways, share of direct transshipments are used.

3.2.3 Equipment

Mobile equipment is not defined by the placement of specific models or objects in the layout, since the equipment is not in fixed positions. Equipment in this sense includes all means of transport that can actively move on the terminal itself and are used for the transport of loading units. For this purpose, not each individual instance (e.g. of a reach stacker) is recorded, but the quantity of all equipment of the same type is described collectively. During the simulation run, it is dynamically selected whether and which concrete instance of a piece of equipment is used for a handling or transport order. The simulation calculates and uses the shortest route for the selected equipment, considering existing restrictions.

The mobile lifter is equipment that can move loading units vertically and is thus able to load and unload means of transport and horizontal transport. In principle, they can move freely on the terminal (subject to restrictions). The stacking height and the time required for a complete lift of load units can be specified so that during the simulation execution the time required to move a loading unit is determined dynamically based on the position of the loading unit.

Horizontal transporters are objects of the handling equipment that can only transport loading units horizontally. Horizontal handling systems are especially solutions for the increasing transport demand of non-craneable semi-trailers by rail. At the time of simulation, all instances of a horizontal transporter move constantly over the terminal at the specified speed.

3.2.4 Module Library

There is a manageable number of models available for the representation of the terminal, with which the layout and simulation model are described. These are, on the one hand, objects that are essential for the structure and behavior of the terminal and carry parameters, and, on the other hand, objects that are more of a visual aid for a realistic representation of the planned terminal and do not have to be parameterized. These objects, also called arrangement objects, are stationary resources of the terminal and have a parameterizable position and physical extent.

Terminal surfaces divide the terminal layout into rectangular areas with different functions. Terminal areas can be logically connected to each other and thus form a network on which means of transport can move. Relationships can exist between the arrangement objects that result solely from the relative position of the arrangement objects to each other.

Yards have a buffer function as intermediate parking areas. They are defined by rectangular areas in which parking spaces for loading units are created in regular structures and addressed by the simulation.

A berth is used for the selection of dedicated terminal areas to entries of the ship schedule. The following applies to the positioning of a ship along the quay wall: A quay edge is defined for ships. Only a fixed allocation can be made, otherwise the simulation randomly selects an available mooring at runtime.

During the simulation, a road network is built automatically. This is done on the basis of the relative position of the roads to each other.

In the model library you will find predefined tracks for half trains (48 20-foot containers à 1 TEU) and full trains (96 20-foot containers à 1 TEU).

The working area of cranes is not defined by the physical model of the crane itself, but by its crane track. This is how you define the area in which a crane is allowed to operate. Cranes can generally handle loading units of all types. Various parameters are available for defining the technical capacity of the crane.

3.3 Backend

The software application makes it possible to transfer a static layout from the frontend directly into a functional dynamic simulation model with stored logistics strategies in the backend.

3.3.1 Layout Design and Path Network

The automatic generation of the static terminal layout created in the frontend is made possible by the fact that each object in the simulation model has all the necessary geometric information. This makes it possible to unambiguously determine the position of each individual object in the plane of the terminal. In addition, the terminal surfaces contain information about whether they can be driven on, who is allowed to drive on them and how they are connected to each other.

From this data, a route network can be generated for each means of transport, which on the one hand contains all terminal areas that can be reached by the means of transport and controls the movement of the means of transport on the terminal site. In order to be able to represent the transport processes in the simulation model, a simple algorithm is sufficient to search for connected routes between a start and a destination node of the route network. If the path from a start node to a destination node exists, the shortest path is selected.

3.3.2 Strategies and Object Relations

In addition to the functionality of the objects, which defines the elementary activities such as loading and unloading, driving, etc., the object behavior is essentially controlled by strategies, which always come into play when there are several options for proceeding at a decision node, e.g. when selecting the next handling order, the suitable equipment and the suitable loading unit (Kaffka et al., 2014; Clausen and Kaffka, 2016; Eckert et al., 2013). The strategies are firmly linked to the simulation logic and are therefore implemented in the backend. The user can only select the strategies for a given decision criterion in the frontend.

Since the terminal is analyzed at the loading unit level, the overall state of the terminal changes as soon as the relationships of the objects used to each other change, i.e. positions or number, of the loading units are modified. This happens when means of transport arrive and depart and when loading units are repositioned on the terminal premises. Repositioning is defined as follows:

- Picking up the loading unit from a means of transport, a horizontal transport or a terminal area.
- Optional transport of the loading unit to another position on the terminal site.
- Setting down the loading unit on a means of transport, a horizontal transport or a terminal area.

This results in several processes that cause a change of state of the terminal:

- Arrival and departure of means of transport
- Loading and unloading of means of transport
- Loading and unloading of loading units (this also includes parking and picking up of loading units on any terminal area or in the same terminal area (restacking))
- Internal transport of loading units
- Checking whether ready for departure (checker/inspector)

In contrast to incoming and outgoing transshipments, which always involve a longer stay on a terminal area, direct transshipments are transported by the equipment directly from one means of transport to another. If both means of transport are of the ship or train type, this is referred to as a gateway. Basically, for each incoming mode of transport containing loading units to be transshipped, a transfer order is created for the equipment for each of these loading units. Destinations are not yet determined, but only when a piece of equipment reports itself as ready. The system then checks whether direct transshipment is possible. This is the case if another carrier has been announced in time or is already on the premises. In order not to transship all loading units directly as soon as the opportunity arises, a weighted distribution is used to select whether a direct transshipment should actually be carried out. The weighted distribution considers all loading units that have already been transshipped up to that point and adjusts the proportion of direct transshipments to the default defined by the user.

3.3.3 Simulation of Terminal Processes

The processes that take place in the terminal are presented below. A process is triggered when a change of state takes place. The conditions for a change of state are defined.

The object class Equipment includes the subclasses MobileLifter, Crane and HorizontalTransport. Even if individual functionalities are executed differently (e.g. travel or handling), the states for the objects involved are basically the same. Each piece of equipment follows the same repetitive sequence: Drive to the pick-up location of a load, pick it up, drive to the drop-off location of the load and drop it off. It is assumed that the source of the load is at the pick-up location before the corresponding order to pick up the load is generated.

The object class means of transport contains the three modes of transport truck, train and ship. While the last two are exclusively passively loaded and unloaded, trucks can behave like horizontal transport, move freely on the terminal and load and unload certain loading units independently. Means of transport can visit several delivery positions. Accordingly, several pick-up positions can be visited after the unloading process. For larger means of transport such as train and ship, simultaneous loading and unloading is possible between pure unloading and pure loading.

3.4 Database

The backend generates data at simulation runtime, which is stored in an Access database to log the relevant values of the simulation run.

3.5 Experiment Data

The data used as a basis for the simulation correspond to those of a classic structure of a typical inland terminal. This consists of:

- six tracks with a length of 700m to accommodate block trains
- four gantry cranes
- two reach stackers
- a quay for barges

4 Results

We separate our results of the study into two main areas. We begin with a short introduction into the functionality, which sets out the workflow. Following this, the simulation results are presented, focusing primarily on the individual equipment units. Finally, the results are explained and thus a basis for discussion is given.

4.1 Functionality

As a result, it can be stated that the communication between frontend and backend works via XML interface. The terminal layout created statically with the visTABLE® software tool is automatically transferred to a dynamic simulation model and simulated with Enterprise Dynamics®. Furthermore, the output and visualization of the individual performance parameters of the modelled inland terminal was carried out.

4.2 Simulation Results

The results of the inland terminal simulation case are presented below.

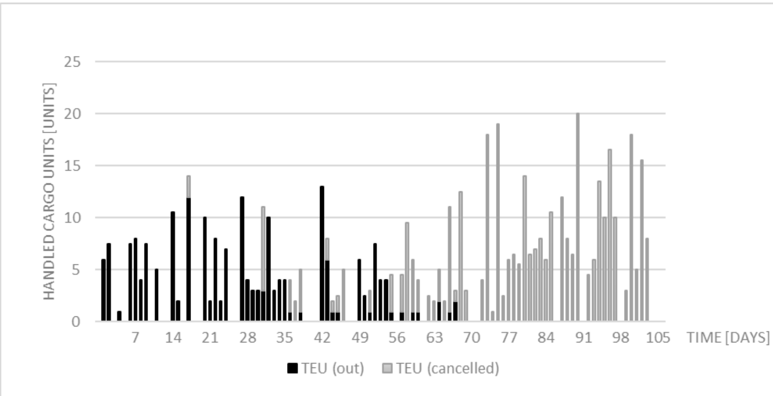

Figure 2: Handled cargo units

The number of loading units handled is of primary interest and indicates how many handling orders have been realized cumulatively per day. TEU (out) indicates how many loading units were regularly handled. TEU (cancelled) indicates which loading units could not be handled because at least one of the means of transport involved in the handling has already left the terminal again. The moving average levels out the fluctuation between the days and reflects the average of the seven preceding simulation days. An asymptotic approximation of this curve is an indication of a converging simulation run and thus an indication of a time range for which the simulation model can be regarded as "settled". Only then statements about the results of the simulation run are actually possible. The reason for this is that the terminal is completely empty at the start of the simulation and therefore no statement can be made about the performance for the first few days. As can be seen in Figure2, the curve has settled after a relatively short period of seven days and shows a surplus of regularly handled loading units at the beginning of the simulation. This situation changes from the beginning of the eighth week of the simulation. From this point on, the number of loading units that cannot be transshipped increases until no regular transshipments take place at all.

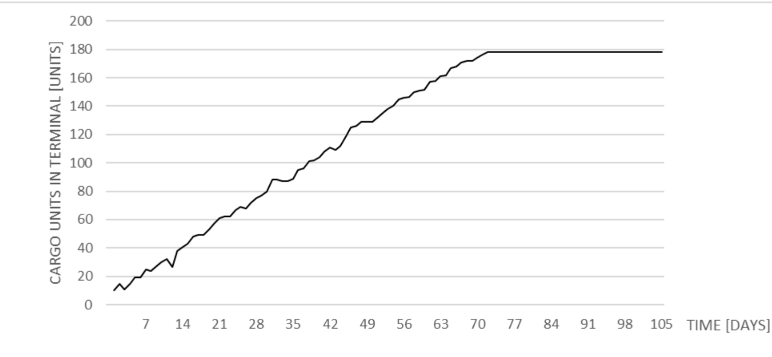

Figure 3: Cargo units in terminal

The size of loading units on the terminal indicates the maximum number of loading units on the terminal on a specific day. This information is independent of the type or size of the loading units. A 20-feet container is counted like a trailer. Figure3 shows an asymptotic approximation of the curve. This indicates that there is either maximum utilization of the equipment or overfilling of the yard. However, the curve shape may also indicate a lack of terminal performance due to the train schedules on file.

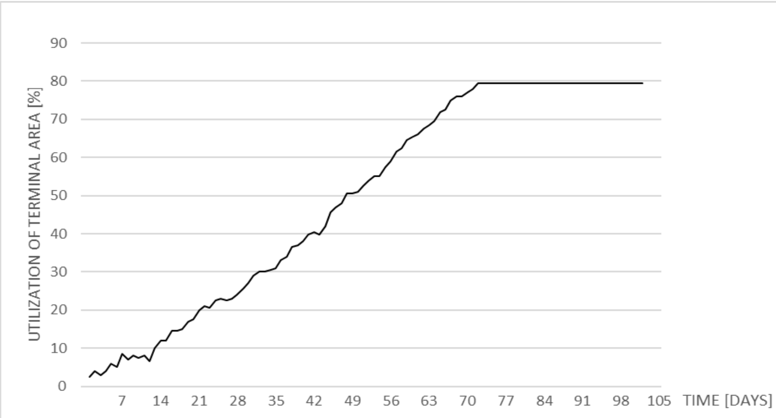

Figure 4: Utilization of terminal area

The utilization of the terminal spaces visualizes the occupancy of the terminal spaces with loading units. Since different loading units also occupy a different number of slots, all different loading units of the terminal are considered here.

If the curve approaches a high level, as shown in Figure4, this indicates a possible limit to the available capacity. This means that it may take a very long time to find a suitable slot for a loading unit. However, it can also be explained by a high number of restacking operations required by the equipment until it reaches the load unit to be transported.

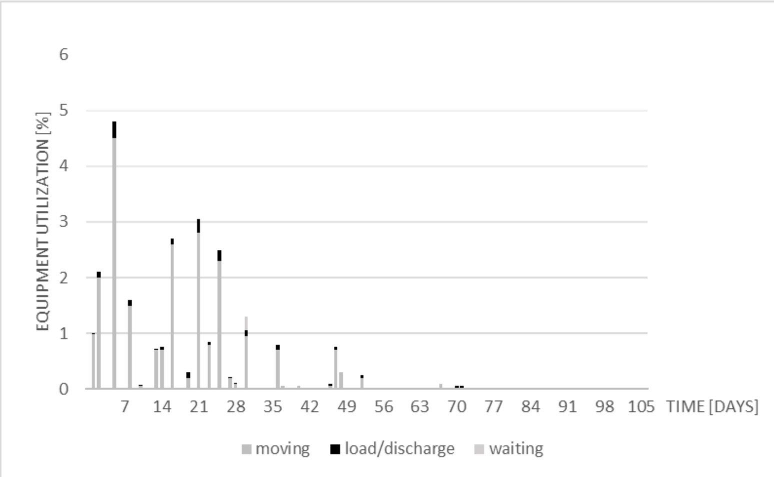

Figure 5: Crane utilization

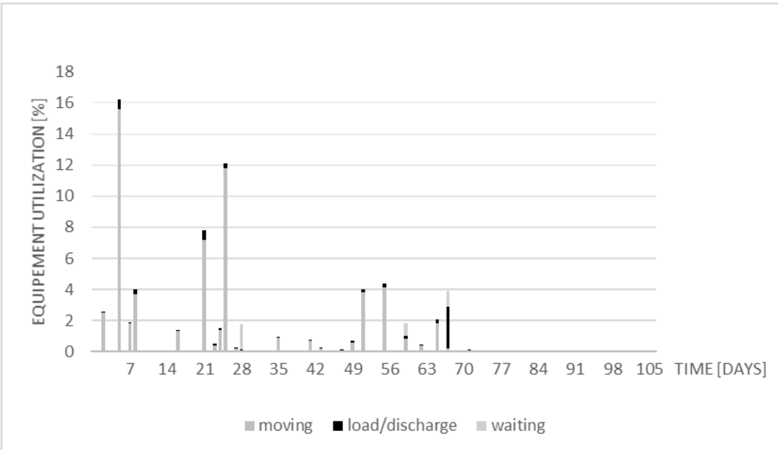

Figure 5: Mobile lifter utilization

For each equipment type it is visualized how this instance was used. The information is given as a percentage of the time capacity available per container. Waiting in this context means that the equipment had to wait for another equipment type to be able to realize a handling order. Driving and loading/unloading are the actually productive time shares during which either a loading unit is moved or the equipment moves to the position of a transfer position of a loading unit. Not shown are the time shares during which the equipment does not perform any activity. This is why the percentages on the left of the coordinate axis rarely range from 0 to 100%. Highly utilized equipment can represent a bottleneck, especially if the terminal areas themselves are only very lightly utilized. As can be seen from Figure5 and Figure6, the utilization of the equipment type crane and mobile lifter is very low. The maximum utilization rate for the crane is 4.8%, while the maximum utilization rate for the mobile lifter is 16.2%.

5 Discussion

The research question in this study aimed to determine how an efficient link between a static layout planning tool and a dynamic simulation tool can be designed. It could be shown that it is possible to implement an integrated solution that is able to communicate via an XML interface and fully automatically create a dynamic simulation modulation from a static layout, simulate it and output results on performance specific terminal parameters. Within the scope of a case study it could be proven that it is possible to design the inland terminal with the provided object library intuitively and efficiently in the graphical user interface of visTABLE® within an adequate time frame. Furthermore, it is possible to adapt the existing layout with little effort and to simulate it again for a later comparison.

Another new insight is that simulations of logistic nodes like inland terminals can be performed without any programming knowledge. This significantly expands the potential range of users of the integrated planning tool.

A limitation of our implementation is the creation of the path network. A possible explanation for this could be that the generation of multiple link points in the backend for each type of equipment used results in very long simulation times depending on the size of the model created. With regard to the parameter annual turnover of loading units, the initial model created on the basis of the classic parameterized inland terminal was restricted and adjusted to 2.000 loading units per year. These results are therefore rather disappointing that this was the only way to ensure a smooth simulation run. The results obtained for the performance of the terminal must therefore be interpreted with caution. Another limitation in this work concerns the question of strategy implementation. By defining strategies, it should be possible to influence the behavior and thus the performance of the terminal without changing the type and number of equipment or the spatial structure and dimension of the terminal. However, only the track usage strategy could be implemented so far, since due to the unexpected complexity a prioritization in the implementation of the strategies had to be done.

Effects for practitioners can be observed especially for operators of inland terminals. This applies in particular to small and medium-sized inland terminals that have no or limited access to expertise. For this mentioned group, the tool can be of great importance. The terminals are under pressure to handle loading units in ever shorter time windows while using as little equipment as possible. The economic circumstances result not only in monetary advantages, but also in ecological ones.

A successful balancing of these operational goals must be considered at an early stage of new construction or conversion, because the layout sets the course for later operation. With the integrated software tool, a layout planning tool and a simulation tool have been intelligently linked to reduce the planning and modeling effort for adaptations and new planning as far as possible.

6 Conclusion and Future Research

The ISI-Plan prototype is to be seen as a first debut work in this field. It aims to generate a benefit for future terminal planners and also operators in investment and planning questions for existing or planned terminals, as well as for expansions in the terminal area.

The major challenge of this work was that a direct coupling between layout planning and simulation with intuitive access for low-effort, responsive input by planners and operators of logistic handling points has not been yet been sufficiently investigated in the past and thus uncertainty existed with regard to the technical feasibility.

With the present work it could be shown on the basis of a case study that it is possible to develop an integrated software application that combines static layout planning and dynamic simulation of logistic nodes. The use of the application is not only intuitive and takes less time than previous solutions, but also does not require any programming. On top of that the synergetic use of known methods and competences of different disciplines as well as an added value for simulation-based planning could be achieved.

Further research could focus on making the simulation process more efficient. Furthermore, additional objects, processes and strategies could be included, as well as the possibility of adding further interfaces to enable the integration of a TOS system, for example. However, there is also the possibility of further developing the present concept in the direction of a digital twin of logistics nodes.

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III.
Maritime Logistics

Fuzzy-based decision analysis on Arctic transportation: A guidance for freight shipping companies

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Purpose: *Due to climate change the Arctic ice is melting, opening new possibilities for the economical use of the Arctic Ocean. However, the decision for shipping companies to transport freight through Arctic waters is based on many factors. The aim of the research is to develop a decision-supporting guidance for shipping companies.*

Methodology: *Based on a literature review and subsequent validation through expert interviews, influencing factors are identified and classified using a framework covering Benefits, Opportunities, Costs, and Risks. A fuzzy set theory to structure multi-criteria decision problems is applied afterward.*

Findings: *The results show that equipment, insurance, and inadequate port infrastructure are the factors with the highest influence in the Costs category and are the most influential factors overall. Security and market potential, the factors with the greatest impact on the Opportunities category, also rank highly as influential overall factors. The strongest Risk factors are weather conditions, delay, and collisions / accidents. The highest influence in the Benefits category are reduced costs.*

Originality: *The influencing factors for Arctic freight shipping have so far only been considered in part with risks focus or other specific aspects, but not in the overall context. To consider multiple perspectives, 24 experts from different domains were involved.*

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1 Introduction

Due to various reasons, the Arctic is recently receiving more and more attention. Arctic sea ice is melting continuously due to global warming, and it is assumed that this development will continue or even accelerate in the next decades. This opens new possibilities for the economical use of the Arctic Ocean (Wang, Silberman and Corbett, 2020). The Arctic routes are significantly shorter and could reduce distances up to 40 % compared to the Suez Canal (Furuichi and Otsaka, 2013), which would lead to cost savings from reduced transit time and lower fuel consumption (Hong, 2012; Lasserre, 2014). Additionally, the most commonly used maritime sea routes like the Suez Canal, Strait of Malacca, or the Panama Canal are reaching their carrying capacity (Schneider, 2018). As the need for new shipping lines emerges, novel routes through the Arctic offer a solution to capacity constraints (Buixadé Farré, et al., 2014). Considering the Arctic routes, transit traffic through Arctic waters remains low, especially when compared to common routes. However, an upward trend is emerging, which could lead shipping companies to establish and evaluate their own business cases for freight transport through the Arctic.

As a result of these developments, trans-Arctic shipping is an arising research topic in the field of maritime transportation, which is reflected in an exponential growth of publications in the past decades (Theocharis, et al., 2019). For example, Lasserre (2014) identified 26 studies dealing with the feasibility of Arctic sea routes compared to traditional routes. Among others, Faury and Cariou (2016) took ice thickness, total transit costs, and transit time into account, whereas Wang, Zhang and Meng (2018) focus on navigation risk, shipping profits / costs, and shipping time as route-specific factors.

There are already research studies that provide an overview of these factors, which were previously considered in detail. For example, Tseng and Cullinane (2018) identified influencing criteria affecting the choice for Arctic shipping, Milaković, et al. (2018) collated challenges related to the use of the northern sea route (NSR). Fu, et al. (2018) identified risk influencing factors for Arctic maritime transportation systems. In addition, the topic of maritime freight transportation through the Arctic was dealt with by numerous authors.

Existing studies being conducted in recent years therefore either deal with a comparison of the profitability of Arctic routes with existing routes or consider a limited number of factors. However, there is as yet no study providing a comprehensive overview of potential factors for assessing Arctic freight shipping. Therefore, the aim of the research is to identify and evaluate criteria for the decision of shipping companies to transport freight through the Arctic. This paper contributes to existing research by conducting a literature review for the identification of influencing factors, and factor classification into a framework afterwards. Based on this, two-round semi-structured interviews for factor discussion and evaluation are conducted. After that, a fuzzy set theory (FST) is applied, followed by a sensitivity analysis. The article is organized as follows. After presenting the theoretical background, factors for Arctic maritime transportation, an overview of the methodological approach is given. The identified factors are placed in a Benefits, Opportunities, Costs and Risks (BOCR) model and are judged and refined through an expert survey afterwards. Subsequently, FST is applied. Afterwards, a sensitivity analysis is conducted, followed by the presentation of the results. After that, a discussion is held and a conclusion is presented in the last section.

2 Theoretical foundation

As already stated in the introduction, a considerable number of research studies have been conducted on influencing factors for Arctic freight shipping.

An overview of the existing studies is given in Table 1, whereby the focus is on the most recent publications with the highest thematic relevance. Furthermore, the research gap of this study is derived.

Table 1: Overview of existing studies

Author (Year)	Title	B	O	C	R
Schøyen and Bråthen (2011)	The northern sea route versus the suez canal: cases from bulk shipping	x		x	x
Furuichi and Otsaka (2013)	Cost analysis of the NSR and the conventional route shipping			x	
Lasserre (2014)	Case studies of shipping along Arctic routes. Analysis and profitability perspectives for the container sector	x		x	
Faury and Cariou (2016)	The Northern Sea Route competitiveness for oil tankers	x		x	
Wang, Zhang and Meng (2018)	How will the opening of the Northern Sea Route influence the Suez Canal Route? An empirical analysis with discrete choice models	x		x	
Tseng and Cullinane (2018)	Key criteria influencing the choice of Arctic shipping: a fuzzy analytic hierarchy process model			x	x
Fu, et al. (2018)	Risk influencing factors analysis of Arctic maritime transportation systems: a Chinese perspective				x
Milaković, et al. (2018)	Current status and future operational models for transit shipping along the Northern Sea Route			x	x
Marchenko, et al. (2018)	Arctic shipping and risks: emergency categories and response capacities				x

Author (Year)	Title	B	O	C	R
Khan, et al. (2018)	An operational risk analysis tool to analyze marine transportation in Arctic waters				x
Christensen, Georgati and Arsanjani (2019)	A risk-based approach for determining the future potential of commercial shipping in the Arctic	x		x	x
Theocharis, et al. (2019)	Feasibility of the Northern Sea Route: The role of distance, fuel prices, ice breaking fees and ship size for the product tanker market	x		x	
Zhang, Huisingh and Song (2019)	Exploitation of trans-Arctic maritime transportation			x	x
Lin and Chang (2018)	Ship routing and freight assignment problem for liner shipping: Application to the Northern Sea Route planning problem			x	
Wang, et al. (2020)	Feasibility of the Northern Sea Route for oil shipping from the economic and environmental perspective and its influence on China´s oil imports			x	
This study	*Fuzzy-based decision analysis on Arctic maritime transportation: A guidance for shipping companies*	*x*	*x*	*x*	*x*

As can be concluded, there is as yet no study providing a comprehensive overview of potential factors for assessing Arctic freight shipping.

In the area of negative influencing factors, quantitative research already exists, but an evaluation of the positive factors, Benefits and Opportunities, has not yet been carried out comprehensively.

3 Methodology

As several papers have shown, the operation of freight ships on Arctic maritime routes is linked to the assessment and evaluation of numerous influencing criteria (Fu, et al., 2018; Tseng and Cullinane, 2018). Therefore, FST was selected as a suitable technique for analyzing the viability of Arctic freight transportation. FST is a systematic method for structuring and evaluating MCDPs (multi criteria decision problems) in which complex decisions have to be made in a setting where there are several objectives and several criteria that affect the decision (Zadeh, 1965). The proposed two-stage methodology approach is illustrated in Figure 1.

3.1 Phase 1: Factor identification and judgment

Initially, the influencing factors for the MCDP were identified. This procedure is a challenging problem due to the limited data and the uncertainty of the available information (Fu, et al., 2018). Thus, the factors were identified in a two-step approach to ensure a comprehensive and reliable register of factors for the development and assessment of the framework. The first step was to determine the factors based on a review of the relevant literature, and to classify them systematically within a framework. We used the BOCR based on Saaty (2004), which allows decisions in MCDP to be treated from four different perspectives: the Benefits (B), positive aspects which could be linked with the decision; the Opportunities (O), potentially positive aspects which might result from the decision in the future; Costs (C), distress and disappointment which would be connected with the decision made; and Risks (R), potential distress and disappointment which might be caused by the decision. To improve the practical validity of the BOCRs found in the literature review, in a second step experts were invited to review the factors identified. The following two criteria for inclusion of participants for the interview and the subsequent questionnaire were defined: extensive practical or research experience in the Arctic area and knowledge in the field of freight shipping. Before the actual survey was conducted, the completed questionnaire was piloted with five experienced researchers.

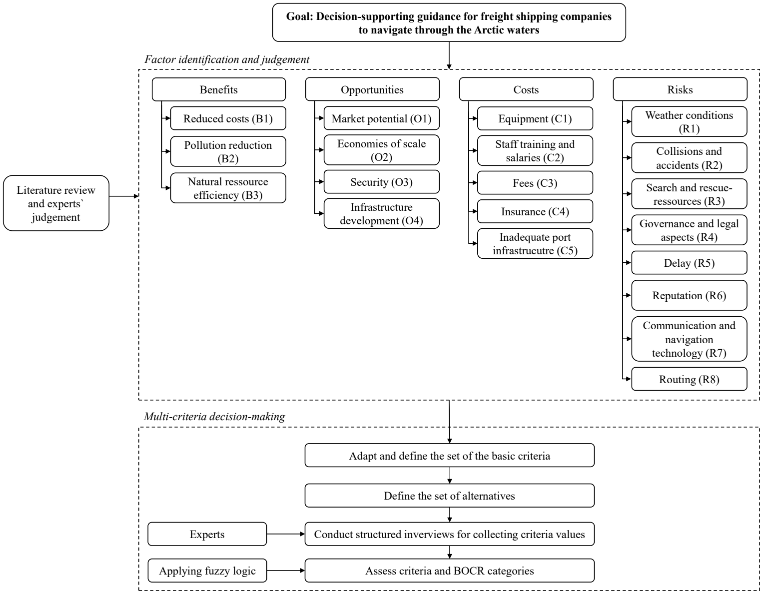

Figure 1: Methodological approach

3.2 Phase 2: Fuzzy synthetic evaluation method

The first step in the FST process was to determine the key criteria. This study established the identified factors for each category of the BOCR framework as the essential criteria. This was followed by the definition of the alternatives as the second step of the FST process. In this model, the set of alternatives represent the possible values of the probability of occurrence (P) and impact (I). For each criterion of the BOCR framework, the values of P and I were surveyed using a questionnaire. Experts were asked to independently assess the impact level and probability of BOCRs in numerical order with the following question: ‘Please assess the probability of occurrence and the impact of the respective criterion'. The following five-point language scale was used based on the number of potential values for P and I, with the appropriate definitions of the possible values for P and I (Kiani Mavi and Standing, 2018): very low (1), low (2), moderate (3), high (4), and very high (5). This approach goes beyond the decision-makers' subjectivity - the underlying linguistic variables truly represent the experts' assessments (Bozbura and Beskese, 2007). Afterward the fuzzy synthetic evaluation method for criteria assessment by Andrić, Wang and Zhong (2019) was utilized. It consists of three steps, which are shown in the following:

3.2.1 Step 1: Assessment of each criterion

The membership function F of each criterion is generated with the collected values of P. In the matrix F, the element f_{ij} of the matrix reflects the level to which the variable a_j represents the criterion i.

$$(F_i^P)_{1x5} = (f_{i1}^P, f_{i2}^P, f_{i3}^P, f_{i4}^P, f_{i5}^P), i = 1, 2, \dots, n \tag{1}$$

In a similar way, the impact of criteria assessed, and membership function F for I is specified:

$$(F_i^I)_{1x5} = (f_{i1}^I, f_{i2}^I, f_{i3}^I, f_{i4}^I, f_{i5}^I), i = 1, 2, \dots, n \tag{2}$$

For each of the alternatives in the set, an appropriate weighting is given: $v_j = \{1, 2, 3, 4, 5\}$. Furthermore, P and I of each criterion are calculated with the equation as follows:

$$P_i = \sum_{i=1}^{5} v_j \times f_{ij}^P \tag{3}$$

$$I_i = \sum_{i=1}^{5} v_j \times f_{ij}^I \tag{4}$$

To rank the criteria, the score (SC) is calculated as the product of P and I using to the equation below:

$$SC_i = \sqrt{P_i \times I_i}, i = 1, 2, \dots, n \tag{5}$$

3.2.2 Step 2: Assessment of the categories

Once P, I, and SC have been calculated for each criterion, the next step is to calculate the SC for each of the four categories. First, the weights of all criteria in each category are evaluated. The weights of P of criterion i are calculated as:

$$w_i^P = \frac{P_i}{\sum_{i=1}^{a} P_i}, i = 1, 2, \dots, a \tag{6}$$

where a is defined as the number of criteria in a category.

Likewise, the weights for I are calculated for each criterion. The evaluation matrix C for each category is the product of the fuzzy combination of the weight vector W and the membership function F. Furthermore, the membership functions of category t for P are determined with the following equation:

$$c_{t,j}^P = \sum_{i=1}^{a} w_i^P \times f_{ij}^P \tag{7}$$

$$(C_t^P)_{1x5} = (W_t^P)_{1\times a} \times (F_t^P)_{a\times 5} = (c_{t1}^P, c_{t2}^P, c_{t3}^P, c_{t4}^P, c_{t5}^P) \tag{8}$$

The membership function for I of category t and matrix C is calculated, respectively. Similar to the calculation of criteria, P, I, and SC of each category are determined:

$$P_t = \sum_{t=1}^{5} v_j \times c_{tj}^P \tag{9}$$

$$I_t = \sum_{t=1}^{5} v_j \times c_{tj}^I \tag{10}$$

$$SC_t = \sqrt{P_t \times I_t}, t = 1, 2, \dots, n \tag{11}$$

3.2.3 Step 3: Assessment of positive and negative dimensions

The next step is to calculate the SC for overall positive (B and O) and overall negative (C and R) dimensions. Again, P, I, and SC of these two dimensions were evaluated as the product of the weighting vector of respective categories and the evaluation matrix. The weightings of P for each category are then estimated by the equations below:

$$w_t^P = \frac{P_t}{\sum_{t=1}^{l} P_t}, t = 1, 2, \dots, l \quad (12)$$

where l is the number of categories within the dimension and $(\sum_{i=1}^{a} P_i)_t$ is the total of P for every criterion in the category C_t.

The weightings of I for each category are calculated in the same way. Next, the membership functions of P and I for the positive and negative dimensions respectively are determined using these equations:

$$d_{l,j}^P = \sum_{t=1}^{k} w_t^P \times c_{tj}^P \quad (13)$$

$$(D_l^P)_{1x5} = (W_l^P)_{1xk} \times (D_l^P)_{kx5} = (d_{l1}^P, d_{l2}^P, d_{l3}^P, d_{l4}^P, d_{l5}^P) \quad (14)$$

This is calculated under the assumption that the membership functions of P, I, and SC for the positive and negative categories are evaluated according to the equations following:

$$P_l = \sum_{l=1}^{5} v_j \times d_{lj}^P \quad (15)$$

$$I_l = \sum_{l=1}^{5} v_j \times d_{lj}^I \quad (16)$$

$$SC_l = \sqrt{P_l \times I_l}, l = 1, 2, \dots, n \quad (17)$$

3.2.4 Step 4: Sensitivity analysis

In order to achieve stability and compatibility of analysis, sensitivity analysis is performed. Sensitivity analysis is a systematic method for identifying the most serious criteria and aims to guide the decision-making process to obtain the right decision alternatives and develop an appropriate strategy. To determine the criteria that have the most influence, the probability of occurrence and the impact for each criterion were increased by the value δ ($\delta > 0$), and the overall rating was estimated using equations (18) and (19) (Phillis, et al., 2018).

$$\Delta_{BO} = \frac{SC\ (P_{B1},\ I_{B1}, \dots P_n +\ \delta, I_n +\ \delta, \dots, P_{O4}, I_{O4}) - SC\ (P_{B1},\ P_{B1}, \dots, P_{O4}, I_{O4})}{\delta} \quad (18)$$

$$\Delta_{CR} = \frac{SC\ (P_{C1},\ I_{C1}, \dots P_n +\ \delta, I_n +\ \delta, \dots, P_{R8}, I_{R8}) - SC\ (P_{C1},\ P_{C1}, \dots, P_{R8}, I_{R8})}{\delta} \quad (19)$$

4 Case study

As mentioned earlier in the paper, the identification and assignment of specific factors to each of the four dimensions is based in a first step on the results of a comprehensive literature review, which leads to a factor catalog comprising a total of 20 factors. Second, the factors were evaluated by 25 experts, whereupon one factor was deleted. In total, a final criteria register was created containing 19 criteria. The descriptions of the various criteria and the sources justifying their potential relevance (and thus inclusion in the analysis) are presented for the positive factors (reduced costs, pollution reduction, natural resource efficiency, market potential, economies of scale, security and infrastructure development) in Table 2 and the negative factors (equipment, staff training and salaries, fees, insurance, inadequate port infrastructure, weather conditions, collisions and accidents, search and rescue resources, governance and legal aspects, delay, reputation and routing) in Table 3.

Table 2: Positive influencing criteria - Benefits and Opportunities

Category	Code	Criteria / Definition	Author(s)
Benefits	B1	Reduced costs (Lower costs due to reduced transit times)	Furuichi and Otsaka (2013), Lasserre (2014)
	B2	Pollution reduction (Reduction of the total amount of air pollution)	Humpert and Raspotnik (2012), Furuichi and Otsaka (2013)

Category	Code	Criteria / Definition	Author(s)
Opportunities	B3	Natural resource efficiency (Reduced fuel consumption due to lower speed)	Schøyen and Bråthen (2011)
	O1	Market potential (Great potential in inter- and intra-arctic transports, especially due to large oil and gas reserves)	Buixadé Farré, et al. (2014), Eliasson, et al. (2017)
	O2	Economies of Scale (No restrictions in size and capacity of tankers)	Arctic Council (2009)
	O3	Security (Increased security, amongst other things due to pirate incidents)	Hong (2012)
	O4	Infrastructure development (Well-developed infrastructure expected in the future)	Buixadé Farré, et al. (2014)

Table 3: Negative influencing criteria - Costs and Risks

Category	Code	Criteria / Definition	Author(s)
Costs	C1	Equipment (High investment costs for expanding the fleet, upgrading existing vessels or ship leasing, and the uncertainty around the operational cost)	Hong (2012), IMO (2014), Tseng and Cullinane (2018)
	C2	Staff training and salaries (Hiring of a suitable crew comes along with higher salary costs)	Furuichi and Otsaka (2013), Lasserre (2014), Pruyn (2016)
	C3	Fees (Transit fees for passing the routes, depending on many factors)	Lasserre (2014)

Category	Code	Criteria / Definition	Author(s)
	C4	Insurance (Level of insurance required, no insurer yet has offered rates because of missing data for calculating and many influencing factors)	Milaković, et al. (2018), Wang, Zhang and Meng (2018)
	C5	Inadequate port infrastructure (Insufficiently developed infrastructure, also along the NSR)	Milaković, et al. (2018)
Risks	R1	Weather Conditions (Polar air temperatures, heavy wind, low visibility due to fog and snow, big waves and hardly predictable ice conditions, depending on the season)	Fu, et al. (2018), Khan, et al. (2018)
	R2	Collisions and Accidents (Collision or accidents caused by external or internal factors)	Afenyo, et al. (2017), Khan, et al. (2018)
	R3	Search and rescue - resources (Inadequate search and rescue resources, equipment is not sufficient to guarantee common SAR standards)	Schmied, et al. (2017), Dalaklis, Drewniak and Schröder-Hinrichs (2018), Benz, et al. (2021)
	R4	Governance and legal aspects (Legal issues that pose obstacles for shipping companies)	Eliasson, et al. (2017), Milaković, et al. (2018)
	R5	Delay (Delay in transit)	Marken, Ehlers and Khan (2015)

Category	Code	Criteria / Definition	Author(s)
	R6	Reputation (Negative reputation due to social and environmental reasons as impact on culture / economic activities of indigenous people)	Brubaker and Ragner (2010), Afenyo, et al. (2017)
	R7	Routing (Selection of the route and Route deviation of ships due to external factors)	Eliasson, et al. (2017), Meng, Zhang and Xu (2017), Tseng and Cullinane (2018)

The method presented in the third section is used to calculate P, I, and SC for criteria given by equations (1) - (5). The results for the criteria are presented in Table 4.

The procedure was exemplified for the cost factor equipment (C1). In case of equipment (C1), 0 respondents (0%) evaluated P as very low, 2 respondents (0.08%) as low, 5 respondents (0.20%) as a moderate, 13 respondents (0.52%) as high, and 5 respondents (0.20%) as very high. Based on the data collected, the membership function of P for equipment is as follows:

$$(F_{C1}^{P})_{1x5} = (0, 0.08, 0.20, 0.52, 0.20)$$

Therefore, the following membership function results for I:

$$(F_{C1}^{I})_{1x5} = (0, 0.08, 0.20, 0.48, 024)$$

With use of equations (3) and (4) P and I are calculated:

$$P_{C1} = \sum_{i=1}^{5} s_j \times f_{ij}^{P} = 1 \times 0 + 2 \times 0.08 + 3 \times 0.20 + 4 \times 0.52$$
$$+ 5 \times 0.20 = 3.84$$

$$I_{C1} = \sum_{i=1}^{5} s_j \times f_{ij}^{I} = 1 \times 0 + 2 \times 0.08 + 3 \times 0.20 + 4 \times 0.48$$
$$+ 5 \times 0.24 = 3.88$$

Finally, the factor score (SC) is evaluated using equation (5):

$$SC_{C1} = \sqrt{P_{C1} \times I_{C1}} = \sqrt{3.84 \times 3.88} = 3{,}86$$

Table 4: Results for probability, impact, weight, and score of influencing criteria

Code	Probability		Impact		Score
	Value	Weight	Value	Weight	
B1	3.68	0.37	3.68	0.38	3.62
B2	3.04	0.32	3.04	0.32	3.04
B3	2.84	0.31	2.84	0.30	2.88
O1	3.76	0.26	3.76	0.26	3.60
O2	3.12	0.22	3.12	0.22	.98
O3	3.68	0.29	3.68	0.25	3.74
O4	3.88	0.23	3.88	0.27	3.41
C1	3.84	0.20	3.88	0.21	3.86
C2	3.64	0.19	3.52	0.19	3.58
C3	4.08	0.21	3.63	0.20	3.85
C4	3.88	0.20	3.68	0.20	3.78
C5	3.68	0.19	3.52	0.19	3.60

Code	Probability		Impact		Score
	Value	Weight	Value	Weight	
R1	4.28	0.18	3.92	0.15	4.10
R2	2.68	0.11	3.72	0.14	3.16
R3	3.76	0.16	3.80	0.15	3.78
R4	3.32	0.14	3.64	0.14	3.48
R5	3.68	0.15	3.52	0.14	3.60
R6	3.32	0.14	3.88	0.15	3.59
R7	3.12	0.13	3.24	0.13	3.18

Furthermore, P, I, and SC were calculated for each category of the BOCR framework using equations (6) - (11). The results are shown in Table 5.

Table 5: Results for probability, impact, weight, and score of categories

Code	Probability		Impact		Score
	Value	Weight	Value	Weight	
B	3.20	0.49	3.22	0.47	3.21
O	3.31	0.51	3.63	0.53	3.47
C	3.79	0.52	3.62	0.50	3.71
R	3.55	0.48	3.68	0.50	3.62

To assess the overall positive or negative dimension, the weights of the respective categories (Benefits and Opportunities for the positive dimension; Costs and Risks for the negative dimension) are determined by using equations (12)-(17). The calculation results in an overall score of 3.35 for the positive criteria (Benefits and Opportunities) and an overall score of 3.66 for the negative criteria (Costs and Risks). The overall results differ only slightly. This highlights that there is no clear tendency for a decision pro or contra the use of the Arctic routes for freight shipping. The results for both positive and negative criteria lie between the linguistic terms “moderate” and “high”. For the positive criteria, the value is closer to 3.00 than to 4.00, which is why they are regarded as moderate. For the negative criteria, the value is closer to 4.00 than to 3.00 and is therefore considered high. A sensitivity analysis is also carried out (equations (18)and (19)), the result of which is the differences in the assessment before and after the increase in probability and impact for each criterion is shown in Table 6.

Table 6: Sensitivity analysis

Category	Criteria	Code	Δi	Rank
Benefits	Reduced costs	B1	0.0315	12
	Pollution reduction	B2	0.0094	13
	Natural resource efficiency*	B3	0.0000	14
Opportunities	Market potential	O1	0.1105	5
	Economies of scale*	O2	0.0000	14
	Security	O3	0.1188	4
	Infrastructure development	O4	0.0806	11
Costs	Equipment	C1	0.1970	1
	Staff training and salaries	C2	0.0872	9
	Fees	C3	0.1080	6
	Insurance	C4	0.1925	2

Category	Criteria	Code	Δi	Rank
	Inadequate port infrastructure	C5	0.1855	3
	Weather conditions	R1	0.1012	7
	Collisions and accidents	R2	0.0962	8
	Search and rescue resources*	R3	0.0000	14
Risks	Governance and legal aspects*	R4	0.0000	14
	Delay	R5	0.0851	10
	Reputation*	R6	0.0000	14
	Routing*	R7	0.0000	14

*The marked criteria all ranked fourteenth, as they were rated identically in the sensitivity analysis.

5 Discussion

In terms of the sensitivity analysis, the critical criteria contribute to the highest increase in the overall rating (a criterion with the highest Δ in Table 6). From the data, it can be deduced that the three most critical criteria are (in descending order) equipment (Δ = 0.1970), insurance (Δ = 0.1925), and inadequate port infrastructure (Δ = 0.1855), all of which are part of the category of Costs. This fact is also reflected in the literature. Several studies dealt with the calculation and creation of scenarios for the use of Arctic sea routes in terms of costs (Hong, 2012; Furuichi and Otsaka, 2013; Lasserre, 2014; Pruyn, 2016; Fedi, Faury and Gritsenko, 2018). In general, the investment for equipment a firm has to take into account, once it decides to operate in the polar areas, is mainly the acquisition of ice-classed vessels (Theocharis, et al., 2019). Further costs arise mainly from the additional safety-relevant, technical equipment of the ships, e.g., redundancy of equipment and a larger stock of spare parts (Budzik, 2009; Hong, 2012), the supply of medicine, food, and water (Liu and Kronbak, 2010), and specially designed equipment to withstand the temperatures and weather requirements (Budzik, 2009; Liu and Kronbak, 2010). Additional costs occur due to vessel inspections (Pruyn, 2016) and increasing maintenance intervals (Xu, et al., 2011; Furuichi and Otsaka, 2013). For insurance (Δ = 0.1925), the findings of the present study also match existing research. The use of Arctic sea routes is associated with high insurance premiums (Xu, et al., 2011; Hong, 2012; Theocharis, et al., 2019; Wang, et al., 2020), as regular insurance does not cover areas in latitudes above 70° north ("excluded trading areas"), special arrangements with the insurer are required, including additional hull premiums (Milaković, et al., 2018). High insurance premiums also result from the limited availability of information on Arctic shipping and lack of transparency (Liu and Kronbak, 2010; Furuichi and Otsaka, 2013; Theocharis, et al., 2019).

Inadequate port infrastructure (Δ = 0.1855) is the third highest on the list. There is a consensus in the literature that all Arctic routes are insufficiently equipped with port structures (Hong, 2012; Lasserre, 2014). There are two main conclusions to be drawn from the lack of port infrastructure. Firstly, a lack of port infrastructure is accompanied by a lack of search and rescue infrastructure. Secondly, commercial interest is also reduced, because there are no ports equipped to receive the containers to be loaded and unloaded during possible rotations (Lasserre, 2014).

One unanticipated finding was that the criterion security (Δ = 0.1188) follows as rank four and is the first criterion of the positive dimension and a criterion of the category possibilities. It has received very little attention in the literature so far. Only Hong (2012) mentions security as an influencing factor and compares it with the safety on other routes. The Arctic region is not characterized by sea piracy (Hong, 2012). Furthermore, there are no politically unstable waters in the Arctic and provocations by individual countries are less threatening there (Hong, 2012).

The criterion market potential (Δ = 0.1105) is ranked second within the positive dimension and fifth in the overall assessment. So far, there are no interesting intermediate markets along the Arctic routes. However, this could change for two reasons: First, the economic development of local communities offers new market potential (Lasserre, 2014); second, these communities are striving to significantly reduce the cost of their consumer goods, which are usually delivered by air, and thus represent a target group. Moreover, the exploration and exploitation of natural resources is booming with the prospect of decreasing ice cover and rising world market prices (Faury, Cheaitou and Givry, 2020).

With a sixth rank in the overall assessment and a fourth rank in the assessment of negative criteria, fees (Δ = 0.1080) are a criterion not to be neglected in Arctic shipping. Fees are payable for icebreaker support (Furuichi and Otsaka, 2013), the inspection required by the Russian authorities before passing the route (Liu and Kronbak, 2010) and the pilotage is a mandatory requirement (Liu and Kronbak, 2010; Furuichi and Otsaka, 2013; Pruyn, 2016). It should be mentioned here that only along the NSR fees are due and the other routes are not associated with fees (Lasserre, 2014). Furthermore, the fees vary depending on various factors (Liu and Kronbak, 2010; Furuichi and Otsaka, 2013; Lasserre, 2014; 2015).

With a seventh place in the overall evaluation and a fifth place within the negative dimension, weather conditions (Δ = 0.1012) is the first criterion from the Risk category. The findings are directly in line with previous findings which described the harsh environmental conditions in the Arctic region (Hong, 2012; Meng, Zhang and Xu, 2017). Especially polar air temperatures, strong winds, visibility, fog and darkness (in the winter months) are characteristic for the Arctic (Khan, et al., 2018; Tseng and Cullinane, 2018). In addition to the weather conditions described, ice also plays an important role and increase the risk for a shipping company (Fu, et al., 2018; Khan, et al., 2018).

6 Conclusion

The freight shipping in maritime Arctic waters is an emerging topic in recent years. Due to the significantly shorter routes, cost savings are likely. A lot of research has focused on the feasibility of shipping through the Arctic. Furthermore, there are also studies dealing exclusively with the costs and risks of Arctic freight shipping. However, in order to provide a holistic decision model, both positive and negative factors should be considered. The aim of this research is to create a comprehensive decision model for Arctic freight shipping by identifying and evaluating relevant criteria. The results of the review are structured using the BOCR method. The identified factors are judged through an expert survey and refined afterwards. Subsequently, FST is applied, and a sensitivity analysis is conducted. The results of this study show that equipment, insurance and inadequate port infrastructure are the main influencing criteria in Costs (C), and also the most influential factors overall. They are followed by the criteria security and market potential (Opportunities (O) category). Weather conditions, delay, and collisions / accident also have a high impact, being the strongest criteria in Risks (R). Reduced costs have the highest influence in Benefits (B), but with comparatively little influence.

With this result, the study offers a contribution both from a theoretical and a practical point of view. From a theoretical perspective, the research creates a quantitative, aggregated overview of influencing criteria. Furthermore, the level of influence is considered and thus supplements the existing theory, especially for the positive criteria. From a practical point of view, the results provide guidance for the assessment of influencing criteria for shipping companies when considering freight transportation through Arctic waters.

Serving as a starting point for further research, there are some limitations to be considered. A general constraint is the continuous development of political and ecological framework conditions in the Arctic. In addition, the technical capabilities are also evolving. Therefore, the results of this study are a snapshot and should be repeated at regular intervals, also with a focus on individual thematic priorities such as technical aspects. Furthermore, the special features of cruise ships are not included. At the same time, it is also possible to select different individual types of cargo ships within the freight shipping industry as a level of consideration or to focus on intra-Arctic transports.

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Digital Logistics as a Perspective for the Northern Sea Route

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Purpose: *This paper aims to provide an approach to the digitalization of the Northern Sea Route. Current research and best practices analysis do not contain solutions for such large-scale projects like the digitalization of the Northern Sea Route (NSR). The findings of this paper can help to ensure support for the development of digital services for the NSR.*

Methodology: *The problem is considered in terms of the Enterprise Architecture approach. This study uses The Open Group Architecture Framework (TOGAF), a modern approach to the information systems development, and the Model Based System Engineering (MBSE) method, based on unified models.*

Findings: *Conducted studies suggest that the Northern Sea Route IT-architecture requires a holistic and consistent approach due to the involvement in the process of many different stakeholders. To create a competitive advantage, digital services of the NSR should be implemented on the basis of available best-in-class technologies, and their implementation requires a specific approach, based on the development of reference architecture models and their evaluation.*

Originality: *The Northern Sea Road implementation is a large-scale project and demands a detailed study and thorough elaboration in regard to different aspects. The results of this paper will create a foundation for the modelling of digital services for the NSR which correspond to a modern level of maritime industry development.*

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1 Introduction

Currently, the Russian Federation (RF) put a lot of effort into the Northern Sea Route (NSR) development. Since the transported cargo on the NSR is increasing annually, experts promise the NSR a great future as one the most important maritime transport routes of the RF. Currently goals and accompanying documents are specified in these regards, including the target for “national container operators to increase cargo turnover by 2024 to 80 million tons per year, mainly on the NSR and to 160 million tons per year by 2035, including at least 40 million tons per year of containerized cargoes” (News Agency TASS, 2019). However, latest data shows that the project will not reach the goal set by the President of the RF in the May 2019 decrees to increase cargo traffic to 80 million tons on the NSR by 2024, and government agencies and companies are discussing the reduction of the target cargo turnover to 50-60 million tons (INTERFAX, 2020).

This active development of the NSR requires a development of innovative and up-to-date solutions that will enable a year-round use of the NSR in an environmentally friendly way.

The digital platform, which is developed by the NSR directorate of the “Rosatom” State Corporation, aims to fulfill this task. The design of this digital platform has been started in August 2020, and currently the concept of an integrated platform of the NSR digital services is being developed. Rosatom was appointed as the NSR infrastructure operator by the Federal Law No. 525-FZ of December 27, 2018 "On Amendments to Certain Legislative Acts of the Russian Federation”. The goal of the digital platform development is to fulfill the need of corporations to provide services on the NSR and the government's goal is to make the NSR more attractive as a new transport route.

The decision to create the platform was also influenced by the increasing growth of cargo traffic along the NSR and as a consequence, the development of a nuclear icebreaker which is needed to provide year-round navigation possibilities. This, in turn, entails the need for a more effective ship navigation management in severe ice conditions, which is the goal of the digital platform.

On the other hand, the need for a digital platform at the state level is determined by the strategic importance of the NSR. This also concerns modernization, development and ensuring reliable operation of the NSR, which are considered strategic priorities of policy by the RF. In addition, it partly concerns the socio-economic growth of the Arctic regions due to the timely transport of goods there, strengthening of scientific, transportation, navigational and partly military infrastructure to reliably secure the interests of the RF in the Arctic, as well as the development of the NSR as a new modern transport way of Russia, which may in the long term, according to estimates, by the 2030s to create a new, additional transport corridor within the Eurasian continent (Volovik 2021).

The development of platform solutions for the NSR involve in several directions. First, they are based on the consolidation of national experiences, combining all the best solutions of existing corporate digital platforms from companies which are currently handling cargo along the NSR and their needs for a uniform digital platform. Secondly there are digital logistic services being developed, which are oriented toward international partners so that the platform is not only to work as a domestic platform but can be linked with global digital logistics platforms.

The platform will focus on a wide range of services. At the first stage two big blocks can be singled out: navigational safety and environmental monitoring on the NSR. Rosatom plans to implement an ice navigator, which will make it possible to create safe routes through the NSR. Later it can be supplemented with other services e.g. further navigational or hydrometeorological services.

Furthermore, there are plans to create a domestic trading ecosystem platform for promoting and sourcing products as well as developing sales strategies and trade execution.

At this stage, foreign companies are not involved in the development of the concept. However, the platform is supposed to be built on the basis of accepted international standards and the platform concept will be discussed with a wide range of participants, in order to make final revisions and adjustments to the best of stakeholder needs.

Currently, the stakeholders can be roughly divided into several subgroups. The first group are the federal bodies of the executive branch of the RF, which are concerned with the Arctic zone in their respective functions. For example, the Ministry of Transport, the Ministry of Natural Resources, the Ministry of Defense, the Ministry of Emergency

Situations, the Border Guard Service and a number of others. Further, the Arctic subjects of Russia, whose sea coastline is the NSR directly as well as the subjects economically connected with it, for example not only Murmansk, Arkhangelsk and Kamchatka, but also St. Petersburg and Vladivostok. The third group is comprised of large companies such as NOVATEK, Rosneft, Sovcomflot, Gazprom Neft, Nornickel, AEON and Kazminerals, and the fourth group are scientific organizations. International companies and organizations will represent the fifth group of stakeholders.

This paper aims to provide an approach to the digitalization of the NSR. The findings of this paper can help to ensure support for the development of digital services for the NSR, which are capable to meet the requirements and characteristics of services for the involved maritime industry participants.

2 Method

"Enterprise Architecture (EA) is a discipline which focuses on the holistic management of the enterprise, based on aspects of its architecture, such as business processes, applications, information, hardware, as well as the relationships between them" (S. Buckl, F. Matthes, 2013).

Currently there are many EA frameworks that have been developed. Normally these EA frameworks cover four interrelated domains:

- Business architecture (business processes of an organization are considered),
- Data architecture (structure of the logical and physical data resources is analyzed),
- Application architecture (landscape of applications, their interactions, and relationships to processes is examined),
- Technology architecture (determines software and hardware capabilities required to support the business processes, data, and application services of the organization).

The Open Group Architecture Framework (TOGAF) is the most widespread open standard which provides a practical, industry-managed way for the design of Enterprise Architecture and it contains viewpoints, techniques and reference models for this design.

- “TOGAF standard considers an enterprise to be any collection of organizations that have common goals. For example, an enterprise could be:
- A whole corporation or a division of a corporation
- A government agency or a single government department
- A chain of geographically distant organizations linked together by common ownership
- Groups of countries or governments working together to create common or shareable deliverables or infrastructures
- Partnerships and alliances of businesses working together, such as a consortium or supply chain.” (The Open Group 2018).

In accordance with TOGAF, “the term Enterprise in the context of Enterprise Architecture can be applied either to an entire enterprise and to one or more specific areas of interest within the enterprise. In both cases, the architecture crosses multiple systems, and multiple functional groups within the enterprise”. Nowadays the term an “extended enterprise” is used frequently and includes partners, suppliers, and customers as well as internal business units (The Open Group 2018).

Thus, the Enterprise Architecture approach can provide support for clarification of digital services for the NSR, as well as elements, layers and aspects of the NSR architecture, but such a large-scale project requires a special methodology for the design and development of the IT-architecture. The Model Based System Engineering approach can be used as an effective tool to reach this goal.

Model Based Systems Engineering (MBSE) is a unified and integrated modeling approach of high-tech activities based on unified models and the System Tool Kit. The model is an artificially created object based on the recording of information about the object using symbols and an accepted notation. The model partially takes into account the entities of the object, replaces the object representation in its applications, and has a variety of uses depending on the target object life cycle stages.

The model typology is represented in Figure 1.

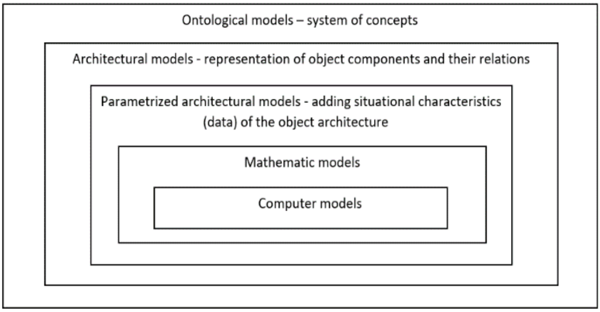

Figure 1: Model Typology [Kondratiev, 2020]

The MBSE methodology is realized via unified models which are consolidated into metamodels, platforms and the System Tool Kit. Parallel engineering and dynamic iterative redesigning is increasingly being used as well. Metamodels and platforms are increasing step by step, starting with the rapid creation of working prototypes; information modeling is transformed into computer modeling, systems become hybrid systems of systems from model and natural components, methodologies are consolidated: multi-physical modeling, engineering, management, cyber systems, computer engineering (Kondratiev 2020).

The reference framework of modelling is a requirements and constraints matrix which contains directories, system structures, metadata, and mathematical models of system constraints. MBSE allows the user to develop a multi-level matrix containing formalized requirements for the system, which in the process of development is broken down and cascaded to target metrics and resource constraints. The simultaneous fulfillment of requirements, achievement of target indicators and satisfaction of resource constraints of the system is achieved by conducting virtual tests.

MBSE tools support capabilities as developing and presenting the structure of ontological and architectural models of systems; forming the description elements reference lists; maintaining element relations tables, as well as model representation and visualization notations.

Thus, the development of digital services for such a large-scale project as the NSR requires a holistic and consistent approach due to the involvement of many different stakeholders in the process. To create a competitive advantage, digital services of the NSR should be implemented on the basis of available best-in-class technologies, and their implementation requires a specific approach, based on the development of reference architecture models and their evaluation.

3 Results

The authors have already written about the creation of digital services platforms and have been made proposals for digital services, which could be provided on the NSR in the past (Ilin et al. 2020). Digital platforms, which exist in the shipping industry were classified based on the Capability Driven Approach – an approach to the information systems development. Capability, in accordance with TOGAF, is a “particular ability or capacity that a business may possess or exchange to achieve a specific purpose or outcome, detailed definition of the capability requires an understanding of how this can be achieved by combining such supporting components as roles, processes, information, and tools” (Sandkuhl 2018). Three major types of maritime shipping industry digital platforms types were identified: the Maritime Community Cloud, the Single Window and the Maritime Business Ecosystem. “The Maritime Community Cloud e-platforms support business capabilities of cross-border trustworthy e-services to all commercial ports and their users in a cost-effective way; the Single Window e-platforms perform submission of standardized information and documents with a single-entry point to fulfill all regulatory requirements; the business ecosystem e-platforms ensure supply chain transparency and agility and support e-commerce capability” (Ilin et al. 2020).

Additional technologies used to operate e-platforms in maritime shipping, were identified, for example the Internet of Things, Cloud Computing, EDI (Electronic Data Interchange), Big Data, Inmarsat and Global Positioning System (GPS), robotic-aided systems, cyber-physical systems, blockchain, radio frequency identification (RFID) tags, and sensors. These technologies are widely used in the maritime shipping industry as digital solutions and will also be used on the NSR as well.

The authors also have identified digital platforms of the logistic sector of the RF (Ilin et al. 2021). “Currently there are several types of digital platforms in the transport industry in the RF. There are digital platforms which enable functional support of logistic operations, another type of digital platforms enable the submission of standardized information and documents to state bodies. But a modern digital platform of the transport sector needs to be able to support a business digital ecosystem. All participants of the Russian transport industry, as well as the Russian government, understand the value of such an integrated digital platform and some steps in this direction have already been made” (Ilin et al. 2021). One project which should be mentioned is the digital platform of “Rossiyskie Zhelesnye Dorogi” (RZD) which enables the activity support of business ecosystems (Marusin, Dmitiev 2019). The implementation of this could be a significant breakthrough in the use of digital services in the logistic sector of the RF as it supports not only the Business to Government (B2G) information exchange, but also the Business to Business (B2B) information exchange as well and provides thus opportunities for all involved parties. Another advantage is the future possibility of value co-creation and the cooperation of involved business ecosystems participants.

Another project, is the implementation of a digital platform in the transport sector of the RF (Zubakov 2019) which was approved by the Ministry of Transport of the RF. “Digital platforms of the transport sector of the RF shall provide B2B, B2G, Government to Government (G2G) information exchanges on local, regional, and national levels and sustain processes of business ecosystem participants such as companies and state bodies. In addition to e-commerce and online bookings, cargo monitoring, and transport process modelling; digital platforms should provide the capability for the Single Window mechanism” (Ilin et al. 2021).

Both projects are currently not implemented but they outline areas of the digital platform development for the logistics sector of the RF. The digital platform of the NSR could provide a number of capabilities to ensure a competitive advantage for the new transport corridor.

In this paper the elements and steps for the modelling of the NSR digital platform are outlined.

The first step of modelling is the identification of the capabilities of the Northern Sea

Route digital platform which are represented in Table 1.

Table 1: Capabilities of the Northern Sea Route Digital Platform

Capability	Functional support of operations	Submission of a standardized information and documents	Supply chain transparency and agility / Trade execution
Roles	Technological processing of information	State control and monitoring	Business ecosystem
Business processes	Shipping management Ice navigation Ship control Terminal management Fleet maintenance Infrastructure maintenance Safety Ecological monitoring	Single Window	E-commerce Cargo monitoring Value co-creation
Information	B2B, B2G Information Exchange on local / national level	B2G, G2G Information Exchange on local / national / international level	B2B Information Exchange on local / national / international level

Capability	Functional support of operations	Submission of a standardized information and documents	Supply chain transparency and agility / Trade execution
Tools	Cloud Computing, EDI, EDM, Big Data, sensors, GPS, Inmarsat, IoT, RFID, sensors, cyber-physical systems, blockchain, Artificial Intelligence		

The NSR is a large-scale national project, that is why capabilities of its digital platforms should not be limited by just functional support of operations but also provide opportunities for all business ecosystem participants. It should provide resources for controlling and monitoring, as well as resources for e-commerce and value co-creation tools. On the base of the NSR digital platform creation the Single Window concept for the maritime logistic of the RF could be realized.

The legislation of many countries require companies which are involved in the international transportation process to submit information and documents to the government agencies, and often to several different agencies, each with their own systems and paper forms. These requirements and the compliance costs represent a significant burden and can also become a major obstacle to the development of international trade.

The requirements of the Russian government are no exception. Information about the vessel arrival need to be submitted by sea agents (representatives of the sea carriers) simultaneously to four government authorities (sanitary control, state port control, customs and border services). Information for sanitary control is sent to the Rospotrebnadzor by e-mail, to the Rosmorrechflot (port control) and customs via departmental information systems of the Rosmorrechflot and CPS "Portal of the Sea Port" of the FCS of Russia, and to the border service - generally in paper form, either by courier or by fax. And only in the Big Port of St. Petersburg the border guards have begun to use e-mail. At the same time the Ministry of Transport of the RF requires the upload of 34 forms of scanned ship documents at every arrival and 39 forms of scanned documents at every departure to the departmental informational systems of the Rosmorrechflot. Also, regardless of the information transmitted by fax or through information systems, sea carriers are required to submit the same 34 and 39 scans of ship documents to border and customs control authorities at every vessel call to the port (Korostelev 2020).

The solution of this problem is the creation of a Single Window where information and/or documents only need to be submitted once at a single point of entry. This approach could improve the information availability and processing, speed up and simplify information flows between businesses and the government and can lead to significant benefits for all parties involved in cross-border trade. Such a mechanism can provide more efficient and effective official controls and reduce costs for both the government and the companies.

The Single Window concept in the maritime logistic of the RF was already proposed by the authors before (Maydanova, Ilin 2018). “In general, the following obligatory characteristics are inherent for the Single Window:

- Existence of a Single Authority that receives information, either on paper or electronically, disseminates this information to all relevant governmental authorities, and coordinates controls to prevent undue hindrance in the logistical chain;
- Existence of a single-entry point for information exchange between the government agencies and business (B2G);
- A single submission and repeated use of the data transferred through single-entry point;
- A uniform standard format of data elements (uniform data model)” (Maydanova, Ilin 2018).

As the NSR development is controlled by the Government of the Russian Federation (Russian Federation, 2019), there are strong opportunities for the adoption of the Single Window concept and thus makes the collaboration of companies and government bodies easier. This concept could be subsequently extended to be used at all maritime checkpoints of the RF.

The creation of a Single Window capability on the NSR will allow for a breakthrough in the relationship between businesses and the government, as well as to reach a new level of international cooperation.

Currently, the creation of digital business ecosystems as a modern way of cooperation and development of companies from different sectors of the economy has become widespread. Electronic platforms are one of the most effective means to ensure the functioning of such digital business ecosystems. The NSR digital platform will generate a new environment for all Arctic subjects of Russia and provide essential support for their access to national and international markets.

It is obvious that the platform needs to be developed on the basis of modern technologies which will secure a competitive advantage and high operational effectiveness. In order to model the digital services of the NSR platform, access to accumulated information on the implementation of the best-in-class technologies is needed. Representation means benchmarking of the implementation of these digital technologies by industry leaders. Such technologies could be used for a digital platform creation but could be refused due to risks and constraints in connection to its implementation. In this regard, the creation of a strategic resources ontology is an important step in the process of the NSR digital services modeling.

The second step of modelling is the setting of motivation elements, which need to be done with the EA approach help.

As was done described above, the NSR digital platforms shall provide to all involved parties certain business capabilities. In turn, “a capability requires or is supported by specific business processes, provided by specific roles, as well as it needs certain resources and IS components. The distinguishing characteristic of the capability is that it is designed to be provided in a specific context. The desired goal fulfillment levels can be defined by using a set of goal fulfillment indicators – Goal KPIs“ (Stirna et al.,2017).

The Balanced Scorecard (BSC) (Kaplan, Norton,1992) indicators are suited perfectly for this task. The Financial, Customer, Internal and Learning and Growth perspectives will provide a complete model, where indicators should be able to be identified, measured, and presented in a coherent way. It is important to note, that BSC metrics need to be done for several levels: the general level, the business-unit level and the business process level.

The BSC area should balance the interest of stakeholders. Different stakeholder groups have different concerns, specific views and often different positions and priorities. For the BSC purpose stakeholders can be divided into external and internal ones. External stakeholders drivers, goals and concerns need to be reflected in the Customer perspective, and internal stakeholders ones – in the Learning and Growth perspective.

Another element of modelling are drivers. A driver is an "…external or internal condition that motivates to define goals and implement the changes necessary to achieve them. As the NSR stakeholders significantly differ, drivers could be grouped according to their goals" (TOGAF, 2018).

The next element is an outcome, which "represents an end result that has been achieved. Outcomes are high-level, business-oriented results produced by capabilities, closely related to requirements, goals, and other intentions" (TOGAF, 2018). Thus, the outcome of the functional support of operations could be ice routing service, and navigational and hydrographic services.

Requirement represents a "…statement of need that must be met by the architecture and represent the "means" to realize goals" (TOGAF, 2018). For example, to maintain ice navigation, satellite images of the NSR once a day are required.

"A principle represents a qualitative statement of intent that should be met by the architecture" (TOGAF, 2018). Principles define intended properties of a platform in a certain context and is motivated by some goal or driver. For example, digital platform services should support safety of navigation.

A constraint is defined as a restriction on the way in which a digital platform is realized. Risks are a wider category and characterize the probability of negative events.

As was described before, strategic resources represent first of all informational technologies, which could be used for digital services development. Other strategic resources could be financial, human and tangible assets.

All elements are addressed and monitored on all architectural layers. Principles, goals, drivers, stakeholders, constraints, and indicators must be combined in a digital model and have their own digital twins, links and digitized influence paths (chains of dependent influences) on each other and on all other elements of the enterprise architecture as presented in Figure 2.

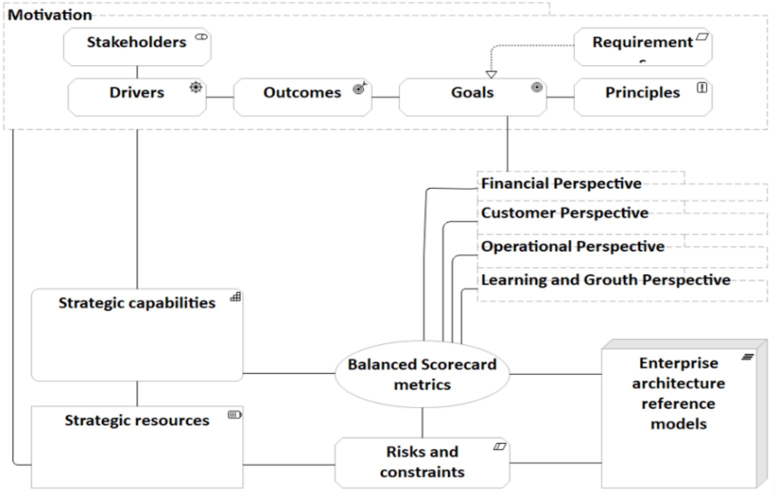

Figure 2: Elements of MBSE Modelling

Thus, to develop a model of the NSR e-platform with the help of the MBSE method, elements of modelling should be identified and combined in a digital twin.

For this propose an approach as follows is proposed:

- strategic capabilities;
- strategic resources;
- motivation;
- BSC metrics;
- risks and constraints;
- EA reference models.

These properties help to represent the digital twin, it should be done on the virtual modelling platform capable to correlate a number of metrics with Enterprise Architecture reference models. For this purpose, a multi-level matrix comparing and linking the indicators and the IT-architecture models is proposed as presented in Figure3.

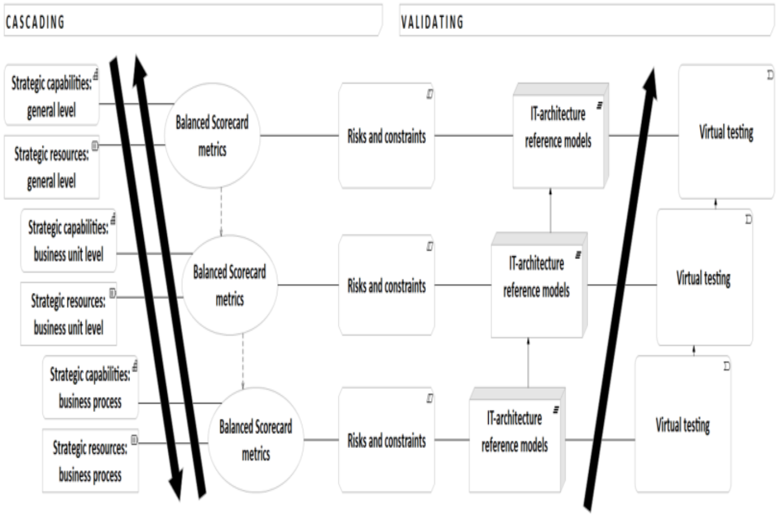

Figure 3: Multi-level Matrix Comparing and Linking Indicators and IT-Architecture Models

This matrix is in accordance with MBSE modelling as the reference framework which contains directories, system structures, metadata, and mathematical models of system constraints. As a result of this process, a large number of indicators and thus a balanced model is guaranteed, while initially the indicators can "conflict" with each other.

The multi-level matrix of comparing and linking indicators and the IT-architecture model is capable to provide a correlation in the process of virtual testing. First on a business process level, then on the business-unit level, and finally on the general level of the NSR digital platform. A top-down or bottom-up approach could be used to define strategic capabilities, resources, BSC metrics, risks and constraints, and the IT-architecture reference models. The choice of the particular approach depends on stakeholders interests and strategic goals.

Thus, the NSR IT-architecture requires a holistic and consistent approach due to the involvement of many different stakeholders in the process. To create a competitive advantage, digital services of the NSR should be implemented on the basis of available best-in-class technologies, and their implementation require a specific approach, based on the development of reference architecture models and their evaluation.

The results of this paper create a foundation for the modelling of digital services for the NSR which corresponds to a modern level of maritime industry development by using EA approach and MBSE modelling.

4 Discussions and Recommendations

This paper considers several aspects of the NSR digital services development. Firstly, it is a review of the capabilities, which should be provided by the NSR digital platforms. Besides fulfillment of the requirements of the companies, which currently handle cargo along the NSR the digital platform need to becomes a powerful tool which is capable to enable a breakthrough and thus a substantially change in all relationships of the participants in the process. This large-scale national project could change the relationships between the government of the RF and businesses as well as create an environment for the development of the Russian Arctic territories and thus could help to change the landscape of international trade.

Secondly, this paper provides an approach to the digital services modelling, by proposing elements and the modelling structure as well. Although the proposed approach provides the benefits of simulating digital services of the NSR by offering a virtual testing of technologies and architectural models, it requires a careful study of the data and indicators obtained as a result of such tests, as well as comparing them with the actual results after implementation to be able to make the necessary adjustments. It is also necessary to conduct a benchmarking process to compare the results of virtual testing with existing best practices. This process could have limitations, for example a structured database of the necessary KPI’s is needed.

5 Conclusions

Currently, the NSR becomes a more and more important transport corridor, the cargo turnover has increased exponentially and beat the record of USSR times cargo turnover on this direction several times from 6.5 million tons in 1987 to 33 million tons in 2020 (Volovik 2021). Nevertheless, state management of the Russian Arctic territory is extremely difficult, the reason lies not only in climatic, environmental or logistical features that affect development, the main difficulty is the critically high cost of human error. The Arctic is one the most dangerous regions in the world, since the price of development mistakes in the Arctic are disproportionally high. (Dolgova et al. 2018).

Therefore, all developments, including the digital services deployment, should be done with transparency and commitment and all stakeholders need to be involved into this process.

The digital platforms of the NSR should not become just new corporate platforms of the state corporation, they could make a significant contribution to the development of the Russian economy, strengthen relations between the government and businesses, and promote international trade relations.

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IV.
Port Logistics

Assessing Performance of Container Slot Allocation Heuristics

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Purpose: *In the last decades, the transport capacities of container vessels have tremendously increased. This leads to longer berth times and greater peak loads at container terminals, especially when schedules are perturbed. Thus, existing container handling processes need to be re-evaluated regarding their adequacy.*

Methodology: *In the first step, the current literature is reviewed: which methods have been used for container slot allocation? In the second step, a simulation study is set up to compare two rule-based heuristics of Güven and Türsel Eliiyi (2014; 2019) with Levelling Stacking and Random Stacking.*

Findings: *It is shown that the two rule-based heuristics of Güven and Türsel Eliiyi lead to shorter berth times than Levelling Stacking or Random Stacking. At the same time, the last two approaches show a clear superiority in workload balancing. The joint storage of container groups at Güven and Türsel Eliiyi leads to congestion at the stacking cranes in both cases for peak loads.*

Originality: *This study is the first to compare these four stacking policies. For generating realistic container flows, data from an existing container terminal have been used. Previously unreported performance indicators are used for comparison. Thus, this study provides new insights for improved rule-based heuristics in future.*

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1 Introduction

The increasing size of container vessels over the last years has affected container terminal operation: instead of a steady flow of containers delivered by smaller vessels, nowadays shipping companies employ larger vessels that approach ports in a lower frequency while the overall amount of traded goods is still increasing (UNCTAD, 2019). This leads to longer vessel calls and larger peak volumes that need to be handled at container terminals (UNCTAD, 2019). In 2020 and the beginning of 2021, the Corona pandemic has put additional stress on the international supply chains: reduced work force capacities in ports lead to longer port calls and such delays are propagated both within the port, terminal, and container services (UNCTAD, 2020). In addition, the reduced trade volumes in 2020 led to the cancellation of several container services. These restructured supply chains seem to be the reason for long queues in front of some ports (Bloomberg, 2020). In this situation, terminal operators need to manage their container terminals efficiently in terms of cost (e.g., low energy consumption of terminal equipment) and time (e.g., serving vessels quickly) while the arrival and departure of containers are subject to great uncertainty due to delay and cancellation.

In academia, the operation of container terminals is subject of active research (e.g., Covic, 2018; Gharehgozli, Zaerpour and Koster, 2020; Wang, 2020; Kizilay and Türsel Eliiyi, 2021). The operation is frequently described as three-dimensional chess, as each container can be positioned at many different places within the yard. Furthermore, the operators determine the sequence the vessels, barges, trucks, and trains are unloaded and loaded. This goes hand in hand with assigning handling jobs: which equipment in the yard (both horizontal transport equipment and stacking equipment) handles which container in which order? If a container terminal turns into a bottleneck in the maritime supply chain, it might be possible to allocate the bottleneck within one of the subsystems of the container terminal. While Lee, et al. (2009) allocate the bottleneck of container terminals at the ship-to-shore gantry cranes, Tan and He (2016) claim that the stacking area throttles the productivity of the average container terminal. Kizilay and Türsel Eliiyi (2021) present the literature related with the integration of quay crane scheduling and yard operations. They classify the existing literature according to the solution methodology into exact methods (e.g., mixed integer programming or constraint programming), evolutionary heuristics (e.g., genetic algorithms or particle swarm optimization), other heuristics (e.g., greedy algorithms or rule-based heuristics), simulation-optimization-based approaches, and others. Voß, et al. (2016) argue that mathematical modelling is often difficult to implement in practice because of the lack of planning information. Information regarding arrivals and departures might be not available, incomplete, or of questionable quality. This improves as the actual container delivery comes closer. This favors online heuristics which choose the container slot just-in-time when the container needs to be stored.

Rule-based heuristics are often not well-defined in scientific literature regarding container terminal operations. Terms such as online optimization (Voß, et al., 2016; Güven and Türsel Eliiyi, 2019), policies (Güven and Türsel Eliiyi, 2014; Gerrits, Mes and Schuur, 2019), and strategies (Yu, et al., 2018; Ambrosino and Xie, 2020) can be understood as synonyms for rule-based heuristics. To create a common understanding, properties rule-based heuristics commonly share are presented:

- Paradigm of solution construction: A rule-based heuristic follows an imperative approach, i.e. the formulation contains a clear control flow. Therefore, the rule-based heuristics can be represented as an algorithm (e.g., written in pseudocode) or a flowchart. This sets it apart from mathematical optimization that follow a declarative approach, i.e. a system of equations is formulated usually without explicit instructions about how to solve it. Instead, (often proprietary) solvers are used to obtain a solution.
- Central coordination: All equipment is coordinated by transport jobs issued by a central control unit. This sets it apart from agent-based modelling that follow a distributed approach. The rule-based heuristic must be formulated in a way that at no point of time an operational constraint is harmed. Likewise, as container handling processes are executed concurrently at the terminal, issues typical for distributed systems must be considered, e.g. deadlock situations must be avoided.
- Greediness: Once a container is assigned to a container slot, this decision is considered fixed, i.e. slot reservations are not swapped or changed later for further improvement. Furthermore, only a single solution is constructed and alternative solutions are not compared. This sets the rule-based heuristic apart from tree-based approaches such as branch & bound since these explore several alternative solutions. The greediness property removes the necessity

of using rolling planning horizons if (a) container slots are allocated in the sequence of the arrival time of a container and (b) the available information regarding later container arrivals is not used. This improves the computational complexity of a heuristic at the expense of suboptimal operations at the container terminal.

- Metric expressing preference: If within the control flow of the heuristic more than one option exists, a decision must be made (e.g. choosing a container slot from a set of free slots for a given container or choosing a vehicle from a set of available vehicles for a given transportation job). This can either be a random decision or an informed decision. For the latter case, some kind of scalar metric is assigned to each option to express the degree of preference. The metric term might contain a notion of time (e.g., urgency), space (e.g., equipment travel distances), or other relevant property. However, there is no guarantee that using a certain metric results in the desired behavior of the system (here: container terminal) over a longer period of observation. This must be shown with simulation studies or numerical experiments.
- Solution quality: The rules that allocate the slot for the container are based on the practitioners' experience. This makes it difficult to justify a heuristic based on its formulation on an academic level. However, the solution quality of the rule-based heuristic can be evaluated with simulation studies or numerical experiments. The proposed rule-based heuristic can be compared with a baseline (e.g., random assignment) or other established rule-based heuristics. Likewise, a comparison with solutions generated with other approaches, especially with exact methods, can be insightful.

These properties highlight some of the benefits and shortcomings of rule-based heuristics. On the one hand, typically their computational complexity is low, the formulation is either simplistic (e.g., first come first serve or nearest job first) or driven by business insights. Common events (e.g., delays or lack of information) are usually considered. On the other hand, the generated solution might be far from optimal. Here, different optima might be strived for, such as (1) a minimal travel distance of the horizontal transport equipment, (2) reducing yard crane movements to a minimum, (3) as little congestion in the yard as possible, and (4) a minimum amount of relocations (Kim and Lee, 2015). Kim and Lee (2015) also state that in practice terminal operating systems do not create a schedule but instead use real-time control (i.e., rule-based heuristics) for container handling assignments and container slot allocation due to the uncertainties of container handling times. Another argument for rule-based heuristics stems from Voß, et al. (2016). They hypothesize that "The human decision makers […] might be more interested in the staff and equipment to employ in future shifts and less in actual slots where containers are stored." Or in more general terms, a simulation model that covers the handling processes in the container yard in detail must also cover the container slot allocation – independent from the actual research question. Here, a computationally efficient rule-based heuristic frees computational capacities for the actual research topic. Hence, the current state of the art regarding rule-based heuristics is worthwhile being examined further.

2 Literature Review

It is quite difficult to compare different approaches of yard management at container terminals in a fair manner. In academic publications, often only a subset of the container handling processes at a container terminal is inspected, e.g. only import containers, export containers, or transshipment containers (Jiang and Jin, 2017; Jacomino, et al., 2019; Ambrosino and Xie, 2020, respectively). Likewise, sometimes the containers are stored in a yard block without modelling the container slots allocation procedure in detail (Liu, Kang and Zhou, 2010; Kastner, et al., 2021). In other words, publications model different aspects of the yard management at different levels of granularity which makes it infeasible to quantitatively compare the approaches for given problem instances. Yet, this is urgently necessary because rule-based heuristics are often only compared to simplistic alternatives which they outperform with little effort (as the reported literature will show shortly). Thus, in this section publications are gathered that are similar enough for a direct comparison in the next sections.

For the literature search, the two bibliographic sources Scopus and Web of Science have been used. Elsevier (2021) claims that their product Scopus contains most high-quality content compared to their competitors for each world region with more than 82 million items in total. Web of Science is used in addition because the Web of Science Group (2020) claims to be independent from any publisher and covers more than 74 million items. Each bibliographic source contains publications unique to them and both of them are among the most used sources to explore relevant research activities (Huang, et al., 2020).

First, synonyms for “container slot allocation” are looked up. This accounts for the rich language in logistics. This leads to the following query string:

> "container terminal" and (import or inbound) and (export or outbound) and ("storage strategy" or "storage space allocation" or "location assignment" or "stacking strategy" or "yard management" or "slot allocation" or "stacking policy")

The query string is applied on the broadest option available at the respective database, i.e. TITLE-ABS-KEY for Scopus and ALL FIELDS for Web of Science. Only articles published in 2019 and before are considered. The search with that query string resulted in 14 hits on Scopus and 10 hits at Web of Science, of which 4 were duplicates. In the next step, those rule-based heuristics that could be compared in a fair manner are extracted from those 20 publications. Here, the following selection criteria have been applied:

- The chosen method must be a rule-based heuristic based on the list of properties presented in this publication.
- For a fair comparison, the rule-based heuristic must follow the free stacking approach - in distinction to remarshalling stacking, reservation stacking or scattered stacking (Kemme, 2013).
- Only container terminals at sea ports are included.
- The rule-based heuristic must cover import containers, export containers, and transshipment containers (no distinction is made for domestic transportation). They are alternatively referred to as inbound for import containers and outbound for export and transshipment containers.
- The rule-based heuristic allocates a suitable slot for a given container.

This sieving process leaves 3 publications for further examination, i.e. (Güven and Türsel Eliiyi, 2014), (Güven and Türsel Eliiyi, 2019), and (Voß, et al., 2016). At the time of writing this conference article, the two rule-based heuristics by Güven and Türsel Eliiyi are implemented and they are examined in the following sections. The six strategies of Voß, et al. are not yet implemented but the work is ongoing.

Güven and Türsel Eliiyi (2014) implement what Kemme (2013) coined as the two complementary stacking approaches of retrieval-time stacking and category stacking. Retrieval-time stacking means that the containers are stacked according to the expected pick-up time whereas category stacking refers to grouping containers according to the corresponding vessel or berth. They report the results of a simulation study that only covers the import process. Among others, the number of reshuffles and the number of used ground slots are reported. The lead times of external trucks, the travelled distances of the yard cranes or a metric to capture the work balancing between the blocks is not reported.

Güven and Türsel Eliiyi (2019) pick up their prior work from 2014 and extend it by adding a mathematical program and a more sophisticated simulation study for new insights. They alter the formulation of the rule-based heuristic by separating yard blocks for import and export containers. The authors further claim that with sufficient free yard capacity, their approach reaches the optimum number of reshuffles, i.e. none. This, however, neglects the delays and schedule perturbations which are often part of daily operations. For the simulation study, among others the number of reshuffles and the travelled distances of the yard cranes is reported. The lead times of external trucks or a metric to capture the work balancing between the blocks is not reported.

The four common goals of container stacking according to Kim and Lee (2015) are to minimize horizontal transport equipment travel distances, yard crane movements, congestion in the road network, and reshuffles. In the following simulation study, the latter three aspects are inspected and lead times are added to the consideration.

3 Methods

By definition, rule-based heuristics provide no guarantee that using them leads to optimal operational behavior – unlike exact methods. This situation is further complicated since there are different conceptions of what is optimal. In technical terms, container slot allocation is a multi-objective optimization problem for which the terminal operator must weigh up competing optimization goals. In this publication, we focus on the core activity performance indicators lead time and productivity (see Ha, Yang and Lam, 2019). While lead time, i.e. vessel turn time and truck turn time, is a rather simple concept to measure and interpret (the shorter the better), the concept of productivity is more difficult to assess. In this study, we decided to focus on potential inefficiencies in the container yard. For each yard crane, the travel distance and the number of reshuffles over time is assessed. Both processes consume time and resources (both in an economic and ecological sense) and the objective to minimize either of them might come at the cost of the other. We avoided the common metric of utilization (see Kizilay and Tursel Eliiyi, 2021) as it is more difficult to interpret: a high utilization of a yard crane might be caused by long travel distances, many reshuffles, poor work balancing, or just a major peak in operations.

Last, the number of waiting trucks (both internal yard trucks and external trucks) at a yard block is recorded. This indirectly reflects the utilization of the yard crane(s) operating in each yard block and as such it comes with all the shortcomings mentioned above. However, this metric provides the additional information of how many trucks are affected by congestions in the system. If a rule-based heuristic leads to shorter queues than others, this is seen as an indicator of better work balancing. In summary, the lead time and a selection of efficiency measures are assessed which represent the time pressure and cost pressure terminal operators are exposed to in daily operations.

As previously pointed out, rule-based heuristics can hardly be examined from an algorithmic point of view when it comes to predicting terminal performance indicators. At the same time, trying out new approaches in the field could potentially result in high lead times which in turn would inevitably strain customer relationships. A simulation study allows to estimate the operational performance metrics without any implications for the daily business. Moreover, simulation has been successfully employed in the past (Dragović, Tzannatos and Park, 2017). Thus, this method is chosen for this study.

3.1 Simulation Model

The simulation model is implemented in Tecnomatix Plant Simulation version 14. The system boundaries of the simulation model as well as its subsystems are depicted in Figure 1. Both the quay side and the truck gates are system interfaces. Here, containers (either 20-foot or 40-foot standard containers) are either delivered or picked up. At the time a container enters the system, all relevant information (i.e., empty or laden, weight, destination, estimated pick up time) is available for container slot allocation. The two approaches of estimating the truck pickup times are further explained in Section 3.3. At the quay side, vessels arrive with containers to discharge. Vessels queue up to berth in a first come first serve fashion. The time for berthing and preparing container handling is

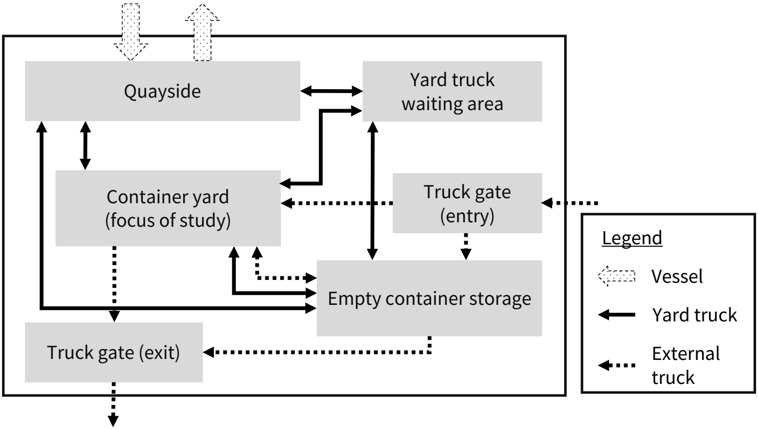

Figure 1: The considered subsystems of the container terminal

set to 106 min (Yu, et al., 2018). Then, ship-to-shore gantry cranes start to operate by loading the first container on a yard truck. If it is an empty container, the yard truck delivers the container to the empty container storage. This storage is coarsely modelled without specific container slots. If the container is laden, the container slot is allocated in the yard and the vehicle moves it there. This part is modelled in detail, i.e. with a road network and a yard block arrangement inspired by the MSC Terminal Valencia. Once 25% of the containers are discharged, the loading process is initiated so that both processes are executed in parallel. After the last handled container, the unberthing process is set to take 81 min (Yu, et al., 2018).

External trucks enter the model from the hinterland through the truck gate. This is coarsely modelled by 5 parallel optical character recognition (OCR) gates the trucks need to pass. Prior administrative processes (such as visiting an interchange) are out of scope of this study and therefore neglected. After passing the OCR gates, the external truck directly heads to the container yard or the empty container storage to either pick up or deliver a container. In case of a delivery, some of the external trucks also pick up a container afterwards, either from the container yard or the empty container storage. Then, the external truck leaves the container terminal through the truck gate without any administrative process. The road network is shared between external trucks and yard trucks.

A gang of 7 yard trucks is assigned to each of the 8 ship-to-shore gantry cranes. Transportation jobs are executed first come first serve. If a yard truck runs out of transportation jobs, it moves to the yard truck waiting area which is coarsely modelled. As soon as a new transportation job is available, it moves out of the waiting area and moves to its new destination. A yard crane always serves the nearest truck first.

In Figure 2, the storage yard layout including the road network and the yard block orientation is displayed. Each arrow indicates the allowed direction of travel. Inside the storage yard, each arrow represents a road with two lanes. The roads that connect the storage yard with related subsystems are only coarsely modelled.

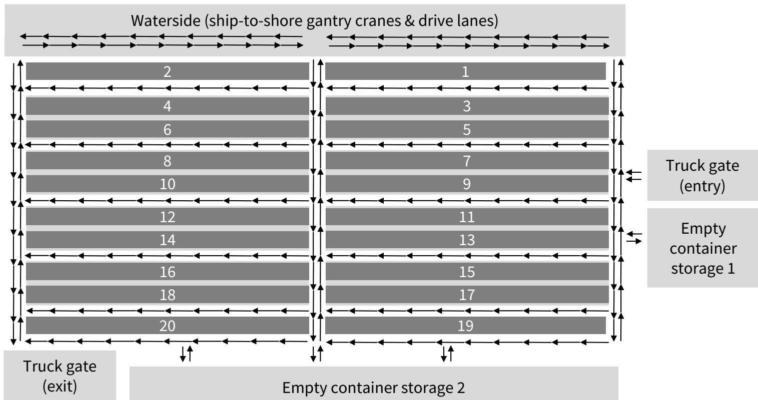

Figure 2: Storage yard layout inspired by the MSC Terminal Valencia

3.2 Generated Data

For this simulation study, special emphasis has been put in the data generation process. All rule-based heuristics are designed to cover import containers, export containers, and transshipment containers. Therefore, all three categories should be part of the generated container streams. The vessel arrival and departure times are inspired by the publicly available data of MSC Valencia between February and July 2020, i.e. 6 months. For each vessel, its service is looked up. If the service does not usually visit the terminal, it is dropped. If sufficient information regarding a container service is available, it is entered into the schedule. The number of containers that a vessel transports are estimated based on the approach of Park and Suh (2019). If no public information is available on a service, it is dropped. As a compensation, those services that reportedly only called the container terminal sporadically have been added to the schedule as frequent visitors. As a final step, the vessel capacities are scaled up to match the reported terminal capacities.

The modal split is generalized from the statistical report of the local port authority (valenciaport, 2019). Thus, it is assumed that the total terminal capacity of 1.6 million twenty-foot equivalent units (TEU) p.a. consists of 54% transshipment and 56% gateway traffic (equal shares of import and export, including domestic ingoing and outgoing trade). In the next step, container flows are generated based on the approach of Hartmann (2004). This approach is further extended to also incorporate the previously prepared vessel schedules including the average number of inbound TEU and the number of ports of destination related to a container service. The number of inbound TEU is varied by plus/minus 10% following a uniform distribution to approximate variations during daily operations. Furthermore, if possible, a truck that delivers an export container is also used to pick up an import container.

Three different workload scenarios are prepared. In the first workload scenario, any kind of peak is avoided and the container arrival and departure streams are quite homogenous. In the second workload scenario, some of the deep-sea vessels are delayed so that the container terminal must handle a few peak loads and additional reshuffles might be necessary. In the third workload scenario, the schedule is designed so that several port calls overlap so that many vessels need to queue up before berthing. This leads to many schedule perturbations and therefore more reshuffles.

3.3 Rule-based Heuristics

Containers enter the terminal either by being dropped on a yard truck on the quay side or they are loaded on an external truck that passes through the truck gate. Only at these two moments, containers are allocated a container slot. The requirements for the slot differ depending on whether it is (a) an import or (b) a transshipment container on the yard truck or (c) an export container on an external truck. For the slot allocation, some operational constraints must be adhered to by all rule-based heuristics:

- The yard crane model determines the maximum stacking height. For our implementation, it is set to 5 containers.
- For each bay, the maximum number of stored containers is limited to allow reshuffling inside a bay any time. Thus, for our stacking height of 5 containers the number of required empty slots for each bay is set to 4 containers.
- Bays are either designed for 20-foot or 40-foot containers. Containers of different lengths are never mixed inside a bay.
- Any container stack can be subject to a reservation. This means that a container slot on top of the stack has already been assigned but the container has not yet been stacked at that position.
- In the two heuristics of Güven and Türsel Eliiyi, the weights of the lightest and heaviest container in each stack are not allowed to differ more than 3 tons. For comparability, the same constraint is applied on the other two heuristics, too.

These constraints are not repeated in the following short formulation of the four rule-based heuristics. For the exact algorithmic definition of each of the heuristics, please refer to the mentioned publications.

Güven and Türsel Eliiyi (2014) present a rule-based heuristic which they call "Strategy 2". It is hereafter called GTE14 based on the authors' names and the publication year. For this rule-based heuristic, each bay is used for one container type (i.e., export and transshipment or import). If the container fulfills the requirements of being placed in the bay, each stack is checked regarding the destination and departure time. Export and transshipment containers can be stacked for the same destination and import containers can be stacked if the departure time of the new container is earlier than the top container in the respective stack. In our implementation, each yard block consists of some bays for 20-foot and some for 40-foot containers. Similarly, some bays are reserved for import and some for export and transshipment containers. The ratio is constant for all yard blocks.

Güven and Türsel Eliiyi (2019) extend the work of GTE14 by reworking their rule-based policy which they call “Policy 2: attribute-based stacking”. It is hereafter called GTE19 based on the same naming convention as GTE14. In this publication, the authors state that each yard block is either used for import containers or for export and transshipment containers. This sets it apart from the bay-wise approach in 2014. Furthermore, in 2014 they sketched out the idea that the container slot should be chosen in order to minimize the future travel distance, i.e. import containers should be stored close to the truck gate and export and transshipment containers should be stored close to the sea side. In our implementation, the import yard blocks are placed as far away from the seaside as possible, close to the exit for external trucks.

The Levelling Strategy is borrowed from Kemme (2013). Following the author’s suggestion, it is abbreviated as LeS. First, the yard block is chosen randomly. Inside the yard block, all permissible bays for the given container are selected. For each bay, all permissible stacks are gathered and sorted by stack height. A random stack is selected from the stacks of the lowest height.

Similarly, the Random Strategy is borrowed from Kemme (2013) and is abbreviated as RaS for the same reason. Here, both the yard block and the bay are selected randomly from the subset of permissible bays inside the container yard.

3.4 Experiment Plan

For the simulation study, a full-factor design has been chosen, i.e. each combination of input parameters is combined. This is depicted in Table 1. The focus lies on the four rule-based heuristics GTE14, GTE19, LeS, and RaS. Each of them is examined in all three workload scenarios. For GTE14 and GTE19, two variations are considered. In the first variation, the time an external truck picks up the import container is already known when the container is discharged from the vessel. This follows the assumption that prior to vessel arrival, the freight forwarders announce (and later successfully realize) the time their trucks arrive at the truck gate, usually through a truck appointment system (TAS) (cf. Zeng, Feng and Yang, 2019). In the second variation, the freight forwarder books a time slot after the container slot is allocated (Karsten, 2020; DAKOSY Daten-kommunikationssystem AG, 2021). Thus, this information cannot be used for the slot allocation. In this second variation, at the time of slot allocation the average dwell time of the containers is assumed. In the following, the suffix “no truck slot” is appended when discussing the second variation. The two variations are skipped for RaS and LeS as their formulation does not make use of the estimated departure time of containers.

Table 1: Experiment plan

Number of experiment	Rule-based heuristic	Truck slot booked before allocating container slot	Workload scenario
1	GTE14	yes	1
2	GTE19	yes	1
3	GTE14	no	1
4	GTE19	no	1
5	RaS	-	1
6	LeS	-	1
7	GTE14	yes	2
8	GTE19	yes	2
9	GTE14	no	2

Number of experiment	Rule-based heuristic	Truck slot booked before allocating container slot	Workload scenario
10	GTE19	no	2
11	RaS	-	2
12	LeS	-	2
13	GTE14	yes	3
14	GTE19	yes	3
15	GTE14	no	3
16	GTE19	no	3
17	RaS	-	3
18	LeS	-	3

For each input parameter configuration, 50 replications are executed. For each replication, the numbers of import containers, export containers, and transshipment containers are randomly varied. For each container, its attributes (i.e., mode and time of arrival, mode and time of departure, weight, full or laden, etc.) are randomly generated. The truck arrivals are generated according to the vessel schedules. First, the yard is filled over a transient phase of 23 days. Then, for 45 days the operation is monitored. This longer period is necessary because many services call the terminal every 7 or every 10 days, leading to peak loads in longer time intervals.

4 Intermediate Results and Discussion

At the time of reporting, the implementation and evaluation of GTE14 and GTE19 including the two different assumptions of the TAS as well as the implementation of LeS and RaS are finalized. The work regarding the heuristics presented by Voß, et al. (2016) is still ongoing. In the following, the intermediate results are presented and discussed grouped by lead time and efficiency indicators. The error bars indicate one standard deviation.

4.1 Lead Time

In the maritime supply chain, container terminal operators are positioned between the shipping companies on the sea side and the freight forwarders in the hinterland. The container terminal operators need to serve both interfaces quickly and reliably to satisfy external stakeholders. Thus, lead times are important performance indicators for third parties when assessing the service level of a container terminal. As previously discussed in Section 3.1, the processes of arrival and departure of a vessel or a truck are only coarsely modelled. Hence, the reported lead times might differ from values achieved in practice. As this affects all heuristics likewise, this has no implications for the comparison.

The average vessel turn times are depicted in Figure 3. This is the timespan between the initiation of the berthing process and the end of the unberthing process. The shortest turn times are achieved by GTE14 for both TAS variations. For GTE19, the average value and the standard deviation are larger than for GTE14 and both TAS variations are very close to each other. The two baseline implementations LeS and RaS perform substantially worse. For the workload scenario 1, the average vessel turn time is approx. 18 h when using GTE14 but approx. 29 h when using RaS, an increase of roughly 67%. The shortest average vessel turn time is approx. 18 h, the longest approx. 40 h. These figures are within the range of publicly accessible data (Comtois and Slack, 2019; Statista, 2021).

The average truck turn times are depicted in Figure 4. Here, clear differences between GTE14 and GTE19 can be identified. Furthermore, the missing container pickup information at the time of slot allocation shows a severe effect on truck turn times when employing GTE19, leading to longer lead times than LeS and RaS. In terms of average truck turn time, these lead times are comparable to GTE19 even with the truck pickup times being previously announced. All reported truck turn times are rather long compared to publicly accessible data (cf. Department of Infrastructure, Regional Development and Cities, 2018). While worst-case values of approx. 45 min seem common, spending more than an hour on a container terminal is not. This can be explained by the rather large amount of trucks in our generated scenarios that both deliver an export container and pick up an import container. Thus, their turn time account for two containers.

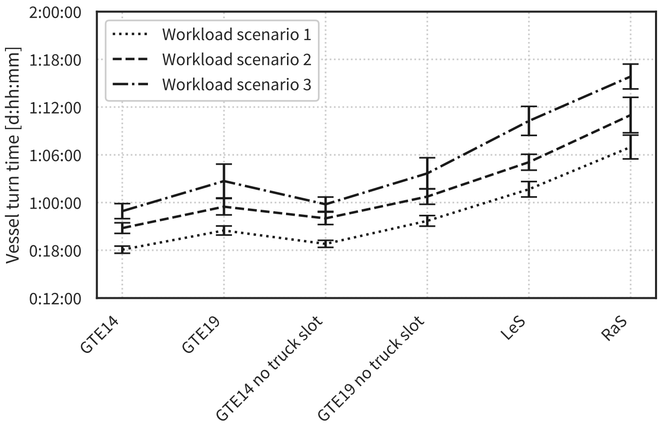

Figure 3: Vessel turn time

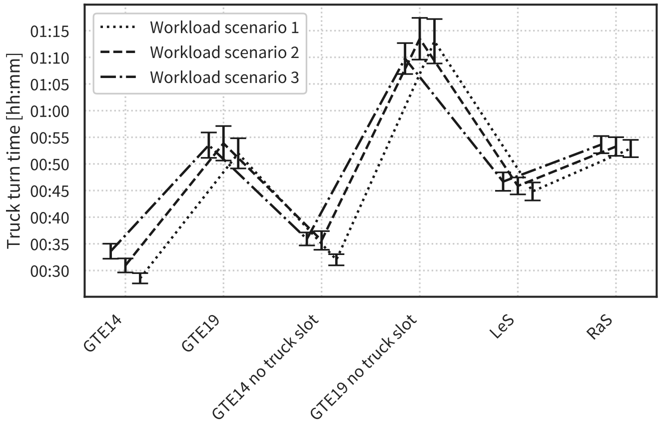

Figure 4: Truck turn time

4.2 Efficient Operations

Within the maritime supply chain, competitors do not only differ in terms of lead times. Similarly important, they need to offer their services at affordable prices. One of the important factors is to move the terminal equipment as little as possible and still obtain acceptable lead times. The more the terminal equipment needs to move, the more energy it consumes which must be purchased in form of petrol, electricity, or similar. In this section, the number of reshuffles and the travel distance of the yard cranes is reported. If a heuristic minimizes these, it reduces the operational costs.

The number of reshuffles for each of the heuristics is depicted in Figure 5. The chart indicates that if the truck slot is booked before the container slot is allocated, this leads to less reshuffles. The difference between GTE14 and GTE19 seems marginal for both TAS variations. LeS and RaS perform significantly worse, RaS causing more than three times the number of reshuffles. Here, often outbound (i.e., export and transshipment) containers need to be taken from the middle of the container stack. For inbound containers, once no slot is booked before slot allocation, the number of reshuffles between GTE14, GTE19, LeS, and RaS diminishes.

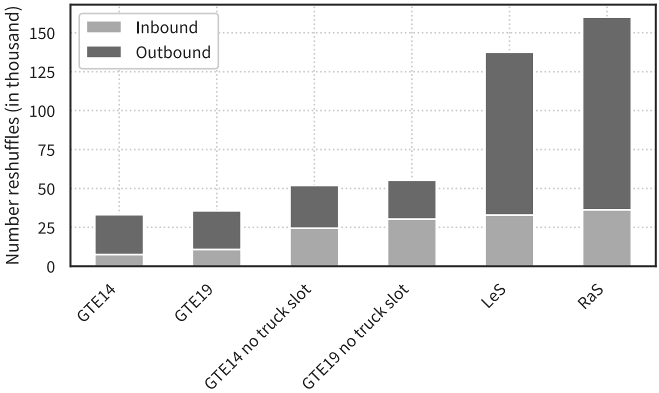

Figure 5: Number of reshuffles over the simulation period

In Figure 6, the average distance a yard crane travels is depicted. It can be seen that GTE19 in both TAS variations leads to exceptionally low travel distances. GTE14 shows slightly higher travel distances. For this performance indicator, RaS outperforms LeS. This can be explained by the levelling approach that prefers the yard crane to travel longer distances to reach a lower stack. RaS, on the contrary, creates relatively higher stacks which in turn increases the probability of reshuffles. For the absolute value range of 6 km to 7 km, the following should be considered: one yard block has a length of approx. 330 m in our terminal layout. Therefore, a yard crane travels approx. 20 times the length of its yard block that consists of approx. 35 bays (some of them 20-foot and some 40-foot container bays). Hence, each yard crane travels approx. 700 bays a day while each yard block has an average throughput of $\frac{1{,}200{,}000\,TEU}{365\,d \cdot 20\,blocks} \approx 165\frac{TEU}{d \cdot block}$ ignoring holidays and excluding empty containers. Hence, each yard crane moves a bit more than $\frac{700}{165} \approx 4$ bays for each TEU that is moved through the terminal. Güven and Türsel Eliiyi (2019) report that to move $2 \cdot 13{,}308 = 26{,}616$ containers, their yard cranes move 4,438 bays (excluding empty containers). Hence, each yard crane moves approx. 1.7 bays for each moved container which is exceptionally well in comparison. This might be related to a lower yard utilization - they report that 13,308 containers leave the terminal each month whereas this this terminal moves 100,000 TEU a month.

Last, the maximum number of waiting trucks (both internal trucks and yard trucks) over all the yard blocks and over the whole simulation time is presented in Figure 7. This metric serves as a proxy to indicate how well the work is balanced between the yard blocks. Here, LeS and RaS clearly lead the comparison with on average maximum 40 trucks waiting. When we recall the difference in the number of reshuffles, this comes as a surprise: while using LeS and RaS, the yard cranes reshuffle more for each workload scenario. Thus, each yard crane is busy for a longer timespan when handling the same capacities. On the other hand, LeS and RaS have a large random component in their formulation so that all the work is shared equally between all yard blocks (not always but with a high probability). These long queues are very unlikely to happen in production as someone of the terminal operation team would intervene, e.g. by manually reallocating the container slots or closing the truck gate until the congestion in the yard is dissolved. Thus, this performance indicator should not be taken at face value. Instead, it highlights potential issues of problematic workload balancing in a comprehensible way.

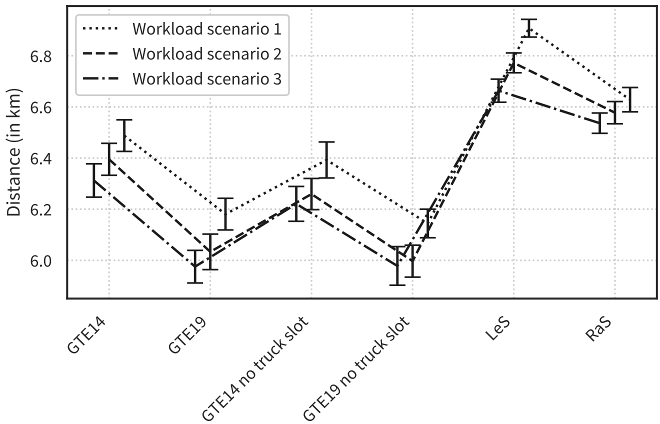

Figure 6: Daily average travelled distance of a yard crane

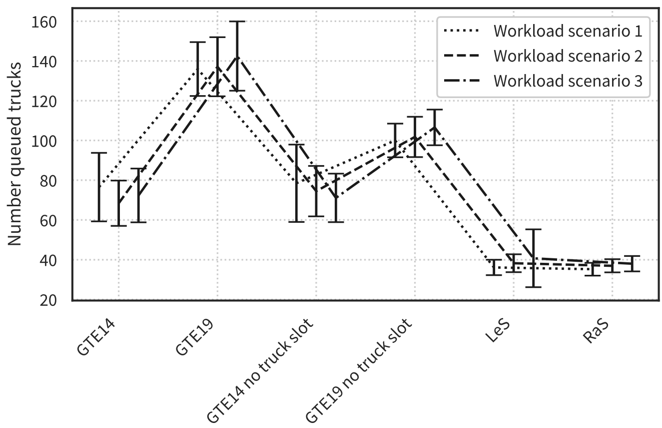

Figure 7: Maximum number of trucks waiting at a yard block

4.3 Discussion

The intermediate results in the two previous sections have provided some insights into the four rule-based heuristics GTE14, GTE19, LeS, and RaS for a given terminal layout inspired by the MSC Terminal Valencia and three given workload scenarios. In terms of lead time, GTE14 has shown superiority while GTE19 apparently struggled to handle the hinterland interface. For reshuffles and vessel turn time, the available TAS information during container slot allocation led to better results. At other times, the lack of the TAS information even showed benefits (e.g., Figure 7). This can be explained by the desire to reduce reshuffles by a consignment strategy-inspired approach and thereby concentrating a lot of work in a single yard block. When inspecting the container yard layout of Izmir as it is used in Güven and Türsel Eliiyi (2019), it can be seen that the container yard is surrounded by ship-to-shore gantry cranes in the West, North, and East. Hence, for each ship-to-shore gantry crane different yard blocks are identified as the closest and therefore the preferred location of stacking containers that will leave the terminal by vessel (Güven and Türsel Eliiyi, 2014). This is not directly transferrable to the layout used in this simulation study. At the MSC Terminal Valencia, all ship-to-shore cranes are lined up and thus the distances between the yard blocks and the ship-to-shore gantry cranes are much more similar. Therefore, the yard blocks close to the sea side are used more frequently. In such a situation, the heuristics might require an extension to ensure better work balance over the yard at the cost of longer yard truck travel distances. It is reasonable to have an operating ratio of yard cranes to ship-to-shore gantry cranes ranging from 2.6 to 2.8 (Sha, et al., 2021) which is currently not ensured by any of the heuristics – as for their assumed layout there might not have been such need.

5 Conclusions and Outlook

In this publication, first relevant rule-based heuristics were searched for in literature databases. In the subsequent simulation study, the performance of four of these retrieved heuristics were examined. For the two heuristics GTE14 and GTE19 which use information regarding the truck pickup time of the container, two variations are considered. In the first variation, the pickup time is assumed to be known before allocating the slot and in the second variation this information is (not yet) available. The heuristics are compared over four performance indicators that represent the time pressure and cost pressure terminal operators face and one to indicate the workload balance. The performance indicators highlight the strengths and potentials for improvement of the examined rule-based heuristics. Based on the observations, GTE14 shows the fastest lead times while GTE19 leads to the lowest travel distances of the yard cranes which in turn indicates a lower energy consumption. Depending on the operator’s requirements, however, the container slot allocation heuristic might need to trade some of the proximity of container slots to the later destination (ship-to-shore cranes for export/transshipment or to the truck gate for import) for a better workload balancing between the yard blocks. These insights, however, are only valid for the examined parameters of this simulation study, i.e. for this specific container terminal layout and the three specific generated workload scenarios.

At the time of writing, the rule-based heuristics of Voß, et al. (2016) are still missing. Furthermore, some publications focus only on the import process (e.g., Rekik, Elkosantini and Chabchoub, 2018; Jacomino, et al., 2019) or only the export process (e.g., Ambrosino and Xie, 2020). These might be also included in the comparison as soon as an appropriate replacement for each of the missing container handling processes is determined, so that the study can cover import, export, and transshipment processes likewise. Further baseline algorithms have been designed by van Asperen, Borgman and Dekker (2013) that might shed some new light on the results. Moreover, a larger amount of representative container terminal layouts (see e.g. Taner, Kulak and Koyuncuoğlu, 2014) might help to further examine the trade-off between minimizing yard truck travel distances and balancing the workload better between the yard blocks.

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Gantry Crane Scheduling and Storage Techniques in Rail-Road Terminals

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Purpose: *A rising global container throughput has necessitated the need for more efficient terminals. This work focuses on identifying past developments, important methods, key performance indicators and the future trends, related to the main decision tasks in an inland rail-road terminal. Prime focus is upon day-to-day operations performed on container entry through trains and trucks.*

Methodology: *A comprehensive systematic literature survey is carried out and a classification scheme developed, which is applied to the considered publications. Various techniques used to formulate the model and common solution approaches are identified for the key decision problems. Limitations in the current literature recognized and potential future research directions suggested.*

Findings: *Crane scheduling and storage space allocation are the most concentrated-upon problems. Simulation platforms have been largely used to model the problems and heuristics is the most common approach to solve other models. Time taken and costs involved are sought to be minimized.*

Originality: *In literature, marine container terminals have received greater attention as compared to inland terminals. Due to differing operation procedures, relevant research results from marine cannot be applied directly to railway terminals. Moreover, some of the existing works related to inland were found to disregard certain practical issues rendering them inapplicable for real applications.*

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1 Introduction

Globalization and the emergence of containerization has led to an enormous growth in freight transport over the years. Along with long distance maritime shipping, inland transportation corridors have experienced huge spikes in demands. The interfacial points where goods are transferred between the different modes of transport: terminals, act as crucial elements in this transport chain and are required to operate at highest efficiency (Guo, et al., 2018; Wang and Zhu, 2019).

Transport of freight essentially consists of many steps: choice of the transport medium (type and single or multi modal), management of the entire network, ancillary services like picking, packing & labeling, and the monitoring of the transit from seller to buyer. Multi modal mode is preferred for inter-continental transport using a single loading unit to tap into the advantages of all types of mediums. The main stretch of the journey is executed by deep sea vessels, trains & barges and the short connecting trips are on road (Dotoli, et al., 2013).

A lot of attention has been directed previously, towards the operations in a marine container terminal but literature on inland rail-road terminals is comparatively scarce. Due to differing operation procedures and rules, the relevant research results from marine cannot be applied directly to railway terminals (Wang and Zhu, 2014). Some of the existing works related to inland were found to disregard certain practical issues like container characteristics, rendering them inapplicable for real applications (Dotoli, et al., 2017). Hence, this work will concentrate on inland rail-road terminals.

Furthermore, the main focus is on operations that happen in a terminal, upon a container entry through train or truck, on a day-to-day basis. There are many decision problems based on the sequence of events that arise. Terminals aim at optimizing, the parking positions for trains and trucks, gantry crane scheduling, storage space allocation, train loading and energy consumption (Jaehn, 2013). Hence, these operation problems are focused on, in this study. Publications related to marine terminals or other kinds of inland terminals like rail-rail and barge terminals are not considered in this work. Concerning rail-road terminals, articles focusing on design and layout, as well as the train and truck routing and scheduling are also not considered.

The aim of this publication is to analyze the developments so far, to point out potential future research areas. To do so, an extensive literature review is conducted, and 67 papers finalized. A classification scheme for these publications is developed and applied to evaluate the current state of research, important methods, key indicators, and promising future research areas.

Chapter 2 presents an in-depth introduction to the field of intermodal transport, the related terminals types, rail-road terminals in detail, and the handling equipment and storage yards used. Additionally, a brief overview of the different operations that take place in a terminal on a daily basis is given. In chapter 4, the approach followed for the structured literature review, along with the search strings are shown. Chapter 5 presents the classification scheme and its application to all the considered publications. Brief explanations based on the different categories are then given. A summary of the prominent results and the potential future directions are listed in chapter 6.

2 Intermodal Transport: Overview

Intermodal transport can be broadly defined as the consecutive usage of two or more modes of transport for the movement of goods from one place to another. An important point to be noted is that the goods are transported in the same loading unit throughout without being handled themselves intermediately. The majority of the journey is through sea, inland waterways or by rail and the initial and last mile is usually covered on trucks by road, which is kept as short as possible (United Nations, 2001).

Intermodal terminals are the interfaces where all the transshipment activities happen between different modes. They act as vital elements in the freight transport chain connecting different shippers and carriers. The loading units can also be stored for a temporary basis before carrying on in their next leg of the journey. On a broad scale, these terminals can be of three types: Port Terminals, Inland Rail terminals and Distribution Centers (Rodrigue, 2020).

Rail-road terminals act as consolidation points for inland transport where containers are exchanged between trucks and trains. Generally, these terminals are small sized, with low container handling rate (300/day), short rail tracks (450-550m) and employing conventional technologies (Dotoli, et al., 2017). The terminals aim at maximizing the container throughput while keeping the waiting and processing time for trains and trucks at a low level. In recent years, there is a shift from road transport to other sustainable alternatives, mainly rail. Trains as compared to trucks require lesser amounts of energy to transport freight and also emit only a quarter of carbon dioxide per ton kilometer. The European commission has proposed a shift of around 30% by 2030 and 50% by 2050, for distances exceeding 300km (Garcia, 2015; Ricci, et al., 2016; Dotoli, et al., 2017; Otto, Li and Pesch, 2017).

The load units used to transport freight can be divided into three different sorts: the regular containers, semi-trailers, and swap bodies. A maritime container terminal handles only a handful kind of containers whereas the diversity in the case of a rail-road terminal can be pretty high. This leads to complications in terms of handling equipment and stackability (Carrese and Tatarelli, 2011; Bruns and Knust, 2012).

The core elements of a rail-road terminal are the driving roads for the trucks, rail tracks for the trains and storage yards to store the containers or other bulk goods for a short while of time. Small terminals make use of reach stackers for the transfer process and normally work on a one-to-one basis (one trackside space for both loading and unloading). In medium to large scale terminals, the transshipment of containers is carried out with the help of rail mounted gantry (RMG) cranes spanning the entire length of the tracks, functioning on a two to one basis i.e. distinct trackside areas for inbound and outbound containers (Boysen and Fliedner, 2009; Guo, et al., 2018).

A gantry crane is a kind of overhead crane with a horizontal bridge supported by two legs. The legs/portal are affixed on rails for movement (RMG) and is the most suitable handling option in a rail-road terminal. They come in a variety of widths & heights and can be powered electrically or by the conventional internal combustion engine. The rails of the crane run along the length of the railway tracks, with the portal moving on them facilitating motion. The cranes are equipped with a trolley to help in horizontal motion and a hoist/hook takes care of the vertical movement (Pap, et al., 2012). If more than one crane is sharing the same tracks, they are not allowed to cross each other and must always maintain a minimum distance to ensure safety. It is common practice to allot dedicated areas to every crane to avoid interference (static assignment), which can sometimes prove to be disadvantageous since terminals aim at minimizing the handling time. Assigning crane moves dynamically is hence catching up, making use of real time information systems with complex scheduling methods (Boysen and Fliedner, 2009).

Terminals aim at reducing the workload of the cranes and their efficiency is measured with crane rate and operating time. Crane rate is defined as the number of times a crane touches a loading unit. The cranes lift heavy loads and being heavy themselves, a lot of energy is expended when a crane operation is to be carried out. Some terminals might have fixed schedules of maintenance for the cranes based on specific horizontal distances they travel, and these maintenance checks can be time consuming and render the terminal inoperable (Jaehn, 2013).

Smaller terminals often use of reach stackers. They are more flexible and less expensive than gantry cranes. In cases of reshuffling, a crane just has to remove the containers that are placed on top of the required containers, whereas reach stackers need to remove all containers between itself and the target container. This has to be considered when choosing the handling equipment (Galuszka and Daniec, 2010; Pap, et al., 2012).

A key element of any terminal, storage spaces are used to store containers temporarily, which are unloaded from trucks and trains. Generally, stack piles three to four layers high can be observed. The assignment of these containers in the storage area, first into blocks if existing and then individually is one of the main decision problems in a terminal. Efficient storage space allocation ensures reduced retrieval times, reduced reshuffling, and increased throughput. The containers are broadly classified into inbound and outbound containers. Containers that arrive on trains from far off places, are stored for a particular amount of time and then carried away by trucks for delivery, are termed inbound containers. Whereas those that are brought in by trucks and leave the terminal on trains are called outbound containers (Wang, Zhu and Xie, 2017).

In these terminals, containers can either be placed directly on the ground and stacked one upon another, or on chassis. Loading containers onto chassis/skeletal trailers has an unusual advantage. These can be later picked up by trucks and need no further handling or crane supervision, hence minimizing double handling which would ensue if the containers were originally unloaded on ground. This is a common practice in North

America. The chassis can be parked parallelly to ease pickup and delivery or also at 60-degree angles to save space. Reefers/refrigerated containers need special provisions like power outlets and offsite depots can be used to store the empties (Rodrigue, 2020).

In medium to large scale terminals, it is a common practice to have two different storage areas. One along the tracks where containers can be unloaded momentarily or containers waiting to be loaded onto the next train can be pre-arranged. The second bigger storage yard which has many rows and columns allow containers to be stacked for an extended period of time. Containers in the temporary storage space can either be placed parallel to the direction of the train or even perpendicular depending on the orientation of the slot. It is a common practice, to store containers to be loaded on to the same train, or those that belong to the same client and will travel through trucks, together (Zeng, Cheng and Guo, 2017).

Freight trains typically travel at night and arrive at the terminals in the morning. They are processed throughout the course of the day and again depart by late evening. When a train arrives, it is assigned a vertical and horizontal parking position, where vertical basically refers to the particular track on which the train will enter and be parked. Horizontal positions are not very significant as the trucks can be parked right next to the target wagon of the train (Boysen, et al., 2013). The trailer or container loading locations are called slots. Utilizing the slots efficiently to increase the aerodynamic efficiency of trains has received some research attention (Lai, et al., 2007; Anghinolfi, Caballini and Sacone, 2014).

Trucks constitute an important means of transit in the inland transportation network, providing the much-needed geographical connectivity. Trucks are generally not bound by fixed schedules like for trains or vessels. The initial shipment from the client and the final delivery is facilitated through trucks. Though there is a drive to convert as much freight traffic from road to rail, the usage of trucks can never be eliminated owing their door to door delivery functionality advantage (Boysen, Scholl and Stephan, 2017).

3 Sequence of Events of Terminal Operation

The arrival and departure times of trains are prescheduled. Every container entering/leaving the terminal comes with certain necessary information: size, weight, position on the train and the corresponding client. Commonly, trains arrive on an entry/exit track and will be directed to a reception/dispatch track, where trains longer than the loading-unloading track are broken down. Once a loading/unloading track is available, the rail cars are moved onto it using a diesel engine. On completion of the required activities, the sequence of events is reversed (Garcia, 2015).

On arrival of trains, the containers are first inspected with regards to their destination. Some containers continue their journey by a different train, some depart by trucks, some are stored in the terminal, and some continue on the same train to a different destination. If the truck has already arrived, the gantry cranes directly unload the containers on the truck. For trucks arriving later, the containers are temporarily stored in the terminal. Those that will depart by another train are again directly shifted between trains provided the second train is on a parallel track already. After the completion of the unloading process, loading starts. If a truck carrying a container, arrives when the train is being loaded, the truck drives straight to the tracks and is unloaded directly by the crane. However, if it arrives earlier, the container will be stored until departure (Garcia, 2015).

A terminal can have two different kinds of storage areas, one under the gantry cranes next to the tracks, and the other located a few meters away. In terminals, the trucks can be loaded/unloaded in both the storage areas. Decisions regarding the patterns of storing are taken by the operator. The containers can either be placed on the ground or stacked one upon another. If stacked, it might result in rehandling when a lower placed container has to be retrieved, but it also implies a higher space usage. In order

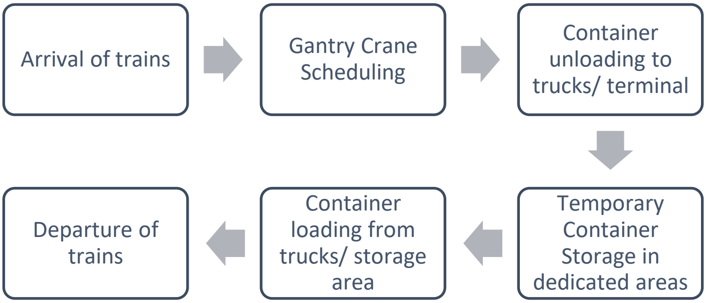

Figure 1: Daily Sequence of operations

to reduce the movements of the cranes in temporary storage next to tracks while loading/unloading, the containers are placed adjacent to the corresponding wagons (Garcia, 2015).

In total, there are three inter-related decision problems: First, selecting the storage area that minimizes container blockages. Secondly, pre-marshaling the containers based on the truck arrival information, utilizing the idle time of cranes. And finally, retrieving the containers from the storage area efficiently (Boysen, et al., 2013). The entire process is depicted in Figure 1: Daily Sequence of operations.

4 Research Focus

A widespread research on the most important scientific databases like Scopus, IEEE, Google Scholar, Research Gate and Science Direct was conducted. From this, an extensive foundation for the literature review was extracted. The keywords/search strings used for the search are shown in Table 1. The cited references for each of the attained papers are checked, and relevant publications meeting the focus of this work are added to complete the search. A total of 67 papers have been finalized for the analysis. These papers range from 1983 to 2020.

Figure 2 shows the paper count per year. A generally rising trend can be seen with a maximum number of publications in 2014. The paper count is expected to keep rising. Out of the total 67 papers, there were 3 papers published before 2000. In the next span from 2000-2005, 5 papers were brought out. 2006-2010 saw the field gaining considerably more attention with 17 papers being published. About 42 papers have come out so far in this decade. A lack of useful and sufficient literature with regards to the rail-road inland terminals in the early years is eminent. Concrete work dedicated to this field commenced from around the 2000’s, more so around 2004-2005. Hence, more importance has been laid to the papers from the past 20 years, with a couple exceptions from before, in which the problems were introduced, and the necessity articulated.

Table 1: Search Strings

Problem Specification		Target Location
Storage & pickup	Gantry crane scheduling	Intermodal rail-road terminals
Container stacking	Loading & unloading	Rail-road container terminals
Assignment of storage locations	Train loading/load planning	Inland intermodal terminals
Container relocations	Container assignment	Inland freight terminal

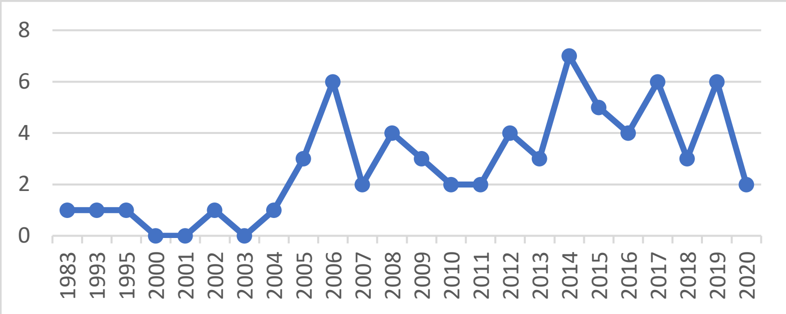

Figure 2: Publications per year

5 Classification

The papers are classified based on various parameters. Five main criteria are chosen, with 31 specifications in total. An overview of the classification parameters along with their individual specifications is given in Table 2. Every single specification can either be true/false, hence taking the value 1 or 0. This classification scheme is applied to the 67 chosen papers and is presented in Table 3.

Since the focus of this study is on the work that happens in a rail-road terminal after a train's arrival, many different decision tasks/problems can exist which are tackled independently. Hence, this is the first method of classification: by the aim or objective of the paper. The second step after aim recognition is to better understand the problems. For this purpose, the papers make use of techniques to model the problems. Hence, this is chosen as the next criterion for classification. The third criterion is the solution approach: after formulating the model, it is necessary to consider some constraints, make required assumptions and solve it, to obtain results. The next is key performance indices: to evaluate different models and to compare the results, certain parameters are necessary which can be quantified. The fifth and the last criterion is the continent of the terminal to which the paper is applied to.

Table 2: Proposed Classification Scheme

Classification Parameter		Specification
Aim/Objective	1	Storage Space Allocation Problem (SSAP)
	2	Selection of Resource Handling Systems
	3	Crane Scheduling Problem (CSP)
	4	Train Load Planning Problem (TLP)
	5	Minimize Reshuffling/Crane Rate
	6	Minimize Make span of container moves
	7	Others
Model	1	Simulation
	2	Integer Programming
	3	NP Hard
	4	NP Complete
	5	Binary Programming
	6	Optimization Problem
	7	Others
Approach to solve	1	Exact Solution Procedure
	2	Heuristics
	3	Genetic Algorithm (GA)
	4	Rolling Horizon
	5	Others
Performance Measure	1	Duration
	2	Cost
	3	Fuel Consumption

Classification Parameter		Specification
	4	Train Optimization
	5	Others
	1	Europe
	2	North America
	3	Asia
Application	4	Australia
	5	Africa
	6	Simulated Terminal
	7	No Application

Table 3: Classification applied to publications

	Aim							Model							Approach					Perfor-mance				
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	1	2	3	4	5
Anghinolfi, Caballini and Sacone, 2014				X									X			X				X				
Anghinolfi et al., 2012				X								X												
Boysen and Fliedner, 2009							X	X						X	X					X				
Boysen, Scholl and Stephan, 2017			X	X					X	X				X		X				X				
Bruns and Knust, 2012				X					X															
Bruns et al., 2014				X					X															
Caballini et al., 2008							X												X		X			
Carboni and Deflorio, 2020							X	X												X				
Carrese and Tatarelli, 2011	X				X					X				X			X				X			X
Cavone, Dotoli and Seatzu, 2016a						X		X												X				
Cavone, Dotoli and Seatzu, 2016b		X						X											X					
Colombaroni, Fusco and Isaenko, 2017					X			X									X				X			
Corry and Kozan, 2004				X				X	X	X						X		X		X			X	
Corry and Kozan, 2005				X		X						X				X				X			X	
Corry and Kozan, 2006a				X				X						X		X				X			X	
Corry and Kozan, 2006b				X									X			X							X	
Corry and Kozan, 2008				X				X	X							X				X			X	
Di Febbraro, Porta and Sacco, 2006							X	X																
Dotoli, Epicoco and Seatzu, 2015				X					X							X								
Dotoli et al. 2013				X								X												
Dotoli et al., 2014	X								X										X					X
Dotoli et al., 2017	X			X					X				X						X	X	X			X
Ferreira and Sigut, 1993							X	X													X			
Ferreira and Sigut, 1995							X	X																
Foti et al., 2012				X								X	X			X							X	
Galuszka, 2009			X		X						X					X								
Galuszka and Daniec, 2010					X						X					X								
Galuszka et al., 2010					X						X					X								
Garcia, 2015							X	X												X				
Garcia and Garcia, 2009							X	X												X				
Gronalt, Benna and Posset, 2007							X	X																
Guo et al., 2013			X						X		X					X				X				

	Aim							Model							Approach					Perfor-mance				
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	1	2	3	4	5
Guo et al., 2018			■			■			■							■				■				
Hejj, 1983		■						■																
Heggen, Braekers and Caris, 2014				■								■						■					■	
Jachimowski et al.,2018	■						■	■												■				■
Jaehn, 2013	■				■	■				■	■					■				■				■
Kostrzewski and Kostrzewski, 2019	■					■								■						■				
Kumar, et al., 2011				■			■																	
Lai and Barkan, 2005				■																		■	■	
Lai and Barkan, 2006				■																		■		
Lai, Barkan and Önal, 2008				■					■															
Lai et al.,2005				■																		■	■	
Lai et al.,2006				■																		■	■	
Lai et al.,2007				■																		■	■	
Lai, Ouyang and Barkan, 2008				■					■	■								■				■		
Malavasi, Quattrini and Ricci, 2006						■	■							■						■				
Mosca, Mattera and Saccaro, 2018		■						■												■	■			
Nie and Wang, 2019			■					■												■				
Otto, Li and Pesch, 2017			■											■	■	■				■				
Pap et al., 2012			■			■								■	■					■				
Rizzoli, Fornara and Gambardella, 2002							■	■																
Ricci, et al., 2016							■	■												■				
Stoilova and Martinov, 2019		■																	■					
Świeboda and Zając, 2016					■											■					■			
Wang and Zhu, 2014			■							■			■			■				■				
Wang and Zhu, 2019							■			■							■			■				
Wang, Zhu and Xie, 2014	■								■				■			■		■						■
Wang, Zhu and Xie, 2017	■		■										■				■	■						■
Xie, Wang and Yang, 2019			■																	■				
Zajac and Swieboda, 2014						■		■												■				■
Zajac and Swieboda, 2015a	■													■						■				
Zajac and Swieboda, 2015b	■													■						■				
Zając and ŻOŁĘDZIOWSKA, 2015	■		■													■				■				
Zeng, Cheng and Guo, 2017	■		■						■							■	■			■				

	Aim							Model							Approach					Perfor-mance				
	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	1	2	3	4	5
Zhang and Zhu, 2019			■										■			■				■				
Zhang et al., 2020			■			■				■			■				■			■				

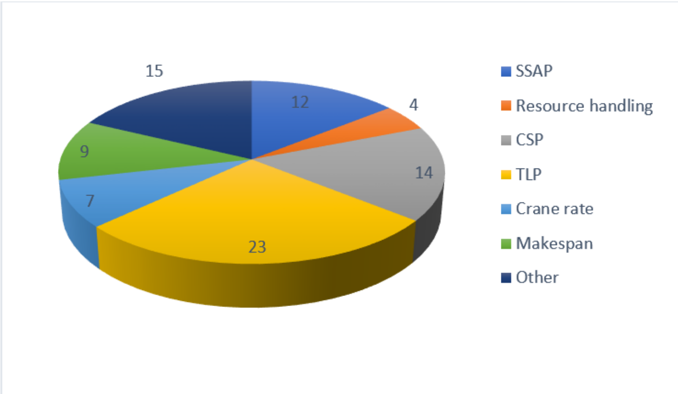

Figure 3: Classification based on Aims

5.1 Based on Aim/Objective Function

Categorizing the evaluated papers according to their aims gave rose to seven different subdivisions. Some of the papers have dealt with more than one problem also. 12 papers deal with the SSAP and 4 focus on resource handling. CSP has received the second most importance with 14 papers, behind TLP that is featured in 23 papers in total. The two optimization goals: make span and crane rate, have 9 and 7 papers respectively. 15 papers have been grouped in the other category, all of which are represented in Figure 3.

5.2 Based on Kind of Model

Many different methods of modeling have been found in literature, with some publications using more than one to compare between them. Figure4 gives the split of the papers and the respective counts. Simulation models have been utilized the most, in a total of 21 papers. Second most frequently used modeling technique is integer programming with 14 features. Optimization models have been used in 9 publications so far. NP hard and complete models are formulated 8 and 5 times respectively. 5

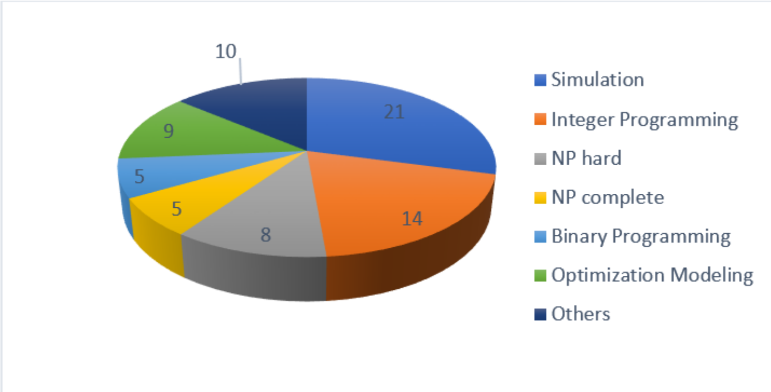

Figure 4: Classification based on Modeling Technique

papers are also found to make use of binary programming techniques. 10 other papers are found to use rare methods and are grouped together at the end.

5.3 Based on Approach to solve

Many different solution procedures are made use of, depending on the kind of solution sought. The problem can either be solved exactly to obtain precise solutions, or in some cases where that is not possible, other techniques come in handy to get a solution. In such cases, the problem is solved to optimality and often a comparison of many techniques is made to choose the best that fits the problem.

Even though GA is a kind of heuristic, due to the extensive use of this method in many publications, it has been set aside as a different specification. Multiple papers have also been seen to solve their models over a rolling horizon to account for the dynamic situations. To consider this, rolling horizon is taken as a specification as well. And the other non-frequent models are grouped together to one specification at the end. Almost every 1 in 3 papers are found to use heuristics, with 22 applications in total. Only 3 papers make use of exact solution procedures from the considered lot. 6 papers

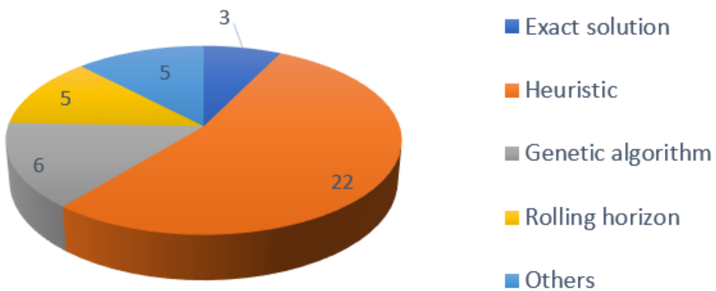

Figure 5: Classification based on solution approach

employ GA and 5 solve their models over a rolling horizon. 5 other papers are found in the 'other' specified group. Figure5 gives the split.

5.4 Based on Performance Measures

These are set as the objective functions in the papers while developing the models. Optimization of the performance measures is pursued, either maximization or minimization. Five main specifications, or sub-categories have been formed. The first being duration of operations (service time, waiting time, computational time, handling time, etc.), followed by cost (operations, purchase, maintenance, etc.). Fuel consumption is another important parameter which is to be reduced. Some parameters related to trains have been listed which are used in problem statements related to TLP problems. Like in other categories, the other left out functions are in the specification 'other'.

Close to half of the evaluated publications, 33 out of 67 have duration/time as their main/one of their objectives to optimize. 7 papers focus on reducing the costs involved and 6 on fuel consumption. Train specific parameters receive attention in 11 papers

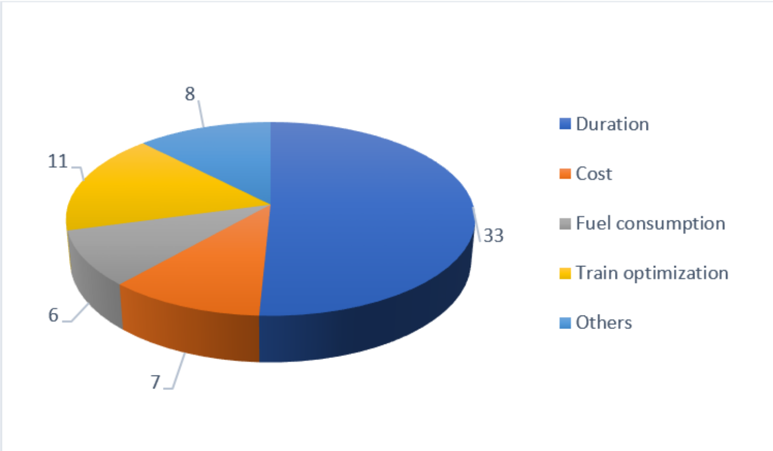

Figure 6: Classification based on Performance Measure

and 8 papers concentrate on other parameters as well. These are shown pictographically in Figure6.

5.5 Based on Continent

This section depicts how many publications have applied their findings to real terminals. Europe, Asia, North America, Australia, and Africa feature in the publications. Some of the papers develop a terminal in a simulation tool, not necessarily based on a specific rail-road terminal. And the remaining papers do not have any application of their approach to a real terminal, which make up the last specification.

Europe is found to be the place where a lot of work has gone into this field, with about 30 papers containing case study applications. 8 papers have focused on terminals and rail systems in North America. Asian terminals have been featured in 5 terminals in total.

Australia and Africa are the least common with 2 and 1 applications respectively.

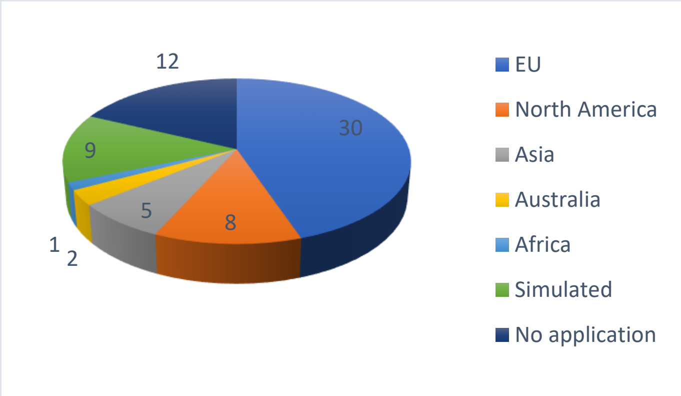

Figure 7: Classification Based on Continents

The pie chart in Figure7 gives a better idea. 9 of the publications considered, have constructed terminals in simulation platforms not necessarily based on a real terminal, and 12 papers do not have any application whatsoever mentioned in them.

6 Present and Future Research Areas

The main highlights of the present research are presented in this section. Gaps in the current state are identified and potential future research areas are briefly pointed out. Firstly, overviews for all the main aims are presented followed by a general summary.

6.1 Storage Space Allocation Problem

For the SSAP, division of yard into various zones and grouping of containers are commonly observed. The categorization might depend on factors like target locations, target trains, departure times, container sizes, and container owners among others (Dotoli, et al., 2014; 2017; Jachimowski, et al., 2018). Utilizing a grid pattern and positioning intermodal transport units (ITU) in defined sections, has proven to provide prominent outcomes (Jaehn, 2013). Some models and approaches have been further developed, which reduce train & truck service time and reshuffling of containers (Carrese and Tatarelli, 2011; Zajac and Swieboda, 2015).

Coming to the models and techniques, heuristics have been frequently used to get near optimal solutions (Carrese and Tatarelli, 2011; Jaehn, 2013; Wang, Zhu and Xie, 2014; Zeng, Cheng and Guo, 2017). Many two stage optimization models with a rolling horizon approach were developed and have proven to be very effectual to incorporate dynamic changes (Wang, Zhu and Xie, 2014; Wang, Zhu and Xie, 2017). An iterative procedure was suggested in Wang, Zhu and Xie (2017) which the authors proved to be very efficient for container assignment.

However, not much research has been focused on the integrated gantry CSP and SSAP. One of the papers Zeng, Cheng and Guo (2017) has formulated a mixed integer programming model and used the backtracking search algorithm (BSA) to solve it. To evaluate the performance, an artificial bee colony (ABC) algorithm and GA models are applied, for comparison. BSA has proven to be the most appropriate among the methods to solve small, medium, and large size problems (tasks and number of cranes)

This integrated crane scheduling and container assignment problem can receive more attention (Jaehn, 2013). Previously suggested models can be applied to real terminals as case studies and further new models and approaches developed. The problem can be further assimilated with the truck scheduling problem, thus considering the terminal as a whole merging the front-line operations to the backyard (Zeng, Cheng and Guo, 2017).

Increased use of mathematical programming models can help to incorporate real time scenarios and restrictions (Dotoli, et al., 2014). Simulation can be a tool which can be used cost efficiently, to inculcate stochastic parameters stimulated by real life information. Some previous works have used simulation for automatic container storage systems but not much application has gone into rail-road terminals (Kostrzewski and Kostrzewski, 2019).

Decision support systems (DSS) are designed to help the decision maker to keep a check on unpredictable events, providing more flexibility (Dotoli, et al., 2014; 2017). DSS can act as useful tools for optimization and automation. It can be directly interfaced with the existing software in the company, making it easily implementable. The DSS used in Dotoli, et al. (2017) can be further tested by applying to more case studies and also, observe under different scenarios, how the terminal performs with a what-if analysis. More applications of DSS for storage allocation problems can prove to be fruitful.

Additionally, a storage approach which takes into consideration and manages, the containers arriving and leaving the terminal at the same time, can be useful. When it comes to the piling of containers, some stacking restrictions were overlooked in previous literature, these might prove to be important as terminals usually operate with different sized containers (Jaehn, 2013). Automated storage space assignment models under uncertainty (delays in trucks and trains causing undefined arrival-departure times of containers) is another area which can be looked into (Wang, Zhu and Xie, 2017)

6.2 Resource Handling

Since handling equipment involve large initial investments, simulation is chosen as the most suitable method for this objective, which allows to study different kinds of scenarios and combinations before a purchasing decision is made (Mosca, Mattera and Saccaro, 2018). The selection of handling resources is found to chiefly depend on factors like cost of procurement, operational costs, stacking capacity, environment friendliness, maintenance costs and flexibility (Stoilova and Martinov, 2019). Small rail-road terminals serving lesser load find reach stackers most suitable. However, for medium and large rail-road terminals, compared to combinations involving reach stackers, techniques which involve gantry cranes are more cost effective (Stoilova and Martinov, 2019). As a result, waiting times for trucks are also found to be reduced. However, the initial investment for a crane is significantly higher, including other costs like floor reinforcement costs, which acts as a trade-off.

Multi criteria decision making methods (MCDM), like the name implies, finds its use when several alternatives are to be evaluated before making a choice. Stoilova and Martinov (2019) studied how this could be applied to a yard handling equipment problem but it hasn’t yet been applied to a real terminal. This could be a potential future application to inspect an existing terminal or also before designing a new one. MCDM methods can also find its appliance to review other kinds of handling equipment or even other sorts of intermodal terminals. Further, it can be beneficial to study if advanced petri nets like colored and fuzzy, can be used to model and solve certain optimization issues (workflows and their processing times, to differentiate container typologies and control strategies with ambiguous information) (Cavone, Dotoli and Seatzu, 2016b).

6.3 Crane Scheduling Problem

A variety of modeling techniques have been used to formulate the CSP. Pap, et al. (2012) uses an exact solution approach. This is obtained using a Branch and bound method, whose implementation is straightforward and requires no additional costs. This is one of the first and noteworthy contributions to the CSP and to intermodal terminal optimization in general. Apart from the exact solution, heuristics have been used most commonly to solve the problem. A model based on Discrete Artificial Bee Colony (DABC) algorithm is proposed, which attains near optimal results within acceptable times. Compared to a GA, the DABC model is found to present better results making it a valuable technique to tackle CSP (Guo, et al., 2013). Alternately, an Ant Colony optimization model also gives near optimal results and is found to be another efficient algorithm to handle CSP problems providing reductions in idle and total handling times (Wang and Zhu, 2014).

A nearest neighbor heuristic has been used to solve a CSP for a special case of multi trailer trucks (road trains) (Boysen, Scholl and Stephan, 2017). Further, a Fix & Optimize approach is suggested to solve a CSP with External Trucks and is found to give favorable results (Guo, et al., 2018).

A BSA is proposed to solve the integrated SSAP and CSP, whose performance as compared to a GA and ABC model is found to be considerably better (Zeng, Cheng and Guo, 2017). The first promising future research could be the application of the DABC, BSA, nearest neighbor heuristic and branch bound models to real terminals and study their behaviors. Some assumptions were made in previous models regarding container dimensions, hence planning crane scheduling considering containers of different size as well as types could be a research direction. Similarly, most of the papers so far have not considered rehandlings when scheduling the crane moves and needs to be looked into (Wang and Zhu, 2014).

Another approach could be the integration of objectives of other stakeholders like transport providers, into the CSP (Guo, et al., 2018). Additionally, application of the Fix & Optimize algorithm proposed in Guo, et al. (2018) to other kinds of optimization problems can be studied. In terms of innovative concepts, a possible attempt could include applying the hybrid scheduling mode of multi-line flexible range loading and the synchronous handling mode to real terminals to study their complexity and also validate them (Xie, Wang and Yang, 2019; Zhang and Zhu, 2019; Zhang, et al., 2020).

6.4 Train Load Planning Problem

The TLP problem as a whole is complicated, making it difficult to get solutions for real size problems quickly through conventional methods. Hence, the model is usually broken down and meta heuristics are made use of, to arrive at near optimal solutions in a reasonable time frame (Corry and Kozan, 2005). The models are developed considering dimensions of containers, required number of pin changes, train height, separation of dangerous goods, maximum axle loads and weight constraints for wagons (Corry and Kozan, 2004).

Simulated annealing (SA) and local search (LS) heuristic models have been used in many articles, out of which SA has proven to be superior in most cases. However, LS takes lesser computation time, making it suitable in some special requirements (Corry and Kozan, 2004; 2005; 2006a; 2006b; 2008). These approaches and models act as a flexible framework for implementing to a range of terminal systems. It can be useful to apply the developed SA models and assignment models to more cases of real terminal systems and hence further validation of these models. The assignment model developed in Corry and Kozan (2006b) currently only applies for containers of same size. This can be extended to deal with different kinds of loading units as well as considering other aspects of a real case scenario.

Parameters like slot utilization, slot efficiency and use of empty loads and their effect on fuel consumption, aerodynamic efficiency and costs have been studied. An automated wayside machine vision system was also developed and an assignment model for load planning proposed (Lai, et al., 2005; Lai and Barkan, 2005; Lai, et al., 2006; Lai and Barkan, 2006; Lai, et al., 2007; Lai, Barkan and Önal, 2008; Lai, Ouyang and Barkan, 2008).

Similarly, the machine vision system proposed, has been developed and applied to trains and terminals in America. The usage or adaptability of such models in the European market can also be studied.

A DSS is also developed with very less computational times hence permitting changes even in the last instant, thus proving to be a great tool for optimization and automation (Dotoli, et al., 2017). Models to plan many trains together are formulated using a rolling horizon approach. And to ensure feasibility in all kinds of situations, a robust load planning model is developed (Bruns, et al., 2014). Real time train planning being integrated with real time crane routing can receive some attention in the future (Corry and Kozan, 2008). The DSS can be improved to include uncertainty, using fuzzy or stochastic programming methods. Improving the robustness models by trying to include uncertainties and also recoverable robustness (a greater choice to react to changes in parameters) (Bruns, et al., 2014).

Usage of CPLEX solvers is found to be satisfactory. These CPLEX solvers are extensively used in the logistics and transportation industry to tackle linear programming problems (Foti, et al., 2012). Loading plans of special cases like, one crane loading more than one train in a contemporaneous manner (Foti, et al., 2012). Another research study could be the combined planning of multiple trains, operated by the same operator departing from nearby terminals (Heggen, Braekers and Caris, 2014). Concerning train loading from road trains, to decide the division of containers across multiple deliveries, remains unsolved (Boysen, Scholl and Stephan, 2017). This model also needs to be validated for a real terminal.

6.5 Minimize Crane Rate

A new heuristic method called STRIPS representation is used to tackle this objective in many papers and it has given a good result (Galuszka, et al., 2010; Galuszka and Daniec, 2010). One of the articles Colombaroni, Fusco and Isaenko (2017) presents a double GA with trust region which provides an additional 5% reduction in the total costs.

The STRIPS representation analysis method presented is mainly applicable for reach stackers but not for cranes. It can be investigated if the same method can be adapted for cranes too, when evaluating larger sized terminals. The double GA method presented is for a situation involving a single crane. The same can be extended to analyze multi crane scenarios. Work needs to be done to also include and study reshuffling involved in dealing with intermodal terminal units of different sizes.

6.6 Minimize Make span

A queuing theory model was developed which has been widely adaptable to different kinds of terminals, dimensions and technologies and hence can be made use of to evaluate the existing terminals as well as while planning new terminals (Malavasi, Quattrini and Ricci, 2006). Applying the queuing theory models to more terminals in the form of case studies and fine tuning it would be a potential work. An approach to compute the total transport time of the goods by integrating the queuing theory model into a broader, more holistic model can be carried out.

In a different publication, a first order hybrid petri net model is proposed which worked well in an open loop condition but not so much in a congested state (Cavone, Dotoli and Seatzu, 2016a). Application of the petri net model to the congested situation needs to be investigated further. The further usage of petri net models to terminals handling other means of transport can be studied.

6.7 General

Simulation models have been used from a long time to evaluate alternate scenarios and make a comparison to choose the best fit, averting expensive investments. They can be used to design and study a wide variety of operations in a terminal. Specific simulations like monte carlo simulation can be employed to identify critical issues, the possible bottlenecks and take necessary actions (Cavone, Dotoli and Seatzu, 2016b). Simulation tools can also serve to evaluate new potential markets.

Mathematical programming models out of all the analytic models are found to be efficient in incorporating limitations and real characteristics (Dotoli, et al., 2014). Exact solution approaches like branch and bound do not involve additional costs for implementing and are found to be user friendly (Pap, et al., 2012). Complicated problems where exact solutions cannot be obtained in reasonable times, are resolved with heuristics. Computation times required in solving these heuristics dictate their application further.

A novel double GA suggested in (Colombaroni, Fusco and Isaenko, 2017) provided better results as compared to a single GA. This can be used to study other optimization problems in the terminal. An MCDM method can be applied to situations involving many criteria before a decision is made. Further, DSS provide high flexibility, and can be used for dynamic scenarios. They can be directly integrated with the existing company software and hence all in all act as a wonderful tool for optimization and automation purposes.

Coming to the future trends, a lot of attention has gone into the energy efficiency problem recently, but a majority of it concerns the marine terminals. Some works are being tailored to the inland intermodal terminals, and to promote environment protection and sustainable development, more attention can be focused on this. A study which concentrates on the effect of indirect energy consumption in rail-road terminals can be included (Wang and Zhu, 2019).

With regards to the external customer trucks, the European and American systems mainly have two different strategies. In EU, the trucks are permitted in the transshipment region whereas in America, the external trucks drop off the containers in the holding areas which are then moved by trailers internally. Both the techniques have their respective advantages and disadvantages. A comparison of the policies can be undertaken (Boysen, et al., 2013).

In the same field, allotment of parking areas to trucks which come into the terminals for dropping off or/and picking up a container has not been dealt with much (Boysen, et al., 2013). In some situations, such as when a train arrives, there might be congestion which leads to delay, hence this is an area which can be explored. A work to study how changing the parking positions of trains can lead to better train processing in tandem with the yard partition problem (Boysen and Fliedner, 2009).

With regards to the container moves assignment to different cranes, many papers have so far concentrated on the static approach (with cranes having separate working areas) but not on dynamic (overlapping working areas). Improvement in crane and terminal efficiency can be seen with the latter (Wang and Zhu, 2014; Otto, Li and Pesch, 2017).

A holistic modelling approach which considers gantry crane scheduling, storage space allocation and TLP problems together has not been undertaken yet (Bruns and Knust, 2012; Heggen, Braekers and Caris, 2014; Otto, Li and Pesch, 2017). Further, exploring different critical scenarios in the operation of the terminal and applying the existing models or developing new ones to enhance terminal resilience (Carboni and Deflorio, 2020).

7 Conclusion

The chief objective of this work is to assess the current state of art with respect to inland rail-road terminals. An extensive literature review was conducted, and 67 relevant publications identified. A classification scheme was developed and applied to the chosen articles. In this scheme, the papers were mainly categorized based on their principal aims or objectives, the kind of models the authors develop to represent the problem, the solution approaches introduced to tackle these models, the key performance indicators used to quantify and compare the results as well as according to the continent of the real case terminals these models are applied to.

A broad overview of the individual categories with their respective publications has been provided. The research area consists of the operations performed when a train and truck arrive at a terminal. It was found that the papers mainly focused on decision tasks like SSAP, CSP and TLP problem among others. Simulation models were found to be used in around half of the papers reviewed, with integer programming, binary programming, optimization modeling and NP models also being occasionally applied. The models were either solved exactly or to near optimum using heuristics of different kind. The objective functions formulated mainly aimed at minimizing the time duration of operations and the costs involved. With regards to case studies on real terminals, about half of the papers were based on European terminals, whereas about one-third of the papers are still theoretical with no practical validation. And finally, the prominent results in each operation problem were listed and possible future research areas recognized.

Overall, the past developments in the topics of scheduling of gantry cranes and container storing strategies are presented and the gaps in literature identified. Key factors are summarized, and the essential methods detected. Judging from the current state, a lot of developments have been happening recently in the domain of inland rail-road terminals along with many works being published. Still, a lot needs to be done and for this, the possible future research directions are listed.

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V. Sustainability

Sustainability: The Italian Case of Eco-Sustainable Contract

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Purpose: *The ecological analysis of contract law allows one to grasp the evolution of the role of contract from that of its traditional function of exchange or circulation of individual goods to that of shared enjoyment and management of common goods.*

Methodology: *Development becomes sustainable in terms of the realisation of human wellness and quality of life, when the full and free development of the human person is assured. The concept of sustainable development brings with it the complexity of values and principles that must be coordinated by using proportionality as an ordering criterion. Environment, market and property constitute a unitary experience.*

Findings: *An eco-sustainable contract is one of the options available for the construction of another economy, one that is circular and shared, supportive and sustainable, in which one asks not only for a product or a service on which the quality of both present and future life depends but for true social and environmental interaction.*

Originality: *Contract loses its proprietary connotation in order to be able to achieve economic benefits that are not directly proprietary, compatible with the full development of human beings, in the light of personalism and solidarity, supporting a move away from proprietary rights in the civil law.*

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1 Sustainability and the Principle of Sustainable Development

This work examines how sensitivity to environmental impact has begun to influence contract law. The goal is to identify the legal framework best suited to the parties' pursuit of their respective interests in a manner that is both constitutional and at the same time in keeping with the tenets of sustainability, solidarity and subsidiarity.

Ideally, the best framework would be both technically sophisticated and flexible, with a focus on applying law to facts, allied to an ability to adapt as the stakeholders' needs require. After all, a framework that is unyielding would be unable to keep pace with the swift changes that technological development is generating in contemporary society.

The interplay between the marketplace (driven by metrics of productivity and the securing of a competitive edge) and the environment (which in turn is intertwined with principles of human dignity and social justice) meets through the principle of sustainable development (Persia, 2018). The assertion of fundamental human rights becomes the means through which a sustainable market can be cultivated, one that might stem the tide of our current environmental crisis. Business operations that are not sustainable harm the individual and the community, to be sure, but they also harm the market's social economy. Competition in the market must be coupled with social stability in order to combine what is useful with what is just.

Sustainability is something quite different from a kind of arbitrary pursuit of *environmental protection*, which fails to take into account the demands for development. The essence of sustainability lies in the understanding that true environmental protection is geared towards protecting humans, and it cannot come about if the needs of the current generations for development are unduly frustrated.

Sustainability predicated solely on environmental protection cannot be reconciled with the need for development, which is intrinsically connected to the protection of the human race. Consequently, sustainable development is not only the point where progress and the environment meet but also a concept that affirms their mutual interdependence, exposing it for the symbiosis that it really is. There is no protecting the environment without allowing current generations to thrive, and there is no future growth of generations without safeguarding the environment (Cappelli, 2019).

The principle of sustainable development entails a broader dimension than just the environment. For this reason, environmental concerns are not simply ranked with other values, but rather must be viewed through a more complex and more holistic lens (Cappelli, 2019). However, there is no well-defined idea of what is meant by sustainability and the rules of conduct through which that concept is expressed. It is a question of trying to reflect on the ordering potential of the *indeterminateness* of principles so as to establish whether it is necessary to identify rules of conduct that can be classified as eco-sustainable or whether indeterminateness, which is typical of rules based on principles (an example is the Italian Constitution), is not an advantage at all.

From this vantage point, one can see the important role that contracts play. They are the pre-established tool intended to govern not the clashing of opposing interests but rather the pursuit of a plurality of convergent interests (Pennasilico, 2018). The goal is to meet the needs of current generations without jeopardising the quality of life and the opportunities available to future ones (Article 3-*quarter*(1) of the Italian Environmental Code). A review of the elements of contract is called for so as to enable an assessment of the influence of environmental concerns (i.e. the reasonable and responsible use of natural resources) in the implementation of the principle of sustainable development. A contract may overcome the constraint of privity (see Article 1372 of the Italian Civil Code, which provides a "contract has the force of law as between the parties") and serve instead as an agreement that protects unknown third parties, and in so doing become eco-sustainable.

2 Ecologically Oriented Contracts and the Right of Ownership in Italy

The best known definition of sustainable development is contained in the 1987 Report of the World Commission on Environment and Development (the so-called Brundtland Report): it is development "that meets the needs of the present without compromising the ability of future generations to meet their own needs".

This notion "carries with it antinomian tensions, since, on the one hand, it postulates a constant need for society to evolve towards greater wellbeing, while, on the other hand, it sets a sustainability limit to development, which refers to the needs both of environmental protection and of rationality in the use of natural resources" (Pennasilico, 2016).

During the World Summit on Social Development, the pillars of sustainability were set out: "freedom, equality, solidarity, tolerance, respect for all human rights, respect for nature and shared responsibility" (Art. I.4, United Nations General Assembly Resolution A/60/1 of 15 September 2005). The Earth Charter also seems to contain the basis for "a sustainable global society founded on respect for nature, universal human rights, economic justice and a culture of peace" (The Earth Charter of 2000).

There have also been attempts to translate the principle of sustainability into specific rules of conduct. As in the case of the UNEP (United Nations Environment Programme) and the UNWTO (United Nations of the World Tourism Organization), which have listed some rules of sustainable tourism.

In particular, "tourism businesses are required to make optimal use of environmental resources, maintaining essential ecological processes and helping to conserve natural heritage and biodiversity, and to respect the socio-cultural authenticity of host communities" (Landini, 2016). Moreover, Article 3(3) of the Treaty on European Union clearly states that the Union "shall work for the sustainable development of Europe based on balanced economic [...] and a high level of protection and improvement of the quality of the environment", while at national level Article 4(4)(a) of the Italian Environmental Code states that environmental impact assessments must ensure a high level of environmental protection and that plans and programmes are to "contribute to the conditions for sustainable development".

The idea of sustainability is based on integrating principles and values, even if they are apparently at odds with each other. In this sense, the principle of sustainable development requires one to reason not in a logic of hierarchy of values and principles but in a logic of complexity of values and principles coordinated by using proportionality as an ordering criterion (Landini, 2016).

The ecological analysis of contract law allows one to grasp the evolution of the role of contract from its traditional function of exchange or circulation of individual goods to that of shared enjoyment and management of common goods. The concept as codified in Article 1321 of the Italian Civil Code, which defines a contract as "an agreement between two or more parties for the purpose of establishing, regulating or terminating an economic legal relationship between them", appears insufficient unless it is accompanied by notions of solidarity and sustainability in the responsible use of natural resources, such that today contracts would give rise not only to proprietary rights but also to the right to claim *sustainable* proprietary rights, which are intended to satisfy the needs of human beings (Pennasilico, 2016).

In this context, contracts would not only express their function in terms of reward or utility, but they would also have a corrective function in the marketplace against the waste of natural resources, overconsumption and environmental damage. The goal that *ecologically oriented* contracts hope to reach is not to protect nature per se but rather to safeguard humanity's ability to survive in a manner consistent with the principle built into Italy's and Europe's constitutional framework, which is the "full development of human beings" (see Article 3, paragraph 2, of the Italian Constitution and the Preamble to the Charter of Fundamental Rights of the European Union).

In Italy, such a contract has not yet been embodied in law, but the aim is to arrive at considering it not as another merely descriptive allegory but as a category capable of grasping and fostering new interpretative, applicative and systematic developments, in accordance with the Italian-European constitutional public order (Pennasilico, 2018).

Indeed, the proprietary model by itself appears incapable of providing a suitable answer, since the idea of ownership under the law has primarily developed around the owner's right of alienation. The model is that of the circulation of assets subject to the law, under the aegis of a marketplace focused exclusively on production and trade (S. Persia, 2018). Adherence to that purely individualistic approach, with the owner at the fulcrum, can be seen, *inter alia*, when one analyses the right of use and enjoyment intrinsic to the right of ownership. The crucial attribute is that of having the power to exclude others from using or enjoying the asset subject to the interest.

The traditional structure of ownership intentionally glossed over the multi-dimensional quality of the concept, ignoring the fact that certain assets constitute an intersection amongst a variety of legally cognisable interests, each deserving of protection, which transcend the owner's official status and instead focus on a plurality of parties.

The *theory of communal property*, without delving into the complexity and the challenge of that particular debate (Carapezza Figlia, 2008), can be credited with embracing the existence of interests other than proprietary interests in the relationship between humans and assets, interests that relate more closely to the fundamental values of the person and to social solidarity (Persia, 2018).

In light of the strict connection between communal property and fundamental human rights (health, for example), an individual's ownership and proprietary claims must co-exist with the non-proprietary interests of the community.

From this perspective, there are certain ancient forms of communal property rights that provide a paradigm. In those times, land was considered the theatre and fulcrum for the values of the local community, the environment, and the landscape. These were not strictly defined structures but rather an uninterrupted generational chain, where the position of any individual would never be detached from the organic structure of the person's home community (Pennasilico, 2018). And it is precisely a view of land as an *ideal value*, a non-proprietary asset, and thus one intended for conservation, with value beyond mere economic value.

From this perspective, the interest held by the owner would not fall into the traditional *use and enjoyment* and *rights of alienation* under Article 832 of the Italian Civil Code (which provides that "the owner has the right to enjoy and dispose of things fully and exclusively, within the limits and in compliance with the obligations established by the legal system").

The enjoyment of the land ends up being a *consideration* such that the right of use and enjoyment, in order to be exercised, demands that the asset be protected from deterioration. The right of alienation, in turn, can be nothing other than functional to such right of use and enjoyment, and is identical to the right to manage the asset in order to protect it from deterioration. Thus, ownership is unshackled from that traditional concept of income, it is no longer the economic profit of the individual arising from use of the *asset*, but rather a communal interest, which makes the common interest in the ideal enjoyment of the asset legally cognisable.

On the one hand, the debate takes up the interest in a more circular than individual management of assets. On the other hand, it requires the sloughing off of the 19^{th}-century-style doctrine of exclusive ownership rights. Natural resources are relevant first and foremost in terms of their preservation and protection against waste. Only then can the circulation of legally cognisable interests therein be considered. They require models of management that ensure communal enjoyment of the asset in accordance with the tenet of intergenerational safeguarding of their utility.

Article 42, paragraph 2, of the Italian Constitution (which provides that "[p]rivate property is recognised and guaranteed by the law, which prescribes the ways it is acquired and enjoyed as well as its limitations so as to ensure its social utility and make it accessible to all") allows for the imposition of limits on proprietary absolutism in order to safeguard certain constitutional values, such as human health, and environmental protection pursued in the interest of the community as a whole.

The desire to align the proprietary interest in using the asset and the non-proprietary interest in preserving natural resources influences the rights of alienation and use/enjoyment held by the person in whom the proprietary interest is vested, and determines the ecological compliance thereof (Persia, 2018).

It appears to flip one of the central issues of the law on its head: the scope of the interest. One can no longer define the *minimum reach*, meaning clarifying the limits within which the legislator might influence the rights of ownership, which are potentially unlimited. Instead, it involves defining the *maximum reach*, meaning setting the limits beyond which a proprietary interest can no longer exist. One must gain an understanding that certain rights, if not functional to the (non-proprietary) interests of the community, are per-se *beyond the scope of ownership*. The maximum reach of the interest does not encompass the right to influence the life of the land and of other persons. This means that beyond ownership lies a communal asset, the community's access to and enjoyment of which cannot be denied, in that it serves the function of satisfying fundamental, constitutionally protected collective interests. In other words, proprietary rights would end where a communal asset begins (Pennasilico, 2018).

Land is a living and vital reality that stands alone in terms of independent value as a productive asset (*res frugifera*) worthy of attention and care because, thanks to its fecundity, it ensures a community's survival.

3 Sustainable Development and the Constitution

The issue of the environment and sustainable development must be tackled using a comprehensive and holistic approach, leveraging the plurality and diversity of available sources (Pennasilico, 2012; Perlingieri, 2016). Development becomes *sustainable* not because of a country's GDP, but through the degree of wellbeing generated, and the quality of human life, when it ensures the full and free development of human beings (Perlingieri, 2016).

On the one hand, sustainability has long since made its way into the realm of individual rights through the implementation of the principle of subsidiarity codified in Article 118 of the Italian Constitution. In franchising agreements, for example, the franchisee might be requested to abide by certain eco-sustainability standards; supply agreements between businesses might require the supplier to commit to producing products according to production standards which are based on a set of sustainability criteria (Landini, 2016). Consequently, citizens, whether alone or in association with one another, have ever greater standing in terms of asserting communal interests. If subsidiarity and contracting can serve to subject communal interests to a set of rules, then a contract is no longer simply a tool to govern the individual and self-centred interests of the parties to the contract (Perlingieri, 2016).

On the other hand, whilst the principle of social utility under Article 41 of the Italian Constitution does not represent an external limit to freedom of enterprise, it does serve to shape it. This requires abandoning a structuralist view of the law and subscribing instead to a more functional approach in order to provide measured responses to concrete needs.

Moreover, the Treaty of Lisbon (Articles 11, 191, 192 and 193) and European case law (ECJ, 14 October 2004, C-36/02) stand for the proposition that human beings should be placed at the centre of the legal system.

Environment, market, and ownership join together in a holistic experience, under which the contract loses its purely asset-driven connotation (Perlingieri, 2016) but instead becomes an option for generating economic utility that is not strictly ownership-based and that is compatible with the full development of a human being. Such in light of the principles of personhood and solidarity, following the trend in the law to move away from a focus on proprietary interests (Perlingieri, 2016).

The impossibility of reconciling the demands of economic development with protecting the ecosystem is a myth that has now been debunked, as made clear by the influence and expansion, both in terms of systems and in terms of mores, of the Italo-European principle of sustainable development. Contracts, in this circularity between environment and market, are now a bearer of not only proprietary but also non-proprietary interests, are consonant with the full development of human beings and are gaining traction as the source of standing to assert non-proprietary interests in sustainability.

The classical notion of contract under Article 1321 of the Italian Civil Code proves insufficient unless complemented by the principles of solidarity, subsidiarity and sustainability. Moreover, the Italian Environmental Code, which provides that any human activity, be it public or private, must abide by the principle of sustainable development (Article 3-*quarter*(1)), bolsters the requirement that any contracting – whether in the public or private sector – must be informed by and comply with the demands of environmental sustainability, "in the communal interest of safeguarding the type of environment where a healthy life can be enjoyed now and in generations to come" (Pennasilico, 2018).

This context would seem to be witnessing the emergence of the concept of a so-called *eco-sustainable* contract, which aspires to claim the role of a new type of contract even if at first sight it seems similar to consumer contracts and contracts between business enterprises in terms of information asymmetry and the consequent need to rebalance contractual positions.

According to its supporters, an eco-sustainable contract differs from the latter because "the environmental interest penetrates and colours the purpose of the contract, emphasising both the convergence of the interests of the contracting parties on environmental benefits, despite the initial asymmetry of information, and the duty to rationally use natural resources for the benefit of future generations". From that standpoint, the principle of sustainable development constitutes a parameter for judging the worthiness of such contracts, with the consequence that, for example, a *green* contract, even if it pursues a lawful purpose, may not be worthy of protection if it is not apt to achieve the concrete environmental interest and hence would not be upheld by the legal system.

The role of contract evolves from the traditional function of exchange or circulation of individual goods to that of shared enjoyment and management of common goods. The very notion of contract pursuant to Article 1321 of the Italian Civil Code would therefore need to be complemented by principles of solidarity and sustainability in the responsible use of natural resources, with the consequence that contracts, today, would be a source not simply of economic legal relations but of sustainable *economic* legal relations (Pennasilico, 2016).

The contract is thus enhanced because the values implicated therein are set by a higher authority, that is the Italian Constitution. In this respect, one notes that contracts are predicated on the principle of reasonableness, or the set of values and principles of the law and the State, on which any analysis of the contract's framework would be premised (Perlingieri, 2016).

4 Moving Beyond Privity of Contract - the Concept of Wellbeing

It is in the very interplay between contracts and the environment that we might move beyond the limits of privity (Article 1372 of the Italian Civil Code). Indeed, the effects of an eco-sustainable contract would not be limited to those in privity of contract, but would impact third-party (current and future generations) interests in using and enjoying communal property. Within this framework, self-governance in the private sector plays a role in establishing rules for, and exercising, common interests, such that the legal acts stemming from private initiative that satisfy general environmentally related interests (communal property for the use and enjoyment of many) create standing in third-party beneficiaries.

Contractual standing will take on a much more dynamic and intergenerational dimension, one poised to involve anyone who, whether before or after the execution of the contract, interacts with the asset. Contracts will be intended to help realise human fundamental rights, and in so doing, contribute to the implementation of social justice. Thus, the equilibrium between the performances on either side of the contract becomes the ideal foundation for the judicious circulation of assets and for a fruitful cooperation of individual freedoms and activities (Persia, 2018).

Although the Italian Constitution does not make express reference to sustainable development nor, consequently, to any responsibility toward future generations, individual standing to protect the environment and the ecosystem is based on an extrapolation from Article 2 thereof as well as on the constitutional principle of *horizontal subsidiarity*, which serves as the legal basis, under Article 118, paragraph 4, of the Italian Constitution for the "the right of citizens, whether individually or as an association, to take action in the pursuit of the common good". Thus, from action taken by the citizenry (using instruments available within civil law) comes an effective means of safeguarding environmental interests for the good of the community too.

A more *evolved* interpretation of certain constitutional provisions allows some issues relating to sustainable development to be grafted thereon and hence covered thereby. Just think of the concept of "social utility" (Article 41, paragraph 2, of the Italian Constitution), the extraordinary breadth of which allows the text of the constitution to adapt to the new frontiers of economic development and environmental sustainability.

Additionally, Article 9, paragraph 2, of the Italian Constitution by virtue of which the Republic of Italy "protects the landscape, and the historical and cultural heritage of this nation", appears to provide the necessary constitutional premise for managing the land in a way that is either mindful of or instrumental to the demands of both the environment and economic development. Or Article 44, paragraph 1, of the Italian Constitution which justifies the imposition of legal duties and encumbrances on private property, in the pursuit of the "rational exploitation of the land" (Pennasilico, 2016).

Supranational sources on environmental issues are likewise on point, where traditional economic and proprietary values are coupled with values relating to personhood and solidarity (see Article 11 TFEU and Article 37 CFREU).

Moreover, by taking a more holistic and comprehensive approach to understanding the State and the law, centred around the value of the human being, a person construing the law – whether for questions of constitutionality or the merits of a contract claim – would be led to base their decisions on the fundamental values that shape the legal system itself, in accordance with the above-mentioned European environmental protection standards.

If the environment can be construed to fall within the scope of Article 2 of the Italian Constitution as an asset to be protected in order to safeguard the full and free development of human beings, then the environment is a constitutional value. Consequently, any judicial review, whether on procedural or substantive grounds, predicated on the guiding values of the system, must construe the contract in a way that takes into account the environment value, thereby undertaking a veritable *ecological* review of private agreements (Jannarelli, 2016).

From this perspective, any independent negotiation that contrasts with the communal interest in protecting the environment (protection of health, psycho-physical wellbeing and human dignity in general) will not warrant legal protection. This merit-based review must be completed by applying law to facts for any given contract, whether of a standardised form contemplated by statute or otherwise, so that one does not run the risk that a private agreement, lawful on its face, is not legally cognisable because it does not achieve an actual environmental interest (Persia, 2018).

In this sense, sustainable development is increasingly gaining space in contractual relationships which, although not expressly defined as *eco-sustainable* contracts, are so in substance.

A few examples of *ecologically oriented* contracts of European origin can be given:

- Green Public Procurement, “in which the public authority, without altering the competitive structure of the market, includes *green clauses* among the award criteria, aimed at selecting competitors who are able to offer eco-efficient products and services, thus promoting environmentally sound management of public procurement and public works” (Pennasilico, 2018).
- Green franchising, “referring to franchisors who also provide their franchisees with know-how in terms of reducing pollutant emissions and whose codes of conduct require franchisees to comply with certain ecological standards” (Landini, 2016).
- Energy Performance Contracts are “agreements whereby a supplier (energy saving company) commits itself, with its own or a third party’s financial means, to carry out a series of integrated services and works aimed at upgrading and improving the efficiency of an energy system (a plant or a building) owned by another party (customer or beneficiary). The defining characteristic is the combination of activities and services instrumental to the improvement of energy efficiency, which is the purpose or function of the contract, which goes far beyond the interests of the parties” (Pennasilico, 2016).

Thus, the analysis of the relationship between constitutionality and sustainable development serves to clarify that the latter cannot but align with the priority afforded by Italo-European positive law to the values of personhood and solidarity.

Therefore, it is within the system’s axiology that a solution can be found to the conflict between economic and technological demands, and the interests in preserving and safeguarding the environment, with the further understanding that respecting human rights serves to expand the notion of *sustainable development* beyond mere environmental protection (Pennasilico, 2016).

True development, therefore, consists not in the possession of technology or tangible goods, as much as in the process of social transformation which eliminates the principal sources of *restraint on liberty*: hunger, poverty, sickness, a lack of democracy, and an indiscriminate use of resources. The pursuit of prosperity should be limited to improving overall quality of life (Perlingieri, 2005). Therefore, if the environment is the backdrop for understanding a person’s outlook, then each contractual relationship must be viewed in light of its implications not only for the contracting parties but also those who are impacted, to a greater or lesser extent, by its terms.

Eco-sustainable contracts, together with other practices that have already been implemented (including ethical finance, fair trade and social tourism), would allow for a different approach to be taken in terms of the economy and consumption (Pennasilico, 2016). That contract would be one of myriad tools available to build a different economy, one that is circular and shared, fair and sustainable, in which any given person is not simply requesting a good or a service, but through that good or service (on which their quality of life depends, not only in the present but in the future) is asking for a true social and environmental interaction (Pennasilico, 2016).

This issue must be tackled in a systematic and axiological way, that is, predicated on the values of the system. Take, for example, Article 30(1) of Legislative Decree No. 50 of 18 April 2016 (the "Italian Public Procurement Code") where the cost effectiveness criterion "may" (but need not) be secondary to environmental protection but "shall" be secondary to other elements that impinge on fundamental human rights.

In that sense, a purely dogmatic approach is unhelpful. There is no *standard* contract or *archetypal* contract, there is only an actual contract with specific characteristics (Perlingieri, 2016). Jurists must weigh the principles that are in play. The idea of sustainability can pave the way for harmonising principles and values which, on the surface, appear to conflict. The concept of sustainable development implies a plurality of values and principles which must be coordinated having regard to the criterion of proportionality (Landini, 2016).

Where sustainability and contract meet, the issue is not justice, but rather reasonableness, in terms of evaluating the contract's framework. Consequently, person, contract, ownership, and business must all be interpreted not merely through the lens of special legislation (the Italian Environmental Code for example) but in terms of personhood and solidarity, in order to create the greatest possible improvement in the lives of people. Only then can one reach truly *sustainable development* (Perlingieri, 2016).

5 Limitations and Outlook

However, the concept of sustainability today appears to be anchored to purely conventional definitions. As a result, the use of the expression *sustainability* for commercial purposes could be a means of influencing the economic conduct of consumers in particular, determining their choices without there being any possibility of verifying the truth of the commercial statements referring to it, thus orienting entire market sectors.

It is no coincidence that part of the literature points out that the concept of sustainable development, despite the fact that it is amply reflected in Articles 3(3), 5(5), 21(2)(d) and 21(2)(f) TEU and Article 11 TFEU, is on the one hand an *insincere* principle, at least whenever it refers to non-renewable resources, while on the other hand, with respect to renewable resources, “it does not give rise to a notion of particular originality, appearing as a modern reinterpretation of the ‘traditional criterion of the rational use of natural resources’, already afforded constitutional value in Article 44 of the Constitution” (Pagliantini, 2016).

If one wishes to avoid the sacking of natural resources to the detriment of posterity, one must predicate rules on conservation and the use of resources and environmental assets on the principle of intergenerational responsibility. What is needed is a *green* culture, from which to draw inspiration for proper conduct which is *responsible in the long term*.

The real limitation of the principle of sustainable development is how to implement it in practice in our legal system. In our time, the artificial duality of sustainable development and solidarity seems to be more a rallying cry than anything that manifests as concrete action. The waste-disposal industry provides an example of a situation in which there is an upstream rejection of the predicates for sustainable development and solidarity, in the name of extreme forms of individualism and hometown hubris, as exemplified by the sad situation in the Campania region of Italy, which became so dire that it required the army’s intervention to restore law and order (Pennasilico, 2018).

The authoritative economist Redclift (2009) noted that the expression *sustainable development* is an oxymoron. Development construed as economic growth is based on increasing profits rather than on social benefits.

A recent series of European Directives (Directive 2004/18/EC, Directive 2014/23/EU, Directive 2014/24/EU, Directive 2014/25/EU and Directive 2004/35/EC) has, make no mistake about it, raised awareness regarding the creation of environmental sustainability within the traditional marketplace, a goal which would seem to hinge on individual wellbeing rather than on maximising consumption. Yet, this is simply another way of doing business which leverages a user's environmental and economic sensibilities, where the archetypal person under the law is more consumer than human being (Pagliantini, 2016). Giving priority to low-environmental-impact production systems requires sizeable investments (as they are predicated on specialised manufacturing techniques), and thus trigger the risk of upsetting market competition (a guiding principle of the European Union) and discriminating against small and medium-sized enterprises (the beating heart of Italy's economic fabric) for the benefit of a few large-scale companies (ECJ, 10 May 2012, C-368/2010).

In light of the foregoing, the greatest limitation of an *eco-sustainable* contract is that it runs the risk of remaining an elegant descriptor rather than a tool for analysing contract law in accordance with the principles and values of the legal system, one that captures and facilitates new developments in interpretation, application, and in the system overall. Think of that attitude summed up by "Not in My Backyard", which generally crops up during protests against works envisioned for the common good that have or are suspected of having a serious environmental impact. Citizen groups that take to the streets in pursuit of specific objectives are taking a political stance against choices made by national and local governments, but they also represent a kind of dissociation from one's duties of social solidarity, and the environment (Pennasilico, 2015).

Environmental protection cannot be predicated on the mere repression of unlawful behaviour or incidents of uncivil disobedience. The public authorities must make a renewed commitment to promote not only a culture of law-abidingness but also one of environmental solidarity.

6 Conclusions

The issue is therefore to reinterpret proprietary-based institutions: ownership, obligation and contract - in light of pre-eminent non-proprietary values, such as personhood and solidarity. This interpretation dovetails into the current trend in civil law, which is to move away from proprietary interests and to turn towards the placement of the person at the centre of the legal system (the approach taken by the Treaty of Lisbon) (Perlingieri, 2016).

However, whereas in the field of obligations, the law requires the creditor's non-proprietary interests to be taken into account (Article 1174 of the Italian Civil Code, which provides that "the performance that is the subject matter of the obligation must be capable of economic evaluation and must correspond to an interest, including an interest of a non-pecuniary nature, of the creditor"), a contract is defined as an agreement that governs legally cognisable proprietary interests between the parties, leading one to believe that the contract's nature is solely proprietary.

In point of fact, an increasingly more relevant use of a contract as a legal instrument "is represented by its ability to generate economic utility through sacrifices which are not proprietary per se, but which are compatible with the full development of a person" (Perlingieri, 2016).

Thus, for example, one would need to approach Article 30(1) of the Italian Public Procurement Code with caution. In that provision, the cost effectiveness criterion "may" be made secondary to environmental compliance. Yet, under that same Code it "shall" be secondary to other elements that impinge on fundamental human rights.

Eco-sustainable contracts, even if not yet expressly regulated by law, lead one to reconsider contracts as an instrument of realisation of proprietary relations only, because "the environmental interest penetrates and colours the purpose of the contract, emphasising both the convergence of the interests of the contracting parties on environmental benefits, despite the initial asymmetry of information, and the duty to rationally use natural resources for the benefit of future generations" (Pennasilico, 2016, Persia, 2018).

In that respect, perhaps considering the *eco-sustainable* contract as an *autonomous* contract, or as a new contract paradigm might be an overreach: what actually exists is a *particular* contract between *particular* parties with a *particular* purpose, executed at a *particular* moment in time, under *particular* conditions. Its peculiarities must lead the person construing it to identify the best solution, without pigeonholing the facts into a pre-existing contract type, an attempt that would prove pointless, day in and day out, given the complexity of real life (Perlingieri, 2016).

The challenge with the environment, and the application of sustainable development must be viewed not only in accordance with the rules of the Italian Environmental Code, but moreover through the fundamental principles of the system, which places the development of personhood and the protection of human dignity front and centre.

Contract, business, and property may be viewed through a lens that takes the *wellbeing* of persons into account, so that their existence might be the best one possible. Reaching sustainable development means, to be sure, economic development that ensures an acceptable quality of life, but economic development must be measured in terms of the reasons for its very existence. There cannot be market just for the sake of market, nor production for the sake of production.

The usefulness of *eco-sustainable* contracts, beyond codification, is that they would make it possible to consider the contract as an expression not only of purely individual interests but also of general environmental interests while respecting the principle of personal protection, allowing a different approach to the economy and consumption. The contract would become an *elective* tool for building *another economy*, “a ‘circular’ and ‘sharing’ economy, based on solidarity and sustainability” (Pennasilico, 2016), in which the consumer does not simply ask for a good or service but to contribute effectively and efficiently to safeguarding the planet.

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Supply Chain Management in the Course of Time – A Systematisation of Past, Present and Future Objectives

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Purpose: *Supply chain management (SCM) has undergone a transformation since its origins in the 1990s as ecological considerations have influenced SCM goals in recent years. This systematic literature review of a preliminary sample of 2,471 publications aims to show how target design has changed over time.*

Methodology: *The systematic literature review is based on Tranfield et al. (2003) and Denyer and Tranfield (2009). Following extraction from the Scopus database and multiple screenings, the top 100 academic publications with the highest yearly average citations from the periods 1996 to 2000 and 2016 to 2020 are included in the analysis.*

Findings: *To highlight similarities and differences, the current and initial goals of SCM are assigned to one of the sustainability dimensions: ecological, economic, social. By comparing the publications at the time of the initial emergence of SCM and the current period, a significant shift in the main objectives of SCM could be derived.*

Originality: *This compact structured analysis and discussion of the change in SCM objectives helps to comprehend past developments, to understand current challenges, and to assess future trends. Furthermore, the comparison of the two periods provides a unique perspective on the development of the research field of SCM.*

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1 Introduction

Supply chain management (SCM) is an important part of business operations (GEODIS, 2017) as the alignment between business objectives and SCM has great potential to improve overall company performance. In a global survey, 77 % of companies acknowledged the importance of supply chains as they devote 5 % of their total turnover to SCM (GEODIS, 2017). A well-managed supply chain also incentivizes social and environmental factors (Jermsittiparsert et al., 2019, Mangla et al., 2018). At a time when climate change issues are becoming increasingly important, there is pressure on supply chains to reduce their carbon footprint (Taleizadeh et al., 2019). Government policies are also increasingly focusing on companies and their supply chains and directly addressing them to integrate economic, environmental and social sustainability into their activities (UN, 2015). This shift in social values is reflected by the fact that companies with sustainable goals experience the most pressure from governments, mass media and their own executives, followed by consumers and investors (Bateman, 2020).

Due to current developments and the ever-increasing pressure on companies, the goals of SCM have changed from its beginnings, in the 1990s, to today. This change in values can partly be explained by the substantial influence companies have on the ecological and social environment. A comprehensive systematic overview of the development of SCM objectives over time can accelerate the related discussion and add clarity and richness to this research field. However, previous literature reviews often focus on specific periods (e.g. Kannan et al., 2020), restricted sustainability dimensions (e.g. Jabbour and De Sousa Jabbour, 2016) or certain geographic regions (e.g. Jermsittiparsert et al., 2019). Thus, the purpose of this article is to provide a systematic overview of the existing comprehensive body of literature of SCM objectives and to discuss how economic, ecological and social goals have changed over recent decades. The research question derived from this purpose reads as follows: "How has the target design of SCM changed over the years?".

This systematic literature review finds that total cost reduction remains a central goal of SCM as supply chains have become longer and more complex. In addition to this relevant economic aim, SCM is increasingly oriented on customers' and society's values, especially environmental and social sustainability. Prominent examples of social and environmental goals include circular supply chains, the reduction of carbon emissions, the reuse of materials, and improving cooperation and networking along the supply chain through the application of information and communication technologies. This paper thus highlights the importance of green economy and the social dimension for the research landscape, provides a useful concept matrix for benchmarking purposes, and offers helpful incentives and potential future research directions.

2 Methodology of the Systematic Literature Review

As the purpose of this article is to provide a systematic overview of the existing comprehensive body of literature of SCM objectives and to discuss how economic, ecological and social goals have changed over recent decades, this paper follows the systematic five step approach developed by Denyer and Tranfield (2009) (see Figure 1). The development and objectives of SCM are categorised according to the three sustainability dimensions: economic, ecological and social sustainability (WCED, 1987).

- Question Formulation

Due to the current interest and the long-lasting change in SCM research, this paper attempts to compare the current objectives of SCM with the original objectives of the 1990s to identify similarities and differences between these two periods: "How has the target design of SCM changed over the years?".

- Selection of Database and Definition of Search Strings

For this review, the Scopus database is chosen due to its comprehensiveness (Adriaanse and Rensleigh, 2013). The applied search string aims to identify articles related to SCM or supply chain in combination with the keywords "objective", "goal(s)" or "target".

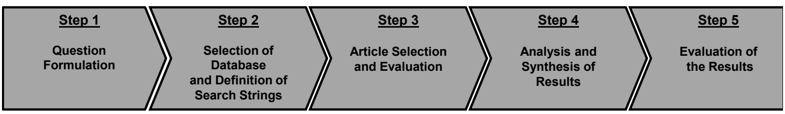

Figure 1: Systematic literature review approach
(based on (Denyer and Tranfield, 2009))

The search in February 2021 was limited to the subject areas Engineering, Business, Management and Accounting, Environmental Science and Decision Sciences. In addition, the query was limited to the periods 1996 to 2000 and 2016 to 2020 to provide an overview of the beginnings of SCM, when the first SCM models were developed, in contrast to the current focus of SCM research. For instance, the Supply Chain Operations Reference (SCOR) model and the supply chain modelling approach by Bowersox were first presented in 1996 (APICS, 2017, Bowersox and Closs, 1996). The resulting number of articles is 2,471, of which 104 have been published between 1996 and 2000 and 2,367 during the second period from 2016 to 2020.

- Article Selection and Evaluation

Prior to the two-stage article selection and evaluation step, the top 100 most-cited publications on an annual average in both periods are identified. The following inclusion criteria are applied for the title and abstract screening of this sample of 200 articles to restrict the wide-ranging thematic research field of SCM to the topic of this literature review: publication date 1996 to 2000 and 2016 to 2020, thematic focus on SCM. The accepted articles are subsequently reviewed in a full-text screening using the following criteria: full-text accessibility, thematic focus on SCM objectives. Applying these criteria reduces the total to 34 articles, of which 15 are from 1996 to 2000 and 19 papers are from 2016 to 2020. Further search strategies such as reference tracking result in the addition of another four sources to the analysis sample. The search and evaluation process is depicted in Figure 2.

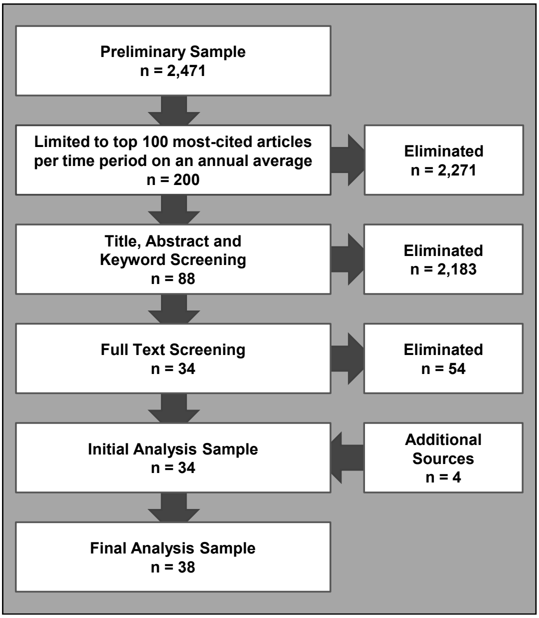

Figure 2: Overview of the article screening process

- Analysis and Synthesis of Results

First, a descriptive analysis based on the author keywords of all 2,471 articles from the preliminary sample is conducted to enable an overview of the main SCM research streams' development over time. Then, a thematic analysis using the 38 identified core publications is performed, and the findings of the literature review are synthesised to identify similarities and differences within and between the two periods under consideration. Since the different goals of SCM are interrelated, a clear assignment of certain articles to specific dimensions was not possible and the findings are included in all relevant dimensions.

- Evaluation of the Results

The findings of the descriptive and thematic analysis as well as the discussion of theoretical and practical implementations are structured within a concept matrix according to the three sustainability dimensions and suitable identified sub-dimensions.

3 Presentation of the Findings

3.1 Descriptive Analysis

The descriptive analysis uses the software VOSviewer (Van Eck and Waltman, 2010) and includes all 2,471 articles of the preliminary sample. The analysis uses the author keywords to provide an overview of the main research streams from 1996 to 2000 (Figure 3) and 2016 to 2020 (Figure 4).

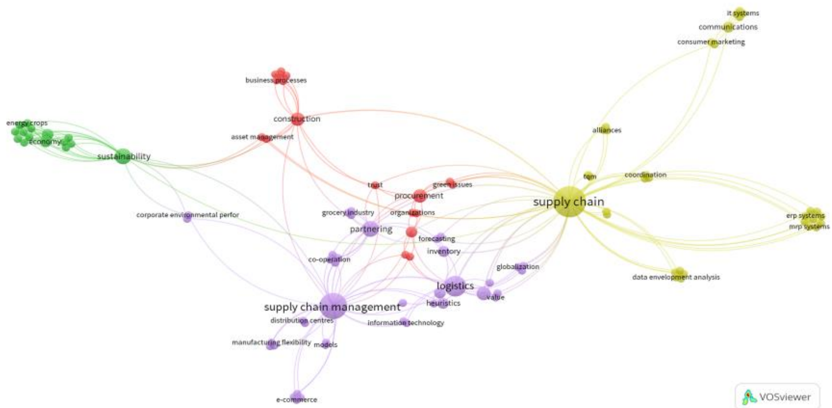

Figure 3: Author keywords cluster map 1996 – 2000

In the first period most articles deal with the topic of SCM, supply chain and logistics. This is in line with the statement that traditional SCM has evolved from logistics (Wisner and Tan, 2000). Sustainability plays a distant role and is not as important as the logistics branch (Ofori, 2000). Supply chains and their management seem to be mainly concerned with the procurement side and only few research papers address the communication to the customer.

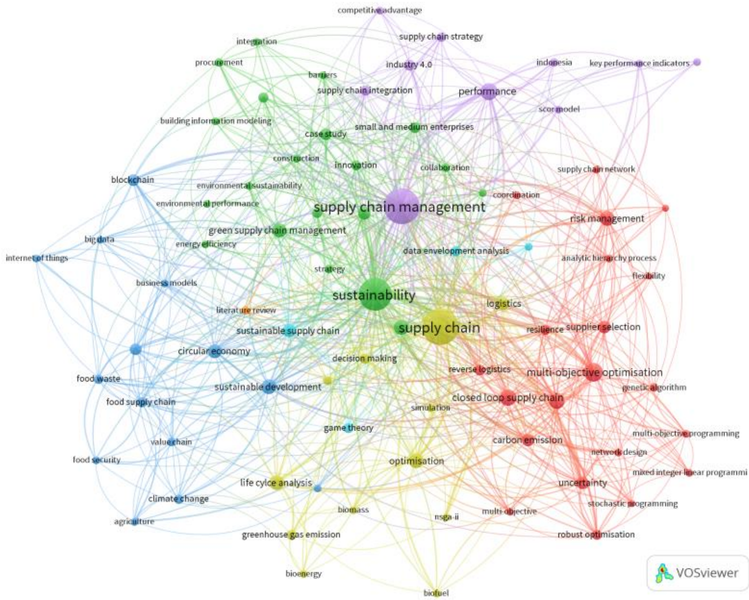

Figure 4: Author keywords cluster map 2016 - 2020

In the second period, the number of articles is significantly higher and there are more than 6,000 different author keywords. To improve visibility and clarity, only keywords that appear more than eleven times are included. Compared to the first period, research around SCM has grown substantially and the research field has become broader. Second, sustainability has gained a lot of importance in recent years (Gupta et al., 2019). Additional novel research fields include new information and communication technologies, supply chain optimisation, risk management and circular economy.

3.2 Thematic Analysis

3.2.1 Overview of the Thematic Analysis

To highlight the economic, ecological and social goals of SCM, the findings are structured within a concept matrix according to Webster and Watson (2002) (Table 1). The sub-dimensions indicated in the table are derived from the iterative reading of the sample publications.

Table 1: Concept matrix SCM objectives

	TP		EcD	EnD			SoD			
	TP1	TP2	Ec	En1	En2	En3	So1	So2	So3	So4
Akkermans et al. (1999)	x		x						x	
Anderson and Katz (1998)	x		x					x		
Badi and Murtagh (2019)		x		x	x	x				
Bateman (2020)		x	x	x	x	x	x	x	x	x
Beamon (1998)	x		x		x		x	x	x	

	TP		EcD	EnD			SoD			
	TP1	TP2	Ec	En1	En2	En3	So1	So2	So3	So4
Caldwell and Down (1997)	x								x	
Chen et al. (2017)		x	x			x			x	
Chuang and Shaw (2000)	x		x				x		x	
Desbarats (1999)	x						x		x	
GEODIS (2017)		x	x	x	x	x	x	x	x	x
Gupta et al. (2019)		x	x			x			x	
Hosseini and Khaled (2019)		x						x		
Jabbour and De Sousa Jabbour (2016)		x		x	x	x				x

	TP		EcD	EnD			SoD			
	TP1	TP2	Ec	En1	En2	En3	So1	So2	So3	So4
Jermsittiparsert et al. (2019)		x	x	x	x	x	x			
Kannan et al. (2020)		x		x	x	x		x		
Lockamy III et al. (2000)	x		x				x		x	
Mangla et al. (2018)		x	x						x	x
Masi et al. (2017)		x			x	x				
Mohammed et al. (2019)		x	x							
Namdar et al. (2018)		x			x					
Narasimhan and Jayaram (1998)	x		x				x		x	
New (1997)	x								x	

	TP		EcD	EnD			SoD			
	TP1	TP2	Ec	En1	En2	En3	So1	So2	So3	So4
Ofori (2000)	x			x		x		x	x	
Pérez (1997)	x								x	
Sarkar et al. (2019)		x	x		x					
Shaw (2000)	x								x	
Somjai and Jermsittipar sert (2019)		x		x	x	x	x			
Spekman et al. (1999)	x							x	x	
Taleizadeh et al. (2019)		x	x		x	x				x
Teixeira et al. (2016)		x							x	x
Tirkolaee et al. (2020)		x	x	x	x			x		
UN (2015)	x	x	x	x	x	x	x	x	x	x

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	TP		EcD	EnD			SoD			
	TP1	TP2	Ec	En1	En2	En3	So1	So2	So3	So4
Varsei and Polyakovskiy (2017)		x	x		x				x	
WCED (1987)	x	x	x	x	x	x	x	x	x	x
Wisner and Tan (2000)	x							x	x	
Wyatt et al. (2000)	x					x				
Zhang and Yousaf (2020)		x				x			x	
Zhen et al. (2019)		x	x		x					

TP = Time Period, EcD = Economic Dimension, EnD = Environmental Dimension, SoD = Social Dimension, TP1 = 1996–2000, TP2 = 2016–2020, Ec = Total Cost Reduction, En1 = Green Procurement, En2 = Green (Reverse-) Logistics, En3 = Green Design, So1 = Customer Satisfaction, So2 = Supplier Selection, So3 = Communication, So4 = Green Human Resources

As illustrated in the descriptive analysis, there are numerous publications dealing with optimization problems. The thematic analysis furthermore shows that a main objective of SCM was and is cost optimization. This is also reflected in the findings of a global survey from 2017 (GEODIS, 2017). As the analysis shows, inventory, transport and storage costs are the biggest cost drivers. So it is not surprising that optimizing and reducing these costs are in practice two of the top goals in SCM (GEODIS, 2017). Sarkar et al. (2019) also consider that transport and storage costs have a significant impact on the maximization of supply chain profit.

We find that sustainability has become more important over the course of time. First and foremost, publications mostly deal with carbon emissions. It is therefore surprising that research and practice assign different preferences to the goal of reducing the carbon footprint. Companies put this target in the 15th position (GEODIS, 2017). A more recent survey from 2020, which focused only on sustainability, found that carbon emissions were ranked sixth among sustainability objectives (Bateman, 2020).

This review shows that sustainability involves environmental, economic and social dimensions. Other goals addressed in the ecological dimension are more environmentally friendly purchasing and logistics. Green design is gaining attention in today's research landscape and in business as well, because redesigning supply chain processes can achieve significant energy and water savings and reduce waste and end-of-life products. For example, Taleizadeh et al. (2019) consider the growing number of end-of-life products as one of the most damaging effects.

In the social dimension, customer satisfaction took a central role then as it does now, which is transferred to the entire SCM. This also reflects the objective of the companies, which see reaction speed, responding to customer expectations and quality as well as shortening delivery times to the customer as major challenges (GEODIS, 2017). Jermsittiparsert et al. (2019) see SCM as a key element in satisfying customers and reducing delivery times.

One objective that has become significantly more important in recent years is the transparency of the entire supply chain. Only 6 % of companies state that they have an overview of the entire supply chain (GEODIS, 2017). This goal includes many of the sub-goals mentioned in the previous section and the mutual reporting of the entire flow of finances, materials and information. Collaboration based on trust and a shared perception is the first step towards this goal. As already seen in the descriptive analysis, new information and communication technologies play a role in SCM. This is based on ensuring the continuous flow of information within the supply chain, and data management and analysis have an immense impact on success. At the same time, implementation supports the agility and transparency of the entire supply chain (Mangla et al., 2018).

The term green human resources is slightly misleading but illustrates that research focuses too much on 'green' areas and does not consider all three dimensions of sustainability as a whole. Nevertheless, the field of human resources is an underestimated factor in publications as employees also advocate for a more sustainable workplace and put pressure on their company (Bateman, 2020). Jabbour and De Sousa Jabbour (2016) also acknowledge the relevance of the human factor and emphasize its consideration in the ecological transformation.

In the research landscape, it is essential to know the difference between Green Supply Chain Management (GSCM) and Sustainable Supply Chain Management (SSCM). While GSCM addresses the impact of supply chains on the natural environment, in other words the environmental dimension, SSCM also deals with the economic and social dimensions of sustainability (Badi and Murtagh, 2019). While interest in GSCM has increased due to environmental concerns, in today's economy the full range of sustainability plays a more important role, especially as the social dimension has greatly increased in value.

3.2.2 Discussion of the Economic Dimension

In the 1990s, the economic goals were the central determinants for the objectives of SCM since the price was the primary incentive for the customer to buy and thus the greatest competitive advantage could be acquired (Narasimhan and Jayaram, 1998). That's why cost reduction was one of the guiding goals of SCM, in addition to customer satisfaction and improved reaction speed (Lockamy III et al., 2000). This is one of the first major differences between the beginnings of SCM and its current situation: in the past companies competed with each other, today the competition is mainly between entire supply chains (Chen et al., 2017).

The conflict of objectives between individual costs and total supply chain costs was discussed intensively in the past (Beamon, 1998), and this area of tension is still addressed today (Chen et al., 2017), but seems to be generally accepted and is rarely addressed in publications. By shifting focus away from the traditional approach to considering the total cost of the entire supply chain, companies have permanently changed how and what they buy. Removing the two-way win-lose perspective allows companies to create a win-win relationship for the entire system. As a result, significant cost reductions and profit increases are obtainable for the entire supply chain (Anderson and Katz, 1998, Spekman et al., 1999).

Successful supply chain managers focused on reducing total delivery costs (Spekman et al., 1999). Lockamy III et al. (2000) also consider transportation costs to be the main cost in the supply chain, but break down total supply costs into factory, logistics and transportation costs. Other researchers (e.g. Sarkar et al., 2019) still consider transportation, inventory and warehousing costs as the most expansive costs of all SCM activities which need to be reduced (see Figure 5). This overarching view means that not only one's own profitability plays a role, but also the economic situation of the entire supply chain and the entire financial flow (Anderson and Katz, 1998). Today, costs still play a role in the supplier selection process, but now environmental and social criteria play a bigger part than in the past (Tirkolaee et al., 2020).

In modern supply chain total cost considerations, the difference between fixed and variable costs plays an important role. The variable costs are of key importance as they are directly related to the ecological objective (Taleizadeh et al., 2019, Varsei and Polyakovskiy, 2017). This again illustrates the above-mentioned conflict between the ecological and social objectives versus the economic aspects. Additional investments and the use of cost-intensive technology reduce carbon emissions (Zhen et al., 2019), provide more job satisfaction and safety for employees and improved communication with customers (Taleizadeh et al., 2019).

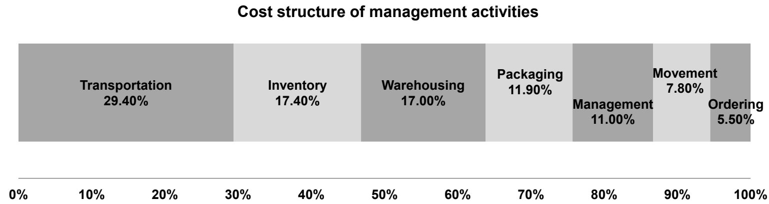

Figure 5: Cost structure of management activities (based on Sarkar et al., 2019)

Another way towards total costs reduction is proposed by Chen et al. (2017) who address the distribution of power within the supply chain. A balanced distribution of power between producers and traders assures the best economic performance (Chen et al., 2017). During the emergence of SCM, the overarching economic goal was to develop improvements that reduce the total cost of the supply chain without sacrificing customer and trading partner satisfaction (Lockamy III et al., 2000, New, 1997). This is in line with the findings of Jermsittiparsert et al. (2019) who considered logistics a core task for SCM. Despite the fact that today's supply chains are larger and more complex (Namdar et al., 2018), and the environmental dimension is included in the total cost by a large margin (Tirkolaee et al., 2020), effective SCM still aims to satisfy customer demand in full while minimising the cost of the activities across the supply chain process (Jermsittiparsert et al., 2019).

3.2.3 Discussion of the Environmental Dimension

In the late 1990s, there was a growing environmental awareness among companies, which has become more and more important over the years until today. With increasing government regulation and greater public interest in environmental responsibility, companies realised that they could not ignore environmental issues. However, SCM was preoccupied with reducing costs and better serving customer needs. These two trends were in conflict at that time, which is why the economic goal was preferred over the environmental one for the time being (Ofori, 2000).

The construction industry, which requires long-lasting products, can be described as a pioneer in retrospect. According to Wyatt et al. (2000), the supply chain of this industry has a strong negative impact on the environment. Therefore, this industry was especially interested in addressing environmental issues and goals at an early stage. The redesign of the supply chain was based on the long product life cycle and the reuse of components or materials was integrated into the product and production design. These concerns from back then are exactly what can still be found in the construction industry today and are also being transferred to other supply chains (Badi and Murtagh, 2019).

Nowadays, criteria such as minimising waste, emissions or risks, along with reducing resource consumption and maximising net profit, are included in the decision-making process (Taleizadeh et al., 2019). The implementation of these ecological considerations in traditional SCM creates important activities that should be implemented in a company: green purchasing, green (reverse) logistics and eco-design (Jabbour and De Sousa Jabbour, 2016, Jermsittiparsert et al., 2019).

Green purchasing had already been a relevant idea in the past and the focus was to reduce, reuse and recycle materials. As the foundation of any sustainable value chain, purchasing requires special attention and cooperation between different companies in the supply chain. The green purchasing approach ensures that only goods that meet the attributes of ecology, which include recyclability, reusability and the use of non-toxic materials, are procured (Somjai and Jermsittiparsert, 2019).

Another goal of SCM is to implement environmentally responsible and resource-saving logistics across the entire supply chain. This is characterised by low impact on climate and environment, pollution, noise and accidents in the fields of transport, warehousing, management and handling (Jermsittiparsert et al., 2019). However, research previously focused only on the addition of reverse logistics to the existing logistics system (Beamon, 1998). Transport and warehousing have a decisive influence on the ecological dimension. The goal of logistics is to create an optimised shipping plan that balances the discrepancy between the carbon emissions and the profit target.

Sarkar et al. (2019) find that multiple use of transport packaging has a major positive impact on transport costs and environmental impact. The design of environmentally friendly packaging goes hand in hand with other aspects of green design (Somjai and Jermsittiparsert, 2019). Self-healing and reusable packaging is a solution in this respect

(Sarkar et al., 2019). So-called end-of-life products should be eliminated as products must be designed to be either reusable or repairable (Taleizadeh et al., 2019). The aim of product and production redesign is to avoid toxic ingredients, optimise the use of resources and ensure easy repair, recyclability and disassembly of equipment and products (Jabbour and De Sousa Jabbour, 2016).

Eco-design or green design involves not only the redesign of products, but the reengineering of the entire supply chain processes (Zhen et al., 2019). Redesign focuses on reducing the energy and resource consumption during the production process, transport and usage (Jabbour and De Sousa Jabbour, 2016). The environmental objective of today's SCM is concerned with greening all activities in the supply chain and between its parties, from production to delivery and reuse of products, to be cost-effective and efficient (Jermsittiparsert et al., 2019). So-called closed-loop chains are circularly designed supply chains that seek that value is created and recovered during the entire product life cycle (Gupta et al., 2019).

3.2.4 Discussion of the Social Dimension

The most important social goals of the 1990s are the timely fulfilment of customer orders, the related customer satisfaction and a fast reaction speed of the whole supply chain on market events (Lockamy III et al., 2000). Customers represent the starting point for all internal and cross-company activities. This great influence and the competitive advantage generated by high customer satisfaction mean that the customer's values have a great influence on the further objectives of SCM, which must be oriented towards the customer (Narasimhan and Jayaram, 1998).

Strategic sourcing, which describes the development of supply channels at the lowest total cost, has a direct positive effect on the goals of reliability, flexibility, cost and quality, which had a positive effect on customer satisfaction (Beamon, 1998, Narasimhan and Jayaram, 1998). More consumers are demanding environmental responsibility from companies and supply chains, so that low prices alone are no longer enough (Masi et al., 2017). This also includes maintaining social justice within a supply chain and avoiding conflicts (WCED, 1987). Supplier selection has a direct influence on costs, quality and reliability. A long-term view, shared beliefs and goals are required for a beneficial cooperation, so the selection of partners is an important task of SCM (Akkermans et al., 1999, Desbarats, 1999). The opinion that supplier performance has a direct influence on costs, quality and delivery is still shared today. As in the past, cost, quality and delivery reliability are relevant, but in recent years sustainability has become another important factor in supplier selection (Tirkolaee et al., 2020). New environmental factors include pollution, resource consumption and waste, as well as social criteria such as workers' rights, number of employees, health and safety of employees (Kannan et al., 2020, Tirkolaee et al., 2020).

Building mutual trust and effective communication between members of the supply chain is a complex task of SCM. Implementing an end-to-end SCM can only be successful if all parties are willing to cooperate intensively and inform each other about their business operations and exchange information about their business plans and processes. Involving suppliers in the product development process can also have a positive impact, not just on the social climate, but also on the overall costs of the supply chain (Wisner and Tan, 2000, Ofori, 2000). Good communication between all parties in the supply chain is an objective pursued then and now. In addition to the flow of materials, the flow of information also plays a crucial role in SCM (Beamon, 1998). To generate a competitive advantage from the flow of information, it is necessary to establish communication within the supply chain using and constantly improving it with the help of new information technologies (Spekman et al., 1999, Ofori, 2000). Response time is one of the most important elements of the social goals of SCM (Wisner and Tan, 2000), which can be greatly reduced through the use of new technology.

With today's approach towards circular supply chains and enforcing green activities, collaboration across organisational borders is more important than ever. There is a need for partners upstream and downstream to work together to allow practices such as product take-back, reuse and recycling (Masi et al., 2017).

SSCM leads to long-term benefits in building effective communication and removing barriers of communication. Traditional supply chains are characterised by a forward flow of materials and a return flow of information (Beamon, 1998). In today's fast-paced world, where decisions must be made in real time to gain a competitive advantage, the flow of data and the analysis of information are of special importance (Tirkolaee et al., 2020). In the information age, knowledge is considered a valued resource on which decisions and changes are made. Therefore, at each point of the supply chain, data is collected, analysed and distributed across the supply chain. A lack of adequate data leads managers to make wrong decisions, so the entire supply chain must be technically connected (Gupta et al., 2019). These actions need to be well coordinated through effective management so each party knows what needs to be done (Chen et al., 2017). For this reason, SSCM relies on active and continuous communication to ensure transparency throughout the supply chain (Jermsittiparsert et al., 2019).

Few articles cover green human resources, although educating all members on relevant environmental issues leads to greater employee engagement in sustainability management (Teixeira et al., 2016). To implement green practices there is a need for support from higher levels of management and human resources. A green corporate culture can only be successfully integrated through the participation of all parties (Jabbour and De Sousa Jabbour, 2016).

The objective of harmony between sustainable social goals and ecological goals, which are in conflict with the economic dimension, becomes obvious (Varsei and Polyakovskiy, 2017). For example, a positive social impact on the region is the creation of jobs. The capacities of recycling, reprocessing or disposal departments would be expanded. Investments in product and production design also support social goals by improving the health, safety and job satisfaction of employees and reducing the risk of customer injury from the product (Taleizadeh et al., 2019).

4 Conclusion, Implications and Limitations

The purpose of this paper is to compare the objectives of SCM during its early years with today's and to provide an overview of the current focus of the research field. We find that a key goal of SCM remains total cost reduction as supply chains have become longer and more complex, which has also made this task more multifaceted and costly. Society's values have shifted towards environmental and social sustainability, which is also reflected in companies' goals. This means that SCM is increasingly oriented on the customer and society's values. The environmental dimension has changed the most. Due to the emergence of environmental issues, these dimensions have evolved from a peripheral issue to a central issue in SCM. Environmental sustainability is now the guideline for supply chain design. The development from a linear supply chain towards a circular form is apparent and will become more relevant in the coming years. In this context, the reduction of carbon emissions plays a lesser role than the environmentally friendly use of resources and the reuse of materials. As social objectives and sustainability are currently playing the biggest role in SCM activities, not only do external factors such as customer satisfaction matter, but there is also an internal call for more social sustainability. New information and communication technologies are an essential part of improving cooperation and networking along the supply chain.

This literature review provides several implications for research and practice. First, it highlights the importance of green economy and the social dimension for the research landscape. Second, circular economy as well as the advancement of the transparency of the entire supply chain are identified as potential future research directions. Third, organisations and supply chain managers can use the provided concept matrix for benchmarking purposes along all processes. Fourth, global social change movements impact future SCM and this review thus offers helpful incentives.

Despite the systematic approach and comprehensive literature search, this literature review is limited by the use of only one literature database. Furthermore, the representativeness of the findings is reduced by the decision to analyse only the top 100 most cited publications in each period.

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Ecological Sustainable Physical Distribution

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Purpose: *Increasing online retailing leads to increased transportation processes on individual levels, which is impacting the environment negatively. Consequently, logistics needs ecological sustainable concepts to reduce its anthropogenic emissions, especially in physical distribution. The paper identifies such solutions, which avoid, shift and reduce such emissions and hence improve the environmental impact of logistics.*

Methodology: *For this study, the paper examines 28 relevant papers out of a sample of 219 contributions, with a content-based qualitative literature analysis by applying the methodology suggested by Fink (2010).*

Findings: *Following the fundamental notions of green logistics as proposed by Wittenbrink (2015), the paper identifies various sustainable concepts, which were condensed into a framework of ecological sustainable physical distribution. The overall goals refer to the protection of the atmosphere, decreasing dependence on fossil fuels and conservation of biodiversity. Drivers of such a concept of ecological sustainable physical distribution include horizontal cooperation to avoid, the use of resource-saving transportation means to shift, fleet management and utilisation of alternative fuels to reduce emissions.*

Originality: *This work applies generic strategies for dealing with emissions to the field of physical distribution and presents a first conceptual frame of reference that can be used to implement ecological sustainable notions to the field of physical distribution.*

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1 Introduction

Increasing online retailing and growing numbers of individual deliveries of goods lead to increased transportation processes and this is negatively impacting the environment (Crainic, Ricciardi and Storchi, 2004; de Mello Bandeira et al., 2019). A representative survey by DS Smith found out that the covid-19 pandemic and the restrictions imposed are further catalysts for online product purchases (Röhrle, 2020), which will lead to even more home deliveries. This final stretch to the end consumer – also known as the so-called last mile (Brabänder, 2020) – requires many individual transport routes, which not only cause high transport costs, but also impact the environment negatively (Liu, Wang and Susilo, 2019).

The transportation function is hereby taken over by courier, express and parcel (CEP) service providers (Brabänder, 2020), who use mostly diesel-powered vehicles (Destatis, 2020; Kords, 2020) and this fossil non-regenerative fuel releases the greenhouse gas carbon dioxide (CO2) when burned and consequently impacts negatively to the climate change (Brickwedde, 2010; Merker and Teichmann, 2018; Pompl, 2019). In Germany, the transport sector accounted for 19 % of the emissions caused in 2018 (BMU, 2019a) and the share of emissions caused by diesel trucks was 73 % (BMU, 2016).

The use of fuels from renewable energies is seen as an opportunity. Currently, it accounts for the smallest share in the transport sector in 2019 with 5.6 % of the total energy required. This shows that physical distribution has a lot of potentials to make a contribution to achieving climate targets and sustainability. In order to realise long-term climate improvements, sustainable changes in economic processes must also be made after the covid-19 crisis (Barbier and Burgess, 2020; D’Adamo and Rosa, 2020).

Thus, this paper focuses on the logistics sector and the need for ecological sustainable concepts, especially in the area of physical distribution. We seek to examine the following question by the means of qualitative literature: To what extent can concepts in physical distribution improve the use of natural resources with regard to ecological sustainability?

The remainder of the paper is the following: the conceptual frame of reference will be introduced in the next section, which is our basis for synthesising the literature. Afterwards, the methodological approach for gathering and analysing the literature will be explained and the subsequent section will present the results of our literature analysis in detail. The paper concludes with a discussion and reference to the research question as well as an outlook for the future.

2 Conceptual Frame of Reference

2.1 Defining Physical Distribution

Outbound logistics or physical distribution is that part of logistics that deals with the delivery of final products to ultimate customers (Gudehus and Kotzab, 2012). Due to the developments in e-commerce, the return of products may also be an important addition to physical distribution (Koether, 2014). Conventionally, e.g. in the fast-moving consumer goods industry, the structure of a distribution system includes multiple echelons between manufacturers and retail stores, where distribution centres are located and serve either as break-bulk and/or consolidation points (Pfohl, 2018).

Since e-commerce gains more importance, distribution systems are expanding and include the last mile, which is the delivery of orders to the homes of the ultimate customers (= end-users) (Koether, 2014). Contrary to traditional distribution systems, where heavy goods vehicles are used for transportation, the last mile logistics is served by courier and express service providers who use smaller vehicles (BIEK, 2020).

Another important development within physical distribution relates to the increasing urbanisation for which specific city logistics solutions are developed (Rodrigue, Notteboom and Shaw, 2013). The overall goal of city logistics is the reduction of inner-city traffic (Wolpert, 2013).

2.2 Defining Sustainability for Physical Distribution

The major ecological targets are the protection of the atmosphere, decreasing the dependence on fossil fuels and preserving biodiversity. According to Hardtke and Prehn (2001), sustainability is defined in this paper as meeting the needs of present generations without depriving future generations of a way to meet their own needs on an equal basis. Furthermore, the concept of sustainability is typically divided into the three sub-areas of ecological, social and economic sustainability (Elkington, 2013). For the purpose of this paper, we focus solely on ecological sustainability and follow the notions of Hauff (2019, p.110), who defines it as "the preservation or improvement of ecological systems or the ecological capital stock". This is also due within the field of physical distribution, where concepts are needed that improve the use of natural resources there.

Natural resources can be split into regenerative and non-regenerative natural resources. Non-regenerative natural resources refer to raw materials that are not recoverable. These are also known as fossil fuels and are, for example, petroleum, ores, coal and minerals (Wacker and Blank, 2016). As non-renewable raw materials are finite, they must be replaced by alternatives to ensure the security of supply (Brickwedde, 2010). Renewable energy sources such as sun, wind, hydropower or geothermal energy are considered alternative energies. According to the current state of technology, they are regenerative or almost inexhaustible (Bundesregierung, 2021).

2.3 The Concept of Green Logistics

Piecyk et al. (2015) understand green logistics as the inclusion of environmental effects when it comes to the execution of logistics processes. In our paper, we follow the notions of Wittenbrink (2015) who sees reduction, avoidance and shift as the main principles of green logistics, which aims at lowering emissions and a reduced use of natural resources (see Figure 1).

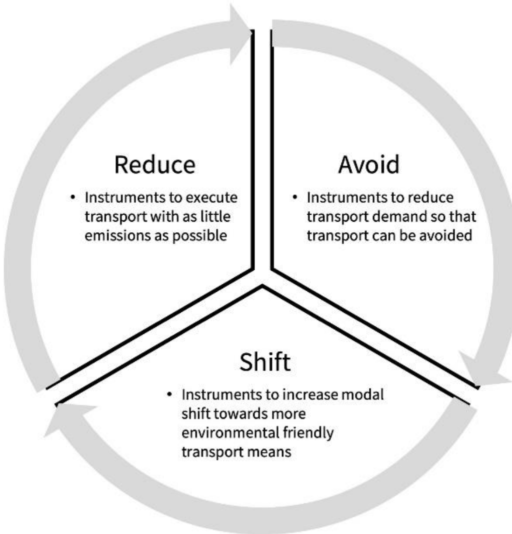

Figure 1: Conceptual Frame of Reference for Ecological Sustainable Physical Distribution (adapted from Wittenbrink, (2015))

In the next step, we apply this framework to the field of sustainable physical distribution and aim to identify specific measures within different aspects of our framework.

3 Methodology

We employ a qualitative literature analysis in seven steps as suggested by Fink (2010), which are extensively described in subsequent Figure 2.

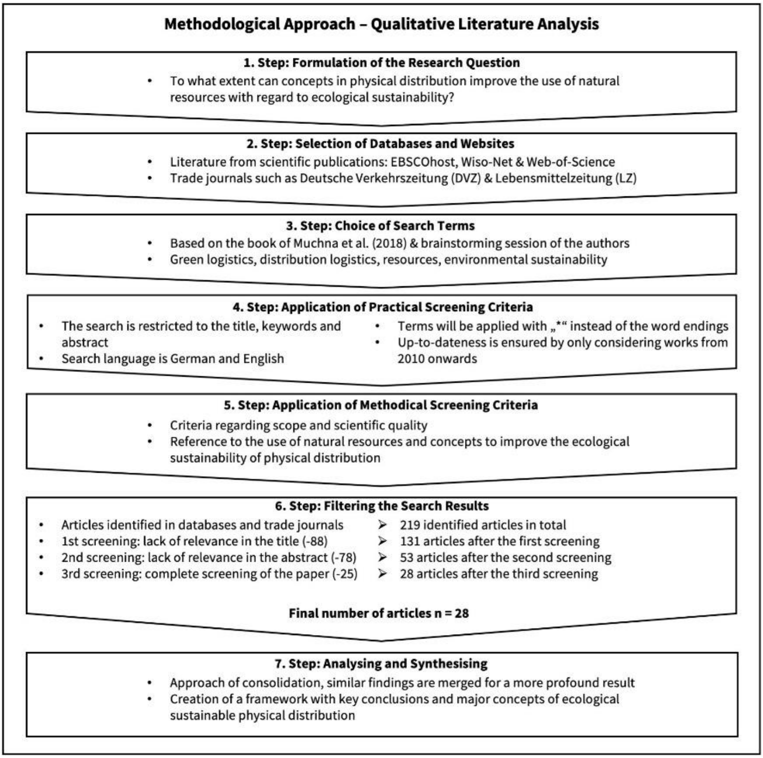

Figure 2: Qualitative Literature Analysis Following the Seven Steps of Fink (2010)

Next, we specify the framework of Figure 1 with the key conclusions from our analysis.

4 Findings

4.1 Avoidance

Avoidance turns out to be the most effective way to conserve natural resources and thus evade emissions. Adequate avoidance strategies were found in the area of horizontal cooperation, which refers to concerted entrepreneurial practices between companies that operate at the same market level (European Union, 2001) intending to save transport routes with the help of various mechanisms.

One mechanism that supports this concept relates to shared resources. These are resources that are made available to cooperating competitors across companies for joint use (Becker and Stern, 2016). If companies do not use the same system, online platforms allow providers to announce their freeloading capacities, schedules and means of transport for upcoming tours and to join forces with other companies (Schneider, 2020). In the area of road freight transport, additional free capacities can be made available by the use of which is made possible via so-called groupage systems, in which transport capacities are shared and bundled through the consolidation of orders from cooperation partners (Kopfer, Schönberger and Bloos, 2010).

The advantages of this type of cooperation are fewer transport routes as the utilisation of capacities is maximised. A reduced number of journeys also reduce wear and tear on the vehicles, lower emissions and less congestion and accidents due to the lower utilisation of the road network. By using the same IT, some express service providers can work 24 hours a day and offer collection and delivery at any time, which means that orders can be processed in a much shorter time (Cremer, 2020).

However, cooperation also has disadvantages. A survey by Cruijssen et al. (2007) showed that there are reasons why cooperation rarely takes place in reality. On the one hand, when contracting out, companies face uncertain planning where the quality of the execution is not known because the cooperation partners have different quality requirements. On the other hand, the selection of partners is a challenge for small and medium-sized enterprises, as the analysis of potential partners is often time-consuming and cost-intensive. The specific distribution of profits also presents itself as an additional problem, as does a lack of trust regarding the provision of sensitive information (Reimann, 2020).

4.2 Shift

In order to effectively conserve resources, the shift primarily requires the use of less environmentally damaging means of transport (Wittenbrink, 2015). Trucks are the most frequently used means of transport for the distribution of goods (BMU, 2016; Kords, 2020). Consequently, shift strategies refer to replacing truck transport with other resource-saving means of transport.

One way is the use of cargo bikes, which release no emissions and consume few to no resources. Rudolph and Gruber (2017) show that cargo bikes have cost advantages over a small delivery vehicle. The purchase, as well as the annual costs for maintenance, taxes, insurance, are low. Other advantages refer to the avoidance of traffic jams via bicycle lanes and the independence from environmental zones. In urban delivery areas within a radius of 5 kilometres, journey times with cargo bikes are the same or in some cases shorter in relation to motorised vehicles. Furthermore, cargo bikes are silent transport means and bike riders do not need a driving licence (Schneller, 2020). Disadvantages refer to lost time advantages, if distances are long. Reorganising logistics hubs would be a costly factor, with high complexity and low profitability (Rudolph and Gruber, 2017). Due to their size, their capacities are also limited, which can lead to the driver having to return to the depot several times and thus losing his time advantage within the city.

In addition, rail freight transport offers a modal shift opportunity. In Germany, 90 % of rail freight transport is electric and is considered climate-friendly due to recuperation (BMVI, 2017; DB AG, 2020). Nevertheless, rail freight transport has a load factor of 57.3 % and could contribute to the ecological sustainability of the logistics sector through a higher load factor as well as an expansion of rail freight transport (Knörr, 2019).

A decisive advantage of rail freight transport, in addition to the resource-saving drive, is the good plannability and reliability. As freight trains are often operated at night and can be easily integrated into the timetable of passenger rail transport, rail freight transport, in contrast to road freight transport, is considered to be less susceptible to disruptions.

Besides, the land consumption of rail as a mode of transport is smaller in terms of area than that of the trunk road network concerning transport performance (Logistikbranche.net, 2020). However, rising warehousing costs are also fuelling the trend towards ever smaller consignment sizes, as a result of which general cargo and express goods are mainly shipped by truck (Wittenbrink, 2015). Bretzke (2014) also describes the transport of goods by rail, for distances of less than 300 kilometres, as slower and more costly than by truck, which is why this transport option is considered unprofitable in these conditions.

Another shift option is inland waterway transport, where an inland freight ship with a loading capacity of 3000 tonnes can replace up to 150 trucks (BMVI, 2019). Particularly heavy and bulky goods can be transported suitably via waterways (BDB, 2020). The share of inland navigation in overall German freight transport was 6.7 % in 2018 and offers a lot of untapped potentials (Keller, 2020). A possible concept for better use of inland navigation is presented by the research project "DeConTrans - Innovative Concepts for Decentralised Container Transport by Waterway", which aims to make the West German canal network usable for regional supply with goods for daily needs (Granzow, 2020). The project envisages the use of small environmentally friendly ship units, the so-called regio-carriers, which can reach secondary routes and canals as well as smaller terminals and transhipment points. The Regio-carriers consist of electrically driven barges that can be coupled and, due to their low height, fit under all bridges without lifting them. Former coal jetties are reactivated and converted into micro depots, from where the goods are distributed over the last mile. However, there are also disadvantages or obstacles in inland waterway transport. On the one hand, the dependencies on environmental influences and, on the other, the cost-intensive expansion and the impairment of nature (Koether, 2014).

4.3 Reduction

After avoidance and shifting, reduction is the last measure to enable resource-efficient distribution logistics. Reduction in physical distribution is primarily aimed at emissions and reduced consumption of natural resources. Since there is a correlation between fuel consumption and CO2 emissions, approaches to reduce fuel consumption are of particular interest (Wittenbrink, 2015). Thus, we focus on fleet management and alternative fuels.

Fleet management serves to optimise logistics processes within the existing vehicle fleet and to monitor and control the flow of goods (Ubeda, Arcelus and Faulin, 2011). This includes all activities that contribute to making the delivery of goods more efficient. This includes telematic systems which, due to digital developments, have hardware and software that optimise logistical processes. The term telematics is a combination of the terms telecommunications and information technology, which refers to the collection, processing, transmission and exchange of transport-related data and information (Bäumler, 2019; Hamidi, Lajqi and Hamidi, 2016; Melheritz, 2013). The data obtained is real-time data for route and route planning or traffic situations, so that unnecessary transports are avoided and thus less fuel is consumed (Eikona AG, 2020; Günthner, 2012). Furthermore, platooning, in which several networked trucks drive close to each other in a convoy, can optimise traffic flow, reduce energy consumption and thus ensure more ecological sustainable physical distribution (BMVI, 2020; eCoMove, 2020). Safety-relevant information, such as a collision warning or the warning of an approaching rescue vehicle, can cause congestion of the radio channel and thus unreliable information transmission during high traffic volumes. Another disadvantage of telematic systems is the high costs for the acquisition and the generation change or the overhaul of the hardware and software of the systems. Also, there are costs for staff training, which is necessary to sensitise employees to new technologies (Waßmann, 2017).

Even non-digital measures can lead to fuel and thus resource savings. Up to one-third of a truck's fuel consumption is related to air resistance. Many manufacturers offer aerodynamic packages which, at a price of about €2,500 to €4,500, result in fuel savings of about 5 %. At a price of 1.15 €/l diesel, this corresponds to pay back after 19 months. In addition, this corresponds to a reduction of over 5,000 kg CO2 per year per vehicle (Wittenbrink, 2013). Limiting the maximum speed from 90 Km/h to 80 km/h can also lead to a diesel saving of about 12 % with a small additional expenditure of time (Wittenbrink, 2014).

The use of alternative fuels for fossil fuels to reduce emissions represents one of the greatest aspects of environmental protection. In the following, the electric drive, hydrogen and biodiesel are presented as alternative fuels.

An electric drive can be installed in a vehicle in two ways. On the one hand, a vehicle can be operated purely electrically via a battery, on the other hand as a hybrid, in which the battery is combined with an internal combustion engine. On average, the installed lithium-ion battery has an energy output of about 140 watt-hours (Wh) per kilogramme (Henne, 2020). The electric delivery vehicle StreetScooter (model: Work L), which is used by Deutsche Post, has a battery capacity of 40-kilowatt hours (kWh) with a range of around 187 km (StreetScooter, 2020). The consumption and thus the costs for the fuel can be derived from this. With consumption of 21.39 kWh per 100 km, at an electricity price of 29.88 cents/kWh, electricity costs amount to 6.39 €/100 km (BMWi, 2020). Comparing the fuel consumption of a diesel-powered Ford Transit (model: 2.0 TDCI Ford EcoBlue 136 kW) with a similar load volume, this is 6.8 litres of diesel, which at an average diesel price in 2019 of around €1.27, results in fuel costs of €8.64/100 km (Ford, 2020; Hohmann, 2020).

Hybrid vehicles can also save about 20 % fuel, depending on the model (Wittenbrink, 2014). UPS reduced road fleet fuel consumption by up to 28.9 % through hybrid vehicles (Dey, LaGuardia and Srinivasan, 2011). In addition to saving energy costs during operation, electrically powered vehicles are quieter, causing fewer emissions such as noise (Dudenhöffer, 2013). But an electric drive also has disadvantages. For one thing, the charging time of the batteries is currently much longer than with refuelling, and for another, the life expectancy of lithium-ion batteries is given as 10 years on average (Henne, 2020; van Basshuysen, 2010).

In addition, the energy output of liquid fuel is 100 times higher, which is why purely electrically powered vehicles have a significantly shorter range than diesel-powered vehicles (Stegmaier, 2019). Another point of criticism is the emissions balance of the production of the batteries and the provision of electricity under the current conditions. According to the Federal Environment Agency, a compact-class passenger car as a purely electric vehicle causes 134 g of CO2 per vehicle kilometre over its entire service life, taking into account production, driving, maintenance, energy supply and disposal - in contrast, a diesel vehicle causes 159 g of CO2 per vehicle kilometre (BMU, 2019b).

Splitting water into oxygen and hydrogen using electricity produces alternative fuel hydrogen. When hydrogen is used as a propulsion system, it is filled into the vehicle's tank in liquid form and converted into kinetic energy via a combustion engine. Water is sufficiently available as a raw material for the production of hydrogen and is added back to the water cycle as a by-product of combustion (Iwan, Kijewska and Kijewski, 2014). Thus, there are no direct emissions from the use of hydrogen and only an electricity source is needed to convert water into hydrogen. Also, Germany has the best network of hydrogen filling stations in the world and produces green hydrogen in Schleswig-Holstein, among other places, which means that it does not have to be imported, resulting in less dependence and lower acquisition costs (Johanning, 2020; Landwehr, 2020). However, keeping hydrogen in liquid form requires cooling of -253°C, otherwise, the hydrogen heats up and returns to its gaseous state and is also highly explosive in combination with air (Iwan, Kijewska and Kijewski, 2014). Furthermore, the market price for a kilogram of hydrogen is €9.50, which is higher than the projected marketable price of €5.00, and the acquisition costs for hydrogen vehicles are currently three times higher than for a diesel-powered model (Johanning, 2020; Neeland, 2020).

An additional way to reduce emissions is to use biodiesel, which is produced from hydrogenated vegetable oils (Koch, 2012). The raw material used is oil obtained from soy or rapeseed (Figueroa et al., 2014). After multiple filtering and the addition of methanol, biodiesel is obtained, which is used as fuel in a mixture with fossil diesel (DBFZ, 2010). Production, processing and use have a 60 % lower carbon footprint than fossil fuels (Koch, 2012). Furthermore, biodiesel has good ignition properties and the high oxygen content prevents soot formation and minimises residues in the engine (VDB, 2020). However, the cultivation of soy and rapeseed has a negative impact on soil and groundwater due to the use of fertilisers and pesticides. Furthermore, the combustion of biodiesel produces higher nitrogen emissions than conventional diesel (Fraunhofer IVI, 2020).

4.4 Synthesis of Results and Discussion

The final illustration (Figure 3) shows the complete conceptual framework of ecological sustainable physical distribution. It includes the condensed and synthesised results of our analysis and includes the ecologically sustainable principles as outlined in Figure 1.

We expand it further by instruments and outcomes for an ecological sustainable physical distribution.

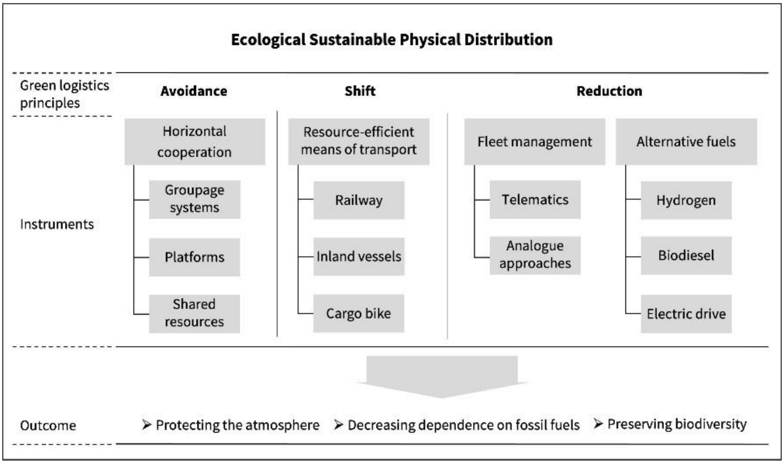

Figure 3: Ecological Sustainable Physical Distribution

Under optimal conditions, such as similar route planning, the same quality standards and a basis of trust, cooperation approaches are promising solutions as all participating companies can benefit from fewer emissions. However, many companies are not willing to work due to fierce competition. Thus, horizontal cooperation makes sense if all participants have equal rights and are willing to negotiate with each other at fair prices.

Resource-saving transport means should also be a sensible substitute for diesel-powered vehicles, so that, for example, the main leg of good shipments can be transported by inland waterway or rail, depending on the shipping point and destination. The pre-carriage and onward carriage, for example from the hub to the end consumer, involves smaller units of cargo and can be carried out over the last mile with the help of cargo bikes. If the use of trucks is unavoidable, investments in fleet modernisation can lead to ecological increases. An exact calculation of the amortisation of the measures is necessary to determine the individual improvements for the respective fleet. All companies should undertake small measures, such as the dismantling of air horns, which require no investment, as the improvement in aerodynamics leads to immediate fuel savings. Other investments in analogue and digital measures, can also lead to higher profitability and may not only make sense from an environmental point of view.

In regard to the research question, systems that have already been tested, such as telematics or the use of alternative fuels promise immediate improvements for the ecologically sustainable use of natural resources. As it stands today, electric propulsion is the most attractive ecological sustainable physical distribution option of alternative fuels, as the acquisition costs are lower than comparable hydrogen vehicles available on the market so far.

Equally attractive is the concept of the cargo bike, which can be used very variably and flexibly for last-mile deliveries and thus drive the reduction of diesel-powered trucks on the cost- and energy-intensive last section of physical distribution.

5 Conclusion and Research Outlook

This paper identified generic green logistics strategies for dealing with emissions to the field of physical distribution and presents a first conceptual framework for ecological sustainable physical distribution. In particular, the avoidance, shift and reduction of the use of diesel trucks in physical distribution as the largest emitter of carbon dioxide, has not yet been placed in this theoretical frame of reference, which can be used to implement ecological sustainable notions to the field of physical distribution.

It should be noted that this work has focused on concepts to improve environmental sustainability in the area of trucks used in physical distribution. In today's globalised world, aeroplanes and container ships are also used in large numbers for worldwide distribution. This area has not been dealt with in this work and thus represents ways to expand the conceptual model.

For this purpose, suitable concepts can be found and supplemented in other research fields. Furthermore, the authors focus exclusively on ecological sustainability. Aspects of economic and social sustainability are not primarily addressed and represent a future scope of research that can be investigated as a complement to this work.

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Assessing the impact of B2C e-commerce in the apparel industry: a logistics perspective

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Purpose: *The significance and pervasiveness of B2C e-commerce raise the question about its impact on employment under a social sustainability perspective. This study is aims to quantify the labour demand in logistics comparing the e-commerce order fulfilment process and the traditional brick-and-mortar one.*

Methodology: *An activity-based model is developed to represent a traditional retailer that both operates online and offline within the apparel industry in the Italian context. The working time related to an average single piece of apparel has been derived for each manual activity performed along the distribution chain.*

Findings: *Results are determined by the development of representative scenarios and the main variables affecting the employment are identified. Evidence shows that e-commerce requires more labour than brick-and mortar retail either in the traditional configuration of home delivery or delivery to parcel lockers. The decisive phase is the last-mile delivery, which requires the majority of labour time, both because of driving time and the consignment itself.*

Originality: *The main originality of the work lies in the perspective adopted to study the employment impacts of B2C e-commerce, providing an analytical contribution to the social sustainability literature of logistics.*

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1 Introduction

Electronic commerce has been a powerful force shaping economy and society from its introduction in the mid-90s. Nowadays, the Italian e-commerce market has reached almost a value of € 32 billion characterized by an always increasing yearly trend (B2c eCommerce Observatory, Politecnico di Milano, 2020). The e-commerce introduction brings along a cascade of innovative business practices, which are drastically changing the relationship between companies and their customers. The logistics field is not excluded from this revolution: in fact, it results being one of the key enablers for the successful implementation of e-commerce transactions, especially business-to-consumer. The shift in business practices is deeply affecting how companies conduct their operations. This has raised many concerns on sustainability. The extant literature has been dominated by scientific studies on the implications that e-commerce has on logistics from an environmental and economic point of view, which are the two of the three pillars of sustainability. On the other hand, the third pillar (i.e., the social one) seems to have been overshadowed by the preponderance of the other two, even if the field has recently witnessed a gain in traction among logistics researchers. Social sustainability is a broad concept characterized by different facades, having employment equity as one of its core elements. Labour is a key vector for the distribution of income that allows people livelihood, but its benefits are not only limited to money and economic growth, ranging from psycho-social welfare to social integration (i.e., paid work that provides social status) (Griessler et al. 2005). Therefore, employment results in being a crucial determinant of social equity and stability, highly affecting the lives of both present and future generations. The present study contributes to the social sustainability literature of logistics by providing evidence on how business-to-consumer (B2C) e-commerce affects occupation from a logistics perspective.

2 Literature review

Two streams of literature on “social sustainability in logistics” and “e-commerce employment effects” emerged from the analysis. Employment is the bridge between the two topics. Indeed, it is a key element to assess social sustainability initiatives, and, at the same time, it is a widely studied variable in macroeconomics to examine growth.

The problem of how e-commerce, and more in general information and communication technologies, affects employment from an economic perspective is broadly investigated within the extant literature. Many authors argue that its introduction has not negatively affected firm and industry level employment (Pantea et al. 2014; Pantea et al. 2017; Biagi and Falk 2017). However, none of these studies adopts a logistics perspective on the social sustainability problem. Researchers agree on the fact that logistics social sustainability has received less and scarce attention compared to the environmental and economic ones (Perez-Fortes et al. 2011; You et al. 2011; Pishvaee et al. 2012; Boukherroub et al. 2014; Sarkis et al. 2010; Jung 2017; Kumar et al. 2019).

Social sustainability expressed in terms of job creation and stability has been considered when designing a sustainable supply-chain (Perez-Fortes et al. 2011, You et al. 2011, Pishvaee et al. 2012, Boukherroub et al. 2014). Drivers' satisfaction, traffic, noise, and accidents emerged as the recurrent terms to evaluate social sustainability in logistics (Hesse 2002, Anderson et al. 2005, Browne et al. 2012, Bates et al. 2018). Logistics activities that received more attention in terms of social sustainability impacts are urban freight transport and last-mile delivery (Behrends et al., 2008; Buldeo Rai et al., 2017; Buldeo Rai, van Lier et al., 2017; Shi et al., 2019; Bates et al., 2018; Buldeo Rai et al., 2018). Here, crowd logistics emerged as one of the most relevant topics for employment-related studies due to the poor social protection of crowd workers. Few empirical and analytical studies on logistics employment have emerged. In one of the most relevant, Zacharias et al. (2015) assess the number of workers needed for different last-mile delivery modes in China to evaluate their social sustainability.

De Vera (2006) and Hesse (2002) emphasize the importance of customer distribution characteristics (customer density), purchasing habits (small size and high-frequency orders), and behaviours as relevant factors influencing e-commerce occupational impacts in logistics. These new habits are inevitably changing business processes, causing value chain reconfigurations (e.g., disintermediation and reintermediation phenomena), and consequently affecting industries employment levels (De Vera 2006). However, disintermediation along the supply chain does not always mean the perfect substitution of the traditional channel, since e-commerce may redefine new roles for intermediaries (Anderson 2003). On the other hand, Americo et al. (2018) claim that e-commerce penetration is correlated with decreasing employment within the traditional retail industry, but the study does not account for e-commerce-related occupation. Other authors focused on e-commerce effects on the geographical distribution of jobs, and they agree on its role as a social growth engine for both rural and metropolitan areas. For instance, Lin et al. (2019) claim that e-commerce is a catalyst for rural areas development in China providing work within the distribution sector. Others point out that it may be a driving force for logistics employment growth in metropolitan areas due to the large number of orders to be fulfilled at a high service level (Anderson et al. 2003). Considering warehousing activities, e-commerce often requires the picking and assembly of the orders within the warehouse. Hence, differences in labour requirements are highlighted by Loewen (2018) when activities need to manage single or few pieces instead of cases or pallets.

The theme of e-commerce and employment is mostly approached by economic literature. While qualitative considerations on how e-commerce may affect logistics labour emerged in the form of intuitions or hypothetical implications, literature has not empirically tested such hypotheses yet. Indeed, e-commerce social sustainability in logistics was identified as an under-researched area, characterized by a dearth of quantitative and analytical studies on employment.

3 Research objective

This study has the objective to fill the identified research gap by developing a model to compare the labour time requirements of the online and offline order-fulfilment processes within the apparel industry adopting a logistics perspective. The reason supporting the selection of a single industry is that the logistics context is highly influenced by the features of the product sold (e.g., its weight, value, or packaging), and by customer behaviours and habits, which deeply vary among different industries. Consequently, these factors influence the labour requirements. For instance, return rates of the apparel industry are on average much higher compared to other sectors and they can reach 30% of products sold online (Ghezzi et al. 2012). Moreover, the relevance of the apparel industry within the e-commerce B2c market is witnessed by its Italian value of around € 3.3 billion in 2019 with a compound annual growth rate of 22% in the last 5 years (B2c eCommerce Observatory, 2019). In addition, this industry is an interesting case to study the complementarities between the online and the offline channel, where points of sale are integrated within the online order-fulfilment process as picking and/or collection point. Indeed, traditional apparel retailers are operating multichannel and omnichannel strategies to increase their competitiveness (Luo et al. 2015). The wide variety of distribution channels proposed by retailers is shaping new logistics challenges and complexities. For instance, the click-and-collect phenomenon, where the customer buys online and collects the order at the retailer's physical store, is becoming widespread and it reached a 25% penetration of online clothing sales in 2016 in the UK (Allen et al. 2018). It reduces the risk of failed home deliveries, the last-mile costs, and it induces the customer to visit the shop, which frequently translates into other in-store sales. Hence, the relevance of the apparel industry B2c e-commerce market and the aforementioned logistics complexities (e.g., high incidence of returns or click-and-collect delivery mode) make it an interesting case study to understand logistics occupational dynamics.

Therefore, the research question the present work addresses is:

RQ: What is the occupational impact of both the online and the offline order fulfilment processes under a logistics perspective?

Specifying further, this work aims at analysing which are the main parameters determining the employment of logistics activities in both the online and offline channels, and how their variation affects the labour demanded by each process. Moreover, different perspectives have been adopted to understand the level of involvement of different types of workers and players.

4 Methodology

The methodology adopted to develop the model is deployed in three phases:

- Definition of the purchasing processes (1st step).
- Modelling the occupational impact for each phase and activity within the model (2nd step).
- Application of the model (3rd step).

The first step consists of identifying the most significant order-fulfilment processes of the apparel industry and their phases. The representative merchant for the model is a traditional retailer, which simultaneously operates both physical stores and an online B2c e-commerce website. Then, adopting an activity-based approach, similar to the one proposed by Mangiaracina et al. (2016) and Giuffrida et al. (2019), the main order-fulfilment phases for each purchasing process, and their constituting logistics activities were identified. The model considers all the logistics phases and activities performed to fulfil a single flat-garment order that has been already placed by a customer, meaning that pre-sale and sale activities are excluded from the scope of this work. Relying on a literature review, case studies, and secondary sources (e.g., specialized logistics websites, videos representing typical operations) the downstream logistics process from the merchant warehouse were mapped. Suppliers and their shipments to the central warehouse are excluded. Moreover, tasks that are automated as well as customers' actions are not included in this analysis, since the focus is only on activities requiring manual labour. Home-delivery, parcel locker delivery, and click-and-collect were identified as three different configurations for the e-commerce purchasing mode, while traditional brick-and-mortar retail is the offline channel. The analysis eventually reaches the post-sale service to customers. More details are presented in section 5 describing the model design.

The second step involves the modelling of the occupational impact measured in seconds per item for each phase and single activity identified in the first step. A literature review, case studies, and secondary sources such as industry/logistics reports, specialized logistics and apparel retailer websites support the identification of the main contextual data within the model. The outcomes of this phase are the working time per item of each individual activity and the selection of the data to describe the reference case for the model application.

The third stage involves applying the model to an average case, which is representative of the apparel industry context in Italy. Then, a sensitivity analysis was performed by varying key input parameters to investigate the dynamics affecting employment.

5 Model

This section deals with a brief explanation of the logistics flow underpinning each identified fulfilment process. For each configuration, the representative flow of products starts from the stock of clothes stored in the merchant's central warehouse reserve area, which is shared between both the online and offline channel.

5.1 Order-fulfilment phases

The order-fulfilment phases of the e-commerce channel, for both parcel locker and home delivery, are adapted from Mangiaracina et al. 2016:

- *Order picking and assembly*: this phase begins with the reception of the order within the merchant's warehouse and it ends with the express courier picking-up the parcels. It includes the replenishment of the forward picking area, picking (low-level and in batches), sorting, packing, and shipment preparation activities.
- *Delivery*: it deals with the long-haul shipment and activities in hubs managed by a third-party logistics provider.
- *Last-mile delivery*: this phase consists of the courier performing the last leg of the logistics chain to complete the delivery of the parcel at the customer's house or the collection locker, depending on the process under examination. It mainly consists of the time spent to drive on the streets to reach the point of destination and to consign the parcel.
- *Post-sale*: it starts with two possible product return modes, which are home-collection and pick-up point (i.e., locker) collection and it ends with the product storing in the merchant warehouse.

Click-and-collect (C&C) offers the customers the possibility to order and pay online and pick-up the product in the store. Hence, the order-fulfilment phases differ from the ones presented before, because the flow includes the merchant's point of sale (PoS). Moreover, the model considers both the picking and assembly of the order in-store or within the warehouse depending on the availability of the order within the PoS depot. Thus, the order fulfilment phases identified are (adapted from Giuffrida et al., 2019):

- *Store replenishment*: this whole phase is performed only within the store-picking configuration. The phase starts with the reception of the replenishment order from the store and ends with the replenishment of the PoS storeroom and shelves.
- *Order picking and assembly*: if the order is not already stored within the point of sale, order picking and assembly are performed as previously described within the warehouse and shipped to the store together with its replenishment order.
- *Product pick-up*: it includes the salesperson interacting with the customer, picking-up of the product within the PoS warehouse, and delivering it to the customer.
- *Post-sale*: the assumption is that the customer buying through the click-and-collect mode returns the product to the store where she collected it. The salesman checks the integrity of the item and eventually stores it within the point of sale.

Finally, traditional brick-and-mortar order fulfilment phases are adapted from Mangiaracina et al. (2016) and they include:

- *Store replenishment*: this phase is equal to the one presented for click-and-collect.
- *Post-sale*: as for the click-and-collect case the assumption is that a customer returns its order into the store where she purchased, and the activities remain the same.

Note that the delivery phase for an offline purchase is the customer trip back home with the product (Mangiaracina et al. 2016), thus, the model excludes it.

5.2 Model architecture

The model grounds on four building blocks: input data, context data, model algorithms, and output.

The input data section represents the model interface where the user can set key parameters to build different scenarios; they allow some degree of flexibility to the analysis. Input data are grouped into three classes: merchant features, customer features and behaviours, and last-mile delivery features.

The merchant's turnover can be large, medium, or low and the model automatically dimensions the area and the throughput of the merchant warehouse accordingly. Store size can be either big, medium, or small, and each type of stores has associated the capacity of the workforce and the daily flow of both traditional and click-and-collect customers. The unsold rate is the percentage of garments that remain unsold in the store.

Customer location can either be a metropolitan area, an urban area, or a rural one, based on Boyer et al. (2009). Moreover, the choices of the customer refer to the delivery mode selected when buying online. Finally, the behaviour of a customer can be modelled by setting the online and the offline return rates.

The model acknowledges three possible levels of complexity for the parcel delivery (high, medium, and low), which affect the average time to consign a parcel at home. Moreover, road conditions and traffic are set through the average speed of the van performing the delivery tour, for both home and parcel locker modes. Finally, the rate of home deliveries that fail at their first attempt is the last input (PL and C&C are assumed to have no failed deliveries).

The context data section refers to all the hypotheses that build the logistics flow of the order. They describe the activities within the central warehouse, the hubs, the store, or communication ones. These data include the main hypotheses to compute the time required by some activities such as picking within the warehouse, or the inefficiency coefficients of logistics operators. Others refer to the time required to perform crucial activities, expressed in terms of seconds (e.g., packing, sorting, set-up times, or communication activities), or percentages of the daily shift for store activities. Finally, other hypotheses regard the size of the average packaging for both e-commerce parcels or bulk freight, the transportation features such as the means involved, their saturations, and the average distances covered.

Input and context data feed the model that combines them through its built-in algorithm to deliver the main output, i.e., the labour time in s/item required by each activity. However, other activity attributes are added to analyse the results from other perspectives, such as the order fulfilment phase, the activity type, the type of worker (e.g. drivers), and the player involved (e.g. 3PL). Indeed, the model automatically computes and present graphs aggregating results by the selected attributes.

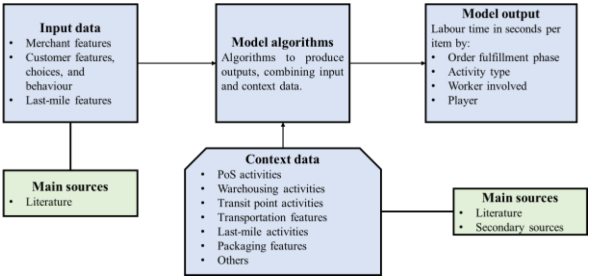

Figure 1: Model architecture

6 Results

6.1 Reference case scenario

The model was applied to a reference case scenario, considered to be representative of the average case of a traditional retailer operating both online and offline. The input data are set based on a literature review and Table 1 collects them (note that the product is returned in-store for click-and-collect and traditional order fulfilment processes).

The results of the model application for the four order-fulfilment processes are shown in Figure 2.

Table 1: Reference case features

Reference case features	
	Merchant features
Turnover	Medium
Store size	Medium
Unsold rate in the store	20%
	Customer features and behaviour
Online return rate	20%
Offline return rate	5%
Online return mode	Home collection (Pick-up point collection)
Location	Urban area (Metropolitan area)
	Last-mile features
Customer delivery complexity	Medium
Average van speed [km/h]	30 (15)
Missed deliveries rate	12% (0%)

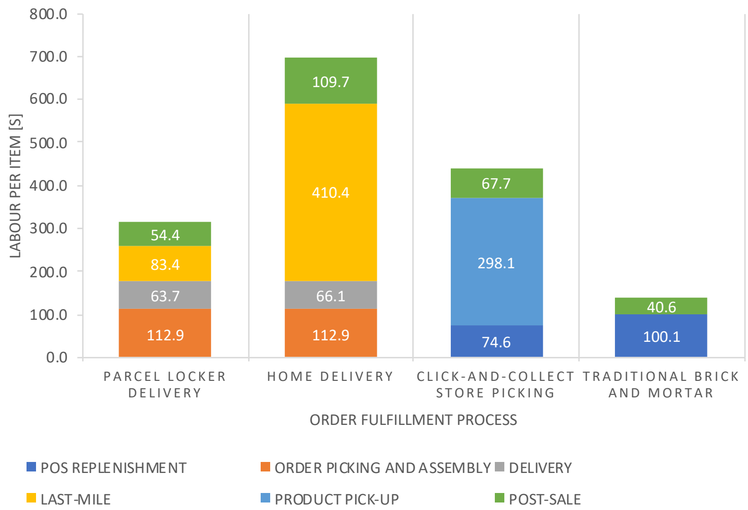

Figure 2: Labour required by order fulfillment process

Results indicate that the e-commerce channel always requires a larger amount of labour time per item with respect to brick-and-mortar retail. However, depending on the delivery type, the needed amount of workforce varies widely.

Home-delivery presents the highest working time (699 s/item), especially because of last-mile delivery, which is the most labour-intensive of all e-commerce phases requiring 410.4 s/item. The second most labour-demanding e-commerce channel is click-and-collect when the product picking is performed in-store (440.4 s/item). Here, the main activity is the delivery of the parcel to the customer (298.1 s/item), which is carried out by shop assistants. Among the e-commerce processes, the most labour-efficient is the order-fulfilment with parcel locker delivery (314.4 s/item), thanks to higher achieved efficiency in both the last-mile and post-sale phases. Finally, the traditional channel results to be the least labour-intensive channel (140.6 s/item), mostly thanks to order-fulfilment phases that are not performed by employees but by the customer (order picking and assembly, delivery, and last-mile). Moreover, additional efficiency derives from the handling and shipping of bulk quantities throughout the process. While in the other order-fulfilment processes logistics workers manage most of the time small lots, composed by single parcels.

6.1.1 Home delivery

In the home-delivery case, the two most labour-intensive phases are the last-mile and the order picking and assembly (they together represent 75% of the overall time), which are characteristically the additional value that this type of channel offers to the customer. Indeed, they represent "work" or effort that is performed by the shopper in the traditional brick-and-mortar setting. The last-mile phase is the most important in the analysis in terms of time (59% of the overall labour time). Its main components are related to the times spent travelling and consigning the parcel, and they equally contribute to make up 88% of the whole phase time, the missing portion is dedicated to the management of missed deliveries (see Figure 3).

Figure 3: Home delivery - Last- mile [s/item]

On the other hand, the relevant role of the order picking and assembly (16% of the overall process time) is explained by the execution of the activities on small batches or single pieces. The study indicates that this macro-phase is especially impacted by packing activities (40% of the overall phase time), which represents time dedicated to a single product, and picking activities (32%, including the replenishment of the picking forward, of the overall phase labour time), which are performed on small batches of products.

Then, manual labour is determined by van loading, other warehouse activities, and item singularization and order assembly (see Figure 4).

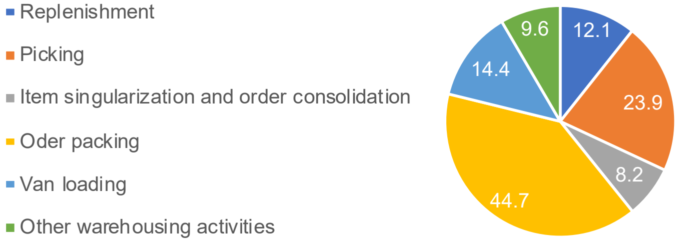

Figure 4: Home delivery - Order picking and assembly [s/item]

Another important share of labour in the home delivery case is represented by the post-sale phase (16% of the overall process time), where the returned products are managed adopting a home collection policy. This is consistent with the typically lenient return policies featured by apparel e-businesses. The high rate of garments working backwards in the supply chain increases the workload and the complexities of this order-fulfilment process. The two most important activities in this phase are the pick-up from the customer's premises (66% of the overall phase time), which replicates the characteristics of last-mile delivery, and the returned product reception and storing (23% of the overall phase time) at the merchant's warehouse. Of course, since not every fulfilled order is returned, such times are weighed upon the return rate.

Finally, the delivery macro-phase (66.1 s/item) is the least labour-intensive one, representing only the 9% of the overall process labour time, since it benefits from the high saturation of vehicles and the high degree of automation in the two transit points.

6.1.2 Click and collect

Click-and-collect order fulfilment process is more efficient compared to home delivery since it exploits the stocks already stored on the shelves of physical shops, avoiding the order picking and assembly, delivery, and last-mile phases. However, it requires a significant amount of labour during the product pick-up phase (68% of the overall time), because of the direct interaction with customers (85% of the overall phase time). Click-and-collect brings inside stores the labour associated with the consignment, hence, stores are a relevant logistics node for fashion online commerce. The PoS replenishment and post-sale phases represent respectively the 17% and 15% of the overall process time. Most of the labour within PoS replenishment phase (78% of the overall phase time) serves to perform handling activities within the store. Whereas central warehouse and transportation activities are very efficient due to bulk quantities handled. On the other hand, albeit returned products do not go back through the nodes of the network, they need gatekeeping, and they require to be individually screened and rearranged. However, returning items in the store (67.1s/item) reduces by 38% the labour time required adopting a home collection policy, because part of the work is done by the customer.

6.1.3 Parcel locker

Parcel locker delivery is equivalent to home delivery in the order picking and assembly and delivery phases. However, the results show that the contribution of each phase to the total workload varies drastically compared to home delivery, which is less equally distributed. Indeed, order picking and assembly becomes the phase that requires most of the process work (36%), followed by last-mile (27%), delivery (20%), and post-sale (17%). The main reasons are related to the adoption of lockers in both the last-mile (see Figure 5**Fehler! Verweisquelle konnte nicht gefunden werden.**) and the post-sale p hases. The labour time for both of them is observed to be drastically reduced by 80% and 50% respectively compared to the home delivery case. Less work is required due to the absence (as assumed) of missed deliveries, the higher delivery density, and the standardization of the locker replenishment procedure, which makes it far more efficient than attending parcel consignment. All in all, parcel lockers generate large efficiency in the last leg of the logistics chain by drastically reducing driving, consignment, and return collection times.

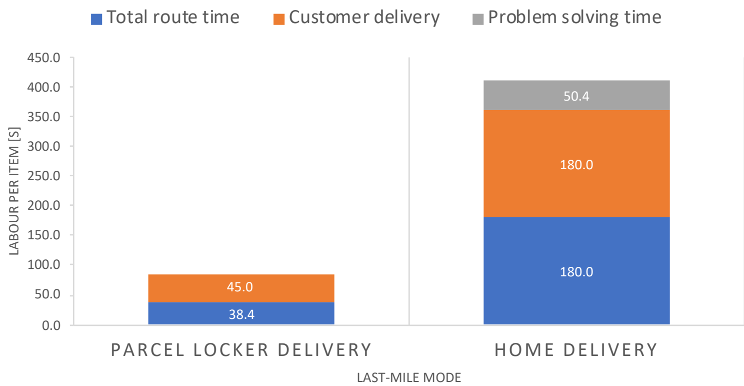

Figure 5: Parcel locker vs. Home-delivery - labour time comparison

6.1.4 Traditional retail

The least working time is required by the traditional channel, the labour is mainly concentrated in the PoS replenishment phase which represents 71% of the process (see Figure 6). Similarly to click-and-collect, handling activities within the store make up to 84% of the overall phase time, since operations in shops are not as efficient as those performed in dedicated logistics facilities (e.g. warehouse or hub). The post-sale macro-phase results to have an important share of working time, nonetheless. The offline channel, additionally to returned products, needs to manage unsold garments, which require the majority (58%) of labour within the phase. Returns are once again mainly affected by the time dedicated to the interaction with customers. While most of the labour for unsold garments lies in the preparation of the shipments to the outlet and in its reception and storing.

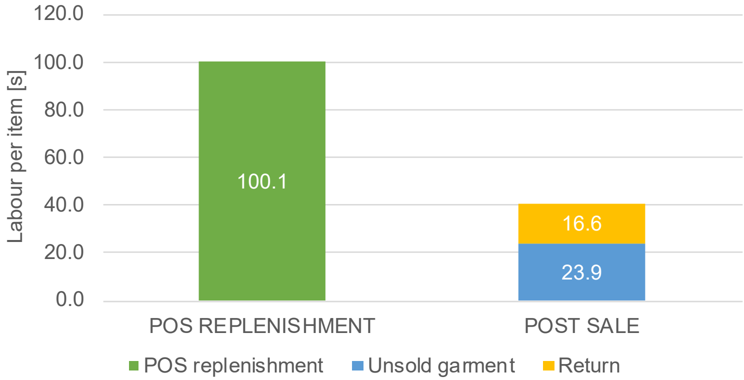

Figure 6: Macro-activities Traditional Retail

6.2 Sensitivity analysis

A sensitivity analysis has been performed to understand how the occupational impact of each order fulfilment process varies compared to the reference case by changing some of the key input data. Several scenarios were developed by changing the input parameters describing the merchant, the customer, and the context of the last-mile delivery.

6.2.1 Merchant type

Three types of merchants were considered, large, medium (reference case) and small, with the following characteristics:

Table 2: Merchants' characteristics

	Merchant type		
	Large	*Medium*	*Small*
Turnover	Large	Medium	Small

Merchant type			
PoS size	Big	Medium	Small
Unsold rate in the store	30%	20%	10%

The impact of the merchant features does not affect the ranking of the four order fulfilment processes, but the effects of the retailer characteristics are different depending on the process examined. Both home delivery and parcel locker delivery do not display any relevant variation in the total labour time required. On the other hand, the two other channels, characterized by the presence of the point of sale, show the tendency to increase their total workload moving from a larger to a smaller merchant. In fact, a large size of the merchant is associated with larger flows, which increase the efficiency of transportation and warehousing activities mainly. Moreover, a larger size of the points of sale is associated with improved productivity of in-store operations. These factors determine a 10% decrease in the total workload for C&C in the case of a large merchant, while the same amount increases by 15% when the retailer is small. Although the same factors influence the labour requirements of the traditional order fulfilment process, their impact is mitigated by the variation in the unsold rate, since larger stores are affected by a higher rate of products unsold. Hence, the model registers almost no variation when the merchant is large and a 9% increase in the total labour time when it is small.

6.2.2 Customer type

Three scenarios were developed based on three types of apparel customer (Cardoso et al. 2010) with the following characteristics:

Table 3: Customers' characteristics

	Customer type		
	Fashion-addicted	*Moderate (reference case)*	*Apathetic*
Online return rate	30%	20%	10%
Offline return rate	8%	5%	3%

The behaviour of a customer is a relevant determinant of the labour required to manage returned products, thus, on the overall occupational impact of each process. However, the analysis reports that the fulfilment processes of the product ordered online are the most affected since the return rates are higher. Moreover, the impact is linearly related to the amount of labour required by the collection policy adopted. Thus, the home delivery process is the most affected, since the home collection policy is the most labour intensive. Click-and-collect with store-picking policy follows, and finally parcel lockers. Obviously, the offline order-fulfilment process is the least affected one, due to the lowest level of return rates, which are driven by the possibility of "feeling and touching" the garment before the purchase, absent possibility in the online shopping.

6.2.3 Customer location

A sensitivity analysis on the location of the customer was performed by considering, besides the so-called urban area, also metropolitan and rural areas. Only parcel locker and home-delivery fulfilment processes are affected by the location of the customer. When home delivery is considered, the location is a crucial factor to determine the workload per item. Indeed, when deliveries are performed in rural areas the total labour time of the process increases by 56% compared to the urban case, because of the lower customer density, which affects not only the last-mile phase but also the post-sale one. Albeit having the highest customer density, the metropolitan area displays similar times (692.7 s/item) to the urban one (699.0 s/item). This is due to the high complexity of the parcel consignment (e.g., difficulty to find a parking slot, walking *etc.*) and to the lower average van speed, which is forcedly reduced by both traffic and densely populated areas. These two factors partially erode the efficiency derived from a shorter route distance.

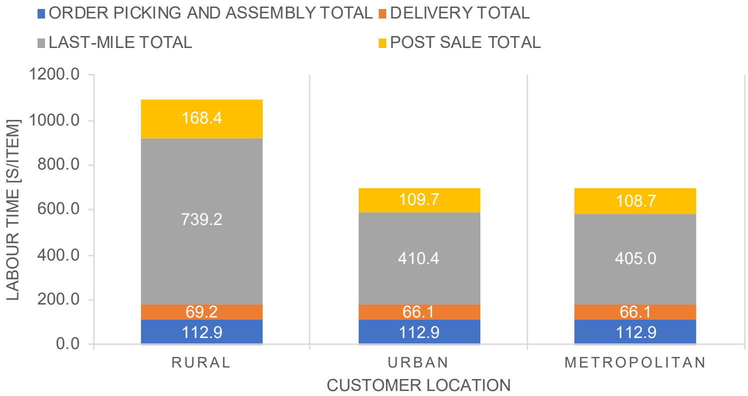

Figure 7: Home-delivery total labour times - comparison

On the other hand, the results show that the effects on locker delivery times are negligible. Because of the absence of any difference in complexities of locker replenishment depending on the area. Differences depend upon van speed and the density of the network of lockers. Ttraffic and congestion can level off the benefits of a higher network density. Indeed, the parcel locker process presents similar times for all three locations.

The observed dynamics underlying home delivery denote that the parcel consignment time (i.e. the time needed to park, unload the van, and collect the customer signature) can be decisive on the total amount of labour generated, especially when the courier is obliged to cover long distances on foot. Nevertheless, parcel consignment time is less impacting when the customer density is low. In fact, rural areas are by far the most labour-intensive ones, though consigning the parcel to the customer requires the least time (e.g. easy to find a suitable parking lot, no need to walk).

7 Conclusions

The main originality and novelty of the present work lie in the perspective adopted to study the employment impacts of e-commerce. This work provides an analytical and quantitative contribution to the social sustainability literature of logistics. Besides the theoretical implications, this study aims at creating a user-friendly tool to support the decision-making process of practitioners and policymakers. The model helps to make more informed decisions from an employment point-of-view. Retailers within the apparel industry can achieve a higher consciousness of how their businesses and choices affect the social tissue, evaluating their impacts from an occupational perspective.

As the main findings show, often the labour needed to fulfil an order is not concentrated in one actor of the logistics chain (e.g., the retailer), but it is spread among different players such as express couriers or 3PLs. Hence, the model helps a retailer to adopt an enlarged employment perspective, which does not look only inside the business but includes the broader picture of all logistics actors involved. Finally, this work gives policymakers an additional point of view on the effects that electronic commerce has on the employment of our society, which can help them in developing more informed public policies.

The model proposed has some limitations due to its scope and the necessary simplifying assumptions made in certain phases. Such limitations may be taken as insights for future research development. First of all, this analysis is concentrated on one single industry limited to the Italian context, hence it does not guarantee that the same results can be extended to other industries where logistics strategies are typically different. Also, the model does not take into account a global e-commerce perspective. Moreover, only one category of fashion product is analysed: folded clothes. Whereas accessories and hung garments are not modelled in the processes, although they require some differences in their handling and in their packaging. The model does not consider the fast-evolving role of automation and the impact that a broader application of automated processes can have on the manual labour demand observed across the various phases. Simplifying assumptions have been made to structure the reverse logistics flow that may follow many different paths and combinations from one player to another. Further research may investigate the impact on employment if other less common reverse flow scenarios were adopted. Finally, the last important limitation concerns the less detailed way through which store activity times have been computed, where, instead of examining each single logistics task performed in stores, times were considered as a predefined percentage of the salesmen's daily working hours.

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Appendix

E-commerce channel – Replenishment activities

Phase	Activity name	Activity type	Player	Worker involved
Order picking and assembly	Replenishment order emission	Management	Merchant	Warehouse operator
Order picking and assembly	Order reception and management	Management	Merchant	Warehouse operator
Order picking and assembly	Order fulfilment	Management	Merchant	Warehouse operator
Order picking and assembly	Picking list emission	Management	Merchant	Warehouse operator
Order picking and assembly	Forklift tour to pick the pallet	Warehousing/ Handling	Merchant	Warehouse operator
Order picking and assembly	Pallet retrieval with a man-on-board truck	Warehousing/Handling	Merchant	Warehouse operator
Order picking and assembly	Items storing (shelves replenishment)	Warehousing/Handling	Merchant	Warehouse operator
Order picking and assembly	Auxiliary and support activities to replenishment e-commerce	Warehousing/Handling	Merchant	Warehouse operator

E-commerce channel – Order assembly activities

Phase	Activity name	Activity type	Player	Worker involved
Order picking and assembly	Waybill emission	Warehousing/ Handling	Merchant	Warehouse operator
Order picking and assembly	Scanning parcel and loading trolley rolling container	Warehousing/ Handling	Merchant	Warehouse operator
Order picking and assembly	Moving parcels on a trolley rolling container	Warehousing/ Handling	Merchant	Warehouse operator
Order picking and assembly	Picking up parcels from the container and placing them in the van	Warehousing/ Handling	Express courier	Driver
Order picking and assembly	Van loading	Warehousing/ Handling	Merchant/ Express courier	Warehouse operator/ Driver
Order picking and assembly	Auxiliary and support activities to shipping e-commerce	Warehousing/ Handling	Merchant	Warehouse operator

Home delivery activities				
Phase	**Activity name**	**Activity type**	**Player**	**Worker involved**
Last-mile	Travel activities	Transportation	Express courier	Driver
Last-mile	Customer delivery	Parcel consignment	Express courier	Driver
Last-mile	Problem-solving activities	Parcel consignment	Express courier	Driver

Parcel locker delivery activities				
Phase	**Activity name**	**Activity type**	**Player**	**Worker involved**
Last-mile	Travel activities	Transportation	Express courier	Driver
Last-mile	Customer delivery	Parcel consignment	Express courier	Driver
Last-mile	Problem-solving activities	Parcel consignment	Express courier	Driver

Literature Review of Installation Logistics for Floating Offshore Wind Turbines

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Purpose: *Currently floating offshore wind emerges as a new technology and thus making offshore windfarms in areas feasible where it was due to certain conditions (water depths, soil conditions) not feasible to install fixed offshore wind turbines. The installation process of floating offshore wind foundations is very different from fixed foundations and thus results in new installation processes.*

Methodology: *In this literature review papers over the last ten years with focus on floating offshore installation logistics will be identified and sorted by relevance, year of publication and quality. The publications will also be grouped into the different foundation types Semi-floater, Spar buoy and Tension-leg. These groups will be subdivided further into costs, technical or processes related to logistics.*

Findings: *The paper will show an overview of current processes and trends in installation logistics for floating offshore wind turbines. Currently the existing reviews lack for example scientific papers and supply chain requirements (Carbon Trust, 2015) or they are focused only on technical issues (Wang, et al., 2010).*

Originality: *This paper is original in the sense that currently no complete, thorough and up-to-date literature review for the installation logistics and the supply chain of floating offshore wind exists.*

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1 Introduction

The financial success of an offshore windfarm with floating structures depends to a high degree on the transport and installation phases and thus the use of appropriate processes. These processes differ from the transport and installation processes for fixed bottom offshore wind structures significantly. These processes also differ between the three different types of floating offshore wind structures (Weigell et al. 2019).

The levelized cost of Energy (LCOE) of offshore wind energy are very high. LCOE for the generation of a MW/h are between 129 EUR and 155 EUR in Europe (Noonan, et al., 2018) For projects in Germany in the year 2018 (Kost, et al., 2018) state a price of 75 EUR to 138 EUR per MW/h. The LCOE costs are defined as: "Levelized cost of electricity (LCOE) refers to the estimates of the revenue required to build and operate a generator over a specified cost recovery period" (U.S. Energy Information Adminstration, 2021).

Since most suitable areas were offshore wind energy will be installed in the future (the East Coast of the US, the West Coast of the USA and East Asia (China, South Korea and Japan) are not as shallow as the North Sea and the Baltic the need for the use of floating offshore wind structures will arise. Because these offshore wind farms will be installed in deeper water depths and farther away from land, floating structures will be of greater importance in coming years (Ferreño González and Diaz-Casas, 2016).

2 Problem description

The logistics of offshore wind is complex and subject to adverse environmental conditions. Floating offshore wind is a very new technology and not yet as matured as offshore wind farms using fixed bottom structures.

Currently there are only a handful of floating offshore wind projects and most of them are single prototypes in operation.

In this paper the authors will show a thoroughly overview over the current scientific literature regarding the installation logistics of floating offshore wind turbines.

It is not a surprise that due to new topic there are mostly "grey literature" by the involved companies available. Also some use cases on the internet by these companies. Additionally there is a great amount of literature in the form of standards and guidelines from classification companies like DNVGL (as of March 2021 only DNV) (DNV, 2021).

For example the DNVGL-ST-0119 – Floating Wind Structures is the main standard when in comes to floating offshore wind. There are off course also standards by the ISO, Class NK, the IEC and the American Bureau of Shipping.

Additional guidelines from DNV in the form of Recommended Practices (RP), Service Specifications (SE) and Standards (ST) are complementing the DNVGL-ST-0119. Examples are DNVGL-ST-N001 - Marine operations and marine warranty or DNVGL-ST-0054 - Transport and installation of wind power plants.

There are also several books who are very useful to familiarize with the topics. The publications of (Cruz and Atcheson, 2016) and (Castro-Santos and Diaz-Casas, 2016) give a stringent overview.

Nevertheless the scientific literature in form of journal publications and conference proceedings is not extensive at this time. Most of the current literature is of a very technical nature and does not deal with the installation logistics of floating offshore wind farms per se but more with loads and CFD (Computational Fluid Dynamics). Even these topics are important and of great interest they should not be the topic of this paper.

2.1 Basics and Definitions

2.1.1 Installation Logistics for Floating Offshore Wind

The processes for the installation logistics of floating offshore wind turbines are very different from the already established installation of fixed offshore wind farms. More processes are carried out on land or in the shipyard than at sea and thus leads to a different supply chain (Weigell, Deshpande and Jahn, 2019).

The following shows a the processes for the installation logistics based on the WindFloat project.

WindFloat is a single protype floating offshore wind turbine installed in the EEZ (Exclusive

Economic Zone) of Portugal. At the same time of the installation of the turbine the prelay "of the mooring was done by an anchor handling and tug supply vessel" (Cruz and Atcheson, 2016). The columns were then pre-assembled and moved to the dry-dock for assembling and then the turbine was moved to the installation site by the anchor handling and tug supply vessel (Cruz and Atcheson, 2016).

The process for this is shown in the following flow chart:

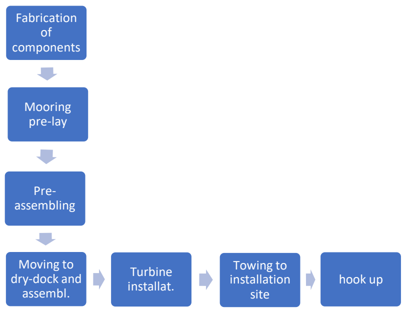

Figure 1: Installation Process Floating Offshore Wind Turbines

Source: Own representation based on (edp, 2015).

2.1.2 Types of Floating Offshore Wind Substructures

Currently there are three main types of floating offshore wind turbine set-ups to distinguish (Uzunoglu, Karmakar and Guedes Soares, 2016).

- Spar-Buoy
- Tension Leg Platform (TLP)
- Semi-Submersible Platfom

These three types are using different technologies to be stabilized in the ocean (Henderson, Collu and Masciola 2016).

- “TLP (Tension-leg Platform) where the floating platform is anchored to the seabed by vertical tensioners” (Díaz, Rodrigues and Guedes Soares, 2016)
- “Semi-sub (Semi-Submersible), where the platform gets most of its buoyancy from ballasted, watertight pontoons located below the free surface, providing very good stability characteristics” (Díaz, Rodrigues and Guedes Soares, 2016) and
- “Spar (Single Point Anchor Reservoir), where the platform is made of a vertical cylindrical floating body with a very large draft relative to its diameter.” (Díaz, Rodrigues and Guedes Soares, 2016)

(Uzunoglu, Karmakar and Guedes Soares, 2016) describe the technical properties in depths. Semi-Sub concepts are already in use in the oil and gas industry since the last sixty years and thus are proven concepts in terms of stability in waves especially for heaves and pitch. (Uzunoglu, Karmakar and Guedes Soares, 2016) The size and thus the loads which impact the structure are however different in floating offshore wind compared to oil and gas. (Uzunoglu, Karmakar and Guedes Soares, 2016). “The semi-submersible concept comprises of columns that provide the main volume under water and connecting members that provide structural integrity to the system as a whole.” (Uzunoglu, Karmakar and Guedes Soares, 2016)

The TLP concept was also first used in oil and gas in the 1980s. (Uzunoglu, Karmakar and Guedes Soares, 2016) The TLP is stabilized by mooring lines which are very stiff and thus resistant to motions. (Uzunoglu, Karmakar and Guedes Soares, 2016) “The typical TLP concept consists of a central column that carries the wind turbine with arms that support the tendons extending from the main body. The tendons are tensioned to provide stability. The number of arms and the angle between them may vary, usually being three or four.” (Uzunoglu, Karmakar and Guedes Soares, 2016)

The Spar-Buoy also has its origin in oil and gas and was first used in the 1990s. The Spar-Buoy is a cylindrical structure. “To provide stability, heavy ballast is used at the lower extremity of the platform, shifting the center of gravity to below the center of buoyancy. Station keeping is provided by catenary mooring.” (Uzunoglu, Karmakar and Guedes Soares, 2016) This concept is especially useful for very deep water depths due to the high weight at the floor of the cylinder which is working as an antagonist against roll and pitch of the structure. (Uzunoglu, Karmakar and Guedes Soares, 2016) It also has due to the cylindrical shape only small yaw motions and also a low stiffness in heave. The yaw forces have to be countered by the mooring lines. (Uzunoglu, Karmakar and Guedes Soares, 2016) Since this systems is targeted at deep water depths the mooring lines have to be very long which will lead to increasing costs of these. (Uzunoglu, Karmakar and Guedes Soares, 2016)

(Ferreño González and Diaz-Casas, 2016) give a thoroughly comparison between the three concepts. The following lines show the different advantages and disadvantages of the three concepts.

The TLP has a low structural mass, has few mowing parts and a high stability. Another advantage is that the turbine can be assembled in port. The disadvantages are however that the installation process of the substructure is very complex and thus there is the need for specialized installation vessels. Due to the technical nature of the TLP there are also high loads on the anchors and the mooring which fastens the TLP. (Ferreño González and Diaz-Casas, 2016)

The Spar-buoy is compared to the other systems less complex and thus can be used for serial production, it requires no active ballasting and the stability of the whole system is very high. (Ferreño González and Diaz-Casas, 2016) There are however the following disadvantages: the Spar-buoy can only be used in very deep waters, for the assembly of the turbine specialized vessels with dynamic positioning capabilities and heavy lift cranes are needed and finally the “large draft limits [the] ability to tow the structure back to port for major repairs.” (Ferreño González and Diaz-Casas, 2016)

The Semi-Submersible can be used in shallow depths and thus give a wider application range than the other floating sub-structures. The installation process is very easy since no specialized vessels are needed, just tug boats and the turbine can be assembled in port as well as major repairs can be carried out in port. (Ferreño González and Diaz-Casas, 2016) The disadvantages are that the Semi-Submersible has a very high structural mass, the structure is with many welded joints very hard to produce and the costs of the active ballasting is also very high. (Ferreño González and Diaz-Casas, 2016)

Based on the current distribution of the planned and fulfilled projects as well as prototypes there is a relatively evenly distribution of the three concepts and the best concept will be based on the particular project and location.

3 Research Methodology

3.1 Literature Review

In this step a structured literature research was done.

To the knowledge of the authors this was the only thoroughly done literature overview over floating offshore wind issues regarding the topic of installation logistics. Nonetheless the paper by (Wang, et al., 2010) looks at the topic of floating offshore wind more from a technical standpoint and less from logistical standpoint. Since the paper is more than ten years old and it is written from a technical standpoint it gives some insights but is not that suitable for the task of this paper. The technological advances for floating offshore wind over the last decade were big. Nevertheless the paper of (Wang, et al., 2010) is helpful to start from because the paper explains thoroughly the different design concepts of floating offshore wind.

In this paper only the logistical part installation of floating offshore wind turbines should be discussed. So all papers which handle the topic of fixed offshore wind structures have to be excluded from the search. Additionally all papers which cover pure technical topics and financial topics of floating offshore wind have to be excluded to. Only Journal articles and other scientific books were included in the search. So all grey literature and internet sources were also discarded from the search. Additionally books and book chapters were also not reviewed.

That leaves peer-reviewed journal articles and conference proceedings which are subject to this literature review. Only journal paper published in English were examined.

Due to fact that the research on logistics for floating offshore wind turbines is still relatively new, the snowballing approach according to (Wohlin, 2014) was used.

The following databases were used for the search were Google Scholar, Web of Science and Scopus.

The following keywords / terms were used: “floating offshore wind”, “logistics”, “supply chain", "installation", "transport", "Spar-Buoy", "Tension Leg Platform (TLP)", "Semi-Submersible Platform" and combinations of these. These resulted in a very high number of publications which had to be narrowed further down. The following shows this as an example for Scopus.

In Scopus there were 3,328 hits for "floating offshore wind", so this was narrowed down to 338 hits for the combination of floating offshore wind" and "installation". Furthermore all publications related to oil and gas were excluded using the limiter keywords "Offshore Wind Turbines", "Wind Turbines" "Wind Power" and "Offshore Wind Farms". This resulted in 274 papers. Furthermore the search was narrowed down to the key word "Floating Wind Turbines". This lead to 56 journal papers. For these 56 papers the abstracts were thoroughly analyzed. After this analysis 22 articles the result. 9 of these 22 articles were further deleted because there content was of a very technical nature and covered the logistics aspect of floating offshore wind turbines to a miniscule degree.

The procedure was done is a similar way for Web of Science and Google Scholar.

After these three databases were analyzed and duplicates were discarded a total of 30 relevant papers was the result. These publications are shown in Tab. 1

3.2 Classification of the literature

The following classification was used to systematically structure the particular literature.

The papers were grouped in the following areas:

Most publications regarding floating offshore wind deal just with the technical and engineering side. Since that floating offshore wind is a relative new technology this is not a surprise. Regarding the installation logistics of floating offshore wind most publications are from a company level and thus "grey literature".

The topic is not extensively discussed in the scientific community at this point. Comparing this to installation logistics for fixed offshore wind turbines it is reasonable to assume that this will change in the near future.

In the papers five groups were identified: General, Planning, Costs, Transport & Installation and Resources. The groups General and Costs stand alone, whereas Planning has four sub-groups, Transport & Installation has two sub-groups and Resources also has two sub-groups.

- General
- Planning
    - Model
    - Prototype
    - Design
    - GIS / Simulation
- Costs
- Transport & Installation
    - Installation
    - Processes
- Resources
    - Vessels
    - Anchors, Moorings, Cables

Table 1: Classification of the literature (Own representation)

	General		Planning		Costs		T&I		Resources	
Authors	General	Model	Prototype	GIS / Sim.	Design	Costs	Installation	Processes	Vessels	Anchors et al.
(Diaz and Soares, 2021)		X		X						
(Ren, et al., 2021)								X	X	
(Crowle and Thies, 2021)							X			
(Barter, Robertson and Musial, 2020)						X				
(Baita-Saavedra, et al., 2020)					X	X				
(Umoh and Lemon, 2020)	X									
(Stefanakou, et al., 2019)		X		X						
(Castro-Santos, et al., 2019)		X		X						

	General		Planning		Costs		T&I		Resources	
Authors	General	Model	Prototype	GIS / Sim.	Design	Costs	Installation	Processes	Vessels	Anchors et al.
(Weigell, Deshpande and Jahn, 2019)				X			X			
(Fontana, et al., 2018)						X				X
(Jiang, et al., 2018)						X	X			
(Castro-Santos, et al., 2018)						X				
(Campanile, Piscopo and Scamardella, 2018)					X	X				
(Fontana, et al., 2018)						X	X			X
(Hallowell, et al., 2017)								X		X
(Matha, et al., 2017)							X	X		
(Fujii, et al., 2016)							X			X

	General		Planning		Costs		T&I		Resources	
Authors	General	Model	Prototype	GIS / Sim.	Design	Costs	Installation	Processes	Vessels	Anchors et al.
(Castro-Santos, 2016)						X				
(Viselli, et al., 2016)			X							
(Castro-Santos, et al., 2016)						X				
(Castro-Santos, Martins and Guedes Soares, 2016)						X				
(Díaz, Rodrigues and Guedes Soares, 2016)						X				
(Campos, et al., 2016)								X		
(Taub, et al., 2015)						X				
(Tande, et al., 2015)	X									

	General		Planning		Costs		T&I		Resources	
Authors	General	Model	Prototype	GIS / Sim.	Design	Costs	Installation	Processes	Vessels	Anchors et al.
(Castro-Santos and Diaz-Casas, 2015)						X				
(Rodrigues, et al., 2015)					X					
(Utsunomiya, et al., 2014)							X	X		
(Castro-Santos and Diaz-Casas, 2014)						X				
(Taub, 2014)						X	X			
(Shin, Cho and Jung, 2014)		X								
(Collu, et al., 2014)							X			
(Utsunomiya, et al., 2013)			X							

	General		Planning		Costs		T&I		Resources	
Authors	General	Model	Prototype	GIS / Sim.	Design	Costs	Installation	Processes	Vessels	Anchors et al.
(Dymarski, Dymarski and Ciba, 2019)							X	X		

Fig 2. shows the number of publications per year:

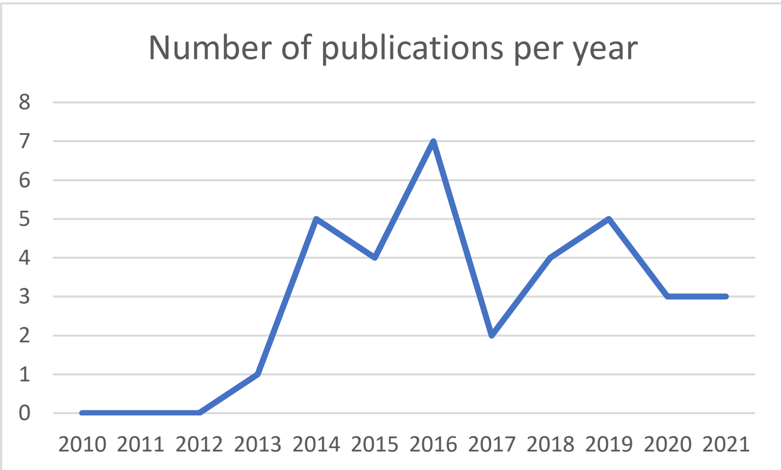

Figure 2: Number of publications per year

Source: Own representation

Interest in the topic started to gain traction in 2014 and there is a peak in 2016 with 7 papers. Due to the overall very small number of papers the trend at this point is not very meaningful. It is reasonable to assume that with more real projects starting in the near future there will also be an increase in publications.

4 Findings

4.1 General

Of the analyzed journal articles there are three journal articles which cover the topic of installations logistics for floating offshore wind in a general overview way. (Diaz and Soares, 2021) for example use multi criteria approach to evaluate different possible areas for floating offshore wind off the Canary Islands. (Umoh and Lemon, 2020) compare in their paper possible chances and obstacles for the use of offshore wind in Scotland (as an already mature market for offshore wind in general and also with the first floating offshore windfarm in the world in operation) with a new market (South Africa). Papers which were not treating the installation part (like technical publications or publications about the operation and maintenance phase) were excluded from this literature overview.

4.2 Planning

Since there is only a limited amount of already installed floating offshore wind projects and thus there is not an established state of the art way to install floating offshore turbines by now several approaches which involves planning were discussed in the publications. The authors divided the publications in the planning group further in the following subsets: Model, Prototype, Geographic Information System (GIS) / Simulation and Design.

(Stefanakou, et al., 2019) created a model for decision support using GIS for the installation phase of FOWT in the waters of Greece. Their findings lead to the conclusion that only small amount of installation sites in the Aegean Sea are feasible for FOWT. (Castro-Santos, et al., 2019) used a very similar approach to identify suitable installation sites off the coast of Portugal. (Diaz and Soares, 2021) developed a model were GIS was coupled with Multiple Criteria Decision Methods (MSDM) to identify the best installation sited for FOWT around the Canary Islands in the Atlantic.

The papers by (Viselli, et al., 2015) and (Utsunomiya, et al., 2013) are discussing the use of prototypes for site selection and for the installation of FOWT. The first one for the VolturnUS off the coast of the US state Maine and the second one is describing procedures for a location in Japan. (Shin, Cho and Jung, 2014) also use a prototype to show its unique installation procedures.

(Rodrigues, et al., 2015) develop a unique design concept to install FOWT by using moveable FOWT to optimize the layout of the offshore windfarm. (Baita-Saavedra, et al., 2020) propose a new floating offshore structure design made from concrete to reduce the installation costs. (Weigell, Deshpande and Jahn, 2019) did a simulation model for the installation processes of a semi-submersible offshore floating platform using the simulation software Anylogic.

4.3 Costs

With 14 publications costs are the biggest topic of the analyzed papers. Since the costs of floating offshore wind energy is currently very high to fixed offshore wind energy or other means of energy generation it is sensible that authors are researching on different approaches to reduce the costs of floating offshore wind energy and to make it more competitive. The following paper are among other items focusing on the installation costs of the LCOE (Levelized Costs of Energy) were installation / logistic costs are a big part of.

Castro-Santos is with six publications especially prolific in this area. She is discussing a broad spectrum in regard to costs of the installation of floating offshore wind turbines. Whether it will be (Castro-Santos and Diaz-Casas, 2014) were the authors analyzed the life-cycle costs of energy, where installation costs are an important factor, (Castro-Santos and Diaz-Casas, 2015) were the authors are doing sensitivity analyses of FOWT or (Castro-Santos, et al., 2018) were the authors develop a methodology to estimate the costs of Floating Offshore Wind Farms. In (Castro-Santos, et al., 2016) the authors develop a model where all relevant costs including transport and installation costs for FOWT are broken down and the authors test their model using a case study with floating offshore wind turbines of the coast of Galicia in Northern Spain. In (Castro-Santos, 2016) put more emphasis on decision variables for the cost model. (Díaz, Rodrigues and Guedes Soares, 2016) also did a cost assessment for a FOWT installation off the northern coast of Spain.

4.4 Transport and Installation

The topic Transport and Installation is divided in the parts Transport & Installation (T&I) and Processes.

(Weigell, Deshpande and Jahn, 2019) show the installation processes of a semi-submersible floating offshore platform. (Crowle and Thies, 2021) give in their publication a very good overview over processes like the processes in the dry dock, the temporary phases during the transport at sea, and the durations of the installation. (Collu, et al., 2014) give a good overview over processes during the transport and installation phase. A very big emphasis is in this publication on stability requirements during the different phases. (Jiang, 2021) gives a very extensive overview over installation processes for offshore wind in general and in this paper there is brief section on installation processes for Spar, Tension Leg Platform and Semi-Submersibles floating offshore wind structures. (Taub, 2014) proposes an system which uses innovative transport and installation processes to lower the Levelized of Energy of floating offshore wind by 10%-15%.

4.5 Resources

Regarding resources there is a much larger emphasis on moorings and anchors than for example vessels. In contrary to fixed offshore wind energy installation this is plausible because floating offshore wind turbines will be brought to the installation site by tug boat whereas for the installation of fixed offshore wind large und more expensive offshore installation vessels are needed. However for the installation of floating offshore wind the installation of the mooring lines and the anchors to install the floating offshore wind turbine are the challenging part.

(Campanile, Piscopo and Scamardella, 2018) develop in their publication suitable mooring designs for the use in medium and deep water depths for floating offshore wind.

(Fontana, et al., 2018) investigate two new anchor systems, one with three mooring lines and one with six mooring lines. In these systems the anchors will be shared by floating offshore wind turbines to lower the costs. In (Fontana, et al., 2019) the authors expand the anchoring system. (Hallowell, et al., 2017) take a look at how reliable a shared anchor system would be.

5 Conclusions

This literature review can only show a current state. This topic is very new and is getting traction over the last years and supposed to be getting more speed over the near future because of more projects in the United States, Japan and Korea. Also it can be said that some of literature for the first demonstration projects were published in Korean or Japanese. Additionally because the topic is new there is a great amount of “grey literature”, books and description of company websites but unfortunately not so many peer reviewed publications. Of these peer reviewed publications the vast amount is from a very technical standpoint and not from a installations logistics standpoint.

The authors structured the papers in the aforementioned five categories: General, Planning, Costs, Transport & Installation, and Resources with sub-categories. Since there is not really a state of the art and some papers tried to put a lot of very important information in the paper there was a high difficulty to separate the papers by these five categories so that some papers a fit more than one category.

The floating offshore wind would definitely benefit if more peer-reviewed scientific publications would be discussing the topic of installation logistics for floating offshore wind turbines.

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