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Changing Tides: The New Role of Resilience and Sustainability in Logistics and Supply Chain Management – Innovative Approaches for the Shift to a New Era

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Changing Tides:
The New Role of Resilience and Sustainability in Logistics and Supply Chain Management – Innovative Approaches for the Shift to a New Era

Prof. Dr. Dr. h. c. Wolfgang Kersten
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Preface

Resilience and sustainability are increasingly becoming the focus of strategic decisions. As recent events have shown, growing uncertainties and supply chain disruptions cause tremendous damage to companies. Digital technologies can help to deal with them and to operate more efficiently and sustainably. To enable the transition to a new era, all units along supply chains face the challenge of adjusting business models and processes.

This year's edition of the HICL Proceedings complements last year's volumes "Adapting to the Future: How Digitalization is Shaping Sustainable Logistics and Resilient Supply Chain Management" and "Adapting to the Future: Maritime and Urban Logistics in the Context of Digitalization and Sustainability".

This book mainly focuses on the new role of resilience and sustainability in logistics and supply chain management. It contains manuscripts by international authors that provide comprehensive insights into topics such as sustainability, maritime logistics, supply chain risk management or artificial intelligence.

We thank the authors for their excellent contributions that advance the logistics and supply chain management research. Without their support and hard work, this volume would not have been possible.

Hamburg, September 2022

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

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Advanced Manufacturing and Industry 4.0

Concept for Material Supply in Fluid Manufacturing Systems

Manuel Hagg [1] *and Robert Schulz* [1]

1 – University of Stuttgart

Purpose: *Through increasing individualization, volatile market demands or shorter product and innovation cycles, existing assembly systems in the automotive industry reach their limits. Different approaches are designed to address the need for adaptable systems. The Fluid Manufacturing System (FLMS), which has been developed within the research campus "Active Research Environment for the Next generation of Automobiles" (ARENA2036), aims to enable flexible and dynamic material flows. However, material supply in this environment is challenging due to new degrees of freedom or volatile demands. Therefore, the purpose of this paper is to describe a concept for short-term-oriented material supply in FLMS. The concept focuses on checking and ensuring material availability.*

Methodology: *The methodology that is used to derive the concept for material supply is based on a step-by-step procedure allowing a systematic concept development using a problem-solving-oriented approach. The concept procedure includes different steps like concept initiation or selection of a solution.*

Findings: *The result of this paper outlines a concept that supports short-term-oriented material supply in FLMS. More detailed, the concept supports checking and ensuring material availability.*

Originality: *The presented concept contributes to check and ensure material availability during the operation of assembly systems under changing conditions.*

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1 Introduction

In recent years, the automotive industry has been changing in regard to various developments. Among others, existing trends are new concepts like mobility-as-a-service, connected and self-driving vehicles or electric and fuel cell drive (Winkelhake, 2021). Moreover, increasing product individualization, volatile market demands, shorter product and innovation cycles as well as new car manufacturer have led to an increasing competitive pressure (VDA, 2021). Many of these developments affect automobile production and related logistics processes. For example, producing heterogenous and customized products at an optimum operating level, using conventional rigidly linked assembly lines that once had been designed for homogenous products, is challenging (Kern, et al., 2015). Even complex assembly line balancing approaches for mixed-model assembly lines have reached their limits due to existing cycle time variations (Swist, 2014). From a logistics point of view, increasing customization, which comes along with a wide range of individual options to choose from and long opened time slots for car buyers to update the configuration of their ordered cars, have led to an increasing number of materials that are delivered from a rising number of suppliers in decreasing planning and delivery cycles (Battini, Boysen and Emde, 2013).

As a consequence, different approaches have been designed and discussed to meet the changing requirements of automobile assembly (Fries, et al., 2021; Kern, 2021). The proposed approaches are often based on the principles of changeability and use flexibly linked process modules that allow e.g. cycle-independent assembly (Foith-Förster and Bauernhansl, 2015). These production systems, however, go along with higher requirements for production and logistics planning and control. As shown in Figure 1, alternatives to assembly line production systems can be characterized by nine principles (Kern, et al., 2015).

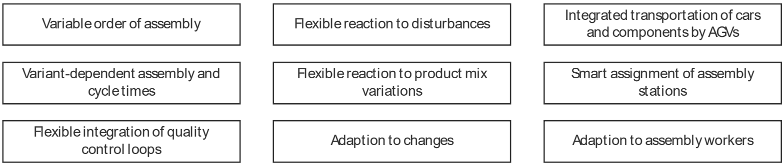

Figure 1: Principles of future assembly concepts (Kern, et al., 2015)

The FLMS that is addressed in this paper provides these principles. As one characteristic, FLMS enables flexible and dynamic material flows. This provides a basis for assembly order rescheduling, e.g. in cases of short-term deviations regarding the initial assembly schedule. Among other items, an assembly schedule contains the planned start time and end time of each job as well as all resources required for processing the assembly steps (Vieira, Hermann and Lin, 2003). As a decision-making process, scheduling deals with the allocation of specific resources to tasks within a defined time horizon (Pinedo, 2016). The process of updating an existing assembly schedule in response to disruptions or other changes is called rescheduling (Vieira, Hermann and Lin, 2003). Schedule deviations often occur during the operating phase of assembly systems, since planning data are outdated at the time of order release (Müller, 2020). Order release is defined as which orders are moved into the assembly system (Vieira, Hermann and Lin, 2003). At the same time, the moment of order release often represents the bridge between planning and control tasks.

There are various real-time events making dynamic rescheduling necessary in FLMS. They can be clustered into two categories (Ouelhadj and Petrovic, 2009):

- Resource-related events are e.g. machine breakdown, unavailability of operator, tool failures, shortage of materials or material with wrong specifications.
- Order-related events are e.g. changing order priorities, due date changes, early or late arrival, order cancellation or changes in processing time.

Basically, orders compete for the same resources and materials during rescheduling in FLMS. This is why complex logistics planning and control structures and logics are required to enable efficient material flows and dependent assembly processes. An assembly product is built by putting all its parts together. As a result of multi-part products, assembly operations can usually only be started when all the required materials are available (Schmidt, 2011). Moreover, these parts are delivered from different sources with the help of various material flows, stressing different logistical processes. As a result, ensuring material availability is challenging (Günther and Tempelmeier, 2016). Internal material supply is one of the major challenges for realizing flexibly linked assembly systems (Greschke, 2020). However, efficient assembly requires smoothly working material supply processes, since missing materials may lead to time and cost-intensive production downtimes.

To operate FLMS, new concepts are needed to accomplish one of the main logistical tasks, namely, providing the right material in the right place, at the right time, in the right quality and amount as well as at the right cost. Therefore, the purpose of this paper is to describe a concept for short-term-oriented material supply in FLMS. More detailed, the concept contributes to close an existing research gap regarding material availability checks in FLMS.

The remainder of this paper is organized as follows: Section 2 introduces FLMS. State of the art regarding material supply is described in Section 3. The concept is introduced in Section 4 and discussed in Section 5. Section 6 provides a conclusion and an outlook.

2 FLMS

The FLMS is developed within ARENA2036. As part of the University of Stuttgart, ARENA2036 is a research campus and innovation platform for cooperation between science and industry focusing on future mobility (Dittmann and Middendorf, 2019).

As an evolution of the Matrix Manufacturing System, FLMS is built up of modular and mobile process modules which are flexibly interlinked (Fries, et al., 2019). Moreover, FLMS is fully built up using Cyber-Physical Systems (CPS). CPS integrate computational and physical capabilities combined with the possibility of human-machine interaction (Baheti and Gill, 2011). As shown in Figure 2, the structure of Cyber-Physical Production Systems (CPPS) consists of the elements physical world, data acquisition, cyber world, and feedback/control structures (Thiede, Juraschek and Herrmann, 2016).

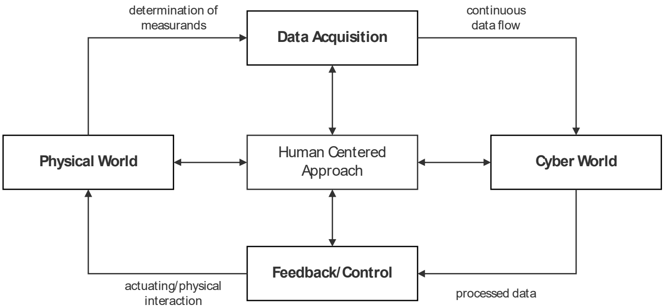

Figure 2: Structure of CPPS (Thiede, Juraschek and Herrmann, 2016)

FLMS is further based on the idea of ad-hoc resource allocation and individual process module reconfiguration (Fries, et al., 2021). Using the benefits of CPPS, process modules can be aggregated from single resources to advanced production systems (Fries, et al., 2021). This allows on-demand adjustments of capabilities and functionalities which leads to specific degrees of freedom that need to be managed within FLMS (Fries, et al., 2019; Fries, Wiendahl and Foith-Förster, 2020):

- Operation sequence specifies the sequence of work operations.
- Work distribution assigns the process modules to the production order.
- Work content defines the competencies of a specific process module.
- Layout position defines the position of production equipment on the shop floor.

These degrees of freedom make more complex planning and control logics necessary. Basically, planning processes will be shifted further into operation which means that planning and control phases increasingly overlap. Previously long term-oriented planning tasks need to be proceeded within short-term decision-making (Hagg, Noortwyck and Schulz, 2020). Moreover, this leads to changes regarding the chronology of how planning and control tasks are executed. For example, due to the high complexity and dynamic, in order to ongoing resource- and order-related events, the step of assembly order sequencing takes place after the task of order releasing (Waschneck, 2020). The uncertainty regarding the unknown production sequence directly affects just-in-sequence (JIS) delivery strategies that are often used in the automobile industry. JIS means that parts are pre-sorted by the supplier or inhouse supermarkets, so that assembly workers can access these materials just as determined by the production sequence (Battini, Boysen and Emde, 2013).

So far, resource and material availability checks have taken place within the initial process of order releasing (Schuh, Schmidt and Schürmeyer, 2014). Therefore, the developments accompanying FLMS have a major impact on the material supply process and ensuring material availability. Using decentralized methods is one possibility to deal with this complexity during the value creation processes. Dynamic scheduling is a decentralized approach that, unlike conventional scheduling, does not create long-term-oriented assembly schedules, but rather generates orders when necessary based on the information available at the moment of dispatching (Vieira, Hermann and Lin, 2003). In FLMS, assembly products are transported by using specific automated guided vehicles (AGV) for workpieces, so that fast reactions in cases of rescheduling are possible. Besides AGV for workpieces, there are also different AGV for material transport in FLMS. Regarding this, efficient scheduling functions must interact with other functions, such as ones responsible for material availability (Pinedo, 2016). Moreover, a critical point of dynamic scheduling is the high real-time requirement and the short time-horizon for material supply oriented decision-making (Zhou and Zhu, 2021). Within ARENA2036, an asset administration shell is used as a basic tool to realize data transfer and communication. Detailed descriptions of how to use an asset administration shell in FLMS and the first logistics-related implementations are already available (Bozkurt, et al., 2021; Ewert, et al., 2021). Besides several publications describing conceptual aspects of FMLS, up to now, different use cases have been implemented and tested as demonstrator on the ARENA2036 shop floor.

The above mentioned capabilities are especially relevant for FLMS, since, compared to other production systems like line based assembly systems or matrix manufacturing systems, control complexity is higher (Fries, et al., 2022). A more detailed description of FLMS and its relation to and differentiation from other production systems can be found in literature (Fries, et al., 2021). Important advantages and disadvantages of FLMS are summarized in Table 1.

Table 1: Advantages and disadvantages of FLMS (Fries, et al., 2022)

Advantages	**Disadvantages**
Ability to iteratively reconfigure in variable steps to the currently required product configuration	High control and scheduling complexity
Easy scalability	High costs of equipment
Changing competencies depending on process modules	Complex material flows
Continuous layout and process adaption	High effort for material supply and ensuring material availability

Heavily simplified, the production planning and control procedure for FLMS that have been designed within ARENA2036 includes three main steps (Hinrichsen, et al., 2022). First, an initial planning takes place to determine a basic production plan. Thereby, a capacity check is performed based on the individual task list of every product including factors like required technologies, personal or material. Based on the planning results, production begins and production control takes over in a second step. As long as there are no unplanned events like missing parts or machine failures, the initial defined production plan will be executed. However, if there are deviations, for example, when a process module is not available as planned or a material is missing, the production planning process is retriggered as a third step. This last step means dynamic rescheduling, as discussed previously.

The presented concept focuses on a material availability check as part of the afore-mentioned capacity check. Assembly system changes affect material flow structures and material supply processes (Blessing, 1999). Thus, the state of the art regarding material supply and approaches for ensuring material availability will be described next.

3 Material supply – state of the art

Material supply is an important design dimension of flexibly linked assembly systems (Schmitt, et al., 2017). Material supply is defined as the task of providing the required material that has already been delivered to the OEM plant, in the right amount and kind, to the right point of use as well as at the right time, to enable further processing (REFA, 1991a). Typically for automobile industry, value creation is more and more removed from the final assembly plant and shifted towards module production at suppliers (Battini, Boysen and Emde, 2013). Material supply is the connecting element between external logistic processes like procurement and the final assembly process (Nyhuis, Schmidt and Wriggers, 2008).

Several functions and parameters are used for material supply. Among others, the basic material supply functions include transport, picking, buffering, warehousing, handling (e.g. material preparation, un- and uploading) and sequencing (Esser, 1996). Material supply methods can be characterized by means of organizational and technical parameters. While the technical parameters include technical- and informational-oriented equipment, the organizational view is characterized by the following parameters (Bullinger, 1995):

- Object of material supply (identifiable by part number)
- Material demand quantity
- Material supply time as latest arrival time
- Material supply source and destination (sink as point of use)
- Material supply type (e.g. demand- and consumption-oriented strategies) and material supply form (e.g. single/set part delivery)
- Competence to trigger and execute material supply functions

Focusing on material supply in flexibly linked assembly systems, different concepts and associated technical equipment have been developed in recent years (Wehking and Popp, 2015; Hofmann, 2018). The so-called rack-concept, AGV-concept or set-concept can be mentioned as examples that have been investigated using simulation (Popp, 2018). A method for selecting the minimum-cost alternative for material supply have been proposed for these concepts (Bozkurt, Popp and Kueber, 2021).

Using the material flow flexibility offered by flexibly linked assembly systems, there might be redundant modules within the assembly layout that offer the same competencies. Hence, one weakness of flexibly linked assembly systems is the high effort for providing the same parts at different locations (Schmitt, et al., 2017). Further, new challenges for material supply arise because of the underlying systems characteristics. Particularly, uncertainty increases concerning the point of use, time of use, demand quantity as well as unknown order sequences (Ranke and Bauernhansl, 2021). This is why new control mechanisms are required (Bozkurt, Hagg and Schulz, 2020).

Further, the suitability and performance of different material supply strategies in the context of flexibly linked process modules have been evaluated and investigated (Ranke and Bauernhansl, 2021). In addition, different material supply strategies for material transport between a supermarket and matrix-structured work stations have been modeled and analyzed by using simulation (Filz, et al., 2019). The results indicate that part variance is one important factor influencing the favored material supply strategies.

Important requirements for the operational and organizational structure of material flow control systems in dynamic production environments that also apply to FLMS are (Blessing, 1999):

- Ability to change and adapt: Fast and low-effort logistical adaption to production systems changes. This may include organizational changes, increasing or decreasing the number of AGV, switch of AGV type as well as changes regarding production equipment arrangements.
- Variability of material supply control strategies: This requirement addresses the ability to switch between different control strategies and combine them without resetting the entire material flow control system. These control strategies may also differ within assembly areas.
- Data actuality and planning support mechanism: In order to deal with failures or unexpected events which may occur, the actuality of system data is important to support planning processes and short-term-oriented rescheduling. This includes e.g. information regarding inventories, material quality, AGV utilization or routes and traffic states.

A service-oriented architecture that enables a dynamic scheduling of material supply operations in line-based assembly systems has been introduced (Kousi, et al., 2016). This system is responsible for detecting the material supply requirements, triggering the material supply operations scheduler and dispatching the scheduled actions to AGV. Based on this architecture, a decision-making framework have been further developed to generate schedules for material supply tasks and assign them to available resources by using a material supply scheduler (Kousi, et al., 2019).

Moreover, first aspects of logistic planning and control in flexibly linked assembly systems are described (Kern, 2021). Central and decentral logistics areas, material supply and transport system design are described. Focusing logistics control, different material supply approaches, ways for monitoring logistical processes or fault management are discussed (Kern, 2021). However, how to ensure material availability is not considered in detail.

If parts are missing at the point of assembly, one of the following reactions is required in recent automobile assembly lines (Boysen, et al., 2015):

- If the shortfall is realized before having finally released the car, requiring the missing material for final assembly, another car can may be released into the free production slot. However, this modifies the initial planned assembly sequence and affects, for example, JIS processes, since parts need to be re-sorted.
- If the missing parts are anticipated early enough, express or emergency deliveries can be initiated and then executed by AGV.
- Another option is to continue with assembly as though nothing had happened and simply skip the missing part. When the left-out part becomes available, it needs to be retrofitted, which is time and cost intensive.
- In the worst case, the assembly line has to be stopped.

Since all these reactions cause costs and the occurrence probability of missing parts is higher in flexibly linked assembly systems with dynamic material flows than in recent assembly lines, more attention should be paid to the question of how material availability can be dynamically checked and ensured.

Checking material availability

This paper focuses on checking material availability. For multi-part products that need to be assembled, checking and ensuring material availability is a challenge that needs to be planned (Günther and Tempelmeier, 2016). Availability checks are used to clarify whether the required equipment and resources are available to perform the production as planned (Schmidt and Nyhuis, 2021). Material availability calculations are important to ensure that the required materials are delivered to the point of assembly in due time (REFA, 1991b). In literature, a distinction is made between static and dynamic availability check procedures (Scheer, 1998).

Static availability checks take place before order release, where it is necessary that all resources that are needed to complete the assembly step are physically available at the time of carrying out the availability check (Scheer, 1998). After the materials are assigned to orders, they are reserved to ensure that they are not allocated more than once. A lot of time might pass between order release and real assembly start, which means the in-time availability of the required material at the point of assembly is not ensured. In contrast to the static availability check, dynamic checks do not require the physical availability of materials until the beginning of assembly processing (Schmidt and Nyhuis, 2021). For example, simulation can be used to forecast order progress and material availability within dynamic availability checks (Scheer, 1998).

So far, little attention has been paid to material availability checks in dynamic production and logistics environments. Because of the ad-hoc allocation of resources that enable shorter system adaption times, however, the time to perform logistic tasks is reduced in FLMS. Moreover, dynamically changing process module positions over time challenge material supply in general and ensuring material availability in particular. In FLMS, the frequent occurrence of order- and resource-based events will make dynamic rescheduling necessary more often. Therefore, a new concept needs to be developed that takes these aspects into consideration and helps to close the described research gap concerning material availability checks in FLMS.

4 Concept for Material Supply in FLMS

4.1 Methodology and procedure

As shown in Figure 3, the concept involves four different procedural steps: concept initiation, searching for objective and task deduction, searching for solution as well as selecting a solution.

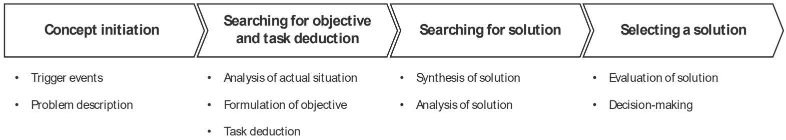

Figure 3: Concept structure and procedure

The methodology that is used to derive the concept for material supply in FLMS is based on a step-by-step procedure allowing a systematic concept development using a problem-solving-oriented approach. The four-step structure of the proposed concept is based on a problem-solving process that can be applied to a wide range of technical products and systems design (VDI, 2019a). In this case, the procedure is adapted to check material availability in the context of material supply and the concept supports decision-making regarding short-term-oriented material supply. Thus, the concept focuses on material availability checks as part of the entire material supply system in FLMS. As result, the concept contributes to ensure material availability during the operation of assembly systems under changing conditions. After the concept has been carried out and, depending on the final decision-making result, the execution of material supply functions might take place on shop floor level. These subsequent steps, which are not part of the concept described in this paper, include e.g. explicit load-vehicle assignment, empty vehicle balancing or routing (Schmidt, et al., 2020).

Before the concept is described more detailed in Section 4.3, important aspects regarding the underlying material and information flow, as well as how the concept will be embedded in the surrounding system, will be outlined.

4.2 Material and Information flow

It is widely known that synchronized material and information flows are important for successfully material supply. Moreover, well-balanced and synchronized logistic and production processes are also essential to operate FLMS. Manufacturing Execution Systems (MES) are important to manage production and logistic tasks, since they ensure process transparency or provide an up-to-date mapping of material and information flows (Kletti, 2015). As a centrally organized and a monolithic software application, currently MES are often integrated between the enterprise control level and manufacturing level within the control levels of a company. (VDI, 2016; 2021). However, in order to accommodate the increasing digitalization and the new requirements coming along, e.g. with production systems like FLMS, traditional MES architecture will change. In future, the monolithically structured MES will be separated into individual and independent applications that will be interconnected and communicate with each other in a decentralized manner during the value creation process (VDI, 2021).

Therefore, the concept presented here can be realized and implemented as a decentralized decision-making module that is able to collect and share all necessary data as well as interact with other system elements. The extensive information access in FLMS permits the use of local as well as global information for decision-making. While global information represents overall system knowledge, local information is only available locally (e.g. specific information of a load carrier that are not relevant for the overall system) (Schmidt, et al., 2020). As mentioned in section 2, the asset administration shell is used for coordinating material and information flows within FLMS.

4.3 Specifying the concept structure

4.3.1 Concept initiation

The aim of this step is to identify events that trigger the concept and to describe the basic problem statement by which the concept is initiated. Figure 4 illustrates the concept initiation procedure.

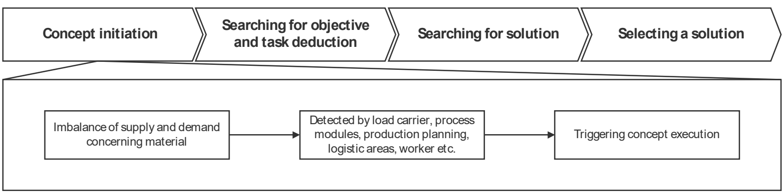

Figure 4: Concept initiation

Trigger events and problem description

In FLMS, changing operation sequences, work distribution, work content and process module arrangements may lead to shifting points of assembly where materials will be required. The problem to be solved occurs if there is a deviation between the quantity of material available at a specific point (e.g. point of assembly) and the material required. Basically, the problem is that the required material is not available where it is needed. Thus, there is an imbalance of supply and demand regarding material.

Because of the fast adaption potential of FLMS, it is expected that this problem will arise more frequently in FLMS than in other production systems. The wide availability of information supports the early detection of resource- and order-related events (e.g. missing or damaged materials), so that material-required actions can be initiated without loss of time. For example, if material that is transported using a CPS-based load carrier is damaged during transportation, these quality issues can be detected by the load carrier itself through implemented sensors and further steps for material replacement can be initiated (Bozkurt, et al., 2021). If the damaged material cannot be replaced or repaired in the remaining time, however, material availability cannot be ensured for this part. Different system entities are able to recognize such deviations between the material needed and actual state availability. Beside load carries, other entities respectively CPS can act as problem-identifiers and concept-initiators, e.g. production and control processes, AGV, worker, process modules, logistics or warehousing areas. Once the problem occurs and has been identified, the next steps can be triggered by these system entities to check if the problem can be solved. Hence, concept execution is usually triggered by events (e.g. unplanned events that require rescheduling).

4.3.2 Search for objective and task deduction

The next concept step deals with searching for an objective. The aim is to conduct a detailed analysis by providing additional information about the actual and target system state. Moreover, the final task is developed within this concept part. Therefore, searching for an objective procedure consists of three parts: analysis of actual situation, formulation of objective and final task deduction.

Analysis of actual situation

The analysis of actual situation aims to get an overview of the current situation. Therefore, it is necessary to take all important factors influencing the material supply system into account. For this purpose, the material supply parameters described in Section 3 are used to get an overview of the actual situation. The result of this step is a detailed analysis of the actual shop floor situation in terms of material supply relevant parameters.

Formulation of objective

Within the next step, the objective formulation takes place. Describing the desired final state makes it easier to search for possible solution alternatives afterwards. The objective must represent the final state that should be achieved after carrying out all the concept steps. Again, the material supply parameters are used to describe the objective situation. In contrast to the previous actual state description, however, the objective is formulated now. This guarantees that material supply parameters for describing the actual state as well as the objective situation match. As result, there is a clear objective formulation.

Task deduction

This step aims to deduce the final task by using the actual system analysis and the objective formulation. The deduction of the task focuses on the question which material supply activities are necessary to transfer the actual system state to the defined objective state (VDI, 2019b).

For this, a deviation analysis is performed to identify discrepancies between the material supply parameters representing the actual situation and those mapping the objective state. To identify the deviations between the target and actual states, the material supply parameters are systematically compared step-by-step. Thereby, all tasks that are necessary to transfer current material supply state to the objective state are identified.

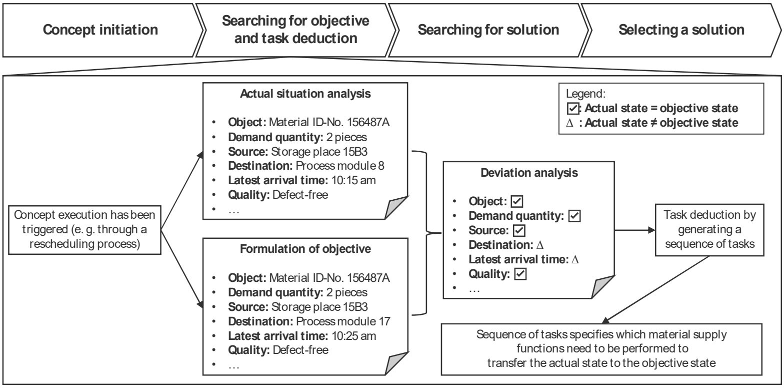

Figure 5: Searching for objective and task deduction

As result of the deviation analysis, a sequence of tasks can be generated (Kousi, et al., 2016). Based on this task sequence, it is known which material supply functions need to be executed to overcome the gap between material demand and material availability. In other words, the sequence of tasks specifies which material supply functions need to be performed to transfer the actual state to the objective state. Exemplarily, the described concept steps are summarized in Figure 5. However, the fact that the actual as well as target states can change dynamically over time in FLMS needs to be considered. As a consequence, several iterations can be necessary and explicit stopping criteria need to be defined.

4.3.3 Search for solutions

Based on the generated task sequence, solution options can be worked out to fulfill the defined task. Therefore, the concept step for searching for a solution consists of the synthesis of solutions and a subsequent solution analysis.

Synthesis of solution

The synthesis of solution aims to identify alternative solution options to execute the sequence of tasks. As a result, a collection of all possible solution options is generated to transfer the actual state to the objective state. These options can be stored, e.g. in a matrix table, for further processing. By synthesizing solutions, different conditions and limitations can be considered to border the number of possible solutions. This reduces the planning effort. Considering specific weight and size rules or the availability of logistic areas are examples for such limitations. Moreover, the available material supply equipment and existing material supply strategies (e.g. for transporting or warehousing) influence the number of possible solutions. For example, if the sequence of tasks contains the task transport and if there are different transportations alternatives available (e.g. AGV or forklifts), there might be more than one solution for the execution of the transportation task. As result of solution synthesizing, there is a collection that contains all possible options for executing the sequence of tasks. One of these option alternatives should be that material availability cannot be realized.

Analysis of solution

Within the next step, the generated collection with possible solution options needs to be analyzed in terms of their properties. The solution alternatives are investigated regarding the resulting consequence if this option is chosen. Therefore, different material supply relevant dimensions can be applied. These dimensions may include cost-, capacity- or time-relevant aspects that are linked to the logistical target system (Droste, 2013). For example, focusing on the time dimension, the solutions options are analyzed regarding the resulting consequences in terms of material supply synchronization or timeliness (Nickel, 2008). The resulting consequences can emerge in different environmental states due to existing system uncertainties, so that different occurrence probabilities can be considered by analyzing the consequences. In addition to the afore-mentioned dimensions, other dimensions, like logistical process sustainability or human ergonomic aspects (Droste, 2013), can be added, since the structure is modular. Figure 6 illustrates the concept steps for solution synthesis and analysis.

Before evaluating possible solution options in the next step, the resulting consequence of every option is analyzed and added to the collection of possible solution options. The result is a collection of all possible alternative solutions and the anticipated consequences that occur if the respective solution option is realized.

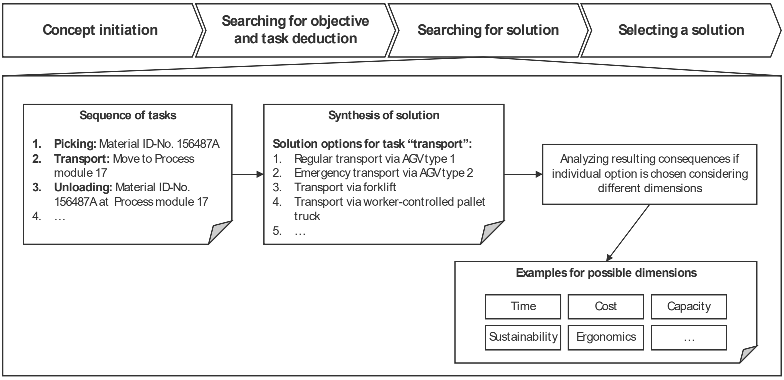

Figure 6: Searching for solution

4.3.4 Selection of solution

The last step of the concept procedure deals with the solution selection and consists of the evaluation and decision-making processes. The aim is to choose the best suitable solution option.

Evaluation of solution

As a basis for final decision-making, the consequences of every solution option need to be evaluated. Therefore, the comparability of the dimensions values and properties must be insured. This is challenging in order to eliminate inhomogeneous value characteristics. Further investigations are necessary to identify suitable methods that allow interpretable evaluation of solution options (e.g. using non-dimensional approaches).

Decision-making

After the evaluation process, the fittest solution option needs to be chosen. However, this option might change over time and depends on individual preferences. Moreover, individual entity goals in FLMS are often conflicting and mutual dependencies exist. In one situation, it might benefit the overall system performance if the solution with lowest material supply cost is chosen. Whereas, in another situation, it might be favorable if material supply processes temporarily cause higher costs to enable the assembly of a highly prioritized product.

In cases of short-term rescheduling processes, it is also possible, however, that material availability cannot be ensured and cost intensive production downtimes arise. This can happen if the remaining time for material supply is not sufficient by using the existing material supply equipment. Then, the production rescheduling process is performed again to check other options for processing the next assembly step.

Consequently, a dynamically adjustable decision rule is required for decision-making. A decision rule is built up by a preference function and a optimization criteria for the preference value (Laux, Gillenkirch and Schenk-Mathes, 2018). Based on this, the evaluated solution options are prioritized in a first step, and then the option with the highest priority is chosen. The full details and final design of such an adaptable decision rule for FLMS need to be further developed. One option might be a decentral-oriented decision rule using dynamic negotiation approaches for dialogues between the system entities that are involved in the material supply process.

The result of the decision-making step indicates whether the material availability can be realized or not. If material availability can be realized, the next steps are initiated (see Figure 7). For example, feedback is sent to the capacity check triggered by rescheduling processes, whereupon process modules can be reserved or required material reservations are initiated. The final execution of the material supply processes and the continuous monitoring of these processes is not part of the presented concept. If material availability cannot be realized, a dismissal is sent to the initiator of the initial request by using feedback loops. As a result, the proposed concept contributes to logistics interacting on par with assembly in FLMS.

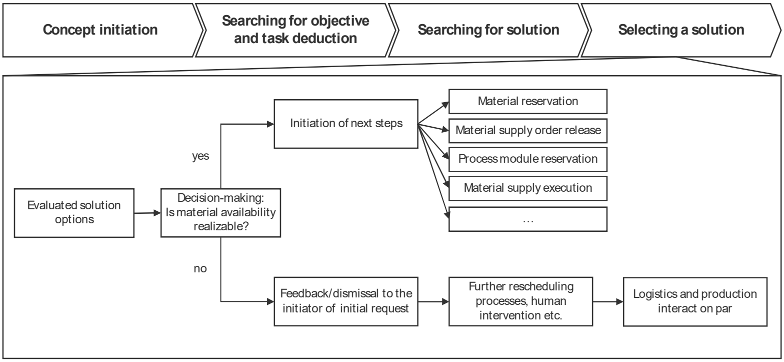

Figure 7: Selecting a solution

5 Discussion

In the last section, a concept that supports short-term-oriented material supply in FLMS have been presented. More precisely, the concept investigates whether material availability can be realized or not. One benefit of the described concept is that it supports using the degrees of freedom that accompany with FLMS. Moreover, it contributes to reduce logistics-related traffic volume and the total quantities of transports. This is possible through an early check of material availability and an effort estimation for the required material supply processes to enable material availability. Additionally, the concept supports the material flow control system requirements described in Section 3 in FLMS environments. Particularly significant are the ability to change and adapt, the variability of material supply strategies and planning support mechanism through data actuality.

However, there are challenges and limitations regarding the presented concept that need to be addressed in future. The required estimation and anticipation of future environmental states is a weakness of the concept. Moreover, missing cycle times complicate material availability calculations. A closer look is necessary to investigate the utility of the proposed concept regarding the material spectrum to be supplied. For example, to clarify how to handle high or low material variance. Under specific production and logistics conditions, it might be beneficial to use a pre-sorted material set that is carried along with the product to be assembled. These conditions have to be analyzed in more detail. Further, logistics and assembly processes are characterized by inhomogeneous responsiveness times for changes and adaptions in FLMS. These aspects should be implemented more explicitly as part of decision-making within the introduced concept. Moreover, solution for other key challenges like technical-, algorithmic- or systems engineering-related concept aspects need to be developed in future.

6 Conclusion and outlook

This paper deals with material supply in FLMS. The result outlines a concept that supports short-term-oriented material supply. More specifically, the concept supports the evaluation of whether the material availability can be realized within a short-term-oriented time horizon. Therefore, the concept involves the following main procedural steps: concept initiation, searching for an objective and task deduction, searching for a solution as well as selecting a solution. These procedural steps have been worked out and described in more detail.

The presented work has implications for research and practice, since it complements related approaches and existing literature for material supply. Moreover, the introduced concept is an important module for efficient material supply in FMLS and it extends logistically-oriented control and planning methodologies for flexibly linked assembly systems.

Further research is needed for a deeper development of the concept and to reduce existing limitations that have been mentioned in Section 5. Efficient mechanisms for avoiding permanent rescheduling processes must be implemented and stopping criteria need to be defined. For example, how emerging deadlocks could be handled, e.g. by rule-based human intervention, should be investigated. The presented decision-making environment is characterized by heterogenous properties like conflicting goals and mutual dependencies that need to be balanced. These points need to be worked out in more detail and can be investigated using simulation.

Acknowledgements

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Supply Ecosystems and The Concept of Resilience – A Literature Review

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Purpose: *Established approaches to supply chain management are increasingly being challenged due to disruptive events that neglect the dynamics and interdependencies of supply chains. Supply ecosystems form a new theoretical view of the supply chain that is more in line with systemic thinking, although it is unclear how these can contribute to increased resilience.*

Methodology: *Based on the assumption that supply ecosystems are complex adaptive systems with a dynamic capacity to adapt to changes in an environment and evolve, we conducted a systematic literature review of 24 peer-reviewed journal articles.*

Findings: *The review identifies the attributes of complex adaptive systems making them resilient and matches these with the concept of supply ecosystems. The resulting framework demonstrates how supply ecosystems contribute to increased resilience through the systemic nature.*

Originality: *The paper extends research on supply ecosystems by conceptualizing them as complex adaptive systems and identifying attributes that can contribute to system resilience. Thus, the study contributes to the emerging research of supply ecosystems.*

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1 Introduction

Over the past years, supply chains (SCs) have followed a management trend to reduce costs while increasing efficiency (Ivanov, 2020). While these optimizations could lead to a competitive advantage in the market, they also increased the vulnerability of many SCs to external shocks (Craighead, Ketchen and Darby, 2020). Various disruptions ranging from interruptions in the transportation or production process, epidemic outbreaks, and global pandemics have highlighted this vulnerability, as many companies have been unable to compensate for the loss of performance caused by these disruptions (Scholten, Stevenson and van Donk, 2020). With this sudden attention, the research field of SC resilience gained significant attention in recent years (Hohenstein, et al., 2015). Especially after the Covid-19 pandemic, many scientists have been engaged in this research area, which has led to new aspects and perspectives of resilience (Chowdhury, et al., 2021). However, while much research on this topic focuses primarily on the resilience that can be developed by the focused company, more recent approaches propose that resilience is achieved not only at the individual level but also within the broader network of actors that are part of a SC (Adobor, 2019; Novak, Wu and Dooley, 2021; Münch and Hartmann, 2022).

In this context, several studies discuss new organizational forms of SCs, such as shifting to an extensive supply ecosystem (SE) as a means to enhance resilience (Ivanov and Dolgui, 2020; Mollenkopf, Ozanne and Stolze, 2021). SEs consists of interdependent actors who coordinate their activities, leading to close cooperation and ensuring business continuity (Stolze, Mollenkopf and Flint, 2016). Thereby, SEs enable joint decision-making and the creation and sharing of knowledge between the different actors (Scholten and Schilder, 2015). As a result, SC stakeholders' evolve from isolated, local suppliers to ecosystem-wide, systematic, and intelligent actors (Ivanov and Das, 2020). This degree of involvement suggests a change in the hierarchical arrangement of companies, which in turn leads to increased innovation dynamics (Luo, 2018). To hold together diverse actors and enable collaboration, SEs need to balance structural flexibility and integrity, overcome cognitive disparities between the actors, and rely on an architecture of participation (Lusch and Nambisan, 2015). To meet these requirements, digital industrial platforms are increasingly being implemented (Teece, 2017), as they act as a technological basis for complementary solutions and a market intermediary between different groups of actors (Gawer, 2014).

In recent literature, ecosystems are often described as complex adaptive systems (CAS) from a theoretical perspective due to their structural composition and properties (e.g., Roundy, Bradshaw and Brockman, 2018; Phillips and Ritala, 2019). Several studies have examined SC resilience from the CAS perspective (e.g., Day, 2014; Zhao, Zuo and Blackhurst, 2019; Adobor, 2020). Although first studies have adopted the CAS concept and underlying characteristics in ecosystem research (e.g., Adner and Kapoor, 2010; Ansari, Garud and Kumaraswamy, 2016), it is not yet evident which characteristics of SEs correspond to the characteristics of CAS. Therefore, this study aims to answer the following research question: *Which characteristics of SEs are consistent with the characteristics of CASs, and how do these characteristics influence the resilience of the SEs?*

A systematic literature review is conducted to answer the research question. First, it examines the characteristics of this system and whether it is suitable to be considered an CAS. In particular, this context explores whether this organizational form is a more appropriate approach to an CAS lens on resilience. Second, emergent characteristics that contribute to resilience beyond CAS theory are elaborated to develop an understanding of the resilience capabilities of SEs.

The remainder of the paper is structured as follows. In section 2, an overview of the theoretical background is given by explaining supply chain resilience and CAS as core elements of this study. The methodological approach is explained in section 3. In section 4, supply ecosystems are conceptualized as CAS by identifying which characteristics of supply ecosystems correspond to the characteristics of CAS and how these characteristics result in increased resilience. In addition, implications for practice are given and limitations and further research needs are outlined.

2 Theoretical Background

2.1 Resilience in The Context of Supply Chains

The concept of resilience, which originates in social psychology (Sitkin, 1992), was adapted to a variety of disciplines over time, such as ecology, engineering, risk- and disaster management, and information systems (Ramezani and Camarinha-Matos, 2020), demonstrating its multidimensional and multidisciplinary nature (Massari and Giannoccaro, 2021). In SC management, many approaches to define SC resilience have emerged over time, and authors have often stressed the lack of a unified definition (Tukamuhabwa, et al., 2015). Nonetheless, authors such as Massari and Giannoccaro (2021) observed general research streams that mainly point in two directions. The authors classified a static and a dynamic perspective that is predominantly represented in literature (Wieland and Durach, 2021). The static perspective on resilience refers to "[…] the system's ability to absorb disturbance and bounce back to the original equilibrium state maintaining its core functions when shocked" (Massari and Giannoccaro, 2021, p. 1). In contrast, the dynamic perspective represents "[…] the ability to adapt to a disturbance by moving towards the original but even new, more favorable equilibrium states" (Massari and Giannoccaro, 2021, p. 1). According to Novak, Wu and Dooley (2021), the static equilibrium-based perspective on SC resilience has to deal with shortcomings since it often rather analyzes the resilience of a focal firm more than the resilience of the entire SC. They argue that the recurring equalization of resilience achieved by the firm and resilience achieved by the entire SC leads to this misinterpretation. Other authors like Borekci, Rofcanin and Gürbüz (2014) also pointed out that the resilience of multiple actors in the SC is greater than the sum of the resilience of the individuals. In this context, the systemic aspect of SC resilience is often highlighted by authors (Adobor, 2019), leading to CAS as a theoretical foundation (Choi, Dooley and Rungtusanatham, 2001; Nilsson and Gammelgaard, 2012; Adobor and McMullen, 2018; Zhao, Zuo and Blackhurst, 2019). This grounding in theory seems reasonable since resilience has been described as an adaptive phenomenon (Shastri, et al., 2014; Wieland, 2021) as, on the one hand, SCs face a dynamic environment and must adapt to changes in the environment if they are to survive (Choi, Dooley and Rungtusanatham, 2001) and, on the other hand, the activities of individual actors also affect the SC environment (Adobor and McMullen, 2018).

2.2 Complex Adaptive Systems

CASs focus on the adaptability of a system and emerged out of complexity theory (Schneider and Somers, 2006). According to its ability to incorporate a more realistic picture of systems that feature complex interwoven structures, it has an advantage over most SCM metrics that often lack the ability to examine the dynamism or evolution of a system (Pathak, et al., 2007). CASs generally describe an interconnected network of autonomous and rational decision-making agents that responds in an adaptive way to changes in the environment as well as other agents in the network (Choi, Dooley and Rungtusanatham, 2001; Tukamuhabwa, et al., 2015). Agents may represent individuals, a division, or an entire organization, depending on the scale of analysis (Choi, Dooley and Rungtusanatham, 2001). They are guided by norms, values, and beliefs that are shared by the system, so-called schemas (Schein, 1992). Causal dynamics, for example in the form of similar goals or concerns within an CAS, apply to every level of the system (Wycisk, McKelvey and Hülsmann, 2008). Individual agents may pursue their own goals but end up causing system-wide similar patterns to emerge (Tukamuhabwa, et al., 2015). CASs are scalable, which facilitates their capability to adapt.

Choi, Dooley and Rungtusanatham (2001) outlined a set of central internal mechanisms of CASs: First, CASs are characterized by being emergent and self-organizing – systemic behavior occurs through the parallel and simultaneous activities of agents, which give rise to nascent structures, patterns, and properties (Choi, Dooley and Rungtusanatham, 2001; Pathak, et al., 2007). The second mechanism is network connectivity. CAS can be described as an aggregation of connections between agents, and their level of connectivity determines the complexity of the network (Choi, Dooley and Rungtusanatham, 2001; Pathak, et al., 2007). The higher the level of connectivity, the more interrelationships between agents exist (Dooley and van de Ven, 1999). However, a critical point of complexity exists that should not be crossed (Kauffmann, 1993), as the establishment of new interrelationships slows down and the system loses efficiency (Choi, Dooley and Rungtusanatham, 2001). The third internal mechanism of an CAS is dimensionality. It defines the freedom of agents in the system to act autonomously (Dooley and van de Ven, 1999). While control in the form of rules and regulations ensures greater predictability of the system, less control allows for more autonomous decision-making of agents and, therefore, more emergent outcomes that are typically more creative (Choi, Dooley and Rungtusanatham, 2001). An increase in connectivity decreases dimensionality as autonomous acting is impaired by a high number of inter-relationships (Pathak, et al., 2007). The fourth aspect is the environment, which is characterized as dynamic and rugged. Dynamism develops when the agents must adapt to a fluctuating environment, affecting the way they perceive their environment or the schemas they follow (Pathak, et al., 2007). Adjustments in CASs are nonlinear regarding the initial alterations (Pathak, et al., 2007), resulting in events having disproportionately negative or positive implications for the system (Wycisk, McKelvey and Hülsmann, 2008). The environment is rugged because of the system's components that are tightly coupled and interconnected, creating local optima, which can blur the conception of an overall optimal state (Choi, Dooley and Rungtusanatham, 2001). Lastly, the aspect of coevolution is presented as an important feature of an CAS (Choi, Dooley and Rungtusanatham, 2001; Tukamuhabwa, et al., 2015). Agents adapt to a shifting environment to maximize their fitness, so they learn from the system's responses and modify their schemas (Pathak, et al., 2007; Wycisk, McKelvey and Hülsmann, 2008; Day, 2014). Therefore, the coevolution of an CAS happens between its members, the system as a whole, and its environment (Choi, Dooley and Rungtusanatham, 2001; Pathak, et al., 2007).

3 Systematic Literature Review

To answer our research question of whether SEs are suitable for an CAS-based perspective on resilience and what emergent attributes they feature, we conducted a systematic literature review. As a well-established methodology in evidence-based practice, it allows for a scientific approach while comprehensively summarizing all relevant existing information on a research topic in a way that seeks to minimize bias

(Denyer and Tranfield, 2009). An systematic literature review also leads to replicable and transparently analyzable results (Rousseau, Manning and Denyer, 2008).

We adapted the five-step process for systematic literature from Denyer and Tranfield (2009), beginning with narrowing the scope and formulating a clear research question (Tranfield, Denyer and Smart, 2003). This work aims to provide a base for future research on SEs. Especially its emergent features are investigated to explore whether SEs are a fitting concept for the utilization of an CAS lens on resilience. Possible resilience-inducing properties are also observed.

The next step was to locate relevant literature. Scopus was selected as a primary source of literature because it is one of the largest databases with 76 million entries available while also containing articles from all notable publishers (Baas, et al., 2020). To check whether relevant literature is excluded, Business Source Complete was used as a complementary database. Figure 1 shows the search string and the applied filters. As current literature defines the components of SEs inconsistently, especially when it comes to business ecosystems, the search string was constructed in a less detailed manner to minimize the risk of leaving out relevant data. The observed publication time range started in 2012 because of the occurrence of SEs-related literature mostly after the beginnings of industry 4.0, which set focus on technologies that are crucial for the development of digital industrial platforms. Examples would be, amongst others, the internet of things, cloud computing, and big data. By searching the databases with the search string, 5524 documents were found.

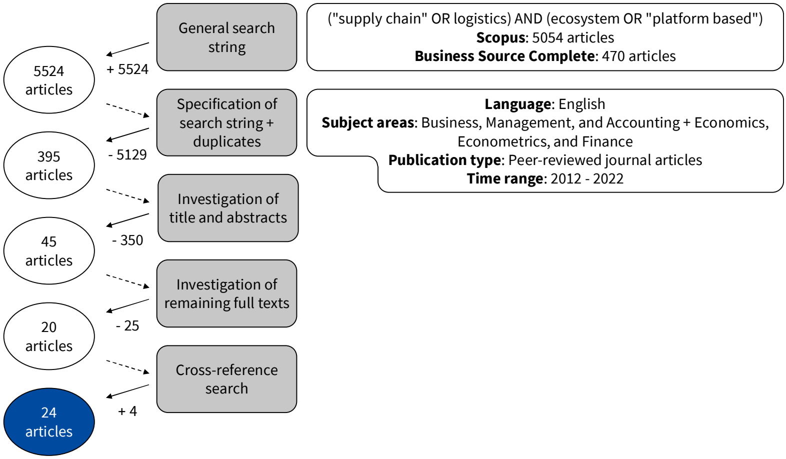

Figure 1: Study selection and evaluation process

Figure 1 also visualizes the process used to select and evaluate studies in the third phase. After the application of time range, publication type, subject area, and language criteria, duplicates were eliminated, which resulted in 395 articles. To ensure scientific quality, only journals with a VHB-Jourqual ranking of C and above were considered relevant for review. Next, the title and abstracts of all remaining results were checked. Publications that did not focus on ecosystem or platform approaches on SCs were sorted out, which narrowed down the amount of potentially relevant articles to 45. The remaining articles were read thoroughly. 25 additional articles were eliminated in the process as they pursued ecosystem approaches that were out of the scope. Finally, a cross-reference search was carried out. Through forward and backward search, as proposed by Webster and Watson (2002), the final number of articles increased to 24.

The fourth step was to analyze and synthesize the final pool of literature. To explore the resilient capabilities of SEs, essential ecosystem and CAS-based resilience capabilities were utilized as a foundation to analyze for its interplay with resilience. For the systematic analysis of capabilities, the publications of Tukamuhabwa, et al. (2015) as well as Ramezani and Camarinha-Matos (2020) were chosen as the foundation for the systematic analysis of capabilities, as they provide a well-structured, detailed summary of their respective resilience approaches, reducing the risk of missing important capabilities.

Analysis was fundamentally guided by open coding, according to Strauss and Corbin (1990). By constantly comparing the similarities and differences of the data and by forming categories of conceptionally similar data, open coding allows for analyses to be carried out with less subjectivity and bias (Strauss and Corbin, 1990).

The fifth step concludes the systematic literature review by reporting and using the results. In this case, the utilized ecosystem and CAS-based resilience categories were assigned to the elaborated emergent features of an SE and discussed.

4 Results and Discussion

4.1 Conceptualization of Supply Ecosystems as Complex Adaptive System to Increase Resilience

Based on the analysis of the underlying characteristics of SEs and the elaboration of Tukamuhabwa, et al. (2015) on how CAS attributes induce resilience in the previous section, it is possible to examine the compatibility of SEs with key features of CASs and make connections to how exactly these features promote resilience in an SEs. Additionally, the utilization of digital industrial platforms to organize ecosystems results in additional features affecting the ecosystem. Table 1 lists the CAS attributes that are reflected in SEs and gives an overview of the moderating role of a digital industrial platform on CAS attributes.

Table 1: Observed CAS attributes in SEs and the moderating role of digital industrial platforms

Reference	**Ability to learn**	**Adaptability**	**Coevolution**	**Scalability**	**Multi-scale / heterogeneous agents**	**Connectivity / interaction (+) ***	**Dimensionality (-) ***	**Self-organization and emergence (-) ***	**Schemas (+) ***
Adner (2017)			x		x				x
Aarikka-Stenroos and Ritala (2017)	x		x		x	x		x	
Argyres, Bercovitz and Zanarone (2020)									x
Ben Letaifa (2014)	x	x	x					x	x
Benitez, Ayala and Frank (2020)	x		x		x	x		x	x
Ceccagnoli, et al. (2012)							x		
Gawer (2014)					x	x	x		x
Gawer and Cusumano (2014)									x
(Giannakis, Spanaki and Dubey, 2019)	x			x		x			x

Reference	Ability to learn	Adaptability	Coevolution	Scalability	Multi-scale / heterogeneous agents	Connectivity / interaction (+) *	Dimensionality (-) *	Self-organization and emergence (-) *	Schemas (+) *
Graça and Camarinha-Matos (2017)		x	x	x	x	x		x	x
Gupta, Mejia and Kajikawa (2019)	x				x		x		
Hein, et al. (2020)	x	x		x	x		x		x
Hermes, et al. (2020)			x	x	x	x			x
Huang, Kang and Chiang (2020)	x		x		x	x	x		x
Jacobides, Cennamo and Gawer (2018)	x		x	x		x	x		x
Jovanovic, Sjödin and Parida (2021)	x		x	x	x	x			x
Ketchen, Crook and Craighead (2014)	x	x		x	x				x
Lin, et al. (2021)	x		x		x	x			

Reference	Ability to learn	Adaptability	Coevolution	Scalability	Multi-scale / heterogeneous agents	Connectivity / interaction (+) *	Dimensionality (-) *	Self-organization and emergence (-) *	Schemas (+) *
Liu, Aroean and Ko (2019)	X					X			X
Riquelme-Medina, et al. (2021)	X	X	X			X			X
Rong, et al. (2015)	X	X	X			X			X
Uusitalo and Laine (2022)	X			X				X	
Wagner (2021)		X			X	X			
Wang and Miller (2020)				X					X
∑	15	7	12	9	13	14	6	5	18

** The direction in which changes occur is marked with + or - and indicates the positive and negative moderating effects a digital industrial platform.*

Coevolution and adaption together were identified most and turn out to be inherent to an SE since actors of the ecosystem adapt and coevolve their roles in the system over time (Moore, 1996). This enables them to adapt to disruptive events and possible changes in their environment. The system considers its environment as it competes and collaborates with other organizations (Moore, 1996; Ketchen, Crook and Craighead, 2014). This circumstance can improve its ability to detect and uncover internal and external threats faster (Tukamuhabwa, et al., 2015).

Schemas emerge in the form of norms and rules that are established by individual members or hub firms (Jacobides, Cennamo and Gawer, 2018), which can include strategies to enhance the system's resilience. In this respect, the reliance on a digital industrial platform introduces an additional layer to the schemas that apply for SEs, since platforms impose their own set of rules on the members (Rietveld and Schilling, 2021). This however has direct implications for the aspect of self-organizational and emergence, as well as the dimensionality of SEs. On the one hand, self-organization as well as emergent outputs of agents, which potentially enhance the adaptability of the system by enabling self-organizing processes, are encouraged by the open structure of the ecosystem. Rules and standards set by hub firms may apply, but they only follow a regulating agenda (Jacobides, Cennamo and Gawer, 2018). They do not prevent members from making their own decisions. On the other hand, the reinforced governance introduced by a platform leader that exercises control over the system and its complementors (Gawer, 2014) counteracts this initial effect to some degree. The same holds true for the dimensionality of SEs, which determines how efficiently members can contribute to self-organization and emergence (Tukamuhabwa, et al., 2015).

While the ecosystem generally allows for autonomous behavior, the platform may impose restrictions on that, as members have to follow the platform's underlying structure and utilize its boundary resources in order to efficiently interact with the SE (Hein, et al., 2020). SEs naturally consist of collaborating, heterogenous/multiscale agents, as their possible members range from individual suppliers or buyers to entire organizations (Moore, 1996), which, despite following their own goals, still aim to enhance the overall health of the system (Wagner, 2021). Therefore, they collectively contribute to the resilience of the system. Furthermore, integrated digital industrial platforms enable easy access to the system, which is why complementors not only directly belong to an SE but can also collaborate without actually being embedded into it (Hein, et al., 2020).

The existing interdependencies within SEs favor nonlinearity as an emergent feature. Accordingly, disruptions concerning any member of an SE can have far-reaching consequences for the system as a whole. Network connectivity and interaction are highly present, as relationships within SEs are interdependent (Ketchen, Crook and Craighead, 2014), and members closely work together to co-create value, facilitating cooperation in cases where the system is threatened. Further amplification of connectivity is achieved through facilitating boundary resources such as standardized interfaces that a platform introduces to an SE (Gawer, 2014).

Its connectivity also complements the ability of an SE to learn. Knowledge is shared between members to mutually benefit their own as well as the system's success. This organizational learning leads to the emergence of system-wide competencies (Ketchen, Crook and Craighead, 2014), of which resilience is a part.

Finally, members of an SE interdependently work together while being guided by schemas. This allows for scalability by making causal dynamics applicable to the whole system. It facilitates the building of resilience by ensuring that the same ambitions are present for a resilient system across all levels of the SE. Rapid deployments of resilience-inducing measures could be enabled this way, especially with the connectivity benefits that a digital industrial platform provides.

4.2 Further resilient attributes of SEs

Apart from the CAS-based perspective, additional resilient properties can be observed in an SEs, which originate in both their construction as an SE and their integration of a digital industrial platform (see Table 2).

Table 2: Resilience characteristics related to the ecosystem aspect of SEs

Reference	**Flexibility**	**Agility**	**Cohesiveness**	**Redundancy**	**Visibility**	**Simplicity**	**Evolvability**
Aarikka-Stenroos and Ritala (2017)			E				P
Adner (2017)			E				P

Reference	Flexibility	Agility	Cohesiveness	Redundancy	Visibility	Simplicity	Evolvability
Argyres, Bercovitz and Zanarone (2020)			E				
Ben Letaifa (2014)			E				
Benitez, Ayala and Frank (2020)			E				
Gawer (2014)			E	P		P	P
Gawer and Cusumano (2014)				P		P	
Giannakis, Spanaki and Dubey (2019)					P		
Graça and Camarinha-Matos (2017)		E	E				
Gupta, Mejia and Kajikawa (2019)			E				
Hein, et al. (2020)				P			P
Hermes, et al. (2020)				P		P	P
Huang, Kang and Chiang (2020)			E				
Jacobides, Cennamo and Gawer (2018)			E			P	
Jovanovic, Sjödin and Parida (2021)			E	P	P		P
Ketchen, Crook and Craighead (2014)	E		E				
Lin, et al. (2021)				P	P	P	P

Reference	Flexibility	Agility	Cohesiveness	Redundancy	Visibility	Simplicity	Evolvability
Liu, Aroean and Ko (2019)			E				
Riquelme-Medina, et al. (2021)	E	E	E				
Rong, et al. (2015)							P
Uusitalo and Laine (2022)					P		
Wagner (2021)		E					
∑	2	3	14	6	4	5	8

Note: E = ecosystem; P = digital industrial platform

As the results show, cohesiveness is represented most in an SEs. The property can be found in the form of trust that is built between members of the system (Benitez, Ayala and Frank, 2020), ensuring its continuity. Trust can emerge thanks to the rules and norms that are set in place for members of SEs. It reduces uncertainty about how partners will act (Benitez, Ayala and Frank, 2020), which benefits the system in case of a disruptive event.

The ability to evolve comes in second place. An SE has evolving features which enhance its adaptability besides its coevolutionary aspect. The platform of an SE also evolves, namely its architecture and governance, which change over time as the system becomes more open and inclusive for complementors (Jovanovic, Sjödin and Parida, 2021). More diverse complementors enhance the system's ability innovative capabilities (Gawer, 2014), which enables an SE to respond more innovatively to disruptive events and, thus, increasing its resilience.

Another feature that should be mentioned is facilitated redundancy in an SE, which is enabled by the systems architecture. By having multiple assets that perform the same function, redundancy ensures the system’s stability in case of disruption-related performance drops of individual members (Ramezani and Camarinha-Matos, 2020). The modular platform architecture of an SE allows for easy access to the system and the option to substitute modules (Hein, et al., 2020). It therefore can facilitate measures such as the implementation of multiple sourcing and backup suppliers, if required.

An SE features simplicity to some degree, as it reduces complexity in the system through its modular structure (Gawer, 2014). It also features visibility, which benefits from the high transparency regarding information flow, enabled by the close relationships within the ecosystem and its facilitation through interfaces the digital industrial platform provides (Gawer, 2014).

Agility and flexibility could be detected least frequently. These two properties, nevertheless, can be found, namely in the collaborative nature of the system (Graça and Camarinha-Matos, 2017). For instance, the sharing of knowledge enables flexible responses to market changes (Graça and Camarinha-Matos, 2017), which can be caused by a disruptive event. Implemented norms and rules (schemas) enable agility by increasing the interoperability of processes and products (Graça and Camarinha-Matos, 2017), which accelerates the system's ability to respond to threats.

4.3 Theoretical Implications

This study identifies which characteristics of CAS are reflected in SEs and thus provides a conceptual explanation of why supply ecosystems and the use of digital industrial platforms lead to increased resilience. Thus, the study complements previous studies that assume that SEs represent a new organizational form of supply chains reflecting today’s changing business dynamics (Ivanov and Dolgui, 2020; Mollenkopf, Ozanne and Stolze, 2021). In this way, the study can be positioned within the emerging stream of research in supply chain management that argues that resilience goes beyond a mere 'being' and corresponds more to a 'becoming', which results from the interaction between the system and the environment (Nilsson and Gammelgaard, 2012; Wieland, 2021; Wieland and Durach, 2021). The results provide a list of attributes that make SEs resilient from a CAS perspective, providing a basis for further research that can reveal how this resilience emerges at the enterprise and ecosystem levels (Roundy, Bradshaw and Brockman, 2018; Phillips and Ritala, 2019).

4.4 Managerial Implications

From a management perspective, the results of this study provide an overview of how SEs as CASs can lead to increased resilience. The adaptability of the system is shown to have a major impact on its resilience. Therefore, practitioners should set their focus beyond an equilibrium-based perspective on resilience, as it does not suffice to be able to recover from a disruption merely. A system should rather be capable to adapt and evolve in the process of overcoming it, emerging from the disruptive event as a stronger version of its previous self. With such an approach, managers could turn a disruption into an opportunity to develop their organization further. One way to achieve this is to open up to other organizations and their interactions, building ecosystems in the process. The implementation of a digital industrial platform can further facilitate certain aspects of the adaptability of these ecosystems. However, it should also be evaluated whether the ecosystem sets up a digital industrial platform or if it joins an already existing one to hone its resilience capabilities further. The establishment of a digital industrial platform can prove difficult if resources or know-how is missing, as a platform requires the successful central implementation of technology in the system.

4.5 Limitations and Further Research

As with other studies, there are some considerable limitations to this work that arise from the research. The first limitation results from the methodological approach of the study. Even though in this paper the studied literature has been searched and evaluated in a systematic, transparent, and reproducible manner (Tranfield, Denyer and Smart, 2003; Denyer and Tranfield, 2009), the data sample does not guarantee completeness. Firstly, in order to limit the scope of the study, the formulation of the search string only included literature with a direct link to SCs or logistics. Consequently, potentially relevant publications investigating SEs may have been missed if the articles were not tagged with these keywords. Second, research on the components of ecosystems is extensive but declines dramatically when it comes to how the concept is defined as an SE. Even though studies have focused on this construct, especially in the recent past (e.g., Ivanov and Dolgui, 2020; and Mollenkopf, Ozanne and Stolze, 2021), the literature so far lacks a conceptualization of SEs. Third, this study provides only an initial analysis that SEs can be assumed to be CAS based on their characteristics. Future studies need to build on this assumption and analyze through exploratory research what capabilities the SE needs to develop to increase resilience and at what level (e.g., system level or individual level) these capabilities emerge.

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Object Detection in Picking: Handling variety of a warehouse's articles

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Purpose: *The automation of picking is still a challenge as a high amount of flexibility is needed to handle different articles according to their requirements. Enabling robot picking in a dynamic warehouse environment consequently requires a sophisticated object detection system capable of handling a multitude of different articles.*

Methodology: *Testing the applicability of object detection approaches for logistics research started with few objects producing promising results. In the context of warehouse environments, the applicability of such approaches to thousands of different articles is still doubted. Using different approaches in parallel may enable handling a plethora of different articles as well as the maintenance of object detection approach in case of changes to articles or assortments occur.*

Findings: *Existing object detection algorithms are reliable if configured correctly. However, research in this field mostly focuses on a limited set of objects that need to be distinguished showing the functionality of the algorithm. Applying such algorithms in the context of logistics offers great potential, but also poses additional challenges. A huge variety of articles must be distinguished during picking, increasing complexity of the system with each article. A combination of different Convolutional Neural Networks may solve the problem.*

Originality: *The suitability of existing object detection algorithms originates from research on automation of established processes in existing warehouses. A process model was already introduced enabling the transformation of laboratory trained CNNs to industrial warehouses. Experiments with CNNs according to this approach are published now.*

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1 Introduction

Handling objects in logistics is often supported by loading equipment enabling standardization and automation of processes. Therefore, processes that require a higher amount of flexibility are still carried out manually (EHI Retail Institute, 2019). Such processes are, for example, picking in commissioning, where objects must be processed in amounts less than stored on a loading equipment or outer packaging. Every object category, e.g., cuboids, cylinders, bottles, or non-rigid objects, must be handled according to their special requirements to successfully pick and place the objects without damaging them. Consequently, enabling automated picking and placing in logistics, automation must be guided according to the flexible environment in order to identify a required object, calculate its corresponding gripping point(s), prevent collisions with other objects, storage facility, and the automation components (Wahrmann, et al., 2019). Analyzing images delivered from a vision system can be used to adapt to the environment. Detecting objects in images experienced a boost by using Convolutional Neural Networks (CNN) with suitable computing capacity within the early 2010s (Sultana, Sufian and Dutta, 2020).

This paper contributes to the question of how to implement an object detection system in logistics environments (e.g., warehouses for picking). Therefore, insights from research on object detection algorithms are used to build an object detection system facing logistics’ requirements and for handling dynamics in established processes and assortments.

This paper is structured as follows. The second chapter describes related work regarding logistics, picking, and approaches to processes automation. This includes addressing object detection as a prerequisite for automated object withdrawal. Chapter 3 outlines the requirements of a picking system according to an object detection system. In chapter 4 the experimental setup concerning the defined questions is described. Results are presented in chapter 5. The paper then concludes with a discussion, conclusion, and possible future research.

2 Related Work

This chapter addresses two research areas: the process of picking in logistics scenarios as well as approaches leveraging object detection to support the automation of such process.

2.1 Logistics and Picking

A core process in warehouses is picking, which is the customer order specific composition of a subset from a total assortment of goods (VDI, 1994). Especially, this composition is often carried out manually as the number of ordered objects of each order line is smaller than the number of objects stored with a loading equipment. Consequently, this requires a specific handling according to the individual requirements of each single object. Therefore, a survey in 2016 showed that 80% of warehouses are still run manually (Bonkenburg, 2016). To assist humans in picking objects, assistance systems were introduced reducing searching time of objects by pick-by-voice systems (Dujmesic, Bajor, and Rozic, 2018) or smart glasses (Rejeb, 2021). Furthermore, by focusing on humans during the picking process, the goods-to-person principle was introduced in which goods are delivered to humans by automated storage and retrieval systems (de Koster, 2018) or mobile robots (Bozer and Aldarondo, 2018). Amazon Inc. introduced a picking challenge to find trends in robotic retrieval from shelves (Correll, et al., 2016), giving the pick-by-robot approach a boost. This challenge was carried out three times.

These technologies help handling the assortment which ranges, for example at Amazon for German warehouses, from 100,000 to 2,000,000 different articles, depending on their product categories (Schwindhammer, 2022).

2.2 Object Detection

For object detection in 2D-images, a variety of algorithms already exists (Sultana, Sufian and Dutta, 2020). The most used algorithms based on CNNs being Mask Regions with CNN features (Mask R-CNN) (He, et al., 2017), You Only Look Once (YOLO) (Redmon, et al., 2016) and Single-Shot Detector (SSD) (Liu, et al., 2016) including their subsequent developments (Pal, et al., 2021).

Different metrics and data sets were introduced for comparing algorithms for object detection (Padilla, Netto, and da Silva, 2020). Yang, et al. (2020) identified that most data sets provide only few classes for object detection, e.g., COCO data set includes 80 classes (Lin, et al., 2014), ImageNet 200 classes (Russakovsky, et al., 2015) and Open Images Dataset distinguishes between 19,794 classes, but only 600 are annotated with bounding boxes (Kuznetsova, et al., 2020) In the context of industrial settings, however, these numbers of classes are not sufficient as warehouses assortments can consist of thousands of articles.

In general, different challenges for object detection algorithms exist, including handling occlusion (Saleh, Szénási and Vámossy, 2021), the imbalance problem (Oksuz, et al., 2020), and the central or decentral allocation of computation capacities (Ren, et al., 2018). Additional challenges are posed by the context of object detection in logistics scenarios: Pathaka, Pandeya and Rautaraya (2018) stated that there is a lack of data sets for object detection in general. Bormann, et al. (2019), and Thiel, Hinckeldeyn and Kreutzfeldt (2018) confirm the need for training data, particularly in the context of logistics applications. Li, et al. (2018) observed that "there is no public data set of logistics warehouse" and consequently Mayershofer, et al. (2020) introduced Logistics Objects in Context (LOCO) data set for warehouse surroundings like pallets or forklift. In 2015, a special data set for object detection in a warehouse environment was published by Rennie, et al. (2015), focusing on a setup such as Amazon's picking challenge. Li, et al. (2019) discussed the complex task of detecting pallets in logistics, particularly illumination conditions and object dimensions. Mok, et al. (2021) also focused on detecting pallets, confirming the complexity of object detection in flexible environments such as logistics. Poss (2019) stated, that continuous changes in logistics, e.g., of containers, are problematic for object detection performance.

Object detection results are categorized into True Positives (TP) (correct prediction: correct object class and location), False Positives (FP) (false prediction: false object or incorrect located), False Negatives (FN) (no prediction but image contains searched object) and True Negatives (TN) (no prediction and no known object in the image)

(Padilla, Netto, and da Silva, 2020). Such categorization is achieved using the Intersection over Union (IoU) comparing the area of overlap of the prediction with the expected result with the union of both. Figure 1 displays the approach of IoU and its calculation. According to related approaches, IoU > 0.5 leads to TP categorization.

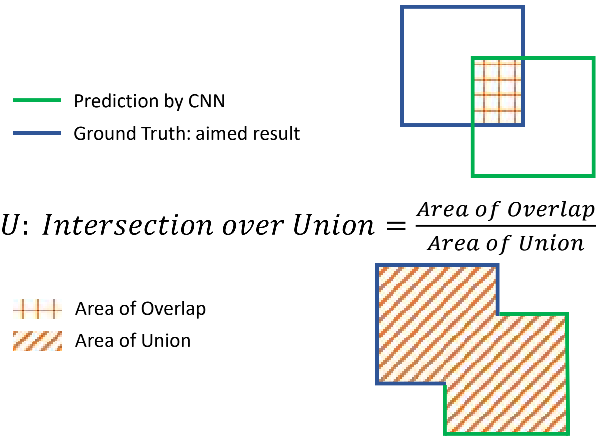

Figure 1: Intersection over Union (modified from Kaggle, 2022)

Categorizing a set of images into TP, FP, TN and FN enables calculating scores for Precision, Recall and F1-score metrics (Hui, 2018):

$$Precision = \frac{TP}{TP + FP}$$

$$Recall = \frac{TP}{TP + FN}$$

$$F1 = 2 \times \frac{Precision \times Recall}{Precision + Recall}$$

Plotting Precision and Recall can be done using a curve. Calculating the Area under the Curve (AuC) gives the Average Precision (AP) (Hui, 2018) also called mean Average

Precision (mAP) in the context of Common Objects in Context data set (COCO) (Lin, et al., 2014).

3 Object Detection in Picking System

In addition to the described discrepancy between number of articles stored in a warehouse and the possibilities to distinguish objects using existing CNN approaches, the topic of changes in a warehouse's assortment has not been addressed yet. The packaging and design of articles, especially in commerce, is changed regularly based on marketing activities or product packaging redesign. Moreover, the assortment within a warehouse is very dynamic, concerning seasonal impact or product lifecycles.

Most publications dealing with object detection, however, neglect such facts. Thus, the dynamic assortments and big number of articles in logistics environments remains unconsidered when designing an object detection system.

In this paper, this issue is tackled by using multiple CNNs to distinguish between all articles. In a nutshell, for every article or article group respectively a CNN is designed. Besides the "positive" images, containing the searched object, "negative" samples must be applied, containing images of all other relevant articles to avoid confusion. Figure 2 gives an idea of the lifecycle of a CNN used in a warehouse for picking. Especially re-training is important to adapt to changes to guarantee a sufficient object detection and picking performance.

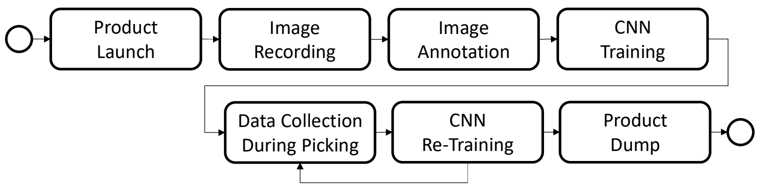

Figure 2: Outline of CNN lifecycle

A setup using multiple CNNs for articles or article groups instead of one CNN for the whole warehouse's assortment bears following advantages:

- Avoidance of framework violation: For YOLO, e.g., the number of articles must be defined before trainings starts (Bochowskiy, 2022). Adding articles later may lead to problems in CNN configuration.
- Re-Training for relevant articles: In case changes occur, only relevant CNNs must be re-trained. These can be defined by applying a confusion matrix to show articles that could be mixed up during object detection. This simplifies maintenance of CNNs during their lifecycle.

Comparing the effect during CNN re-training experiments are defined in Chapter 4.

4 Experiments

A custom data set was designed for first experiments showing effort and effects of the setup described in Chapter 3.

4.1 Data Collection and Preparation

Images were recorded with a Picture Recording Machine (cf. Figure 3), hence, enabling automated recording with a custom definition of number of images at a possible object rotation of 360° and camera movement of 90° each in steps of 1°-movement.

Next, recorded images were annotated using YOLO Mark (Bochowskiy, 2020), and object detection was done using YOLOv4 (Bochowskiy, Wang and Liao, 2020), where 2,000 training iterations for each article of the set is recommended (Bochowskiy, 2022). The training was run on a working station equipped with a Nvidia GeForce RTV 3090. During training the images are augmented. In other words, changes to the images are being applied for training purpose increasing the robustness of trained CNNs with respect to changes in images, lighting, or surroundings. For YOLOv4 MixUp, CutMix, Mosaic, Bluring data augmentation, and label smoothing regularization methods are applied (Bochowskiy, Wang and Liao, 2020).

4.2 Data Set

The data set contains 16 different ceramic cups and is used for initial testing with, showing effort and effects of the setup described in Chapter 3.

For each object, pictures were recorded in 9°-steps on the turning table and 5°-steps with camera movement, resulting in 760 images per object class. Example images for classes one to three are depicted in Figure 4 (surrounding cut off to focus the objects). On the left-hand side with a view of about 45° and with 0° camera view (recording starts from top view) on the right-hand side to emphasis the challenge of object detection dependent on perspective to the object. Figure 5 displays all sixteen articles.

Figure 3: Picture Recording Machine

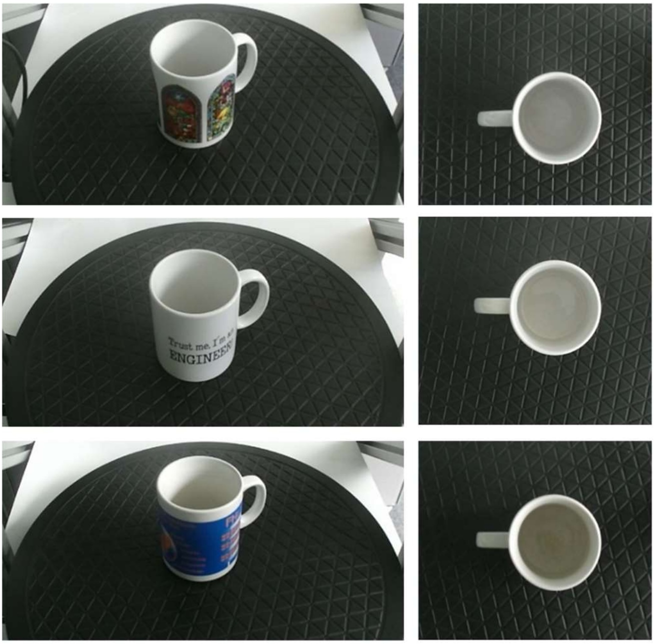

Figure 4: Pictures of ceramic cups (article one - three, from top)

The pictures of the data set are allocated randomly to either training (60%), testing (20%) or validation (20%) subsets. Training and testing subsets are used during training for adjustment of CNN parameters. The validation subset is used for experiments. The separation is done to avoid a CNN to “know” validation images from training. As the distribution to training, testing in validation subsets is done for the whole setup the numbers may differing between the classes.

Figure 5: Pictures of articles one to sixteen, starting in upper left

4.3 Setup

This section describes the setup of the experiments conducted. Figure 6 supports the understanding of follow up sections by describing used CNNs and their configurations.

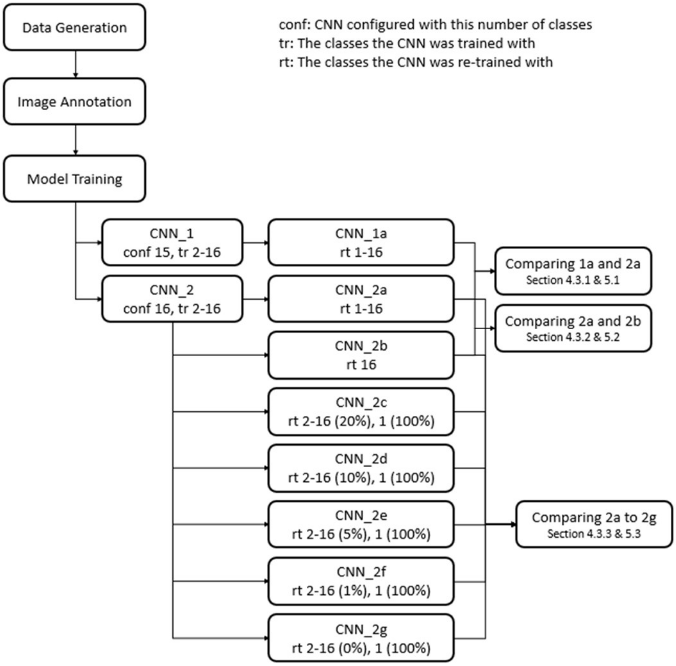

Figure 6: Pipeline of experiments

4.3.1 Extension of number of articles

When training CNNs, first the number of classes (objects to distinguish) must be defined. In case other articles are added at a later stage, the configuration of the CNN must be adapted accordingly. To test the effect of re-training, a YOLOv4 CNN was configured and trained using fifteen classes with object classes two to sixteen (CNN_1). Later, article one was added to the training set for re-training (CNN_1a).

The alternative test is the configuration with sixteen articles but only handing over samples of article two to sixteen (CNN_2) and using all sixteen articles for re-training (CNN_2a).

4.3.2 Use of negative samples

Further tests evaluating the impact of re-training onto object detection performance were conducted: CNN_2 was used to show "unlearning" of a CNN by re-training with images of all classes (CNN_2a) and images of article one only (CNN_2b). The object detection performance was then compared according to TP and FP.

4.3.3 Amount of negative samples

When equipping each article with a CNN begs the questions which images to use for training as training requires images of other articles to avoid erroneous object detection. Considering the number of articles in a warehouse, an additional follow-up question regarding the number of images required to train for one article arises.

Using the result from previous sections, CNN_2 was used as basis and CNN_2a as benchmark. For re-training articles of all sixteen classes were used, differing in the amount of negative samples: CNN_2c with 20%, CNN_2d with 10 %, CNN_2e with 5% and CNN_2f with 1% of training and testing samples as well as CNN_2g without training and testing images of classes two to sixteen.

5 Results

This section presents the results of experiments introduced in Chapter 4. Figures 7-10 display the first 2,000 iterations of training, as biggest changes of loss and mAP occur in this training phase. Training loss is displayed in black color. Additionally, Figures 7-10 indicate the mAP in red color located on the upper right as continuous line, starting with iteration 1,000. In most cases mAP is very low for previous iterations and the mAP calculation starts from iteration 1,000 to safe computation power (Bochowskiy, 2022).

5.1 Extension of number of articles

This section shows the comparison of adding an article to a CNN when configuration must be changed for re-training (increasing the number of classes) (cf. Figure 7) compared to a configuration with the final number of classes at the beginning of the training (cf. Figure 8).

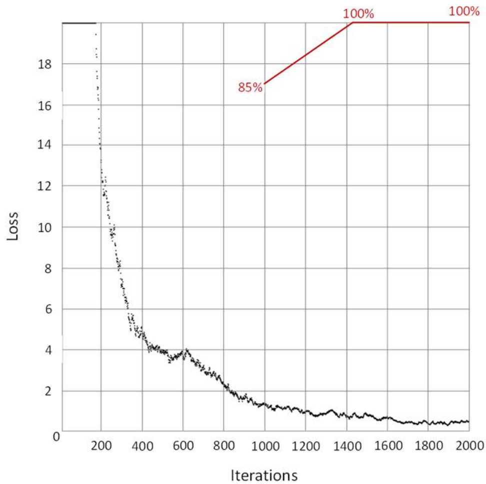

Figure 7: Training of CNN_1

Comparing Figures 7 and 8 shows that by re-training after adding an article in CNN's configuration, training seems to start from beginning. This is indicated by the fact that the course of training loss is similar for Figures 7 and 8. On the other hand, Figure 9 shows the initial training and Figure 10 the re-training resulting in a different course in Figure 10 meaning that the CNN's weights can be refined during re-training (Figure 10) in contrast to re-configuration (Figure 8).

Comparing Figure 7 and 9 regarding to mAP, training with an "empty" class at CNN_2 (Figure 9, no images of class one are used) affects the CNN's detection performance negatively in early training stage as mAP does not reach 100%.

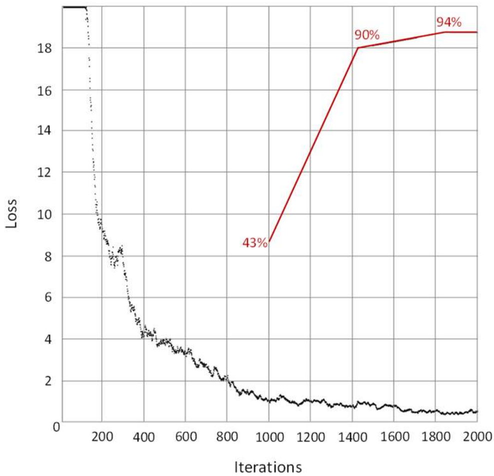

Figure 8: Training of CNN_1a

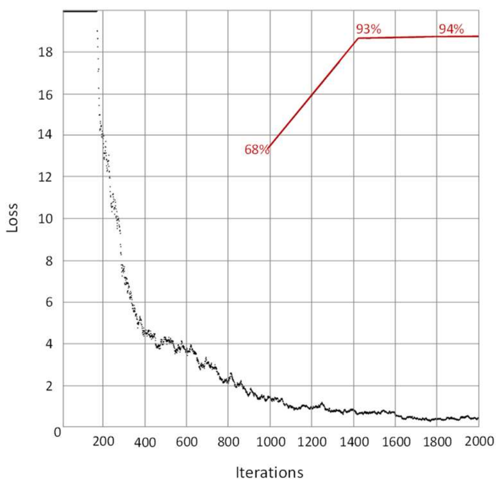

Figure 9: Training of CNN_2

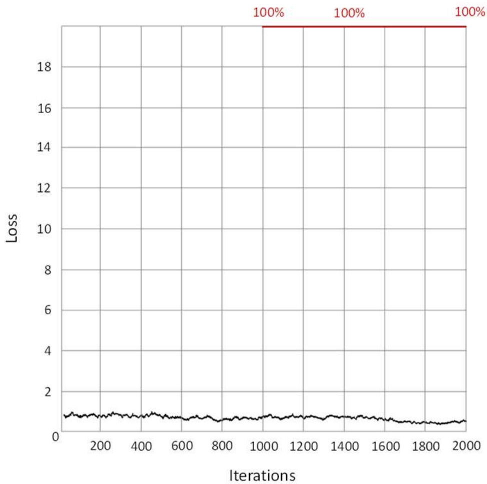

Figure 10: Training of CNN_2a

5.2 Use of negative samples

Numbers in Figures 11-16 are related to the validation data sets to which 20% of the images belong. The distribution for class differs, as distribution was defined by random numbers. Compensating this, presented numbers are relative, providing the rate of TP and FP for different classes in relation to the number of images. A rate higher than 100% results from multiple detections for one image that can occur in early stages of training but normally disappears with training duration.

Figure 11 shows the course of TP and FP for class one and the average for classes two to sixteen over the re-training phase after every 100th iteration. For re-training only images of class one have been used resulting in a constantly decreasing TP-rate for classes two to sixteen.

Figure 11: Re-training without negative samples (CNN_2b)

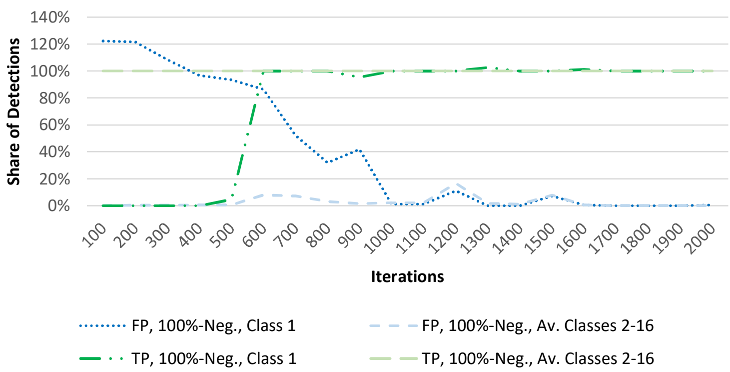

Figure 12: Retraining with 100% of Negative Samples (CNN_2a)

Figure 12 shows the result for the same experiment but using all images off all classes. This results in TP-rates for all classes near 100% and rates of near 0% as well.

Consequently, the data of existing classes is crucial for re-training to remain sufficient object detection performance for these classes.

5.3 Amount of negative samples

This section presents results from re-training a CNN that was trained with images from classes two to sixteen with images of all class. The share of images of classes two to sixteen used varies between 0% to 100% in different steps, all images of class one were used. Figures 13 and 14 show the number of TP for class one (cf. Figure 13) and classes two to sixteen (cf. Figure 14). The lower the number of images of classes two to sixteen, the faster a TP-share of around 100% is reached for class one. For all experiments, except 0%, the number of TP-share for classes two to sixteen remain at about 100% with some outliers above 100% resulting from multiple detections for one image.

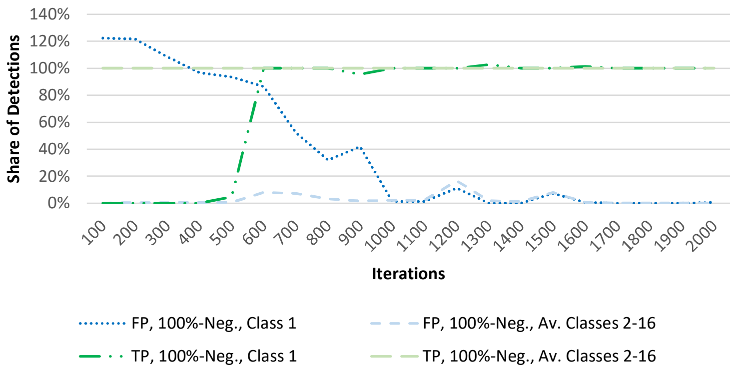

Figure 13: True positive detections for class one

A similar effect regarding FP can be observed comparing Figures 15 and 16. A faster decrease of FP-share of class one results from a higher number of images of classes two to sixteen (Figure 15). The share of FP for classes two to sixteen increase after re-training start near zero but coming back to the area of zero after some peaks.

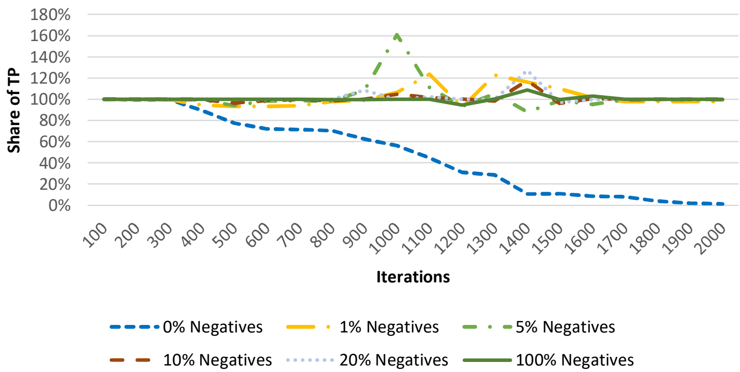

Figure 14: True positive detections for classes two to sixteen one

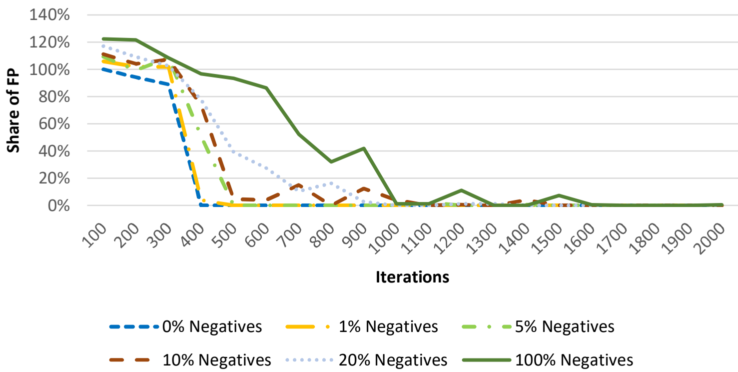

Figure 15: False positive detections for class one

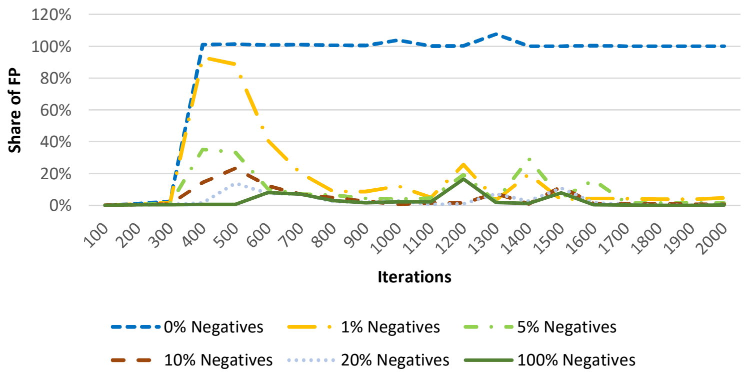

Figure 16: False positive detections for classes two to sixteen

6 Conclusion

This paper introduced state-of-art approaches of automating logistics warehouses and object detection for picking. Further, the requirements for object detection in dynamic logistic scenarios were discussed and from an industrial approach view. Experiments with CNNs examining the configuration and maintenance of CNNs for object detection in warehouse were conducted. Therefore, a custom data set of similar looking ceramic cups was defined and images recorded by a Picture Recording Machine. YOLO algorithm was used to train different CNNs to compare the object detection performance of different CNN configurations.

While the general use of CNNs for object detection is well established, the use of CNNs for object detection in the context of industrial settings can be expended. Existing approaches do not cover industrial settings, and most existing research only addresses the problem regarding a limited number of classes being treated by one single CNN. In the context of product lifecycles, changes to warehouse assortments occur frequently, and remains unconsidered in object detection research. For industrial applications, however, this resembles a serious challenge.

The experiments conducted in this paper provide an idea of how an object detection system for picking in logistics environment may be designed using multiple CNNs instead of one CNN processing the whole assortment. Therefore, different states of CNNs were compared and the impact of increased number of classes as well as the amount of images from known classes during re-training was analyzed. The results indicate that multiple CNNs are suitable for object detection in warehouses if a concept for continuous data gathering and CNN update, respectively maintenance, is applied. The experiments have been conducted in a laboratory environment, but the transformation from a laboratory CNN to warehouse employment was treated yet (Rieder and Verbeet, 2020).

In further research two different domains must be addressed: First, real-world applications in the field of logistics must further validate the presented results. The application of the presented approach to an industrial warehouse can also help to overcome the limitation of using laboratory images only. Furthermore, the number of articles must be increased to a real-world scenario.

Second, further investigations of how multiple CNNs interact with each other must be conducted. This provides the potential that different CNNs might be configured in a less complex way, leading to shorter training phases, increased picking performance and less resource usage in general.

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Outlier Detection in Data Mining: Exclusion of Errors or Loss of Information?

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Purpose: *Our research emphasizes the importance of considering outliers in production logistics tasks. With a growing amount of data, we require data mining to cope with these tasks. We underline that the widespread exclusion of outliers in data pre-processing for data mining leads to a loss of information and that using outlier interpretation can be used to address the issue.*

Methodology: *The paper discusses the data pre-processing of data mining in production logistics problems. Methods of outlier interpretation are collected based on a literature review. In addition to the literature-based investigation, the work relies on a case study that illustrates the individual evaluation of outliers.*

Findings: *This work shows that outliers take a special focus on the information generation. Within data pre-processing, a distinction must be made between an outlier as a defect and an outlier as a special datum. This can be conducted by methods presented in the literature.*

Originality: *This paper adds to existing literature in the research field of insufficiently analyzed outlier interpretation and shows a need for research in data pre-processing of data mining.*

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1 Introduction

In 2020, the manufacturing sector in Germany continues to be characterized by the quality claim of the “Made in Germany” brand with approximately 23 % share of gross value added in Germany (Statista, 2021), which is complemented by logistics as one of the most important economic fields. Steady developments in production led first to mass production and later to customized mass production according to Chen, et al. (2015). This is accompanied by a volatile competitive environment of the manufacturing companies. An important unique selling proposition is product quality, which enables companies to win customers and meet their expectations (Jacobson and Aaker, 1987). In order to meet the requirements of customized mass production in a competitive environment, various developments are being used in the context of digitization (Kusiak, 2018). Buzzwords such as Industry 4.0, Big Data, intelligent production and communication systems, and business intelligence have been shaping trends in recent years. At the same time, these also condition the field of logistics through collaboration, globalization, and just-in-time production. All the mentioned trends imply information in companies about the heterogeneous production situations, which is indispensable for a modern production infrastructure (Pennekamp, et al., 2019). Addressing increasingly complex production systems (Alkan, et al., 2018) implies a high level of internal and external information exchange, so that concrete knowledge about production and logistics can be used for implementation, improvement, and quality assurance (Kersten, Blecker and Ringle, 2020). Without suitable analysis procedures, with increasing data volumes, contained information and contained knowledge are no longer tangible for analyses. This knowledge is to be interpreted as a valuable enterprise resource and, thus, requires special attention (Wenzel and Stolipin, 2017).

Increasingly, knowledge discovery methods in databases (KDD) are used for this purpose, with data mining (DM) being the most important process step. For many manufacturing companies it is unclear which methods to apply in DM. An implementation of every DM technology requires a data pre-processing matching the specific DM algorithm, which deals with data quality deficiencies and ensures the structuredness of the data. While the literature includes manifold sources for removing noise, handling missing values, and detecting outliers, a detailed analysis is rarely sought for the latter. This is exacerbated in the KDD context, where outliers are mostly excluded from DM after detection, resulting in an exclusive definition of outliers as defects without more-detailed analysis. This creates the possibility of information loss and, thus, risks for the analysis in the KDD process. Especially for critical systems and products, such a defect can have serious consequences. The consideration of outliers is of particular interest for various application areas, such as credit card fraud, clinical trials, network security (Ben-Gal, 2005), but also fault diagnosis, detection of structural defects, time series analysis, or erroneous entries in databases (Hodge and Austin, 2004). Also, in the domains of production and logistics, time, security, and increasing costs are highly relevant for a detailed examination of outliers to improve analyses.

This paper points out the critical gap in the literature in the area of outlier investigation in DM for manufacturing and logistics. For formal derivation of the argument, data and information quality are separated by their definitions. Furthermore, the relevance of a differentiated consideration of outliers is discussed against the background of existing literature. Here, a discussion of data pre-processing methods for DM takes place, identifying possible reasons for information loss due to outlier exclusion. The research reinforces the use of outlier interpretation to consider outliers in production logistic issues.

The paper is structured as follows: In Section 2, the required terms are first put into context. Against the background of the DM literature, the terms data quality and information quality are separated. Furthermore, the pre-processing of data in DM is discussed in particular. In this context, different methods from the literature are compared and classified. Section 3 discusses technology support in the area of data analysis with a focus on dealing with outliers in the domain context. Section 4 presents a case study including the testing of a selected method described in the previous chapters. The thesis concludes in Section 5 with a summary and outlook.

2 Theoretical Background on Information in Outliers in Data Mining

In the following sections, the necessary basics for the work are discussed and differentiated from related research fields. First, the necessary terms are explained, and data quality is distinguished from information quality in particular. After a short summary of the usual procedure in the KDD process, data pre-processing methods of the DM are classified.

2.1 Data and Information Quality

Both information and knowledge are based on data (North, 2022). For data to be used, they must first be generated, collected, or measured, and then stored. The data are then available in different formats, structures, and qualities in companies. While the question of the correct format can usually be answered in a sufficiently trivial manner, the choice of the appropriate structure of the database is subject of debate. Even though relational databases are most common in companies (Saake, Sattler and Heuer, 2019) other database structures up to the polyglot persistence of a data network are possible (Khine and Wang, 2019). In particular, NOSQL databases such as graph databases are cited as a natural representation option in logistics contexts such as supply chains (Hunker, Scheidler and Rabe, 2020).

The stored data cannot be used directly by the viewer. According to North (2022), data become information when meaning is attached to them and they enable action. This meaning can be assigned by formal description criteria (Piro and Gebauer, 2011) or by the observer himself. In the context of production logistics, information includes, for example, details of processes, intended uses, and decision support. The interlinking of different information denotes North (2022) as knowledge.

Defects are possible in data and information. The International Organization for Standardization (2010) defines a defect as a result-altering problem, a failure to meet requirements, and a designation for an error. Making a connection of the defect definition to data and information inevitably leads to data quality and information quality, with quality as the degree to which requirements are met (International Organization for Standardization, 2015). Data quality and information quality are often used interchangeably in the literature (Gebauer and Windheuser, 2021). Gebauer and Windheuser (2021) define data quality as the suitability of the dataset to fulfill quality characteristics and meet specified requirements. Accordingly, data quality serves conceptually as a classification of the problems arising during generation, collection, measurement, storage, and merging. Thus, high data quality is equivalent to few relevant errors in the dataset. The separation of data and information quality was investigated by preliminary work at the department IT in Production and Logistics (ITPL) and is possible via the data and information concept. The data quality evaluates the mapping quality between the real world as well as the representation by the data and the information quality evaluates the suitability of the data to fulfill a certain purpose (Mengering, 2021).

Even generated data, e.g., through data farming (Brandstein and Horne, 1998), may contain data quality deficiencies. Measured and collected real data are mostly burdened with data quality deficiencies, e.g., due to faulty data collection measures, missing data, or definition inconsistencies (García, Luengo and Herrera, 2015). In the case of real production data in particular, their heterogeneity is also reflected within the data quality. The data quality is, thus, in the context of the structure and the format of the data, but it is also dependent on manifold influencing factors on the level of data storage and analysis (Oliveira, Rodrigues and Henriques, 2005). Collected data are subject to external factors at various levels, such as environmental phenomena, strategic changes, or changes in machine behavior. Information about the external factors is necessary to be able to quantify the partially influencing factors. This also requires a consideration of the different levels of aggregation within the available production and logistics data. Various works in the literature propose different dimensions to evaluate the data quality. Internationally used sources in this respect (Miller, 1996; Redman, 1996; Wang and Strong, 1996; English, 1999) have already been supplemented by German-language ones in preliminary work at the ITPL (Müller, 2000; Rohweder, et al., 2011) as well as examined in the supply chain context (Türkmenoglu, 2021). These were synthesized into the following dimensions: format, consistency, accuracy, completeness, comprehensibility, lack of redundancy, trustworthiness, accessibility, security, timely and accrual-based posting, response time, relevance, and timeliness. Before using data to generate information, data quality can be used as an assessment, accordingly. Similarly, the information quality must be quantified before the information is used.

According to the definition of information, information quality must evaluate the suitability of a piece of information for use. This definition of information quality is consistent with many sources in the literature, which describe information quality specifically in terms of suitability, which is evaluated intrinsically or externally, of a piece of information for use (Stvilia, et al., 2007). This evaluation is supported by Lee, et al. (2002) in the following 15 dimensions for the measurement of the information quality: accessibility, appropriate amount, believability, completeness, concise representation, consistent representation, ease of operation, free-of-error, interpretability, objectivity, relevancy, reputation, security, timeliness, and understandability. These differ significantly according to the application domain, e.g., in the context of Big Data the appropriate amount is questionable. The occurrence of low data and information quality is not synonymous with information loss, but there is a correlation. At the same time, the underlying data quality to which the information refers to is relevant for the information quality.

While information quality is directly related to data quality, studies on the use of information need to consider data and information quality separately. For example, poor data quality does not exclusively lead to poor information quality, even if there is a correlation. The inherent information of each dataset can be used with caution even when data quality is poor. Already Parsons (1996) discusses the handling of imperfect information as a consequence of basing information on data that are real-world and uncertain. Accordingly, in addition to considering data quality as a whole, individual datasets must be examined for their information content and placed in the context of relevant data quality deficiencies. However, an unpredictable data situation is not synonymous with disruptions, errors, or poor planning. There may be information in the data that has not yet been allocated or that cannot yet be estimated. When evaluating the suitability of a datum for generating information, deficiencies like noise, missing values, and outliers exist apart from database-specific data quality. Both noise, which can be seen as a corruption of real data (Dong, Chan and Xu, 2007) and as an unintentional obstacle for the analyst (Chandola, Banerjee and Kumar, 2009), as well as missing values, which do not allow use as data, are negatively associated in the context of data quality in the literature. In contrast, outliers occupy a separate role and are sharply distinguishable from noise (Chandola, Banerjee and Kumar, 2009).

Outliers are data with a sufficiently big difference from expectation, suggesting a deviant mechanism of origin (Hawkins, 1980). For outliers, there is no fixed basis of occurrence (Barnett, 1978) which can be, e.g., a measurement error or an undetected external influence in the data. Aggarwal (2017) adds the terms abnormality, discordant, deviation, and anomaly used in the literature for outliers. Furthermore, Aggarwal names inliers, which, unlike outliers, do not deviate from the expected data model. Wainer (1976) lists the designation of fringeliers, which are to be categorized between the outliers and inliers and for which no direct classification as outlier or inlier is possible. An overview of outliers, fringeliers and inliers is shown in Figure 1.

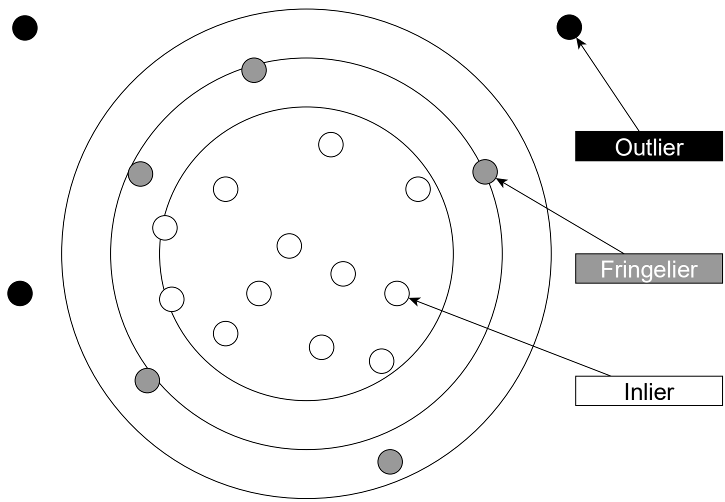

Figure 1: Concept illustration of the outlier (black), fringelier (grey) and inlier (white)

Already Beckman and Cook (1983) give reasons for dealing with outliers: special interest within the research question, detection of special alternative phenomena, accumulation of outliers, and influence of outliers. The consideration of outliers is, however, likewise in KDD processes and statistical procedures a part of the data pre-processing, even if outliers should not represent the actual investigation goal.

It is to be expected that information can also be extracted from data declared as outliers. In some areas, such as quality assurance or risk analysis, sometimes explicitly the outlier data themselves as well as findings about the outliers represent the relevant information or have a significant influence on it. For this reason, outlier detection and interpretation, also explanation or description, receive special attention here.

2.2 Data and Error Processing in Data Mining

KDD is concerned with extracting useful information and knowledge from large amounts of digital data (Fayyad, Piatetsky-Shapiro and Smyth, 1996). Diverse process models with different focuses developed in KDD are presented in the literature, such as the model of Fayyad, Piatetsky-Shapiro and Smyth (1996), the Cross Industry Standard Process for Data Mining (CRISP-DM) (Wirth and Hipp, 2000) or the Sample Explore Modify Model Assess (SEMMA) of the SAS Institute (Azevedo and Santos, 2008). The KDD process, according to the overlaps of the models, is based at least on the research question, data selection, data pre-processing, DM, and post-processing of the data mining result (Scheidler and Rabe, 2021). Figure 2 gives an overview concerning the classification of the phase results of the KDD process according to Fayyad, Piatetsky-Shapiro and Smyth (1996) on the knowledge staircase (North, 2022).

While the research question and the evaluation mostly provide the contextual reference to the use case, the DM is to be considered as the central aspect in the KDD process and to be understood as a collective term for knowledge extraction procedures. DM is already used in the context of production for various applications, such as quality assurance and improvement (Köksal, Batmaz and Testik, 2011), but also maintenance and special production processes (Harding, Shahbaz and Kusiak, 2006). The phase results of DM are patterns discovered in the data. The pattern term is polysemous in definition and representability in the KDD context.

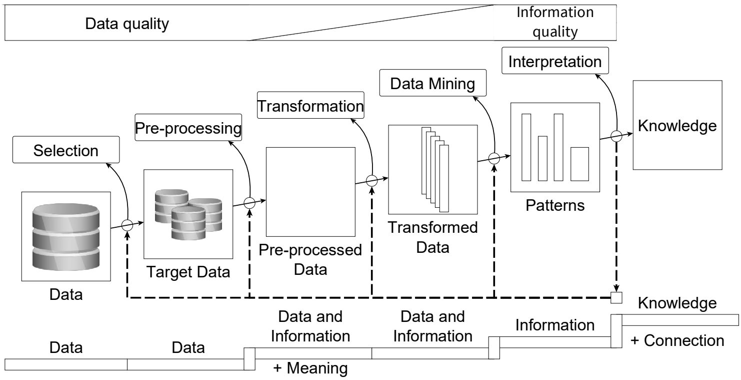

Figure 2: Data, information, and knowledge in the KDD process based on Fayyad, Piatetsky-Shapiro and Smyth (1996) and North (2022)

Nevertheless, there is the possibility to compare patterns (Geng and Hamilton, 2006) and to examine them for their interestingness (Silberschatz and Tuzhilin, 1995). To ensure the analysis quality of the KDD process, data pre-processing is essential, as it compensates for data quality deficiencies and is a mandatory perquisite for the application of data mining methods. In most KDD processes, data preparation consists of data integration, data cleansing, data normalization, filling missing data, identifying noise, data transformation, and reducing data (García, Luengo and Herrera, 2015). In this paper, a special focus is given to the KDD model of Fayyad, Piatetsky-Shapiro and Smyth (1996).

Data integration addresses the merging of different data sources and the handling of the resulting sources of error, such as the different formatting of the weight column in different databases as weight in grams or kilograms. However, the model of Fayyad, Piatetsky-Shapiro and Smyth (1996) assumes an already integrated database.

Data cleansing, data normalization, filling missing data, and identifying noise is addressed in the KDD model of Fayyad, Piatetsky-Shapiro and Smyth (1996). In data cleansing, data errors are corrected, which can include entry errors, data transmission errors, and errors in the data processing system. For example, an entry *Dortmund* in the column *Postal code* is cleaned. Data normalization ensures that data inappropriate to the

DM algorithm are converted to a different form so that new attributes with appropriate values can be generated and used for analysis. A treatment of missing values is essential for the use of most DM algorithms, insofar as they are not robust. Common practice is the exclusion of the respective dataset with missing values, but also an estimation of the missing values via dependencies and similarities to other values. When identifying noise, the imperfect data must be cleaned of corruptions. In particular, noise hinders the calculation of sharp boundaries, e.g., for clusters. At the same time, however, it also hinders other analyses. Solutions in the DM context provide robust learners, a partial exclusion of noise, or a filter to eliminate noise.

The data transformation aggregates raw data values to adapt the value ranges or distributions according to the requirements of the underlying DM algorithm. Both the data transformation and the subsequent data reduction are assigned to the transformation step and not to the data pre-processing step in the KDD model of Fayyad, Piatetsky-Shapiro and Smyth (1996). The goal of data reduction is to address the curse of dimensionality, avoiding the unnecessary processing of too much data. In this process, data are cleverly excluded so that the DM process produces the same or a nearly identical result (García, Luengo and Herrera, 2015).

The treatment of outliers different from exclusion in data pre-processing and the overall KDD process of Fayyad, Piatetsky-Shapiro and Smyth (1996), the CRISP-DM, and SEMMA, is not provided for. This leads to an incomplete knowledge discovery and consequently to a lower analysis quality as well as non-consideration of the formation mechanisms of unexpected data. Changes to the patterns, which were extracted under exclusion of the outliers, can influence the result of the knowledge discovery and the information contained therein can be lost. This is especially relevant in application fields with required high analysis accuracy, such as medicine, and high-performance applications, or with focus on data deviations, such as the considered outliers in quality control. For these reasons, usage-intended detection of outliers is an important, but not explicitly listed, step in data pre-processing. The literature on outlier detection, i.e., declaring data as outliers, has been extensively studied from general procedures to domain-specific algorithms. A good overview about the general topic of outliers can be found in Chandola, Banerjee and Kumar (2009) and Aggarwal (2017).

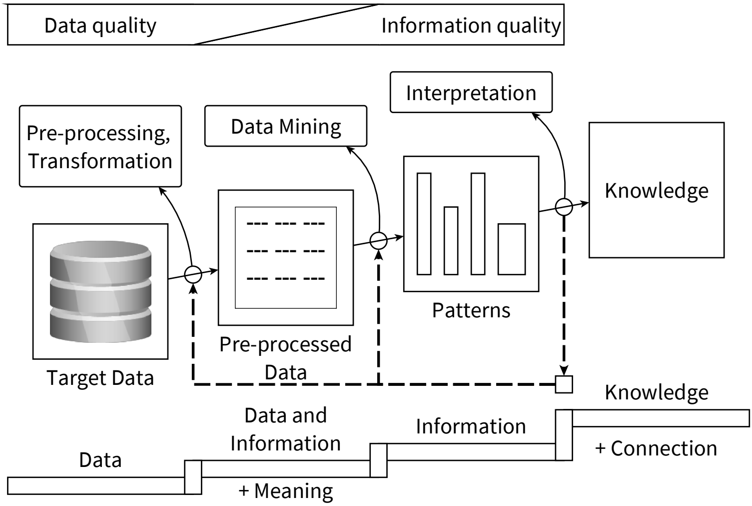

Figure 3: Data, information, and knowledge in the aggregated KDD process based on Fayyad, Piatetsky-Shapiro and Smyth (1996) and North (2022)

In the model of Fayyad, Piatetsky-Shapiro and Smyth (1996) the selection step is predominantly determined by the research question and a subset is formed from the existing database. The database formed by this process was reduced by a large number of records, which changes the subsequent analysis result. For the result of the KDD process, it is irrelevant whether by the selection the relevant data are extracted from a database or exclusively relevant data are collected in a database without selection. For this reason, the selection step must be evaluated separately from the rest of the KDD process. The step of transformation, which includes data reduction and data projection, is integrated into data pre-processing in the context of this work. The background is the missing transformation of data, information, and knowledge on the knowledge staircase. The underlying object of consideration, i.e., data and information, is not changed, but the set of the respective data is reduced as well as formatted for the data mining step. According to the statements of Fayyad, Piatetsky-Shapiro and Smyth (1996) and Han, Pei and Kamber (2012), no or almost no change of the result takes place in the transformation step, which is why the merging has no effects on a global level. These adaptions result in the presented reduced KDD model in Figure 3.

3 Information Loss Prevention in Data Mining Pre-processing

In the following section, the technology-supported implementation of DM is discussed and outlier interpretation is considered. Here, conventional methods are distinguished from technology-supported methods postulated in the literature against the background of large datasets.

3.1 Technology Support for Data Pre-Processing of Data Mining in Production Logistics

In production logistics, more and more use is being made of technology-supported analysis methods such as DM. As data volumes in companies continue to grow, consideration of data exceeds the manual manageability and evaluation of datasets. Production and logistics data, most of which are stored in relational databases, are not only being more frequently collected by sensors, but the level of detail and the scope of the data are also increasing. Thus, the increase in the network size of supply chains also leads to more complex subordinate processes, which in turn leads to larger databases (Scheidler, 2017). New parameters add to the previous considerations and dimensionality of the data. This increases the complexity of the DM, but especially also that of the data pre-processing, in data reduction, data cleansing, and the consideration of outliers.

Even for frequently performed analyses, subject matter experts are needed who are familiar with DM methods and can at the same time classify the issue under consideration from a technical point of view. The prevailing shortage of subject matter experts also necessitates extensive technical support for pre-processing and analysis execution. In this way, subtasks can be further automated or reduced in complexity.

3.2 Method of Outlier Detection and Outlier Interpretation

Within the KDD process, outliers are addressed within the data pre-processing and as a result of the DM as explained in Section 2.2. Here, it is to be distinguished whether the outliers represent the analysis result of the DM or a research question is examined, in which outliers were detected as a secondary result in data pre-processing.

In both cases, different detection methods are used, and their selection depends on different factors, such as the types of data, the amount of data, the knowledge about former outliers in the dataset, and the interpretability of the detected outliers (Aggarwal, 2017). After applying the detection procedure, procedure-dependent results are presented to the analyst for his interpretation. The classification is complicated by possible false positives, i.e., inliers that are classified as outliers, and false negatives, i.e., outliers that are classified as inliers. Both types of incorrect classification occur more frequently in the region of fringeliers.

Conventional detection algorithms list outliers and inliers. Here, the analyst lacks contextual information that facilitates interpretation. Regarding the background of the research question, the detected outliers are compared to the existing knowledge about former outliers in the dataset. Application-specific rationales are also reviewed, such as detected outliers before a machine failure occurred. The consequences and causes of the outliers can be classified by the precise technical examination and used in subsequent analyses of similar data. However, the effort required to interpret the respective outliers represents a significant disadvantage. The individual examination of each outlier quickly exceeds the time frame and, thus, also leads to increasing analysis costs. The ever-increasing data volumes justify the expectation that there will also be more outliers in the data. At the same time, there are few analysts available due to the shortage of skilled labor, and this work is quite expensive. For these reasons, only specially selected outliers can be considered in detail or the interpretation of the outliers must be simplified.

By using outlier scores in detection algorithms, data are ranked according to their outlier tendency or according to the distinctness of the outliers, without considering the context. Based on the ranking, the most relevant outliers should be estimated. However, when forming the ranking, it cannot be determined which outliers are relevant for the

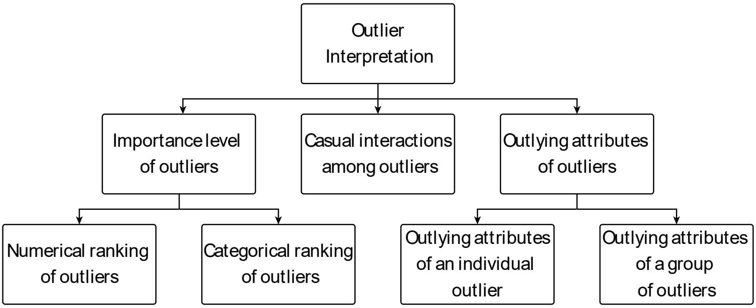

Figure 4: Categories of outlier interpretation according to Panjei, et al. (2022)

underlying research question. Particularly conspicuous outliers, such as decimal shifts resulting from entry errors, may overshadow those of technical interest. The incomplete examination of outliers also leaves the problem of undetected influences on the dataset and the question of exclusion or inclusion in analyses unresolved (cf. Section 2.2).

Outlier interpretation methods address the above problems. Panjei, et al. (2022) provide the only current overview of outlier interpretation methods and Xu, et al. (2021) a comparison of different outlier interpretation methods with a focus on algorithmic effectiveness. Panjei, et al. (2022) postulate three categories of interpretation methods: the importance level of outliers, causal interactions between outliers, and outlying attributes of outliers. An overview is shown in Figure 4.

The sources provided by Panjei, et al. (2022) particularly focus on the *interpretation of the outlying attributes of an individual outlier*. Both *numerical ranking of outliers* and *outlying attributes of a group of outliers* are addressed in only a few sources, *causal interaction among outliers* in two sources and *categorical ranking* in only one source. Panjei, et al. (2022) evaluate the given outlier interpretation aspects derived from the explanatory classification of Molnar (2019). At the same time, outliers contain information (cf. Section 2.1) and information is provided to the analyst by methods of outlier interpretation. Both are, thus, dependent on information quality. A comparison of the information quality criteria according to Lee, et al. (2002) and the aspects of Panjei, et al. (2022) is shown in Table 1.

Table 1: Comparison of criteria of outlier interpretation aspects and information quality criteria. *Added by the authors of this paper.

Outlier interpretation aspects according to Panjei, et al. (2022)	**Information quality criteria according to Lee, et al. (2002)**
Contrastive	-
Selected	Appropriate amount Ease of operation
Focus on the abnormal	-
Social	Interpretability
Truthful	Accessibility Believability Free-of-error Objectivity Reputation Security Timeliness Understandability
Consistent with prior beliefs of the explainee	-
General and probable	Completeness
Understandable for the explainee*	Concise representation Consistent representation

By comparison of the outlier interpretation aspects and the information quality criteria an overlap can be identified. This paper derives the outlier interpretation quality criteria from the overlap and divides it into three categories: *the effect on people*, the *research question*, and the *mapping of reality*.

The dimensions named *selected*, *social,* and consis*tent with prior beliefs of the explainee* can be mapped to the category *effect on people*. This category is in clear contrast to the information quality criteria since the information itself and not the *effect on people* is the object of consideration. Nevertheless, *appropriate amount* and *ease of operation* are related to *selected* by ensuring the relevance of the information. *Interpretability* and *social* can be recognized as *connected*, which represent the possibility of the interpretation kind of the respective viewer. No information quality criterion verifies that the information is *consistent with prior beliefs of the explainee*. The *effect on people* represents a central component of information loss prevention. A possible misinterpretation of given information is prohibited by methods of technology support only by a representation type adapted to the viewer.

Contrastive and *focus on the abnormal* are assigned to the second category *research question*. Both find, by the attempted assurance of the information quality in the associated criteria, no agreement to a deviation-centered view. The intersection with the third category is also found here. In the context of the predefined question, the expressions are to be associated with a trivial validation.

The third category of *mapping of reality* includes *truthful* as well as *general and probable*. *General and probable* implies a result-centered view of the completeness of given information, which is expressed by *completeness* in the information quality criteria. *Truthful* expresses the correct representation of reality on data as well as on information level. Therefore, most of the information quality criteria can be assigned to *truthful*. The expressions of this category are to be associated with a kind of verification.

In the study published by Panjei, et al. (2022), presentation types, e.g., *concise presentation* and *consistent presentation,* find no consideration as a derived criteria. However, references exist, e.g., to “lookout” of Gupta, et al. (2019), which deal intensively with information visualization for outlier interpretation. Accordingly, the consideration of Panjei, et al. (2022) must be extended by *understandable for the explainee*, which can be assigned to the category *effect on people*. As a direct result of the comparison of the work of Panjei, et al. (2022) and Lee, et al. (2002) in Table 1, an overview of the derived categories and dimensions of outlier interpretation quality is presented in Table 2.

In reference back to the direct use of outlier interpretation in the context of the DM, the literature confirms existing relevant information in outliers. This is already to be considered in the data pre-processing step of the DM, which is why an inclusion of suitable outliers provides the analyst with additional information in the data pre-processing and in the DM itself. The analyst's review of the information content is ensured by the *effect on humans* and *understandable for the explainee* in particular.

In summary, in the case of technology support, information loss within outliers in DM can occur at three different levels. At the data level, outliers may not be detected or may be incorrectly excluded. At the information level, information may be placed in the wrong context or declared unimportant, creating incorrect information or excluding correct information. Lastly, at the human interaction level, communication problems can lead to incorrect evaluation of the information.

Table 2: Derived outlier interpretation quality categories and dimensions

Effect on people	**Research question**	**Mapping of reality**
Selected	Contrastive	Truthful
Social	Focus on the abnormal	General and probable
Consistent with prior beliefs of the explainee		
Understandable for the explainee		

4 Exemplary Investigation of a Technology-Supported Outlier Interpretation Method in Production

In the domains of manufacturing and logistics, to the best of the authors' knowledge, technology support through outlier interpretation has not been significantly studied so far. Only Xing, et al. (2015), with an investigation of cabs in a regional traffic model, as well as Zhang, Diao and Meliou (2017), who use synthetically generated supply chain data from an airline, are in the domain of logistics. In accordance with the focus on outlying attributes of an individual outlier in the literature, this paper examines the category as an example. The case study will be based on the COIN outlier interpretation method provided by Liu, Shin and Hu (2018) and a production dataset. The COIN method builds context-based outlier scores for relevance evaluation of individual outliers.

The copper wire production line dataset, published on Kaggle by Oscar (2020), contains 16 days of recorded disturbance data from a production line. The application of the COIN method to the dataset was complemented by increasing the iteration steps to ensure convergence. In Figure 5, the calculated contextual outlier score of the dataset by the COIN method is illustrated.

According to the study conducted by Liu, Shin and Hu (2018), the detected outliers with a higher outlier score are more likely to be true outliers than those with a low value. At the same time, they describe the outliers with high outlier score as more technically interesting. For example, for rows 93, 94, 102, 103, 110, 111, 121, and 126, the low outlier scores of the values suggest the defective machine 8, on whose basis a cluster of outliers was generated. Line 72 has an outlier score of 10.5 in connection with machine 8 and at the same time marks the point in time after which machine 8 exclusively produced outliers. Thus, exactly this outlier contains information of particular interest and is assigned a high outlier score.

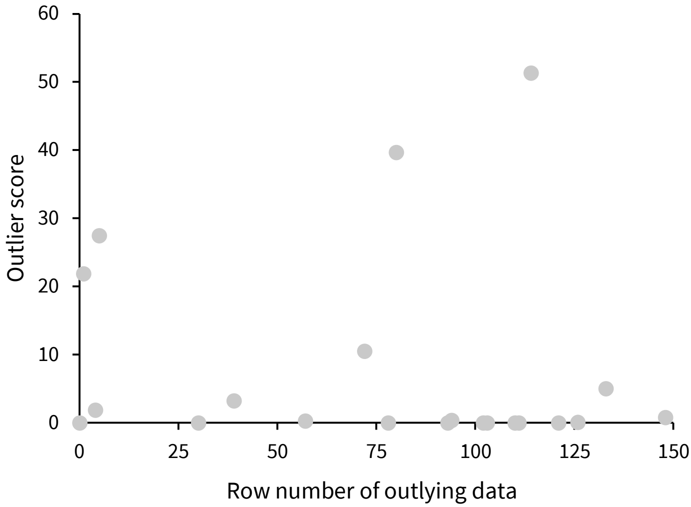

Figure 5: Outlier score of the copper wire production line dataset computed with the COIN-Method

The outliers in Figure 5 with an outlier score higher than 20 exhibit clear dependencies on multiple clusters and are, thus, also highlighted objects of study. Liu, Shin and Hu (2018) postulate for this case that they must be true outliers, but do not make any statement about included information. It must be recommended to consult experts of the production plant for these outliers.

Based on the sources mentioned above and the exemplary study presented here, it can nevertheless be shown that methods of outlier interpretation can in principle also be applied in the domains of production and logistics.

5 Summary and outlook

This paper discusses the possibilities of information loss prevention in DM data pre-processing in the domain of production logistics. In this context, relevant definitions of data and information quality were gathered, and methods of outlier interpretation were pointed out as well as classified. At the same time, the relevance of technology support in the given field was highlighted and placed in the context of information loss issues. In particular, three levels of possible information loss sources in outlier interpretation were highlighted: the data level, the information level, and the human interaction level. In addition to the literature-based argumentation on outlier interpretation methods, the exemplary case study also shows a possible evaluation of the interestingness for information stored in outliers. Due to the incomplete literature base on outlier interpretation in the domains of manufacturing and logistics as well as the DM context, a comprehensive classification of this work is difficult. Also, the exemplary domain suitability study needs to be extended by the case study with close subject matter expert contact based on various outlier interpretation methods.

In subsequent research the research field of outlier interpretation requires a framework concept for application in the KDD process. Here, the use of DM methods in outlier interpretation may result in a multi-phase implementation of a KDD process. A linkage of the KDD process with methods of outlier interpretation could generate improved analysis results by inclusion of all suitable information.

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II.
Artificial Intelligence and Blockchain

Framework for the Adoption of Blockchain in Maritime Cold Chains

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Purpose: *This analysis aims to develop a conceptual framework for the adoption of blockchain-based solutions in maritime logistics. Using the application area of maritime cold chains, we examine which characteristics are crucial for the use of blockchain and which requirements need to be met for adoption.*

Methodology: *The method follows the approach of empirical data collection with expert interviews. From the interviews, a conceptual framework for the implementation of blockchain-based solutions into the maritime cold chain was developed using qualitative content analysis.*

Findings: *Within the interview study, we identified the potential for the use of blockchain in the maritime cold chain in providing an open and neutral platform in which data from different actors are securely integrated. The adoption of the technology requires considerations regarding economic evaluation, stakeholder integration, process development, data security, and legal compliance.*

Originality: *The implementation of blockchain in the maritime supply chain is a well-studied research area, but there remains a lack of the integration of data from the material flow such as sensor data. This research aims to fill this gap.*

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1 Introduction

The relevance of temperature-controlled global supply chains has strongly grown in recent years. This trend can be explained by globalization and the demand for offering various foodstuffs all year round (Fan, Behdani and Bloemhof-Ruwaard, 2020). Besides food, pharmaceutical products, or temperature-sensitive chemicals are transported under temperature-controlled conditions (Castelein, Geerlings and van Duin, 2020).

With the increasing complexity of the supply chains, it is becoming more important to obtain sufficient information in the supply chains to be able to react more quickly to risks (Scholten and Schilder, 2015; Schröder, et al., 2021). Due to the rapid perishability of the goods and susceptibility to temperatures, it is required to maintain the necessary environmental conditions, such as temperature and humidity level, as well as to avoid interruptions during the transport (Behdani, Fan and Bloemhof, 2019). Disruptions in the cold chain contribute significantly to the generation of food waste (Mercier, et al., 2017). A particular issue is the need to continuously maintain an appropriate cargo environment from the start to the destination of the cold chains (Filina and Filin, 2008; Bömer and Tadeu, 2014). In addition, customers and authorities are increasingly interested in receiving provenance knowledge to enhance the quality, safety, and sustainability of the products (Montecchi, Plangger and Etter, 2019).

An important role to ensure the ongoing material flow is the exchange of information enabling the coordination between the stakeholders (van der Horst and Langen, 2008). In the course of the digital transformation, information and communication technologies (ICT) such as cloud computing, artificial intelligence, or the Internet of Things are increasingly used in maritime logistics (Fruth and Teuteberg, 2017). While many processes are already digitized, there are still potentials to improve processes between and within companies through the integration of different data sources (Heilig, Lalla-Ruiz and Voß, 2017). Therefore, digital platforms are becoming increasingly important to facilitate collaboration and transparency in supply chains. For example, visibility platforms such as project44, Fourkites, or shippeo integrate various data sources to provide their customers better insights into their supply chain, allowing them to automate their processes (Behrend, 2022).

These platforms also integrate data from sensor devices in cold chains, which are collected by specialized monitoring providers such as Sensitech or Visilion via wireless sensor systems (Bruno, 2022). Another approach for monitoring temperature-controlled shipments is the concept of smart containers (Dittmer, et al., 2012). There are initiatives, like the remote container management (RCM) of the Danish ocean carrier Maersk. RCM allows the customer to monitor the shipment within a web-based portal in real-time (A.P. Moller Maersk).

Blockchain technology is seen as one approach to the secure integration of information flows in supply chains (Kshetri, 2018; Gurtu and Johny, 2019). While applications for the exchange of documents in maritime logistics or the end-to-end tracking of food or pharmaceutical products are well advanced, there is no conceptual link between these two domains.

This paper aims to fill this gap by providing a conceptual framework that incorporates the business value of blockchain technology with potential application areas in the maritime cold chain. Through this approach, we aim to answer the following research questions (RQ):

RQ1: What business value is seen for blockchain in maritime cold chains?

RQ2: What are potential application areas for blockchain in maritime cold chains?

RQ3: Which are crucial requirements for the adoption of blockchain in maritime cold chains?

The remainder of this paper is structured as follows: in section 2, we define the key characteristics of blockchain and review the related literature for blockchain adoption in supply chains, focusing on use cases in maritime logistics and cold chains. In section 3, the methodology to answer the research questions is introduced. Based on the interviews, the process value, application areas, and requirements for the adoption process of blockchain are elaborated on in section 4. These results are discussed in section 5. Finally, in section 6 we draw conclusions and limitations.

2 Background Literature

2.1 Blockchain Technology

Blockchain is characterized by a decentralized database that enables verified transactions, which are stored immutable (Hackius and Petersen, 2017; Chang, Iakovou and Shi, 2020). By providing smart contracts, which are in a sense shared program code between different organizations, it is possible to automate the process between different actors (Wang, et al., 2019). Consensus mechanisms, such as proof-of-work, proof-of-stake, or practical byzantine fault tolerance, ensure that transactions are valid and that all nodes maintain the same database (Casino, Dasaklis and Patsakis, 2019).

Blockchains can be distinguished into two basic types: public and private blockchains (Casino, Dasaklis and Patsakis, 2019). Public blockchains are characterized by the fact that anyone can send transactions and view the state of the database. In contrast, access to private blockchains is restricted by a central authority and only authorized users can read and send transactions. Another distinction is the access to the transaction validation. In permissionless blockchains, any node can join the network and verify transactions, while in permissioned blockchains transactions are verified by a set of predefined nodes (Nærland, et al., 2018). Applications using public permissionless blockchains are e.g. cryptocurrencies such as Bitcoin or Ethereum (Wust and Gervais, 2018). In maritime logistics, mainly permissioned blockchains are used, which offer advantages in terms of data protection and system performance (Munim, Duru and Hirata, 2021). In addition, using sidechains or storing information off-chain allows for increasing the confidentiality and exchange of huge data amounts, while only the hash of the transaction is stored on the main chain (Hepp, et al., 2018).

2.2 Blockchain in Supply Chains and Logistics

Research on the topic of blockchain in supply chain management can be found in the literature from around 2014/2015 (Casino, Dasaklis and Patsakis, 2019). The domain of maritime logistics is specifically addressed since 2018 (Munim, Duru and Hirata, 2021). The areas of application cover various aspects of SCM, such as tracking the origin of products, the exchange of documents, certification, or the integration of the internet of things (Hackius and Petersen, 2017; Kshetri, 2018). In the following section, an overview of the developments of blockchain in the context of maritime logistics and cold chains is given.

Due to the potential to increase trust, approaches for the usage of blockchain can in particular be found in the verification of luxury goods and sensitive goods such as food and pharmaceutical products (Wang, et al., 2019). For example, Tian (2016) presents a concept for a system in which the various process steps can be securely integrated with the help of blockchain and RFID to increase traceability.

The digitization of document exchange and the reduction of manual processes are particularly relevant in the context of maritime supply chains (Pu and Lam, 2021). A prominent example is TradeLens, a blockchain-based platform initiated by IBM and Maersk. TradeLens aims to provide a platform for the secure exchange of data and documents enabling shippers to gain end-to-end visibility of their supply chains (TradeLens, 2022). An important element of TradeLens is the digitization of trade documents such as the Bill of Lading (Nærland, et al., 2018; Chang, Iakovou and Shi, 2020). In addition to TradeLens, many other initiatives are aiming to digitize the Bill of Lading like WaveBL or CargoX (Bavassano, Ferrari and Tei, 2020).

A different concept is followed by the start-up T-Mining with the “Secure Container Release”. This blockchain-based solution in the Port of Antwerp aims to increase the security of the container release (T-Mining, 2021). Previously, a pin was issued by the shipping line to the freight forwarder and the terminal operator for the release of the container. The freight forwarder passes this pin on to its contractors, which authorizes them to pick up the container at the terminal gate. Based on concepts of blockchain, self-sovereign identity, and privacy, T-Mining enables a more secure process and potential for more efficiency and automation. Hackius, Reimers and Kersten (2019) investigate a similar use case in the port of Hamburg. They found opportunities for blockchain in the unification of the information flow, the standardization of communication, and the increase of formal security.

For the integration of the Internet-of-Things, approaches can be found in particular in pharmaceutical supply chains (e.g., Bocek, et al., 2017; Fournier and Skarbovsky, 2019).

Blockchain could serve as a basis to simplify the complex process to reach compliance with legal requirements such as Good Distribution Practice (GDP). It also enables verification of the sensor unit without having to rely on a third party, which can be costly and time-consuming (Chanson, et al., 2019). One example of this application area is the eZTracker of the Singaporean pharmaceutical distributor Zuellig Pharma. Through the blockchain-based application, patients can verify whether the drug originates from an authorized source by scanning a QR code (eZTracker, 2022). As medical products such as vaccines need to be stored in temperature-controlled conditions, users are enabled to verify that the products are safe before being used.

In addition to the application areas and potentials, the literature also deals with barriers and challenges to the adoption of the technology. In particular, the high latency times for transactions and low storage capacity are seen as a challenge (Tian, 2016; Reyna, et al., 2018). By providing a transparent network, privacy is a challenge for the use of blockchain (Reyna, et al., 2018; Hackius, Reimers and Kersten, 2019; Papathanasiou, Cole and Murray, 2020). Besides technical barriers, barriers can also be found in the organizational area, both within and between companies (Saberi, et al., 2019). For example, the lack of knowledge and successful deployment examples is identified as a barrier to adoption (Papathanasiou, Cole and Murray, 2020; Zhou, et al., 2020). Another barrier can be found in the lack of technology readiness of many players, which is attributed to a low level of digitalization or the traditional character of the logistics industry (Papathanasiou, Cole and Murray, 2020; Balci and Surucu-Balci, 2021).

While the implementation of blockchain in maritime logistics and the use of the Internet-of-Things in supply chains have been explored, a conceptual link between these domains is missing. Jabbar and Bjørn (2018) show based on three use cases that the blockchain encounters an existing infrastructure when it is introduced into maritime logistics. Therefore, an adjustment is required for both, the configuration of the blockchain and the information system. As shown in Figure 1, the maritime cold chain consists of a complex network of public and private actors with different objectives (Fan, Behdani and Bloemhof-Ruwaard, 2020). These actors exchange trade documents, as well as planning and status information, via various forms of communication such as telephone, mail, email, or EDI (Jensen, Bjørn-Andersen and Vatrapu, 2014). Besides this information, real-time information for monitoring temperature and other environmental parameters is increasingly exchanged (Castelein, Geerlings and van Duin, 2020). Improving the exchange of information could increase efficiency in the supply chain to better utilize equipment, save resources and proactively monitor quality in real-time (Mercier, et al., 2017; Fan, Behdani and Bloemhof-Ruwaard, 2020).

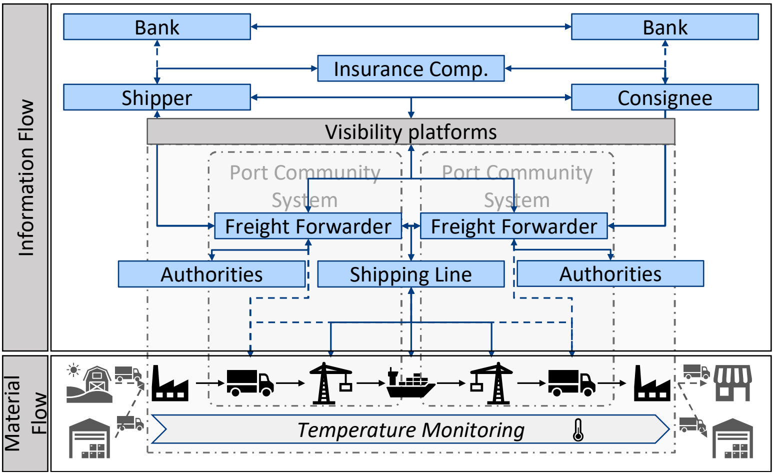

Figure 1: Key Stakeholders and Information Flow in Maritime Cold Chains (van Baalen, Zuidwijk and van Nunen, 2008; Behdani, Fan and Bloemhof, 2019; Fan, Behdani and Bloemhof-Ruwaard, 2020)

This study aims to develop an understanding of the existing information infrastructure in the maritime cold chain and how blockchain contributes to its further development by providing an overview of its application areas, opportunities, and requirements for adoption. However, the analysis will not be limited to how blockchain technology can be implemented, but also what general conditions need to be addressed to apply new ICT in the domain of maritime (cold) logistics.

3 Methodology

To develop a framework for the adoption of blockchain in the maritime cold chain, we conducted sixteen semi-structured interviews in two cycles. The interviewed experts were selected based on a combination of the criterion and purposeful random sampling (Patton, 2002). In particular, the aim was to include perspectives from the different functional areas of the maritime cold chain as shown in Table 1. Twelve interviews were conducted in German and four in the English language via telephone or video telephony due to the social distancing during the corona pandemic. The interviews lasted between 20 and 104 minutes, with an average of 60 minutes.

In the first interview cycle between July and September 2020, we selected particularly experts from the operational business to develop an understanding of the process and to derive the need for new ICT in maritime logistics. In the second interview cycle between December 2021 and April 2022, the focus was primarily set on understanding the adoption of blockchain in the logistics process. The ten interviewees in this cycle can therefore primarily be found in the areas of service providers for ICT and experts with previous experience in the implementation of blockchain-based projects.

Table 1: Demographics of the Interviewees

ID #	Organization Type	Expert Position
1	IT-Service Provider	Project Manager, Head of Business Development
2	Ocean Carrier	Sales Executive
3	Insurance Service Provider	Managing Director
4	Fruit Importer	Head of Quality Management
5	Logistics Consulting	Partner

ID #	Organization Type	Expert Position
6	Logistics Service Provider	Project Manager
7	IT-Service Provider	Freelancer
8	Insurance Service Provider	Head of Business Development
9	Electronics Producer	Head of Tracking-Division
10	Logistics Service Provider	Chief Technology Officer
11	IT-Service Provider	Chief Information Officer
12	IT-Service Provider	Head of Technology
13	IT-Service Provider	Managing Director
14	Electronics Producer	Head of Cloud Development
15	Pharma Producer	Head of Supply Chain
16	Terminal Operator	IT-Manager

To structure the interviews, an interview guideline was developed in advance. The aim was to understand on the one hand the drivers for the digitalization of the supply chain and on the other hand to understand the potential role of blockchain. For this purpose, the interviews were divided into two parts: in the first part, the current process in the cold chain was discussed to gain an understanding of the structure of the process, the involved stakeholders, and the challenges that occur during the cold chain. In the second section, opportunities, and challenges for the use of blockchain were discussed, and in which areas of the supply chain blockchain could be beneficial.

The interviews were recorded, transcribed, and analyzed in a qualitative content analysis according to the approach of Mayring (2010). For this purpose, codes were formed based on the transcripts, and codes with similar statements were grouped. In the next step, the codes were combined into more general codes and assigned to the three analytical categories of the value of the technology, application areas, and requirements.

4 Development of the Conceptual Framework

Based on the identified categories, we analyzed the (1) process value of blockchain which is summarized in Table 2, (2) application areas for blockchain in maritime cold chains as shown in Table 3, and (3) requirements that need to be considered for adoption as shown in Table 4.

4.1 Value of Blockchain

A key value of blockchain can be found in the integration of different information flows. The maritime supply chain consists of a complex ecosystem of actors, many of which maintain their own data systems. In addition, new data sources emerged in recent years such as temperature data generated by the use of "intelligent containers" or real-time temperature loggers (Jedermann, et al., 2014). Blockchain is seen by experts as a suitable solution to integrate these data with the document flow of the shipment, thus simplifying the direct assignment of information to a shipment

Table 2: Values of Blockchain for Maritime Supply Chains

Value	Elements	Interview Reference
Integration of information flows	Integration of information flows from several stakeholders	1, 2, 4, 5, 9, 10 (5)
	Enabler for standardization and participation	7, 11, 13 (3)

Value	Elements	Interview Reference
Increasing data security	Increase trust	7, 8, 9, 13, 14 (5)
	Increase data integrity and avoid manipulation	5, 7, 8, 11, 13, 14 (6)
Open and neutral network	Decentralized network without a gatekeeper	7, 12, 13, 16 (4)

This enables data consumers to retrieve information directly from the source without being transmitted via intermediaries, avoiding media breaks which increase the transmission time and are a potential source of errors. In addition, blockchain can be an enabler for the standardization of processes, as illustrated by expert #13 on the example of TradeLens in which blockchain "*is only [used] to authenticate documents*", but "*even without that, the system would be quite useful*", as this kind of standardization not only allows to standardize the system but also to standardize "*the structure of the process*" which enables the communication between the different systems in the industry.

Besides the integration of data sources from different stakeholders, blockchain can serve to ensure the integrity of the data. Blockchain appears as an application "*with the goal that you get data integrity, meaning reliable data points in an application area where many stakeholders come together who do not know each other respectively do not trust each other."* (Expert #8). This benefit is particularly useful in the financial domain but also to ensure the immutability and integrity of documents in supply chains.

A key potential for the implementation of blockchain in supply chains can be found in the ability to exchange data in an open and decentralized network. This is especially true for permissionless blockchains, such as Ethereum, in which every participant has the same rights and, according to expert #7, should work "*like the internet. Not owned by anybody.*" Blockchain-based solutions in logistics, however, are usually permissioned, so as in conventional systems, there is a gatekeeper. This contradicts the benefit that could be achieved with a blockchain, expert #16 going so far as to say, "*And if you can't get it to work in such a decentralized way, then the question is whether I need a blockchain at all.*"

4.2 Application Areas for Blockchain in Maritime Cold Chains

The exchange of documents plays a crucial role in maritime transportation (Jensen, Bjørn-Andersen and Vatrapu, 2014). For example, in food supply chains it is of particular importance that "*everything that has been used in terms of pesticides, [...] certification status on the subject of sustainable production CO2 [...], social responsibility […]*" is documented and communicated in advance (expert #4). Besides product-specific documents, this includes transport-related documents such as the packing lists or the bill of lading. Missing or erroneous documents can result in problems at the points of transfer, delays in the registration process at customs, or failing acceptance at the receiver of the goods. Through its verifiability blockchain provides a basis for the digitalization of document exchange.

Table 3: Application Areas and the Contribution of Blockchain

Application Area	Contribution of Blockchain	Interview Reference
Documentation of the shipment lifecycle	Digitize document exchange	4, 6, 7, 9, 11, 13, 16 (7)
	Documentation of transport process	1, 2, 3, 5, 14, 16 (6)
Automation	Automation of information exchange	2, 3, 4, 8, 13 (5)
	Automation of financial flows	8, 10, 13, 15 (4)

Application Area	Contribution of Blockchain	Interview Reference
Data-driven decision making	Improve coordination in logistics	2, 4, 7 (3)
	Real-time information on deviations in the process	1, 2, 9, 12, 14, 15 (6)
	Support data-based decisions of customers	1, 2, 8, 9, 12, 15 (6)

For cold chains, reliable documentation is of particular importance when the cargo does not arrive in the ordered condition. Although the temperature is recorded during the intermodal transport, important information is often missing in the phases before and after shipment and is hardly standardized as shown by a statement of expert #3: "*This transparency, the fruit is hanging on the tree, the fruit is in the warehouse and [then] cooled and packed, that is [still a] gray area, there is a lot of information missing."* Multiple interviewees mentioned the potential of blockchain to consolidate different data sources in one place, as highlighted by expert #5: "*[With blockchain] you can define the risk transitions much more precisely and track them much more accurately. […] if you bring together the relevant parameters, it would be much easier. Today, it is still a bit of detective work*". By integrating all relevant information securely in one system, blockchain is found as a suitable approach for the documentation of the transport process. The integration also promotes the automation of the information exchange, so that documents for the clarification of claims are directly available, avoiding the time-consuming exchange of documents.

By integrating the different stakeholders, a blockchain-based platform could contribute to better coordinating the processes in the supply chains. With the integration of data from several steps of the supply chain, the quality-oriented approach 'first expire - first out' instead of 'first in - first out' could be implemented, as is already frequently discussed in the literature (e.g. Jedermann, et al., 2014). This approach could be for example used to prioritize discharge orders at the terminal as suggested by expert #4. If the data could be exchanged with the relevant stakeholders in real-time, there would be significant potential for improvement as „*If you could simply adjust the order at short notice [...], we would already be a huge step ahead* “.

4.3 Requirements for Adoption

4.3.1 Economic Evaluation

The adoption of new technological solutions is often associated with high costs (Tian, 2016; Tan and Sundarakani, 2021). The infrastructure for information sharing needs to be set up and surrounding processes must be digitized. Concerning the digitization in cold chains, investments are required for the sensing hardware and the setup of the communication infrastructure. Particularly for cargo with a relatively low monetary value, even small increases in cost can have a significant impact on the margins of the involved trading parties. This is described by expert #4 in the following way: “*[What we have to] make clear with fruit and vegetables, with such […] fast-moving consumer goods that we are more in a low-price segment. Costs naturally play a very large role here. [...] [If there is] no low-cost sensor technology, we do not get anywhere, because this option will not be used*." Therefore, it seems necessary to develop on the one hand solutions that are economically feasible for the potential users and on the other hand demonstrate which benefits they can derive from using the application to incentivize participation.

The implementation of blockchain technology seems even more difficult in the cold chain. Since customers usually engage the services of a supplier directly, there is no reason seen to question the data integrity. It seems in many cases questionable whether blockchain technology is the best solution to achieve the actual goal. The selection of the technology should therefore consider the actual needs of the users, instead of focusing on the implementation of a specific technology.

4.3.2 Stakeholder Integration

An important requirement for the successful adoption of blockchain can be found in the integration of the relevant stakeholders as organizations engaged in global supply chains are confronted with a multitude of platforms and interfaces when communicating with each other. This impedes collaboration in supply chains and increases the complexity as expert #2 points out: "*If you do not have enough data points, it may not even be enough for the customer to use that because they say: 'One of my important three customers is not mapped.'*" Therefore, it is necessary to create the conditions to enable the integration of all relevant stakeholders.

A major challenge lies in the fact that on the one hand, the organizations in the maritime industry are in intense competition with each other, but on the other hand, they are dependent on collaboration, as demonstrated by multiple consortia or vessel-sharing agreements between competitors (Elbert, Pontow and Benlian, 2017). The challenge is to get actors from different supply chains, as well as authorities from different countries onto one platform as described by expert #2: "*Bringing customs, veterinary authorities, government [...] all of them onto one platform is not that easy. Because you are not doing anything else than bringing all of them [together] and telling them: 'give me your data'. Everyone. And that is not easy. It does take time.*"

Besides the barrier posed by the competitive situation, the experts also claim that many stakeholders are reluctant to share information, as they fear providing too much transparency. Currently, a change towards increased transparency is ongoing, but this is still in its infancy. Expert #3 uses Maersk's remote container management as a positive example to illustrate that the idea of "*show[ing] [the customer] what is happening*" only works if "*the entire corporate philosophy is adapted that way.*"

Table 4: Requirements for the Adoption of Blockchain

Category	Requirement	Interview Reference
Economic evaluation	Economically feasible solution	4, 5, 6, 7, 8, 13, 14, 15, 16 (9)
	Incentivize technology adoption	1, 8, 13, 14, 16 (5)

Category	**Requirement**	**Interview Reference**
Stakeholder integration	Problem and customer-oriented development	7, 8, 10, 11, 12, 13, 14, 16 (8)
	Integration of relevant stakeholders	1, 2, 3, 8, 10, 13, 14 (7)
	Change of corporate philosophy to enable transparency	1, 2, 3, 5, 7, 9, 11, 12, 14, 16 (10)
Process development	Digitization and verifiability of data capturing	4, 5, 6, 7, 8, 10, 11, 12, 13, 15 (10)
	Standardization of processes	11, 13, 16 (3)
	Adaption of processes	7, 11, 14, 16 (4)
Data security and legal compliance	End-to-end data integrity	7, 8, 14 (3)
	Tailored information flows	1, 2, 13 (3)
	Legal framework for technology adoption	5, 7, 11, 13 (4)

4.3.3 Process Development

As the verification of transactions on a blockchain only appears useful once the data has been recorded digitally and in a sufficient quality, it is required to digitize the processes to utilize the benefits of blockchain. For Expert #10, using the Blockchain requires first overcoming the manual input of data because "*as long as we're not at a level where all this data is [digitally] available, [as long as] integrating it does not do anything.*" An important aspect in cold chains is e.g., to ensure that the measurement of temperature is done correctly, as Expert #8 points out: "*If you measure nonsense, the blockchain does not help you either, because then you just verify a nonsense measuring point.*"

The implementation of new technology requires not only the digitization of the process but also adapting existing procedures. As expert #11 points out, "*blockchain [...] is a tool*." whose implementation is not just a technology project, but part of comprehensive change management, because "*what we are talking about is the improving business processes."*

Especially for a collaborative technology like blockchain, it is therefore required to standardize the process and ensure a mutual understanding of data. In maritime logistics, various initiatives and associations are working on standardizing the exchange of information. For example, UN/CEFACT and the industry association SMDG maintain the standards for the EDI messages. In addition, the World Customs Organization (WCO) manages a data model for communication with customs, and most recently the Digital Container Shipping Association (DCSA), an association of major shipping lines which aims to further promote the digitalization of maritime logistics through the development of standards (Schleyerbach and Mulder, 2021).

4.3.4 Data Security and Legal Compliance

Privacy requirements are one of the biggest concerns when implementing a blockchain-based network (Hackius, Reimers and Kersten, 2019). Generally, organizations strive to protect their business information as much as possible. Therefore, it should be ensured that the stakeholders only receive "*tailored information flows [...]. Not everyone gets to see everything.*" as stated by expert #2.

Besides ensuring the confidentiality of the shipment information, it is also required to protect information on business relationships as described by expert #6, "*the forwarder [...] lives from his network of carriers or ocean carriers to purchase at the best price and to sell that to the customer with a certain margin [...].*" If the service provider becomes known to the shippers, they could approach the service provider directly.

One challenge is that the blockchain only proves the data security of the data within the blockchain. For the data generated and processed outside the blockchain, the so-called Oracle problem arises or, as described by expert #14, the need for a "*chain of trust*": the data in the blockchain can only be regarded as secure if the integrity can be ensured from the source.

A technical solution must not only consider requirements regarding technical data security but ensure compliance with the legal environment. The challenge here can be that in many cases the legal basis for the use of the blockchain is not yet in place, such as with the electronic bill of lading. In addition, requirements regarding the location of data storage and data protection must be met, which can differ depending on the jurisdiction.

5 Discussion and Implications

Based on the analysis of the interviews, we could identify documentation, automation, and data-driven decision-making as three basic application areas which could benefit from the adoption of blockchain-based solutions. This is in line with the findings of Pu and Lam (2021) whose framework we were able to complement in particular with the elaboration of requirements for adoption, as well as the highlighting application areas and the business value of the blockchain, as shown in Figure 2. Tsiulin, et al. (2020) identified, another important application area in financial processes, which was only discussed as part of process automation in this study.

Contrary to our expectations, we found deviations in the benefits of the blockchain for the process. While the original expectation was that the sensor data itself in particular could be exchanged securely, it can be determined, at least for the maritime sector, that the stakeholders do not see the need for increased verifiability.

However, the potential for blockchain can be found in the secure integration of the document flow with the material flow data as an area of application. This enables the stakeholders to access the data via a single point of entry and thus, depending on the respective authorization, to obtain all relevant information from one place without having to build a time-consuming integration with each system they need to connect to.

The potential of the blockchain can only be utilized if the prerequisites in the technical and organizational areas are fulfilled. These are, in particular, the digitalization and standardization of processes, as well as the creation of awareness for data security. A major challenge here is the dependency on the partners in the supply chain. Even with smaller service providers, processes must be digitalized, and the corresponding technology must be available. As already noted by Chanson, et al. (2019) and Wang, et al. (2019), ensuring integrity from the source is one of the biggest challenges for integrating sensor data into the blockchain.

Establishing transparency along the supply chain was identified as one of the most important requirements. This is in line with the findings of Papathanasiou, Cole and Murray (2020), who in their study identified in particular the traditional culture and lack of will to change as a barrier to the use of blockchain in the maritime industry. Although a change already seems to be taking place here, as shown by the initiative of Maersk, there is still a lot of potentials to increase transparency.

However, establishing transparency should not be understood as simply disclosing data. It must be possible for the providers of data to control who receives the data and how it is used in the process. A frequently mentioned challenge during the study was the aspect that users are confronted with a large amount of data due to increasing transparency. Therefore, it seems necessary not only to provide the users with the data but also to provide them with additional means to avoid misinterpretation as far as possible.

Framework for the Adoption of Blockchain in Maritime Cold Chains

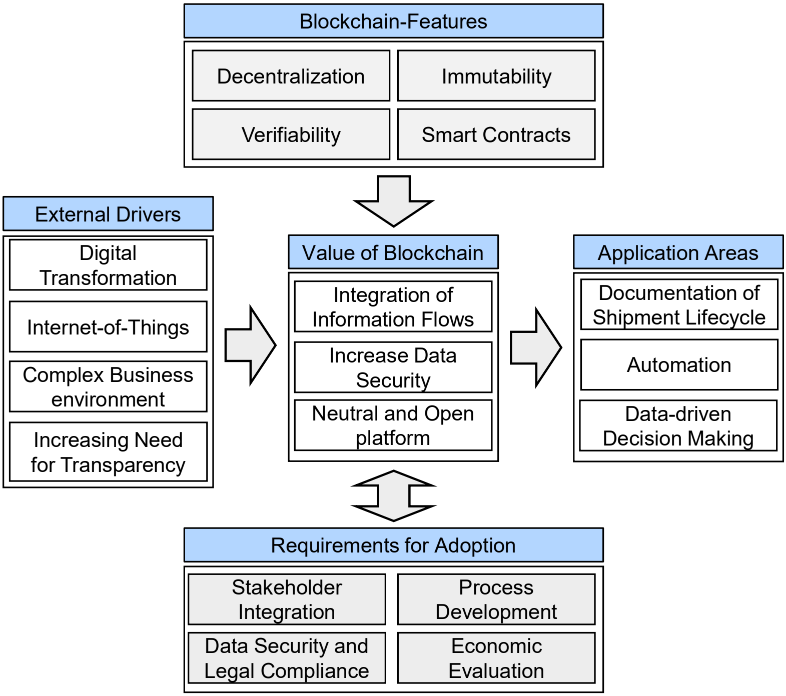

Figure 2: Conceptual framework for the Adoption of Blockchain in Maritime Cold Chains

Lastly, the implementation of blockchain-based applications should not only be seen as a technology project but rather as a tool to change processes. The development of technical applications should be oriented on the needs of the stakeholders and the underlying process behind them. Blockchain appears to be particularly suitable in cases where the stakeholders have little trust in each other, and the exchange of assets is involved. Although blockchain can be seen as the last level in the digitization of a process, the example of TradeLens shows that technologies such as blockchain are certainly suitable for driving the process of digitization and standardization in a complex network of actors, even if the role of blockchain in technical terms is rather minor.

6 Conclusions, Limitations, and Future Research Directions

This paper aimed to develop a conceptual framework for the adoption of blockchain in maritime logistics based on the use case of maritime cold chains. Therefore, we conducted sixteen semi-structured interviews which revealed three main application areas in the documentation of the shipment lifecycle, automation of information flows, and data-driven decision making. To implement blockchain into those application areas, especially requirements regarding the economic evaluation, stakeholder integration, adaption of the process, and data security need to be considered.

Thereby, blockchain should be seen less as technology and more as a concept to advance the digital transformation in supply chains. There is no doubt that blockchain offers advantages in secure integration, but the identified requirements demonstrate that most of the challenges are not exclusively related to the technology itself but rather to general issues in the governance of the information flow in supply chains.

This research is not without limitations. During data collection, it was not possible to separate the characteristics of the maritime cold chain from those of the general maritime supply chain. However, the boundary is becoming increasingly fluid for example Hapag-Lloyd announced to equip all its dry containers with sensor devices until 2023 (Johnson, 2022). We assume that the found requirements and steps for implementation also apply to these use cases as the stakeholders remain the same.

In addition, this research does not consider further or more general technology adoption models. To develop a more distinct understanding of the technology adoption process, it appears necessary to evaluate the findings of this research with other technology adoption processes.

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Smart Order as a new Instrument for Production Control

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Purpose: *Smart contracts are transaction programs with an "if-then logic" in relation to the blockchain technology and offer new possibilities for production control. Smart orders are derived from production orders and they are based on smart contracts. Therefore, they are created with the addition of an "intelligent" component. Basically, smart orders contribute to the ability of self-organised production systems. Blockchain-technology serves as the necessary infrastructure and, due to its properties, offers additional protection, decentralization and data security*

Methodology: *An extensive literature review is conducted to evaluate the current state of research in the area of the Smart order concept. Based on these results, a concept for the creation and use of smart orders is developed.*

Findings: *According to the literature analyses, preliminary conditions and solutions for blockchain based production control use cases are identified. Based on these findings conceptual considerations are presented for a production control system based on the use of smart orders.*

Originality: The research shows the status quo of blockchain based solutions in the area of production control. Furthermore, first results of a new production control system based on smart orders is presented. The findings demonstrate the ability of creating self-organized production systems by blockchain technology.

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1 Introduction and Motivation

Traditional centrally controlled production systems are based on extensive basic data management. Work schedules and parts lists are added to each order from the basic data management and the production process starts. If customer requirements change, a production machine breaks down or the topology of the production system changes, large-scale re-planning is necessary. Likewise, in the case of new planning or re-scheduling, there are often gaps in documentation and data security can be problematic. In today's dynamic production environment, expensive and lengthy re-planning is dangerous for a company's market position.

Companies in the aerospace or defense industry usually process on order-related basis, with the store floor organized as a workshop. The production system must be flexible enough for one-off production, but powerful enough to produce small batches economically. This scenario is prone to the problems mentioned above. To handle these problems we present the current state of our research of Smart order (SO) based production control. The SO can described as self-organizing production order that runs autonomously through the production process using smart contracts (SC). In case of a malfunction, the "smart" component becomes active and presents alternative solutions that can be selected after considering operational requirements. We aim to answer two research questions:

RQ1: How can a concept for decentralized production control using smart orders be designed?

RQ2: Is there a suitable consensus mechanism for decentral smart order based production control?

The structure of the paper is the following: Section 2 describes the methodological approach and presents the results of the structured literature review. In section 3, we give a brief insight into BCT and the features that are important for the concept. Furthermore, we define what SC are and how they work on the blockchain. The concept of the SO and the problem of validating physical measurement values in a production system is also a part of this section. Section 4 provides a more in-depth explanation of how the conversion of customer orders into production orders takes place and how the smart contracts of the SO are generated. The summary and an outlook on further research work conclude the last section.

2 Structured Literature Analysis

To identify the relevant sources, we conducted a comprehensive structured literature anaylsis (SLA). As suggested by authors Denyer and Tranfield and Hökkä et al, we use the four steps below to conduct the SLA:

Step 1: Definition of the research objects,

Step 2: Creating a framework around the research object to delineate,

Step 3: Data collection using inclusion and exclusion criteria,

Step 4: Analysis and synthesis of the research results (Denyer and Tranfield, 2009; Hökkä, Kaakinen and Pölkki, 2014).

2.1 Definition of the Research Objective

This article presents the current state of research on our smart order concept. With the SO, it should be possible to establish a self-organizing production control. In this context, the BCT serves as a secure data infrastructure and as a runtime environment for smart contracts. Smart contracts are an integral part of SO and ensure the "self-execution" of orders in the production system. In addition, when production orders are derived from smart orders, an "intelligent" component is added in the form of a production agent that takes over control in the event of deviations in the production process.

2.2 Creating the framework

Our research focuses on the development of a concept for the use of SO in production control. Previous research has shown that smart order based production control can best show its advantages in a cyber-physical system (CPS). In general, however, the logic is also applicable to partially networked production systems, where the necessary hardware and software prerequisites are available to be able to use SO in a way that increases value creation (Y. Zhang et al., 2017). The scope around the research project should be as large as possible in order not to miss any relevant sources. In doing so, we defined the terms "blockchain", "cyber-physical system" and the related terms "production" and "manufacturing". Terms such as "smart contract" were deliberately not listed in a dedicated manner, as this would lead to a narrowing of subsequent hits.

2.3 Data Collection

In order to perform a SLA according to scientific criteria, it is necessary to define databases, search criteria, keywords and other filter settings. We use the databases Web of Science (WoS) and Science Direct (SD) for our research. Both databases provide a sufficient number of hits and offer various filter settings for refining search criteria. Queries in other databases do not lead to a significant improvement of the results. As already mentioned in section 2, we follow the adapted search process of Denyer & Tranfield and Hökkä et al:

Step 1: Identification of relevant publications in the field of blockchain, cyber-physical systems in the context of production and manufacturing,

Step 2: Restriction of the results by adding further search criteria. Searched in "Computer Science", "Engineering", "Business, Management and Accounting" and in "Decision Sciences".

Step 3: Exclusion of further hits due to lack of content relevance or non-availability of the source.

Step 4: Subsequent full text analysis of the remaining publications and further reduction of the number of hits.

In the first step, the keywords were used that could be identified through preliminary research from the basic sources on the respective topic. In the first run, even more keywords were used than already noted in section 2.2. However, the use of terms such as "smart contracts" or "distributed ledger" led to a significant reduction in the number of hits. This risks that we overlook relevant publications in the field of production control related to BCT or smart contracts. The search query conducted in this way resulted in over 7,000 hits on the WoS and SD databases.

In the second step, the authors added more search criteria to focus on the actual research question. On the one hand, we wanted to find all the basic principles that would help in the development of our concept. Second, we wanted to identify and evaluate all possible research by other authors in this area. Furthermore, to the search terms, other search criteria were added and the search in the database was narrowed down to "Computer Science", "Engineering", "Business, Management and Accounting" and in "Decision Sciences". This step is necessary because SD also returns hits that have nothing to do with the research object, but our keywords were used at some point in a non-relevant article.

The third step involves the initial analysis of the title and abstract of all remaining hits. Depending on the content relevance, assigning a numerical value to the document, with a higher value corresponding to a higher content relevance. In the context of analysis, content relevance means whether the title and abstract are related to the production or production control in combination with BCT. At this point of the analysis, there are still many hits in the list of potentially usable sources, because they contain the keywords we are looking for. However, a large number of the articles have a different focus. As an example, the paper by Abbas et al. contains all the identified keywords, but has nothing to do with our research topic, but rather with the use of blockchain in the context of pharmaceutical supply chain management (Abbas et al., 2020). In contrast, 4 publications received the highest content relevance (more on content relevance in section 2.4). This does not mean that our research question is answered, but that the authors are already doing very sound research in the field of production control using BCT.

This initial analysis was performed in the literature management software Zotero. Table 1 shows the summarized research complex, technical term, and specific search terms used in the database. The * symbol can be used as a placeholder. Thus, different spellings of the same term can be included in the search.

Table 1: Identified search terms and keywords

Complex of themes	**Technical term**	**Search term / Keyword**
Blockchain Technology	Blockchain	"Blockchain*", "Block-Chain", Block Chain"
	Distributed Ledger	Not used
Cyber-physical System	Cyber-physical System	"Cyber-physical System*", "Cyber physical System*"
Production/Manufacturing	Production	"production", "product*"
	Manufacturing	"manufacturing", "manufact*"
Smart Contract	Smart Contract	Not used
	Intelligent Contract	Not used

2.4 Analysis and Synthesis of relevant Literature

The search in both databases resulted in a hit count of 5,541. After removing 169 duplicates and 1,478 hits of none relevant research areas, 3,894 publications remained for further processing. As described in Section 2.3, we assigned the remaining hits with a numerical value. The values ranged from 1 (none content relevance) to 5 (high content relevance). Documents with a score of 1 or 2 were consequently excluded. These sources have no direct value for our research object, but show the importance of our research for other areas. The group with a value of 1 has no has no relevance to our research. However, they are still kept in our literature database because they have already been roughly analyzed. In case of a new research we can avoid additional work by automatically, removing possible duplicates of unimportant sources. Hits with a score of 3 or higher were fully analyzed. Remarkable was that four articles received a score of 5, because, to all appearances, they present decentralized production control concepts based on the blockchain. After full analysis, all four articles were downgraded to a score of 4. They have similarities with our concept, but in the final analysis, they address a different focus. The result is a set of 237 publications for detailed analysis. In the further course of the analysis, we primarily pursued the identification of prior work by other researchers in the context of SO. In the end, 59 sources form the basis for further analysis and synthesis into the smart order concept for decentralized production control. Figure 1 shows the selection process of the found literature from the scientific databases.

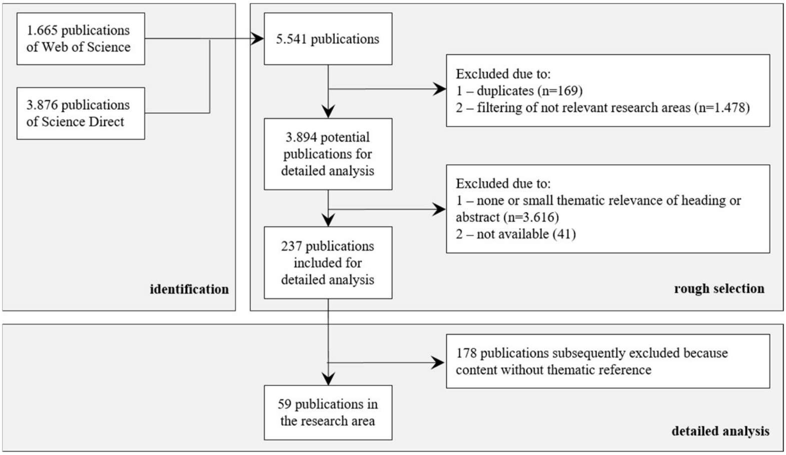

Figure 1: Selection process of relevant literature (Moher et al., 2009) (modified)

The comprehensive literature review conducted is integral to the following considerations. All relevant prior work in the field of blockchain-based production control had to be evaluated and assessed. This enabled the research gap to be clearly identified and the SO concept to be developed. However, the temporal focus was on publications between 2017 and 2021, which allowed us to guarantee that we could find all relevant recent work in the search results. At the same time, we exclude publications that are too recent. Preliminary research has shown that only from 2017 onwards BCT has been analyzed in a significant number in production.

Some researchers are already looking into the application of SC for decentralized production control. So far, there is no real use case. The team around Grey et al. use SC for the use and coordination of different agent types within a robot system. The basic idea is that agents can subcontract other agents to ensure task completion. Problematic here are the growing complexity and the possibly malicious behavior of some agents. The authors aim with their concept primarily at the extension of human abilities and less at the automated production control (Grey, Godage and Seneviratne, 2020). Li et al. focus on distributed consensus building in cyber-physical systems. Consensus building in CPS is critical, because it needs to be fast and resource efficient. To achieve this, some assumptions have been made. For example, that there are two types of nodes - active nodes and inactive nodes to save resources. What is remarkable about the work of Li et al. is that they assume changing topologies in the system. Therefore, there may be changes in the speed at which consensus is reached (Li et al., 2019). Shukla et al. go one-step further, modelling the entire CPS as a multi-agent system. They assume that every object in the CPS acts as an agent. As mentioned in Li et al. they also use BCT to implement SC. The introduction of SC in the multi-agent system is to prevent harmful behaviour of the agents and thus enable distributed plan execution (Shukla, Mohalik and Badrinath, 2018).

3 Blockchain-Technology in Production Control

3.1 Origin of Blockchain-Technology

In 2008, the end of the financial crisis raised many questions about the functioning and safety of financial institutions, such as banks or other financial service providers. When the bubble burst in the U.S. real estate market, many of affected people did not have the opportunity to react appropriately to the market movements. One of the main reasons was information asymmetries between the financial institutions and investors (Schinckus, 2020). As a result, the pseudonym Satoshi Nakamoto postulated the Bitcoin Whitepaper. Instead of an account at a bank, users are supposed to create "digital addresses" on a decentralized network, the blockchain. Instead of FIAT money, cryptocurrencies can be sent from one address to another without relying on a central entity, such as a bank (Nakamoto, 2009).

However, currently common payment systems such as SEPA or payment service providers such as Klarna or PayPal use a central node in form of a bank. The bank, as the intermediary, therefore has more control over the transaction than the parties involved do. In addition, the rules and conditions can be influenced or even changed by the central node. Furthermore, an attack on the central node in the network can cause severe damage and lead to a loss of trust among all network participants. This means that even after restarting, the network can suffer permanent damage (Yli-Huumo et al., 2016). In contrast, the blockchain structure corresponds to a decentralized database. In an open blockchain, everyone has the opportunity to participate in the network and execute transactions. In case of being an active node, you download a complete version of the blockchain to your local hardware. You are also authorized to validate transactions and create blocks yourself if you have sufficient computing power. In the Bitcoin blockchain, this is the mining process (Christidis and Devetsikiotis, 2016; Skowronski, 2019; Berneis, Bartsch and Winkler, 2021).

The best-known use case of BCT is the cryptocurrency Bitcoin. With a price of almost 67,000 U.S. dollars in November 2021, bitcoin again became increasingly popular (coinmarketcap, 2022). Therefore, the BCT also increasingly attracting the interest of industry and research. Chapter 3.2 describes the general structure and explains the most important features.

3.2 Structure of Blockchain-Technology

The name blockchain is derived from the way information is stored (see Figure 2). It does not matter what kind of information is stored. On the Bitcoin blockchain, transaction data is stored, but on other blockchains, it is also possible to store images or video files. The Genesis block is the first block of a blockchain and is created via software or the personal preferences of the blockchain's creator (Christidis and Devetsikiotis, 2016; Christidis et al., 2021).

A blockchain is decentralized, which means there is no central entity and no third party that can change the rules or conditions without the agreement of the participants. A blockchain-based network consists of nodes, each of which has a complete version of the blockchain on its local hardware. Consensus is required to change rules or confirm transactions. In the Bitcoin blockchain, the consensus mechanism is the so-called Proof of Work (PoW) (Schinckus, 2020). At this point, it should only be noted that there are a variety of consensus mechanisms that can be chosen according to the later use case (Hazari and Mahmoud, 2019; Liu et al., 2019; Berneis and Winkler, 2021). Because our research objective is production control using BCT, PoW is not suitable due to the resources required.

Each block consists of a unique hash value, a transaction list, and other information such as a timestamp or the nonce. The block header contains the hash value of the previous block. This creates a concatenation that makes the blockchain longer and longer. This ensures that it is almost impossible to change the data stored. If someone tries to change the data in one block, the entire blockchain must be changed from the block in which the change is made (see figure 1) (Z. Zheng et al., 2017; Alphonse and Starvin, 2020; Christidis et al., 2021).

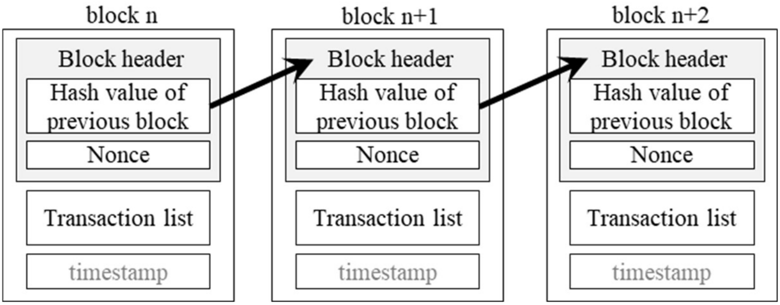

Figure 2: exemplary blockchain structure (Rathore, Mohamed and Guizani, 2020) (modified)

3.3 Key features Blockchain-Technology

The decentralization and the linkage of blocks building the structural basis for the key properties of BCT, which makes it so interesting for many applications. Every blockchain is based on distributed ledger technology (DLT), which means that the ledger is completely shared and updated by all participants. Thus, a blockchain-based solution is secure and transparent. Additionally, the data in a blockchain is immutable. Using the Bitcoin Blockchain as an example, changes could only be made if one party had more than 51% of the computing power of all participants at its disposal. Due to the size of the Bitcoin blockchain, this scenario seems very unlikely (Iansiti and Lakhani, 2017; Schinckus, 2020). Research in the context of cyber-physical production systems (CPPS) shows further advantages of BCT. Adding new participants to the production system is quickly and securely. It is also possible to assign a losable stake to each participant and thus implement sanction mechanisms physically as well as in the cyber layer (Skowronski, 2019).

In summary, it can stated that a PoW based Blockchain is a decentralized, transparent and immutable database and thus offers a high degree of security. Any type of data or information can be stored in concatenated form. It works without a central entity and has no central point for attacks from outside.

3.4 Smart Contracts

Nick Szabo is the father of smart contracts. Vitalik Buterin, the founder of Ethereum, uses the fundamental research and defines smart contracts as a code or data that represents a business logic and runs on a blockchain with a specific address (Szabo, 1997; Buterin, 2014). Ante describes the smart contract as a script that is stored on the blockchain and uses it as a runtime environment. Just as the transactions are visible, the conditions in the smart contract are also visible to all parties involved. Therefore, trust between the parties is not necessary and yet the respective interests of the contracting parties are protected to the maximum. Smart contracts operate based on mutually assured terms and require a trigger event to execute the next step. Without a trigger, such as a transaction, the SC does not become active (Ante, 2021).

Primarily SC are used for automated payment processing between two or more parties. They are electronic transaction protocols that run on the blockchain and thus have properties such as the immutability of the code. The main components of SC are the mutually assured agreements, contract data and the expiry routine in the code (Baygin, Baygin and Karakose, 2020; Ante, 2021).

3.5 Smart Order as Instrument for Production Control

Modern fully connected production systems have to control a multitude of machines, conveyor vehicles, but also human personnel. Often, this task is carried out by a central unit and results in the order processing process. In the classic order fulfilment process, a central point receives the customer order. The customer order is then enriched with further information, e.g. materials from external sources, and forwarded to the appropriate areas (Schuh and Stich, 2012). All sales orders in total and demand forecasts form the basis for production program planning, quantity planning and the planning of required capacities. After release, the sales orders become production or purchase orders. Now it is the task of the production control to carry out the machine occupancy planning based on the detailed scheduling. Evaluating of deviations in the production process because of a continuous actual-target comparison (Kellner, Lienland and

Lukesch, 2020). The concept we will present starts with production control, i.e. detailed scheduling and the associated machine assignment planning.

We propagate the smart order as an innovative concept for the self-organization and self-execution of customer orders. Smart orders are derived from the respective customer order. The process begins when the customer places the customer order. This can be done via various channels, e.g. an account integrated into the blockchain. Already through the login, various information is available that was stored in the database through the previous customer account creation. The customer order contains all the information needed to create the production order, such as order items, quantities, deadlines or special conditions, such as packaging requirements. The customer-specific information is supplemented with the data from the basic data management. Required routings (in-house production or external procurement) and parts list information are added. Now, the system assembles the SO by automatic generated SC, which have been programmed in advance and are tailored to the respective product. The SC are generic in that the source code is automatically adapted based on the order data. For example, quantities, deadlines or special conditions are automatically recorded by customer input and implemented at the appropriate points in the SC. In addition, a distinction is made between parts from in-house production and purchased parts (see Figure 3). This means that only the information required for execution is stored in the SC. This makes the SC more secure and reduces complexity. In practice, overly complex SC lead to execution and comprehension problems (Garamvolgyi et al., 2018; Ante, 2021). This procedure is performed for each order item. The approaches from Section 3.4 use agents to execute production control, which leads to the problems already mentioned. We execute production control using the “if-then logic” of smart contracts. The production agent of the SO primarily has an inactive observer status. If an unanticipated incident occurs, such as a machine failure, the status will be changed to active. The core task of the manufacturing agent is to present solutions. He can check whether another machine is suitable for the upcoming operation and search for free capacities.

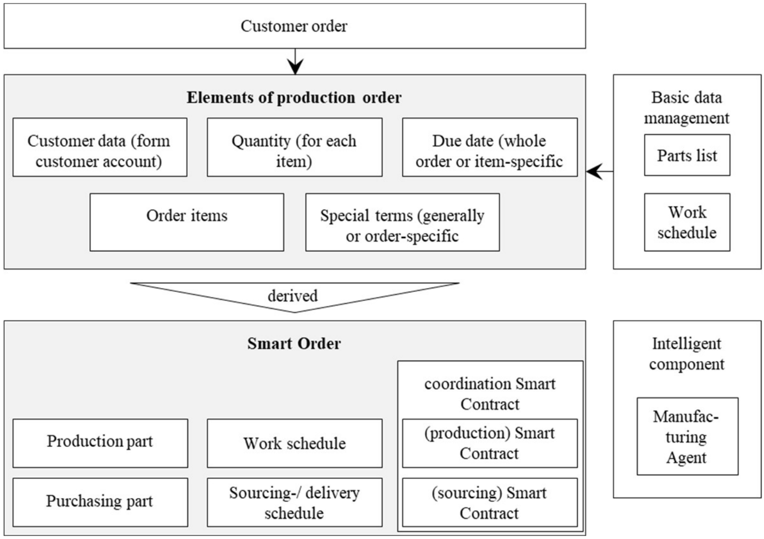

Figure 3: Derivation of the smart order from the sales order for one order item

3.6 What to validate?

A consensus mechanism is required to validate the data to be stored or to change the system status. Since the blockchain has a decentralized structure, the participants must find a consensus (Kobzan et al., 2018; Hazari and Mahmoud, 2019). Due to the growing number of blockchain-based applications, various consensus mechanisms have evolved. The best known is the Proof of Work (PoW) for validating transactions in the Bitcoin blockchain. The PoW is not only used for verifying and validating transactions, but also for creating new Bitcoins, called mining. To create a new block, the miner has to solve a cryptographic puzzle. The other nodes can confirm the solution very quickly. If there is a sufficient match, the block is appended to the blockchain and the successful miner receives a reward in the form of Bitcoin. Criticism of PoW arises from the high energy consumption required to solve the puzzle (Xu et al., 2017; Kobzan et al., 2018; Hazari and Mahmoud, 2019; Xu, Chen and Kou, 2019).

So far, most consensus mechanisms arise from applications in the fields of finance and cryptocurrencies. For new applications, e.g. in the area of supply chain management, these are modified or fulfill their task without adaptations (Decker, Seidel and Wattenhofer, 2016; Kraft, 2016; Z. Zheng et al., 2017). The work already presented in section 3.4 also uses the paradigm of validating transaction data. From our point of view, it is questionable to validate only transaction data in a production system that manufactures physical products. We would only determine that the correct data capturing and that the process execution is correct according to the SO. However, we do not know if the physical characteristics of the product, such as length or weight, are as specified. Deviations from the desired product properties can occur, for example, because incorrect calibrated or externally compromised machine.

In CPPS, information flows trigger the corresponding material flows, i.e. after order release, making the raw material available at the workstation by an autonomous transport system. The release and the individual transport steps already represent trigger events for the smart contracts in the smart order. This automates the process. After the processing operation on the workstation, the component is subjected to a quality inspection. The inspection is performed independently of the workstation to prevent false positives. The inspection can be performed with simple optical or mechanical devices. The inspection information is transmitted and analyzed via the sensor technology, e.g. via RFID, of the inspection equipment and, if it matches the target values, it is entered as data in the next free block and validated by the network. As soon as the validation has been published in the network, the SC of the smart order is triggered again and the next processing step can start. This ensures complete and secure traceability of the information and material flow.

The analysis of the properties of the different consensus mechanisms show that they are only suitable to a limited extent or not at all for use in the SO based concept for production control. Table 2 shows the comparison of three available consensus mechanisms that may be suitable for use in blockchain-based production systems. For example, PoW is not listed because it is neither scalable nor resource-efficient (Hazari and Mahmoud, 2019). They only require the available computational power that is already in the CPS, but the process for reaching consensus is not ideal for all three mechanisms.

Table 2: Comparison of possible production consensus mechanisms (Nandwani, Gupta and Thakur, 2019; Manolache, Manolache and Tapus, 2022; Singh et al., 2022)

Consensus mechanism	**Proof of Participation**	**Proof of Authority**	**Proof of Importance**
Election of block-creator	Height of participation level	Reputation level instead of assets	Importance for the entire network
Registration of nodes	Yes, incl. testing according to specified rules	Yes, preference is given to nodes that have been verified	No, fake accounts are possible
Decentralization	Partly	Partly	Partly
Energy consumption	Reduced*	Reduced*	Reduced*
Computing power	Reduced*	Reduced*	Reduced*
Motivation for block-creation	Block-reward	Increase of reputation level	Block-reward

*Compared to Proof of Work (PoW)

During the development of a Proof of Quality (PoQ), the measurement data of the physical measurement is recorded by a separate measuring point and presented to the network. If the measurement data from the production station and the measuring point match the target values from the design and construction documents, these are validated by the network participants. The PoQ is currently under development.

4 The Process of Smart Order Creation

In this following chapter, we will go into the required (pre)services that the production system must provide in order to be able to use the SO. First, we provide a brief insight into the process of creating a production order by means of a customer order. Then, we briefly outline the general process for creating the SO, including the generation of the required smart contracts.

4.1 Creation of the Production Orders

The concept of the smart order aims to productions with reference to customer orders. Because of this reference, an inspection process is consequently initiated with each sales order. This includes the classic tasks of production planning and control (PPC), i.e. production program planning, quantity planning, scheduling and capacity planning. The order is released when all planning tasks have been completed positively. To avoid overloads in the production system, scheduling and capacity constraints are used to ensure a workload-oriented order release (Schuh and Stich, 2012; Lödding, 2016). The customer logs in via a verified account and already provides the first information through his login. He now selects the products he wants. A new order item is created for each product. Likewise, the delivery date and the desired quantities are recorded. By adding other conditions, the customer completes his order. In the simplest case, there is no production order with this order item in the production system and the customer has selected just one order item (see Figure 4).

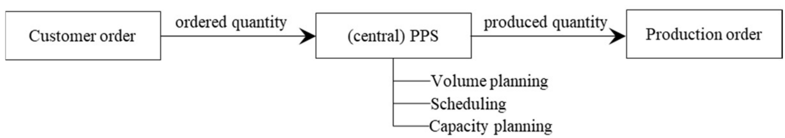

Figure 4: Production order equals to the sales order (Lödding, 2016)(modified)

In business operations, other variants of sales orders occur. First, a sales order often has more than one order item, meaning that a sales order triggers more than one production order (see Figure 5).

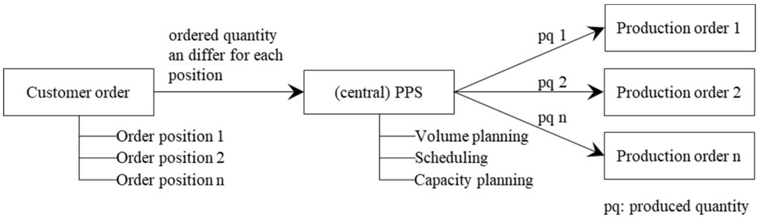

Figure 5: Sales order generates multiple production orders (Lödding, 2016)(modified)

On the other hand, it can also happen in order-related production that several customers order the same product. In this scenario, it makes sense to combine the various similar order items into one lot (see Figure 6).

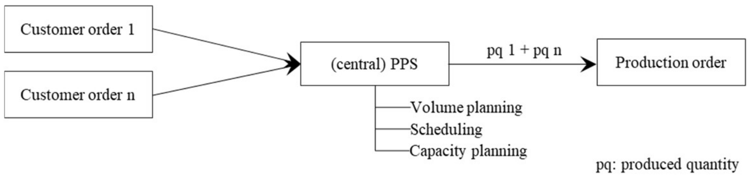

Figure 6: several similar sales orders are combined into one production order (Lödding, 2016)(modified)

4.2 Smart Contracts as Core Element of Smart Orders

The creation of the SO forms the transition from the centralized to the decentralized paradigm of the concept presented. The smart contracts are the mainpart of each SO. For each production order, all necessary SC are tailor-made. The smart contracts are created generically and automatically for each product. Care must be taken to maintain a uniform standard for the master data. In this way, the respective code components can be inserted in the correct places in the SC template using an algorithm. The smart order contains several smart contracts. On the one hand, there is the production-SC. This contains all the information from the work plan, i.e. the technological sequence of the work steps and process instructions. At this point, we assume (partially) flexible work plans, i.e., under certain circumstances, other sequences can be used for machining (first grinding, then drilling) or manufacturing technologies can be substituted (waterjet cutting instead of laser cutting). This increases flexibility in the CPPS. Using the “if-then” logic of smart contracts, automated queries can be made regarding alternative routes through production. The sourcing-SC contains the procurement or delivery plan. The information needed for automated order execution comes from the bill of materials and any inventory query. Both SCs are in mutual exchange of information. The higher-level Coordination smart contract is responsible for the correct assembly of the production order into the finished sales order.

Smart contracts offer versatile applications in the production context due to their very good customizability. Due to the complexity of the source code, they also carry risks, such as incorrect execution of work plans or transactions (Hewa, Ylianttila and Liyanage, 2021; Omar et al., 2021) We therefore envision designing a template and having the missing code automatically filled in. Each SC has a unique hash value and an action list. This list in turn contains the specific information from the basic data management. Once a step has been completed and validated by the network, the SC recognizes this trigger event and continues as scheduled. If it is not possible to continue according to plan, the SC contains a routine for calling the production agent. This agent checks autonomously and by communicating with other active agents what options exist for rectifying the problem. Once the SC and thus the production order has been processed, the completion routine is initialized. The coordination smart contract now checks whether the other production SCs, if any, are ready and initiates the assembly or the compilation of the order for the customer.

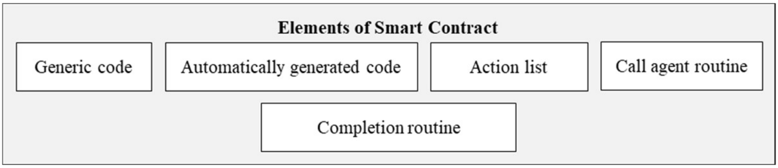

Figure 7: Basic parts of smart contracts for building smart orders

4.3 Advantages caused by Smart Order Utilization

We recommend implementation in a cyber-physical production system in order to fully exploit the potential of the concept presented. Production control through smart orders requires resources that are only available in their manifestation in a CPS. CPS are production systems that have a physical and a cyber-component. Both dimensions influence behavior equally. At the core of CPS are embedded computer systems and networks. These are fed information from sensors in the physical world, process it, and reflect it in the form of actions in the physical world. Comprehensive actuator technology, such as a robot, is necessary for implementation (Lee and Seshia, 2017; Barenji et al., 2020).

With the introduction of SO based production control, we expect direct and indirect improvements. The transition from the centralized to the decentralized paradigm will increase the flexibility of the production system as a whole. The (partially) flexible work schedules of SO will increase the flexibility in individual areas through the possibility of re-routing. Therefore, machine utilization will increase and we will get measurable cost and lead time reductions. Compared to classical production systems, a reduced number of human interventions can be assumed. In the event of a malfunction, the SO's production agent should independently develop and present proposed solutions. The personnel finally make the selection of the measures.

The indirect improvements can only be evaluated with a real application. Nevertheless, we assume that the needs of some industries will be satisfied significantly better (see section 1). The increase in resistance to unauthorized access, especially from outside, is noteworthy. The use of BCT already leads to an increase in security due to its technological features (see sections 3.2 and 3.3) (Bartsch and Winkler, 2020). Additionally, real production data is recorded through external measurement and validated by the PoQ. If an attacker wants to compromise a machine, it is no longer sufficient to attack only the machine, but also the measuring station.

5 Conclusion and Outlook

To answer the first research question, we have presented initial considerations for decentralized production control using the smart order concept. The required SC are generated automatically and are composed of various modules. For the most efficient use of machine capacities, (partially) flexible work schedules are used, which allow switching to other production technologies or changing the work steps. In contrast to the approaches in the literature, the concept refrains from the active use of agents in normal operations. The use of agents is primarily limited to passive observation of the production process. This reduces the complexity of the system and excludes harmful behaviour of agents. In the case of a deviation from normal operation that cannot be solved by the SC, the status of the agents is set to active. This is to present proposed solutions using historical data and the analyses from the observations. The solutions are then discussed by the staff and either accepted or rejected.

The aim is to map and simulate the concept in a suitable simulation model. Production data with a classic centrally controlled production and a production controlled by the smart order concept are to be compared with each other. There is a need for further research:

- A uniform standard and a mechanism for the completeness and correctness of the basic data must be found. Since this data will later be automatically integrated into the smart contracts, major disruptions in the production process are to be expected if the basic data is incorrect.
- Based on this, a suitable template for the smart contracts must be found, tested and verified.

The second research question about a suitable consensus mechanism cannot be answered conclusively. For a target-oriented simulation with realistic latency times and data transmission rates we are currently developing the Proof of Quality. Initial approaches for a PoQ are already available. The data from the machine-independent measurements will be validated.

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Critical Evaluation of LOCO dataset with Machine Learning

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Purpose: *Object detection is rapidly evolving through machine learning technology in automation systems. Well prepared data is necessary to train the algorithms. Accordingly, the objective of this paper is to describe a re-evaluation of the so-called Logistics Objects in Context (LOCO) dataset, which is the first dataset for object detection in the field of intralogistics.*

Methodology: *We use an experimental research approach with three steps to evaluate the LOCO dataset. Firstly, the images on GitHub were analyzed to understand the dataset better. Secondly, Google Drive Cloud was used for training purposes to revisit the algorithmic implementation and training. Lastly, the LOCO dataset was examined, if it is possible to achieve the same training results in comparison to the original publications.*

Findings: *The mean average precision, a common benchmark in object detection, achieved in our study was 64.54%, and shows a significant increase from the initial study of the LOCO authors, achieving 41%. However, improvement potential is seen specifically within object types of forklifts and pallet truck.*

Originality: *This paper presents the first critical replication study of the LOCO dataset for object detection in intralogistics. It shows that the training with better hyperparameters based on LOCO can even achieve a higher accuracy than presented in the original publication. However, there is also further room for improving the LOCO dataset.*

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1 Introduction

Object detection is a rapidly evolving through machine learning technology, which is one of the most important computer vision applications. It allows to detect, identify, and track objects in images and videos by using advanced level of neural network algorithms (Benjdira, Khursheed and Koubaa, 2018). Object detection, unlike object recognition, involves finding the coordinates of the detected object on the image. With the coordinates found from the detection information, the object is determined in the area where it will be enclosed with a bounding box.

There are two types of approaches to create neural networks for detecting objects on images. First of them are two stage object detectors which break down the detection application by means of identifying object regions and then classifying the image within its region to determine object classes. The popular two stage algorithms, such as Faster R-CNN, use a Region Proposal Network (Zhao, Xu and Wu, 2019), which simultaneously makes a prediction for object bounds and objectness scores at each position in the image. Since there are multiple iterations running at the same time within the algorithm, it slows down the detection speed in the application and makes it inconvenient for real time detection in videos.

Secondly, the other approach to create object detection neural network is called one stage algorithm. You Only Look Once (YOLO) is one of the best examples for one stage algorithms in object detection (Bochovskiy, 2020). It can process the image so fast that it predicts the class and coordinates of all objects in the image by passing the image through the neural network at only one time. The basis of this estimation process lies in the fact that it treats object detection as a single regression problem. The algorithm first splits the input image into SxS grids. These grids can be divided into 5x5, 9x9 or 21x21 tiles. Each grid in the image is responsible to figure out, whether there is any object within its individual region. If there is an object detected, it will recognize the classes with length, height information for bounding box information. This formulation functionality makes YOLO perfect in object detection. That is why, YOLO is also preferred in our study.

Logistics applications are one of the most suitable areas where object detection technology can be adapted (Li et al., 2019). The so-called Logistics Objects in COntext

(LOCO) dataset originates from the Technical University of Munich and is the first available open source dataset with relation to intralogistics (Mayershofer et al., 2020). It was created to detect five different types of objects: pallets, small load carriers, stillages, forklifts and pallet trucks. It contains a total of 151,427 annotations from 5,097 images. The dataset is available on GitHub (GitHub, 2022a) and described in the paper from Mayershofer et al.. A critical examination of the content of the dataset and its potential to train algorithms for objection detection has not been available so far. Therefore, the objective of this paper is to describe a re-evaluation of the LOCO dataset and its capabilities.

2 Related work

There are significant studies accomplished in artificial intelligence field about re-evaluating the existing datasets by using different evaluation parameters and setting high variety of performance indicators (Pipino et al., 2002). Keeping the main evaluation parameters of the origin of the related datasets is suggested in most of the re-evaluation research. Moreover, it is also advised to include some additional performance indicators or bringing own evaluation methodology (Al-Riyami et al., 2018), depending on the machine learning application. Mayershofer et al. train the LOCO dataset by using YOLO and Faster R-CNN algorithms and evaluated them by using mean average precision (mAP)@50 results (Bochovskiy, 2020). Within our studies, we also kept the mAP@50 parameter as performance indicator. At the same time, to check the responds of the YOLO algorithm in different object types, we used highly diverse test images (about 500) from online platforms. Furthermore, since object detection algorithms are mostly used in real time video detections, it was important part of our study to examine the performance of the LOCO dataset with YOLO algorithms. Mayershofer et al. mentioned in its publications that they tested the performance of the LOCO dataset in real time. However, testing experiences about the real time performance of the LOCO dataset are not available in GitHub.

Tuning hyperparameters is mostly suggested in re-evaluating a dataset (Nematzadeh et al., 2022). Tuning has an important role to improve the accuracy of the evaluations.

Because of that, we made over 35 different trainings by changing hyperparameters, until we find the best weights of our YOLO model.

Moreover, even though the state of art neural network is used for object detection application, it is always possible that there might be a chance of improvement in detection performance. The training datasets are one of the strongest pillars that sustain machine learning algorithms. If the desired output for object detection is not attained, some further techniques should be accomplished on the dataset to improve its positive results. In the previous studies, it was experienced that the increasing the amount of data artificially, improves the detection results augmentation (Apple Developer Documentation, 2022) can be used by enhancing the dataset artificially. The dataset is an element that affects the efficiency in the object detection application considerably. There are two possible methods to increase the amount of data artificially: data augmentation and preparation of synthetic data. Within our study to increase the number of data artificially, we used data augmentation techniques. (Sessions and Valtorta, 2006).

3 Methodology

We use a research approach with three steps to re-evaluate the LOCO dataset. Firstly, the images on GitHub were prepared for the training and analyzed for a deeper understanding of the dataset. The json file called “loco-all-v1.json” is already shared including all labels for each annotated image. However, annotations in this file are stored in COCO format (COCO - Common Objects in Context, 2022). Therefore, the data is converted from COCO format to YOLO format in the following stages of the data preprocessing. At the same time, since the data is too detailed for our object detection application, the required information for our training should have been sorted out. That is why, at the beginning, the necessary columns for each annotation are reduced by using pandas library to order the data properly.

Training in YOLO needs a txt file for each image with classification and localization information of objects in the image. Localization information is given within the bounding box coordinate system in txt files. There are different mathematical coordinates for each COCO and YOLO formats in bounding box representations (13.3. Object Detection and Bounding Boxes — Dive into Deep Learning 0.17.5 documentation, 2022) and bounding boxes for each object had to be converted. Table 1 shows, how the bounding box coordinates differ between COCO and YOLO formats .

Table 1: Bounding Box Orientations for COCO and YOLO Formats

Format	**Arrow**	**Example**
COCO	[x_min, y_min, x_max, y_max]	[98, 345, 420, 462]
YOLO	N[x_min, y_min, x_max, y_max]	[0.153125, 0.71875, 0.65625, 0.9625]

Secondly, after the dataset was ready to train in YOLO format, an appropriate method had to be chosen to reach high processing speed to reduce the training durations. A workspace in Google Drive was created and Colab Pro+ was used to have priority access to Google's Graphic Processing Units (GPU) to train with the LOCO dataset by using YOLOv4 and YOLOv4-tiny algorithms. Most of the time NVIDIA Tesla V100 was assigned to us by Google servers. The biggest advantage of choosing YOLO algorithms is its superb speed. it is excessively faster than Faster R-CNN in detection speed where the frame per second (FPS), while giving higher mean average precisions, as shown in the Figure 1 (Kim et al., 2020).

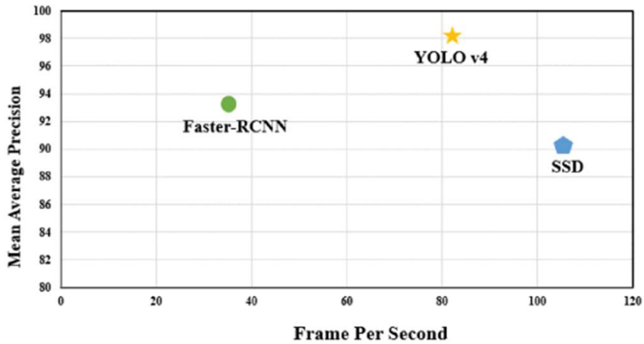

Figure 1: Faster R-CNN and YOLOv4 comparison

On the last part of our study, we focused on finding answers for our research questions. First question of the project is to examine whether it is possible to replicate the findings from LOCO Dataset according to its publications and the information on their GitHub repository. The second research question, which is to define the strengths and weaknesses of LOCO Dataset, is examined by using the high number of trainings with variously tuned hyperparameters. The algorithm was also tested with a wide range of images from a test set to examine whether the dataset gives satisfactory results in different kind of intralogistics environments. Finally, as third research question, some data augmentation techniques on object detection are examined in the LOCO dataset.

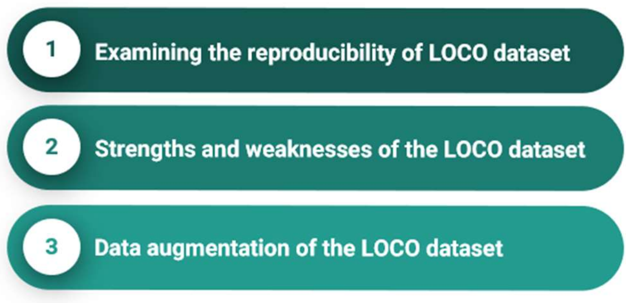

Figure 2: List of research questions

At the end of our studies, all these questions are answered objectively to increase the overall performance of the LOCO dataset for better object detection in the field of intralogistics. To be able to find some answers for our questions raised while detecting forklifts and pallet trucks, we supported our ideas with an additional study at the Institute for Technical Logistics. Our results regarding to this study are shared as suggestions within the paper .

3.1 Examining the replicability of LOCO dataset

The LOCO dataset has been the first open source dataset, which is prepared to be used in the intralogistics field. While this dataset was shared with the public in the GitHub repository, a paper was also published (Mayershofer et al., 2020). In this paper, it is possible to find information about the LOCO dataset. Mayershofer et al. shared so much information about the data collection process of the LOCO dataset and the evaluation results by using LOCO and Faster R-CNN algorithms were shared clearly. Especially, the information shared in the preparation of the dataset draws attention to the points to be considered for those who want to prepare such a dataset in the future.

There are remarkable points about video and photo capturing, which leads data acquisition process to high level. Firstly, images are captured from five different warehouses in real life scenarios while people and other vehicles are moving around. When images are examined in detail, it is realized that this brings high amount of diversity on the dataset. It was also important to visit several warehouses, as the color and model differences of the objects used in each warehouse increasing the variety in the dataset for real life scenarios.

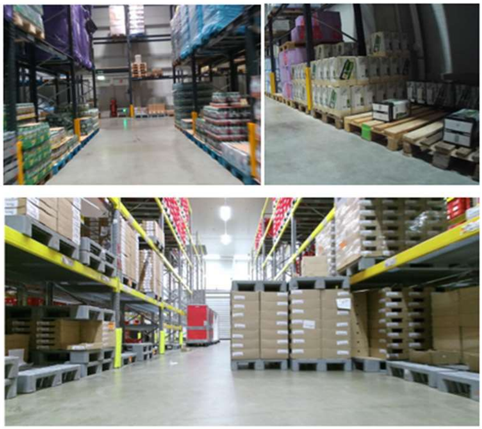

Figure 3: Blue, gray and different shades of brown colored pallets from different angles

In addition, the different size in the warehouses affect the way pallets are stored, and it also enables the collection of object images from a longer distance in large warehouses. Furthermore, the images are mostly collected within different brightness levels. Sometimes sun from the window is shining to the lens of the camera and sometimes images are captured in shady corners of the warehouse. All these different conditions enable mobile robots to be trained for different cases which might help to perform better in unexpected circumstances.

Images are collected by using five different cameras which are the commonly used in robotic applications. Each of the camera has high resolution values which differs between 1920 x 1080 and 1280 x 800 in pixel.

Table 2: Cameras in Use - Images were captured using different cameras

Camera	Data	Resolution in pixel
MS Kinect v2	RGBD	1920 x 1080
Intel Realsense D435	RGBD	1920 x 1080
SJCAM SJ-400	RGB	1920 x 1080
MS LifeCam HD-3000	RGB	1280 x 800
Logitech C310	RGB	1280 x 800

Table 3: Number of Images According to Width and Height in Pixel

Number of Images	Width	Height
560	1280	800
617	1280	960
1460	1280	720
1655	1920	1080
805	1920	480

On the other hand, images are collected in five different pixel values as shown in the following table. The object detection algorithm, which is trained with distinct size of images, causes image and video tests with diverse sizes to give better results. In addition, even if randomization from the hyperparameters is set to none during training, images with five varied sizes are sufficient for diversity. At the same time, however, it should be kept in mind that large image sizes will mostly cause insufficient CUDA memory problem in GPUs.

Another important sensitivity in the LOCO dataset is personal privacy. As mentioned before, capturing images while workers working in the field with forklifts and pallet trucks are important to create a more realistic dataset. However, it causes some personal privacy concerns in the dataset. Within the study, it must be elicited that there is no invasion of a worker's privacy in taking and publishing pictures. Because of this reason, Mayershofer et al. deployed a neural network for automated face recognition so that workers' faces can be detected and made then unrecognizable, even before images are saved in the hard drive. Unfortunately, no further technical information was shared about how this process can be automatized: which neural network is used and how images are saved automatically in hardware. That is why, this section will not be giving so many technical insights to those who want to remove the human face from the dataset in the future.

Machine learning algorithms used in object detection applications have a very important role in obtaining high accuracy from the dataset. To evaluate LOCO dataset, Mayershofer et al. used the Darknet (GitHub, 2022b) and Detectron (GitHub, 2022c) framework to train three different neural networks: YOLOv4, YOLOv4-tiny and Faster R-CNN. The average precision (AP) metric at an intersection over union (IoU) of 0.50 was chosen as key performance indicator (Bochovskiy et al., 2020). Their results are available on the following table.

Table 4: Evaluation Results From the LOCO Dataset Publications

Model	**YOLOv4-608**	**YOLOv4-tiny**	**Faster R-CNN**
Dataset	**LOCO**	**LOCO**	**LOCO**
mAP@50	41%	22.1%	20.2%
Small load carrier	27.7%	18.1%	28.3%
Pallet	65.0%	36.2%	19.8%
Stillage	53.1%	31.3%	37.6%
Forklift	31.3%	11.6%	2.9%
Pallet truck	28.1%	13.3%	12.5%

Within our studies we preferred to work only with YOLO algorithms as both YOLOv4 and YOLOv4-tiny is compiled in Darknet framework and these two algorithms are already enough to make decisions during our critical evaluation. We reached significantly better results in both YOLOv4 and YOLOv4-tiny trainings, after 35 different training sessions. Training durations are varied from 12 to 36 hours according to hyperparameters and GPUs assigned by Google Colab services.

Table 5: Evaluation Results of Our Study

Model	**YOLOv4**	**YOLOv4-tiny**
Dataset	**LOCO**	**LOCO**
mAP@50	64.54%	49.98%
Small load carrier	62.33%	50.18%
Pallet	68.39%	54.38%
Stillage	67.31%	51.26%
Forklift	60.76%	48.39%
Pallet truck	58.01%	42.2%

Since the original publication does not contain a detailed description of the hyperparameters, it only can be speculated about the different results in terms of accuracy of the trainings. A potential reason could be the different data splitting approaches.

Splitting of data into training and test datasets is an important aspect of a machine learning tasks. Having a correct amount of distribution among train and validation datasets will bring significantly better results. Data splitting for training dataset can be given 60 percent of all data, if the dataset is relatively small which has got up to 1,000 labels. At the same time, however, it is also suggested that if there is high number of labels about 1 million, the dataset can even be split with 99% for training and 1% for validation, since there are already 10.000 labels in validation set which is still more than enough to validate a model.

In LOCO dataset there are exactly 151,427 labels in 5,097 images collected from five different warehouses and separated to five distinct subsets from each warehouse. They divide the five subsets as follows: subsets two, three and four serve as training purposes, while subsets one and five are used in evaluation. This results in ratio of 3/5 training and 2/5 validation split. However, within our study, the distribution of dataset is changed about 15-20 percent to make the training stronger. We included subset five to the training dataset and left the biggest subset one alone for validation purposes. Subset one has about 1,140 images and the split among images for train dataset increased to about 78 percent. This can be one of the reasons why our validation results are performing better results than evaluation results shared in LOCO publications.

On the other hand, object detection applications are generally used in real time scenarios. It is known that when it is related to being able to recognize and detect the objects in real time videos over 30fps, one stage neural networks such as YOLO algorithm performs better than two stage neural networks like Faster R-CNN algorithm as shown in Figure 2. However, no experience is commented for these two different types of algorithms in performance level within the publications from LOCO dataset. On the other hand, in the LOCO dataset publications, it is said that a video is available online(https://github.com/tum-fml/loco) to see how the algorithm trained by LOCO dataset works in video. However, the related video cannot be found on the GitHub repository.

When all the conditions for the replicability of the LOCO dataset are examined, it can be said that a lot of information has been shared about the preparation of the dataset. Image collection techniques are clear and repeatable according to its publications. However, even though training of a dataset is always an important step in object detection applications, there is no detailed information shared how algorithms were tuned with various hyperparameters.

3.2 Strengths and weaknesses of the LOCO dataset

The availability of open datasets is crucial for the development and training of machine learning algorithms. Therefore, it is even more important to examine the capabilities of these datasets and identify potentials for improvement. This paper presents the first critical replication study with the LOCO dataset for object detection on logistics. It shows that the training based on LOCO can even achieve a higher accuracy than presented in the original publication, as also mentioned in the previous part. However, even with these significantly better results, there is still noticeable room for improvement of the LOCO dataset, while obvious strengths of dataset are substantial. That is why understanding of both strengths and weaknesses is important.

Obtaining object detection successfully is mostly dependent on the conditions of the environment and the object to be detected. The LOCO dataset gives most of the time impressive results in pallet, small load carrier and stillage detections, even though these objects are smaller than others and the way how they are stored in warehouses is so random and not well organized. There are some conditions, which make the object detection harder to be accomplished with a favorable result such as long distance or half appearance of the objects in the image frame. However, as it can be seen on the Figure 4, there are many pallets detected even from far away on the right hand side of the picture.

Figure 4: Detected pallet object from far away

In addition, stillage detection gives mostly positive impression even under difficult conditions. For example, two stillages draw attention in Figure 5. Even though both stillages have a half appearance on the image, they can be identified correctly by the algorithm.

Figure 5: Efficient stillage detection

The reason why the LOCO dataset is very efficient in detecting these objects is revealed when the labels in the dataset are examined. Most of the LOCO dataset consists of pallets with approximately 120,445 labels. Then, it is followed by small load carrier with approximately 22,151 labels and stillages with 5,047 annotations. The fact that the storage work is handled with these three objects, which are the most common in warehouses, makes the high number of labels acceptable. This has resulted in the LOCO dataset giving mostly very strong results for these three types of object and specifically absolute good detection results for pallets.

Table 6: Number of Annotations per LOCO Classes

Category	**Number of Annotations**
Pallet	120,445
Small load carrier	22,151
Stillage	5,047
Pallet truck	2,827
Forklift	598

In addition, the number of forklift and pallet truck annotations in LOCO dataset is lower, when we saw the label amount for these classes at the beginning of the study. Later in the test phases of our study, it was noticed that the concern was justified, and some noticeable mistakes needed to be shared. In Figure 6, there is a forklift which is not so far away causing a confusion on the algorithm by recognizing both as forklift and pallet truck object at the same time. This situation clarifies how serious the current error among these LOCO classes is. Moreover, having such a mistake caused us to spend more time on forklifts and pallet trucks later in the study and the possible reasons are investigated with more images in the following phases.

Figure 6: Confusion in forklift detection

The following group of pictures are from a warehouse which only includes all the LOCO objects to be detected. The image in Figure 7 is taken in relatively close distance to the objects than the image in Figure 8. In Figure 7 most of pallets, small load carriers and also stillages are detected correctly. However, even though pallet trucks and forklifts are in the same distance and angle, while pallet truck is detected with about 73 percent and this can be accepted as decent performance, the forklift is not detected with our algorithm. On the other hand, Figure 7 is only couple of meters more far away than Figure 8. There are question marks raised again for the white forklift, since it is detected as pallet truck which is a confusion of the algorithm.

Figure 7: LOCO objects in detection test - close

Figure 8: LOCO objects in detection test - away

Another factor that makes it difficult to detect forklifts is that various forklift types with very different functionalities have been developed and used in warehouses in the last decades. The total number of forklifts in the LOCO dataset is around 598 which is already a limited number for forklift annotations in the LOCO dataset compared to other classes. As it is explained previously, there are already some obvious problems while detecting traditional forklifts. On the other hand, the LOCO dataset should be considered one more time for innovative forklift vehicles developed with today's technology for extensive needs in warehouses. For instance, the following images show the test results from warehouses with relatively innovative forklifts. One of the forklifts is not detected, while others are recognized as pallet truck by the YOLO algorithm.

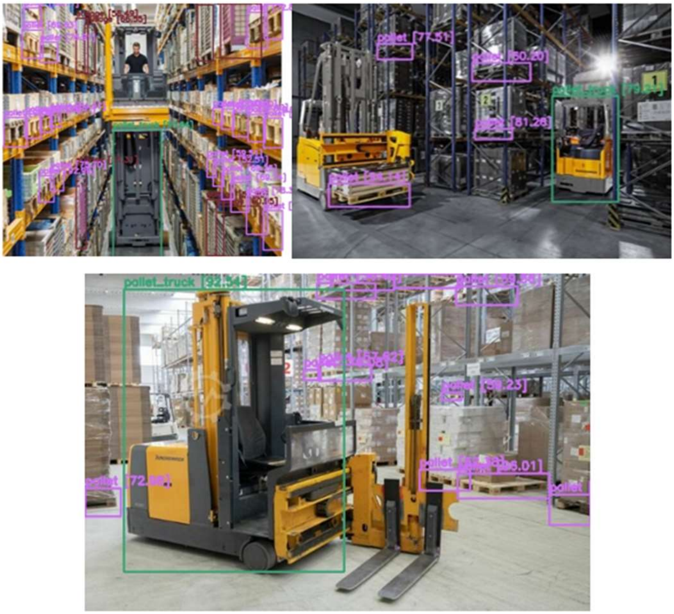

Figure 9: Innovative forklifts detected as pallet trucks

Moreover, while working with the LOCO dataset, it was noticed that annotated pallet trucks differ significantly from each other. Some pallet trucks are electric, some are non-electric and sometimes even fully manual. In addition, in some models, the operator can get on the pallet truck and move inside the warehouse with the vehicle, as they are drivable. However, the fact that all of them are defined as a single class and the number of annotations is obviously not very sufficient for such a diverse class. This causes the model not to learn properly during training. Therefore, the high confusion in the algorithm is noticeable during the test phase.

Figure 10: Electric powered and manual pallet trucks having different appearances

Figure 11: Operators can get onto some of pallet trucks

To be able to make the pallet truck class more precise, it could be suggested to separate it into three different classes and each of them should have a higher number of annotations within their classes. The suggested names for each of these pallet truck types could be called as: electric pallet truck, manual pallet truck, and drivable pallet truck.

3.2.1 Additional Study with Forklift and Pallet Trucks

Due to the unsatisfactory results of the LOCO dataset in forklift and pallet truck detection, we decided to create our own dataset with pallet trucks and forklifts. The goal was to experience by ourselves how to create a valuable dataset for object detection. The dataset is created and used as completely different study than the LOCO dataset. These two datasets are not combined anytime during our studies.

Data collection was carried out by using forklifts and electronic pallet trucks in the laboratory facilities of the Institute for Technical Logistics at the Hamburg University of Technology. A total number of 621 different images were collected from these two different vehicles. While collecting the images, operators and pallets were used as figurants to increase the suitability of dataset for the real life scenarios. The images of the vehicles were taken from different angles, heights and distances, thus increasing the diversity of the dataset. Some photos included in the dataset can be seen from the following Figure 12 and Figure 13.

Figure 12: Image samples from a single forklift

Figure 13: Image samples from a single pallet truck

At the training phase of our additional study, the YOLOv4 algorithm was trained with this dataset, which only includes forklift and pallet truck images. A high number of tests wase carried out to evaluate the algorithm.

This dataset performs well for various types of forklifts, see the following Figure 13. These forklifts could not be detected by the algorithm trained with the LOCO dataset. However, after training YOLOv4 algorithm with our own images, the algorithm was able to detect these forklifts without problem. We made a small examination at the end of this part for the reasons why our dataset gives very good results in such forklift types, while the algorithm with LOCO dataset fails most of the time.

Figure 14: Forklift detection results with good impression

On the other hand, our dataset does not perform well under various conditions. Especially when there are multiple forklifts in the image and if some of the forklifts are far away, the detection results are so unsatisfactory. Some unacceptable errors were received during the test phase as it can be seen on Figure 14. The detections from algorithm trained by LOCO dataset were still not so good but still better than the test results from our additional study.

Figure 15: Significant mistakes in forklift detection

To be able to give some more general insights to researcher's studies in data collection, we would like to explain clearly what was missing in our dataset from our additional study so that these suggestions can help to make their data much accurate. There are several points to highlight as general suggestions for data preparation:

- An artificial area was created in the middle of the lab to collect images of vehicles. Moreover, the collected images would have been performing better, if they had been collected from regular working atmosphere in real scenarios.
- Our images are only focused in one forklift in each image. That is why, after the training the algorithm with our dataset, the algorithm was not aware of being able to detect multiple objects in the image.
- Forklift and pallet trucks are completely visible in our images. That is why, the algorithm does not perform well, when there is obstacle in front of the object.
- Forklifts and pallet trucks are mostly in the same distance range between two to four meters. That makes it harder to detect forklifts, which are more far away on the image.

- While creating our dataset, only one type of forklift and pallet trucks is used. When the algorithm is tested with different types of forklifts and pallet trucks, it will not give good results.
- Both of our forklifts and pallet trucks have yellow colour. That decreases the efficiency of the detection, even we test the algorithm with the same shape of vehicle but different colour of forklift.

This additional study let us to understand better about how to prepare a dataset for object detection applications. During data preparation, it is important to pay attention some main points which affect the diversity of the dataset respect to objects' variety with colour and types, environment conditions and object positions according to distance and angle between camera and object.

To sum up, after this part of our study, it can be interpreted better the strength and weaknesses of the LOCO dataset. The LOCO dataset gives outstanding detection performance for detecting pallets, small load carriers and stillages compared to detection of pallet trucks and forklifts. Our first suggestion is that LOCO dataset would give much better results for pallet trucks, if this class is extended as three different classes as explained before. Secondly, more forklift and pallet truck annotations are required than currently existing number of annotations in the LOCO dataset.

3.3 Data augmentation of the LOCO dataset

Data augmentation is a useful technique to enhance the performance of algorithms by increasing the amount of data with artificially modified copies of already existing images. Data augmentation is the preferred method in computer vision applications. In our study, we created copies of images artificially and included them into the LOCO dataset so that we could increase the size of overall dataset. There are many libraries and methods that can be used to create artificial copies for data augmentation. The imgaug library (imgaug — imgaug 0.4.0 documentation, 2022) provides so much flexibility for machine learning applications. It gives wide range of augmentation techniques to execute them in CPU cores. Moreover, there are also many methods included in imgaug library such as rotating, scaling, translating, flipping, adding blurry effect, changing brightness etc. In our augmentation study, we focused for rotation, scaling and translating the images in both x and z axis. Our augmentation study includes 3 different augmentation methods respectively: rotation, scaling and translating of each image exists in LOCO dataset. First, we randomly rotated each image between -10 and 10 degrees. Secondly, we decreased the size of those images between 80% to 90% of its original size. Lastly, we translated augmented frame randomly in both x and y directions about 5% of its augmented frame size. There are relative examples in Figure 15.

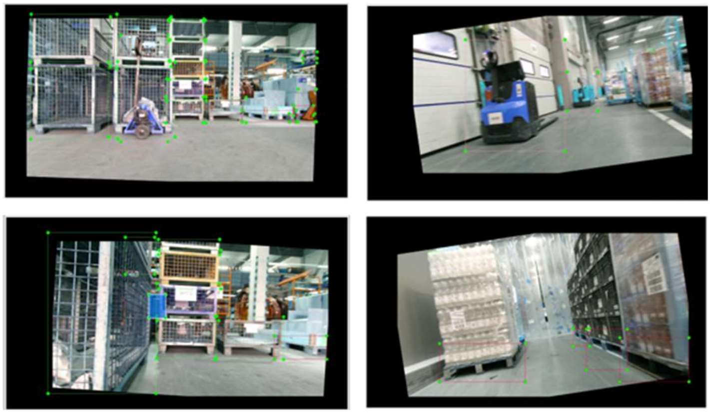

Figure 16: Augmented image samples

Since data augmentation is one of the basic methods to increase the accuracy in computer vision applications, we wanted to experience the effect of our own augmentation data which is later combined with LOCO dataset and trained both together in YOLOv4. Our result is only one percent better mAP compared to the evaluation results with the LOCO dataset. mAP@50 64.79 percent results for the validation results are the best results we have, as it can be visible in the Table 7.

To summarize, data augmentation by using rotation, scaling and translation improved our results a little bit less than we had expected. However, it is still in good order to experience improvements in the evaluation results. Since imgaug library offers many other augmentation use cases, in the future, some other variations of augmentations such as flipping, blurring, contrasting etc. can be examined with different combinations to improve results in the LOCO dataset.

Table 7: Evaluation Results of Our Study After Augmented Data Included

Model	**YOLOv4**
Dataset	**LOCO & Augmented Data**
Map@50	64.79%
Small load carrier	62.21%
Pallet	66.91%
Stillage	71.03%
Forklift	58.29%
Pallet truck	59.24%

4 Conclusions and future work

We presented our study about evaluating the LOCO dataset, which includes 5,097 annotated images with 151,427 labels from five different classes of objects: pallet, small load carrier, stillage, forklift and pallet truck. We concluded our research objective within three main results. Firstly, we are determined that the LOCO dataset is possible to replicate the findings according to its publications. There are significant points pointed out clearly about image collection techniques in object detection processes. However, there are several information missing about how the dataset was trained and with which hyperparameters three different object detection algorithms are tuned. Secondly, we examined the strengths and weaknesses of the LOCO dataset. We realized that YOLOv4 algorithm after training by the LOCO dataset gives impressive results, while detecting pallet, small load carrier and stillage. On the other hand, in the further stage of our study, distinctive errors are noticed about pallet truck and forklift detections. The algorithm was most of the time not detecting forklifts and pallet trucks on the test images or sometimes algorithm was confusing pallet truck and forklift object classes with each other. There are two root causes recognizable for poor detection in these classes. First of them is the limited annotation numbers for both forklifts and pallet trucks. Second of them is the superficial classification for pallet trucks. We suggested within our study that pallet trucks could be classified in three different classes because of its physical appearance and functionalities. Thirdly, as last research question, we investigated the data augmentation effect for the LOCO dataset. We augmented all the images in the LOCO dataset by using rotation, scaling and translation functions in imgaug library. After combining augmented images to the LOCO dataset, our performance indicator, mAP@50, is increased about one percent in evaluations.

After our critical evaluations, we summarize of three main suggestions to be able to reach state of art object detection in intralogistics by using the LOCO dataset. Firstly, the LOCO dataset must include a greater number of annotations for forklifts and pallet trucks to increase its detection capability. Secondly, while increasing the number of annotations, the dataset should be fed by up to date innovative variations of these vehicles according to what is used in intralogistics sector currently. Lastly, there should be an expansion while classifying the pallet truck objects. Pallet truck classes can be separated as three groups and these classes can be called as: electric pallet truck, manual pallet truck, and drivable pallet truck.

Within our study, we examined the LOCO dataset and its publications according to object detection requirements in intralogistics. After finding answers to our research questions, we briefly explained what can be done to improve the LOCO dataset in the future along with our recommendations. In addition, we hope that the findings we have explained will help the future studies in the field of computer vision while preparing the dataset. We wanted to contribute to the work for creating a more advanced and reliable dataset in the field of intralogistics within this manner.

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Preliminary Analysis on Data Quality for ML Applications

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Purpose: *This publication investigates preliminary data quality analyses to estimate the efforts and expected results of the use of data sets for ML solutions already in the data understanding phase of an implementation. Knowledge about the necessary data cleaning efforts and result qualities allows potentials to be estimated early in the process.*

Methodology: *Through a literature research, characteristics of a time series as well as methods of data cleaning are analysed. Based on the results, a test environment is implemented in Python, enabling the evaluation of individual methods using sample data sets from the process industry and comparing them with different error analyses.*

Findings: *The publication describes a detailed overview of data cleaning procedures and addresses a first Indication of a connection between the final achievable forecast quality and the degree of error of the original data set. Insights into the influence of the choice of preprocessing method on the achievable quality of the AI-based forecast can be concluded.*

Originality: *Within the publication, the link between data characteristics in time series and preprocessing methods is established to draw conclusions in advance about the quality improvement to be expected from selected data cleaning methods and to provide decision support for the selection of the method.*

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1 Motivation

Corporate supply chains and business units have changed significantly in recent decades due to increasing globalization and local constraints. Corporate networks are becoming more complex and at the same time need to become more responsive to meet growing and changing market demands. As a result, planning inventory, production capacity, and transportation is becoming increasingly important.

The focus of companies is shifting more and more from pure product competence to flexible customer service, speed, and on-time deliveries at the lowest possible cost (Wassermann, 2013). Consequently, the entire production process and the logistic periphery must react immediately to market fluctuations if they cannot be planned in advance with sufficient quality using advance planning methods (Erben and Romeike, 2003). In order to improve the quality of planning despite growing market demands, data-driven methods are increasingly used, especially in the areas of demand forecasting, production, pricing, and delivery (Dash, et al., 2019).

The level of integration and operational use of these data-driven technologies varies greatly by company and by industry. One industry with comparably low implementation levels of Artificial Intelligence (AI) or Big Data (BD) technologies is the process industry (Winter and Peters, 2019). Despite the strong suitability of the basic conditions in the process industry for AI use cases due to the already strong data collection by distributed control systems in the past (Ge, et al., 2017), there are large differences in implementation by sector and application (see Fornasiero, et al., 2021) and a broad and systematic strategy for implementation is not yet in place (Wostmann, et al., 2020).

For a uniform understanding, the term AI according to Kreutzer et al. is used within this article as a top-level term for Machine Learning and Deep Learning. Machine learning describes the first stage of knowledge generation with the aid of self-learning algorithms and is supplemented by the area of deep learning, which deals with more in-depth learning methods. Here, the algorithm works with larger data sets and can achieve better quality with decreasing result transparency due to higher complexity handling. As a related topic, the term Big Data within this article describes a mostly quantitatively large amount of data (used in the context of AI applications) that additionally contains qualitative information for processes or company operations (Kreutzer et al., 2019).

This paper focuses on the process industry as an example to analyse the reasons for the restrained use of new technologies and to identify possible solutions for individual problem areas. Findings and results in this paper with reference to the process industry originate in the research project AI-CUBE. In this European Union (EU) funded project, the focus is to help exploit and optimise the potential of AI and BD in the European process industry. To achieve this, the project AI-CUBE has the following specific objectives:

- Create a multi-dimensional AI and BD map (or "CUBE") that identifies available best practices and assesses the current state and level of penetration of AI and BD in different organizational processes
- Identify AI and BD solution white spaces that can be covered by adapting best practices from other process industries, and create an adaptation roadmap
- Define the data requirements and capabilities as well as research and innovation requirements for future AI and BD business cases emerging across process industry sectors.

This paper primarily addresses the topic of data requirements and explores preliminary analyses to estimate the effort and expected results of using a dataset for ML solutions already in the data understanding phase of an implementation process. In particular, the focus is on data quality, which according to a study in the AI-CUBE project is one of the main obstacles to the successful use of data-driven methods.

The research question to be addressed within the article is thus: Can a data set be tested for usability within an AI application with a preliminary analysis or can the effort required to prepare the data set be measured with the help of a key performance indicator? The goal here is to measure data set characteristics and to link them to the necessary data preparation effort. Thus, the aim is to develop a concrete translation scale of data characteristics and processing efforts, which is currently not available in sufficient quality. Due to the heterogeneity of the research field, the focus is limited to a data set from the process industry.

In Chapter 2, the term data quality is first introduced in the AI context and, building on this, the classic implementation processes of an AI application with the different phases of data preprocessing are presented. The focus of the paper here is on data cleaning. By means of a literature review, characteristics of data sets as well as methods of data cleaning are analysed (Chapter 3). Based on these results, a test environment in Python is implemented, which allows to evaluate individual methods using sample data sets and to compare them with different error analyses (Chapter 4).

The publication thus describes a detailed overview of possible data cleaning methods and addresses the relationship between the ultimately achievable forecast quality and the degree of error of the original data set. From this, conclusions can be drawn about the influence of the choice of preprocessing method on the achievable quality of the AI-based forecast.

2 Data Quality in AI implementations

The quality of the database is both a requirement and a challenge for AI implementations. As will be shown in the following, ensuring the necessary data quality is a major implementation barrier both in general and in the process industry and therefore also represents an important and demanding step in the adoption process.

2.1 Data quality as an implementation barrier (focus on the process industry)

For AI implementation projects as for every information technology (IT) or information system (IS) adaptation, there are a lot of different barriers and challenges that can hamper the implementation or even cause it to fail. A review on existing studies on implementation barriers for data driven solutions like artificial intelligence or big data technologies shows that the already identified and validated barriers can be structured in the three categories of *organizational and environment related barriers*, *technological and data related barriers* as well as *human related barriers* (Alsheibani, Cheung and Messom, 2019; Dasgupta and Wendler, 2019; Moktadir, et al., 2019; Eager, et al., 2020).

The occurrence and relevance of the different categories and individual barriers changes with the area of application and the industry or company specific environment. Through a survey of users and solution providers in the process industry as part of the AI Cube research project it was found that the most important and influential challenge here is the barrier of data quality in the context of technology and data-related barriers.

Building on this observation, factors and concepts enabling the successful adaptation of data-driven solutions can also be positively formulated from the observed barriers. In the literature these factors are summarized as AI readiness factors (Najdawi, 2020; Jöhnk, Weißert and Wyrtki, 2021) or success factors (Bole, et al., 2015; Hughes, Rana and Dwivedi, 2020). While some of the identified factors are well known for IT/IS implementations (e.g., top management support, financial budget), some factors are more technology specific. Regarding the process industry in Europe, the survey from the AI Cube research project shows that besides existing personnel and strategy related factors, the two data related enabling factors *data availability* and *data quality* are rated as most influential. Missing data quality is considered a critical challenge for data-based solutions because of its strong influence on the final performance and suitability (Jöhnk, Weißert and Wyrtki, 2021).

Recognizing the potential barriers and success factors can improve AI adoption and boost the overall development and adoption rates of AI and Machine Learning solutions (Alsheibani, Cheung and Messom, 2019). In the specific case of data quality, it is also important to assess the quality of the available database as early as possible, to be able to predict expenses that will arise later in the process. Both for the development of new solutions and for the transfer of existing solutions, the creation of the necessary data quality involves great effort.

2.2 Data quality in AI implementation process models

To achieve the necessary data quality, special focus must be placed on data preprocessing within the implementation process of an AI application. As schnell

eckenberg and Moroff (2021) have shown based on a literature review, most Machine Learning (ML) and AI developments and implementations follow iterative methodologies that are closely based on the Cross Industry Standard Process for Data Mining (CRISP-DM) or other knowledge discovery in data bases (KDD) process models such as SEMMA or the basic KDD process. The different process models, which have been developed into different forms in recent years (SEMMA, CRISP-DM etc.) as presented in Figure 1, are very similar in many phases and include many of the same central aspects and sequences. Universal and generic steps can also be extracted here, even if there are of course deviations and specifications to specific use cases (Kurgan and Musilek, 2006). Due to this strong use of KDD related process models for the management of AI and ML developments in research and in industrial applications, these processes are also considered in a focused manner within the scope of this work.

However, the data preprocessing phase can be found within each model, which shows the special importance of this phases. In addition, data preprocessing is also the most demanding phase, as it is here that the quality of the AI application is significantly determined.

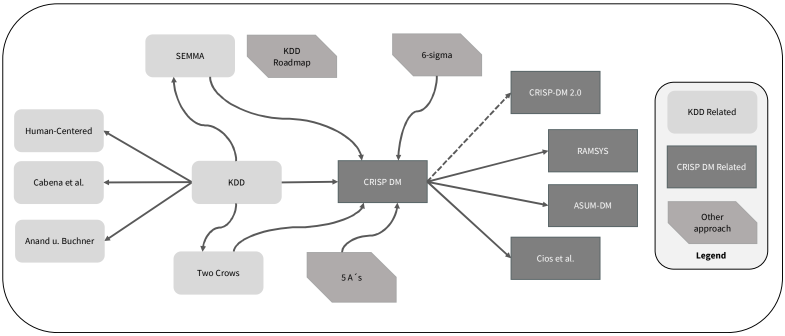

Figure 1: Development of KDD process models (Martinez-Plumed, et al., 2020; Plotnikova, Dumas and Milani, 2020)

Kurgan and Musilek found in a survey in 2006 that most of the effort within an AI project goes into data preparation as shown in Figure 2. The area of data preparation is further categorized into the sub-areas of data integration, data cleaning and data transformation and deals with the preparation of data and pursues the goal of generating usable data content from raw data. Here, techniques are used to minimize problems caused by data noise, inconsistent scales, or missing values (Data Cleaning and Transformation) (Alasadi and Bhaya, 2017).

To harmonize the concept of data quality and the closely related data preprocessing, the respective application must be considered (Jayawardene, Sadiq and Indulska, 2015). In general, two concepts can be followed when characterizing data quality: The *informational focus* (Data definition, data presentation and content data quality) and the *user-based focus* (Features of the dataset). In our publication, we restrict ourselves to the informational focus and especially on the aspect of *content-related data quality* and here we establish the connection to the data preparation process. We deliberately exclude the user-related approach, since a much broader focus of data quality is assessed here (e.g., accessibility, comprehensibility, or interpretability), and thus the transfer into an evaluable KPI system is a further challenge or research need.

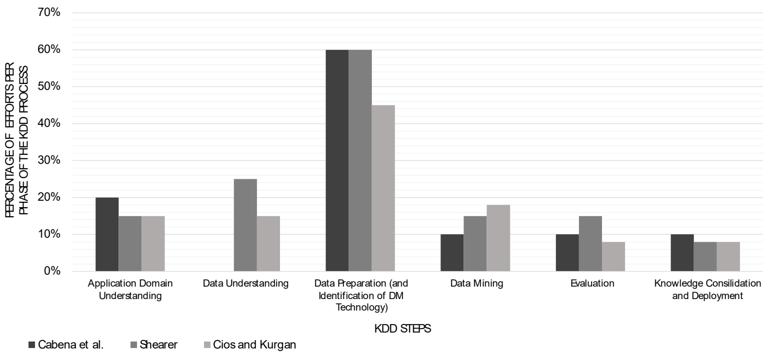

Figure 2: Relative effort spent on specific steps in the KDD process (Kurgan and Musilek, 2006)

The informational focus approach to data quality assessment focuses on assessing data definition, data set content quality, and data presentation. These three modules provide the basic framework for defining information-related data quality and were further detailed by English (1998). The first module focuses on the data collection framework. Only adequately specified data can be used to measure quality. The second and third module focus on content correctness in terms of uniqueness and completeness and with the availability of the data. Parameters for this part are, for example, the time of availability and compliance with the format.

In the further course of the work, we are particularly interested in module two, since the actual quality of the data set is checked here (freedom from errors, completeness, etc.). This is directly related to data cleaning, where existing data points with errors are corrected using different methods. The remaining phases of the data preparation (transformation, normalization, etc.) focus on the extraction of information by connecting different data sets or the transformation into processable formats for the algorithm. However, they do not revise the core information of the data set as is done in data cleaning, for this reason, data cleaning is usually performed before the rest of the data preparation steps (Brownlee, 2020).

The usability of a data set is thus directly related to the success of data cleaning, since the correctness of the data is the basis for the success of an ML model. At the same time, besides the high potential, there is also the highest risk in data cleaning, since due to adjustments the data set can be processed too much and thus the core information can be lost. Therefore, to reduce the effort for data preprocessing or explicitly data cleaning, an estimation of whether a dataset can be successfully revised during data cleaning would be helpful to avoid costly and unsuccessful data reprocessing. When analysing the current scientific literature for thresholds of statistical quantities (number of missing values, number of outliers, etc.) that give you information about when a data set can be used for a machine learning model, the formulations remain only general and vague (Brownlee, 2020). The following article will therefore provide an indication of how effective data cleaning is at a given level of uncertainty, with the aid of statistical parameters. It is important here that the outliers considered in the further course are regarded as clear errors in the data series and not as information to be interpreted. Here it must be considered whether e.g., a 20% share of outliers must not already be interpreted as information pattern, so that no correction takes place.

Due to the high importance of data cleaning for AI implementations both in terms of effort and cost as well as in terms of result quality and the associated perceived usability of the developed solutions, the thresholds for evaluation support proposed here also have a major impact on industrial practice. Especially in the process industry, there are often problems with incomplete and error-prone data (Khaydarov, et al., 2020) despite the fundamentally very extensive data collection and evaluation already in place. Thus, this industry represents a good use case for considering the influence of data quality on ML implementations. As the results of the survey on existing barriers show, the hurdle of insufficient data quality and high data complexity is also well known in the industry, so that methods for assessment and process optimization can be integrated very well into currently existing implementation or technology transfer efforts here. As shown in the context of a self-examination of the European Process Industry by the A.SPIRE association, especially such methods for dealing with insufficient data quality in the industrial environment are not yet available and require a deeper consideration (Winter and Peters, 2019).

3 Methods for data cleaning in preprocessing and basic characteristics of time series

After discussing the challenge of data quality and the overall context of data cleaning in the data preprocessing process in the previous section, this section will focus on specific data cleaning methods that enable a dataset to be optimised for a Machine Learning application. For content limitation, only methods for numerical values or time series values that can be used in demand forecasting will be discussed in this paper. This is a special case in the field of data preprocessing since data points influence each other over time and are not independent of each other.

The method used in this chapter to conduct a literature review on different data cleaning methods is based on the methodology formulated by Randolph (Randolph, 2009). The steps presented there for developing a complete literature review and its goals are themselves based on Cooper's taxonomy (Cooper, 1988). The five phases of the research that were followed are: 1. Problem formulation, 2. Data collection 3. Data evaluation, 4. Analysis and interpretation, 5. Public presentation. The goal of the research is the analysis and synthesis of scientific findings. According to Cooper's taxonomy, therefore, the objective is to be found in the "Research Outcome". The problem to be addressed hereby is: What types of time series error types exist and what techniques are suitable for correcting them. The data is collected in the scientific databases Web of Science, Scopus and IEEEexplore, since these cover the topics Computer Science, Engineering and Economics. To ensure the relevance of the publications used, the data base is limited based on timeliness. Starting from 2016, there is a continuous increase in publications, therefore the year 2016 is set as the limit for the timeliness of the publications. The evaluation follows the research question and examines the publications for the types of errors in time series data mentioned in each case, procedures for dealing with the errors mentioned, and correlations between usability of the data and the degree of errors. In the following, these results will be summarized, and the further procedure is derived.

When errors in time series are mentioned, reference is usually made to the three categories of *noise*, *outliers*, and *missing values*. These errors make it difficult to use the data set in data driven applications and need to be handled in the phase of preprocessing. The extend of these errors in a data set can be determined and analysed directly with statistical quantities, so that a direct overview of the current state of the data set can be given. The understanding of the three error categories used in this paper and the statistical quantities for identifying the errors are described in the following:

- **Outliers**: Values within a data set that deviate too far from other observations within the same data set. Outliers can be determined by analysing the number of values that are outside the expected value. These numbers can still be legitimate data points, which makes identification more difficult (Rustum and Adeloye, 2007).
- **Noise:** Random or irregular fluctuation of a measured value caused by random errors overlaying the original true value (Lazzeri, 2020) that can be identified though a high standard deviation
- **Missing values:** Observations for which no value is stored. This can have various reasons, for example, values can be lost during transmission or there can be an error in the recording system. Identification of missing values is possible through the number of undefined or unrepresentable values within the time series (Rustum and Adeloye, 2007).

Preliminary Analysis on Data Quality for ML Applications

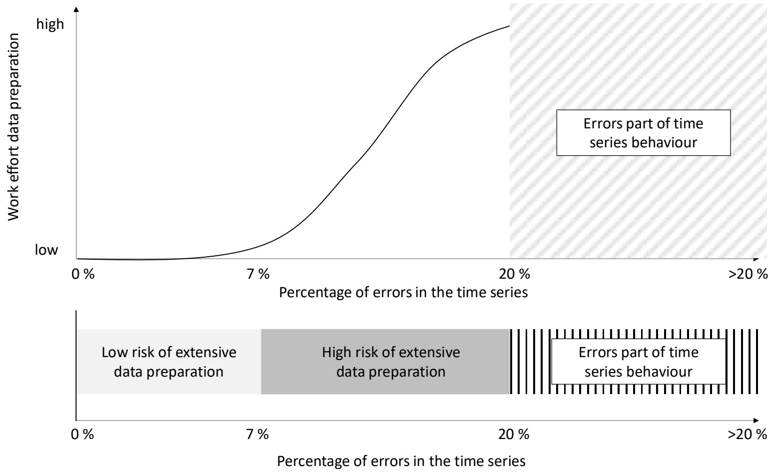

Figure 3: Presumed correlation of percentage of errors and work effort

One strategy for estimating the effort of data preprocessing that will be presented in this paper is thus to find a threshold value that evaluates the effectiveness of a data preparation (e.g., "up to 8% outliers can be in a data set to use it"). This pre-analysis can help in estimating the usability of the dataset after data cleaning. In Figure 3, this concept is graphically broken down and explained in detail based on the error types. In the field of time series analysis, the "Replace" strategy is mostly used to avoid generating gaps within a time series. Based on the literature review, the most frequently used methods identified for the replace approach for the different errors were identified (see Table 1). A detailed mathematical description of these individual methods will not be given in this paper, as the focus is less on the concrete mode of action and more on the results of the various methods relative to each other. More information on the described methods can be found in the literature of Garcia, Luengo and Herrera (2015).

Table 1: Methods for Replace-Strategy per error category

Error category	Methods for replacing erroneous data points	
Missing Values	• Mean and Median Imputation • Forward/ Backward Imputation • Linear Interpolation	• Moving Average Interpolation und Rolling Median Interpolation • Weighted Moving Average Interpolation
Outliers	• Mean und Median Imputation • Moving Average und Rolling Median Imputation • Linear Interpolation	• Weighted Moving Average Imputation • Nearest-Neighbour Regression • Forward/ Backward Imputation
Noise	• Moving Average Imputation • k-Nearest neighbour Regression	• Weighted Moving Average Imputation

Apart from these error types and methods for improving the data quality of the original time series, broader strategies like filtering of different parts of the time series or differentiation and integration can be used depending on the basic characteristics of the time series before the actual data cleaning: Time series are composed of different characteristics, whose superposition results in the pattern of the time series (see Figure 4). The characteristics are *trend*, *seasonality*, and *structural breaks*. The effectiveness of the individual strategies depending on the timeline characteristics is examined below. (Montgomery, 2015; Lazzeri, 2020; Mukhiya, 2020)

After identifying and presenting the most common types of errors and existing methods for correcting these errors as well as basic characteristics of time series, the following chapter shows how the effects of these methods on different time series were collected and analysed.

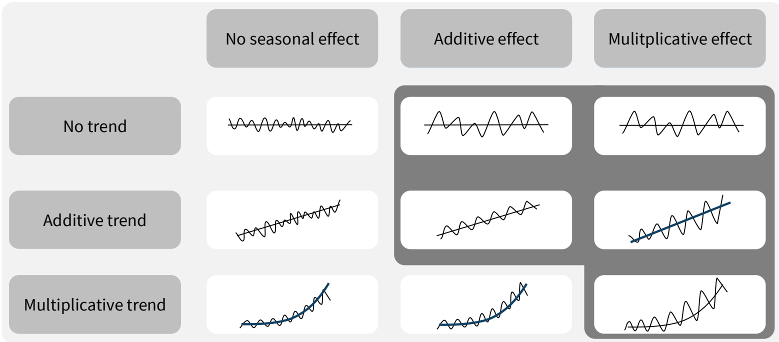

Figure 4: Demand Patterns resulting from trend and seasonal components

4 Experiments and prognosis results

Due to the fact, that the demand forecasting is one of the most important research subjects in supply chain management (Bertolini, et al., 2021), the optimization of the data basis and the prediction of potentially achievable forecast qualities are important when AI capabilities are to be implemented in the industry. As time series provide the basis for forecasting (Koller, 2014), it is important to determine the influence of their different factors and characteristics on the accuracy of the forecast and to explore strategies to further improve the results. This Improved forecast accuracy corresponds directly to more effective planning and better availability of inventory (Kuhn and Hellingrath, 2002; Crone, 2010).

4.1 Experimental plan

To determine correlations between the mentioned error types, cleaning methods and forecast accuracy, as well as between the characteristics of the time series and forecast accuracy, the following model is established: A selection of sufficiently large timeseries of demands of individual products from the chemical sector in the process industry with different combinations of characteristics (marked grey in the following illustration) were chosen as data basis.

The products selected here each represent specific product groups with comparable demand patterns. The individual error types analysed further were artificially added to each of these time series. In this way a new data basis is generated from the original time series with different error types of multistage occurrences (phase 1) that can be cleaned and used for an ML based prognosis. After performing this experimental design to determine the influence of error and data cleaning on the forecast performance, different approaches are formulated to eliminate the influence of the basic time series characteristics on the forecast (phase 2). While phase 1 will show the improvement of the data quality and the corresponding prognosis quality through data cleaning methods, phase 2 will show the influence of the characteristic-depending cleaning strategies.

The artificially implemented errors in the data sets are processed with the listed data cleaning methods. Outlier and missing values are replaced by imputation methods and noise is removed using smoothing methods. In the subsequent step, the cleaned data basis is used for forecasting with a selected ML model. A random forest regressor is used as the Machine Leaning model, which offers the advantage of low training time while maintaining high forecasting accuracy (Darapaneni, et al., 2019; Du Ni, Xiao and Lim, 2020; Lu, et al., 2021). At the same time, it is one of the most widely used ML methods in time series forecasting and therefore represents a method that is particularly representative in decision trees. The results worked out here in the paper are not transferable 1:1 to other procedures, since they require other conditions in the processing of the data basis particularly with fundamentally different model architectures (e.g., vector-based). Parameter tuning of the random forest is performed via a random grid search in which a suitable parameter setting is determined for the given data set. Depending on the results in both phases for the different error rates, general threshold values can be estimated up to which recognizable error rates in the original data a sufficient data quality for subsequent AI forecasts can be achieved by data cleaning. Both the root mean squared error (RMSE) and the mean absolute percentage error (MAPE) were calculated as error values. The RMSE indicates how much the forecast deviates on average from the actual values and the MAPE allows a good interpretation, or serves as an indicator for the relationship between the forecast and the actual observation. It is clearly interpretable and at the same time dimensionless. In the following the general calculation formulas of the error values are shown.

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|y_i - \hat{y}_i|}{\hat{y}_i} \tag{1}$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \tag{2}$$

In the formulas, $\hat{y}_i$ stands for the actual value of the demand, y_i for the predicted value, and n for the number of predicted values.

The experiments are performed based on a single-factor model. The different data cleaning methods form the individual parameters of the respective experiment plan. The number of errors of one type in the time series set represents the level intervals of the experiment and the resulting prediction accuracy maps the effect to be investigated. (Siebertz et al. 2017, S. 1–7) In this way, the effect on forecast quality can be determined for each error type and data cleaning method. Not considered in this experimental design is the interaction from different error types within the same time series.

In both phases of the experiment described in Figure 5, twenty variations of manipulation were integrated into the original time series for each error type (missing values, noise, outliers). The error rates were increased step by step from 0% (original data set) up to 20%. For example, this means that in the manipulated time series for 20% missing values, 20% of the data points are missing. Per phase, this leads to an experimental plan of three times twenty run-throughs per original time series. While this approach evaluates the effectiveness of the data cleaning methods in phase 1 and allows initial error thresholds to be determined for the successful use of the methods, phase 2 focuses on the further improvement of preprocessing through the upstream manipulation of the data series using characteristic-dependent strategies and its influence on the identified thresholds.

In Summary, ten original time series were manipulated with twenty proportion variations per error type, leading to 600 time series per phase that are each cleaned with 3 types of data cleaning methods (constant, linear, non-linear) with 2 specific methods each. Combined, in each phase, 3600 prognoses were calculated.

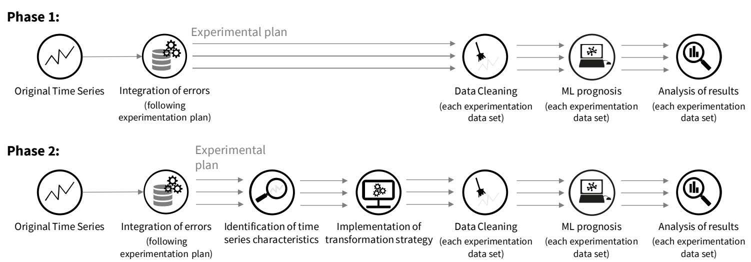

Figure 5: Phases of the experiment

4.2 Results from the different prognoses and phases

In this chapter, results of the observations from both experimental phases are presented and underlying explanations and interrelationships are identified.

Results of Phase 1: Data Cleaning without characteristic-depending manipulation

Regarding missing values, a clear trend can be observed, that the forecast quality decreases as the number of missing values increases. This behaviour is independent of the time series character and was observed in every test series. In the area of outliers, a similar behaviour emerges, the higher the number of outliers, the poorer the forecast quality. However, an interesting phenomenon is that trended time series can be forecasted with constant quality if the outliers are in the direction of the future trend development. As a last error type, an artificial noise was integrated into the data set. Here, as with the missing values, there was a decreasing forecast quality with an increasing proportion of noise in the data set.

Looking at the achieved improvements in forecast quality through the various data cleaning methods, especially the linear *interpolation* and the *moving average* could achieve good results (across time series). When using the *Weighted Moving Average*, one can see a clear difference between the forecast quality for seasonal time series (second best method) and time series with structural break (worst method). Thus, a preliminary analysis of the time series is essential here. In the following Figure 6 the used data cleaning methods are ranked by quality in the range of the considered error type (1 best result and maximum value worst result).

In addition to the evaluation of the data cleaning methods on the test data sets, limit values were also determined to estimate the effort of a data preparation with the help of a preliminary analysis. The limit values were connected to the time series characteristics (Structural Break, Trend, Seasonal) in the analysis to enable a first general statement.

		Seasonal / Stationary	Trend / Non-Stationary	Structural Break
Noise	Weighted Moving Average Imputation	1	2	2
	k-Nearest neighbor Regression	2	1	1
	Moving Average Imputation	3	3	3
Outlier	Mean Imputation	5	1	1
	Median Imputation	1	2	2
	Backward Imputation	8	4	7
	Forward Imputation	7	7	6
	Linear Interpolation	6	6	5
	Moving Average Imputation	4	5	4
	Rolling Median Imputation	2	8	8
	Weighted Moving Average Imputation	3	3	3
Missing Values	Mean Imputation	7	6	6
	Median Imputation	7	7	5
	Backward Imputation	6	5	8
	Forward Imputation	4	4	4
	Linear Interpolation	1	1	1
	Moving Average Interpolation	3	2	2
	Rolling Median Interpolation	5	7	3
	Weighted Moving Average Interpolation	2	3	7

best
worst

Figure 6: Achieved forecast improvement by data cleaning method

The goal of the analysis was to identify the so-called *elbow area* in the time series, which describes a percentage of errors in the data set. From the *elbow point*, the data set can no longer be corrected using the data cleaning methods to obtain a similar result as with the original data (loss of forecast performance). The following Figure 7 shows a representative result diagram from the experimental plan for the exemplary determination of the *elbow area*. The highlighted area indicates the percentage of error after which the forecast quality decreases significantly.

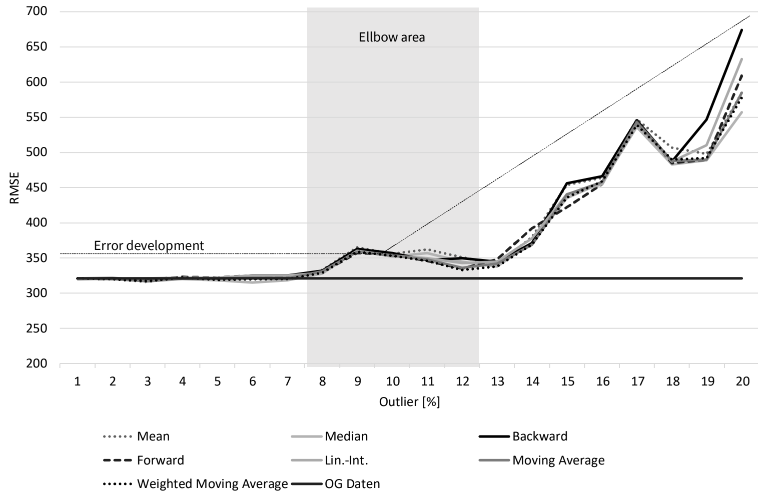

Figure 7: Identification of the elbow area

In the range of the error type "missing values", an elbow range can be identified at approx. 6-8%. As soon as the number of missing values exceeds 8%, the forecast quality decreases significantly. The elbow range is to be defined the same over all timeseries types and thus in the case of the test scenarios independent of the timeseries characteristics. In the analysis of outliers, the range was identified at 5-7% for seasonal (stationary) time series and at 3-6% for trending (non-stationary) time series.

So here we can summarize that a small number of outliers have a positive influence for the forecast results (result from the previous analysis), but as soon as the error percentage is above 6%, the forecast quality reduces again. In the area of outliers, only a valid calculation of the elbow range for seasonal products could be performed (7-12%), since the remaining time series did not show a common pattern. In general, the time series specific characteristics must be considered for the limit values, so that the determined values (shown in Figure 8) cannot be used as limit values, but as orientation values. This individuality will be used in phase 2 to further improve the forecast quality despite high error rates.

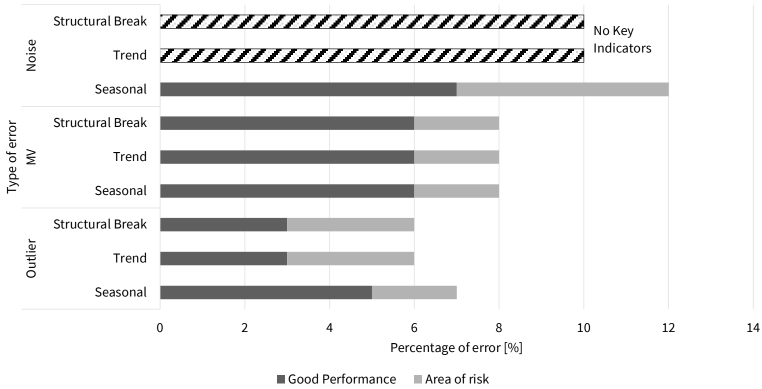

Figure 8: Limit values of the elbow areas by time series specific characteristics

Results from phase 2 (Usage of characteristic-depending strategies)

To account for the individuality of the time series, three strategies depending on the time series were used to perform preprocessing of the data before applying data cleaning procedures. The data basis is thus already prepared in advance.

(A) Trend or Seasonal: Derive, perform forecast, integrate

(B) High Noise: apply median filter,

(C) Structural Break: split data set, use actual data to train and test

In the following Table 2, the potentials are briefly shown by a time series specific preparation (always compared to the initial accuracy without data cleaning and other preprocessing strategies). The evaluation shows the percentage development of the forecast quality compared to a non-preprocessed data set. The positive development due to the integration of contextual knowledge can be seen well, especially when considering the time series with structural break, since here the time series has experienced a break in content and the sections must therefore be considered independently.

Table 2: Potentials of the different strategies for prognosis accuracy

Characteristic-depending strategy	Development Baseline accuracy	Development Accuracy after data Cleaning
A	+1%	+1-10% (depending on the error type)
B	~0%	+10%
C	+25%	+30%

Based on the identified potentials, a flowchart is drawn up in the following section (see Figure 9) that provides a strategy for analysing data sets in advance. In addition, the procedure offers the possibility to make an estimation based on the calculated critical values whether there is a high risk for an effort-intensive preprocessing.

4.3 Recommendations for the use of data cleaning methods and preprocessing efforts

The process of preliminary analysis using the flowchart presented in Figure 9 starts with the general analysis (visual or analytical) of the time series. Based on the identified characteristics (noise, trend, season, or structural break), a strategy for preprocessing is proposed (split time series, filter, integration). After preprocessing, the error types of the time series are evaluated (e.g., number of missing values) and compared with the limit values from the previous analyses. If the critical values are exceeded, it can be assumed that the effort in data preprocessing will be much more intensive. Based on the results, the original data set can be adjusted again (collection or addition of data points), or one or more data cleaning methods can be selected for further processing. In the following figure, the process is described again graphically with the help of a flowchart.

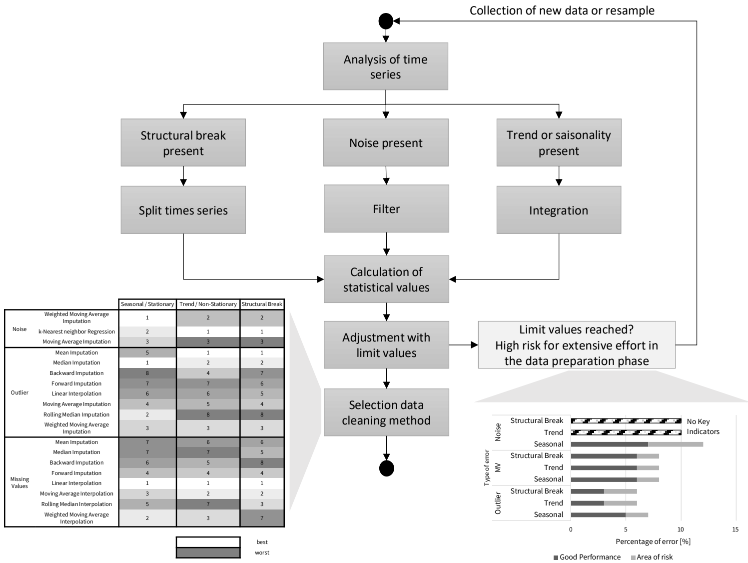

Figure 9: Flowchart for strategy for analysing data sets in advance

It should be added that the flow chart should be used as an orientation and does not claim to be complete in the selection of preliminary analyses and data cleaning methods. It is only intended to provide a systematic procedure for estimating the effort required for the data preparation phase.

5 Conclusion

The analyses presented in this paper provide recommendations for dealing with the existing errors and characteristics of time series so that they can be cleaned optimally in the preprocessing phase. While the identified data cleaning methods for individual error types (noise, missing values, outliers) improve the subsequent ML-based prediction in the presence of errors with great reliability, the characteristic-based strategies improve the forecast results noticeably only for certain characteristics. While especially time series with structural breaks can be preprocessed quite effectively for subsequent data cleaning by using strategies beforehand, the influences on the results are not so reliably attainable in the case of trends, seasonality, or high noises. Nevertheless, positive influences have also been observed for these time series characteristics. Especially the combination of characteristic-depending strategies like splitting, filtering, or integration with the classical methods of data cleaning influence the prediction results well.

By means of the flowchart shown in Figure 9, a procedure model has been developed which provides an assessment of the suitability of time series for forecasting with little effort through limit values per error type (Figure 8) and, in the event of a positive outcome, provides indications of the next steps by evaluating the effectiveness data cleaning methods in Figure 6.

It should be emphasised, however, that the limit values and suitability descriptions presented were determined based on the underlying time series originating from the process industry, so that possible structural properties or errors may have been included here. Thus, they are only first indicators of these limits, which must be verified in the future by other data sets from other application areas or industries. Nevertheless, the initial evaluations on this data set show the described good indicators for the determination of the limit values. By conducting comparable experiments in other application areas or industrial environments in further research work, it will be possible to identify both the reproducibility of the results and any environment-related influencing factors.

In particular, the transferability to other algorithms or compositions of the original data represents a further research need for the future, as the effectiveness and the statements were only assessed for the random forest approach used initially. Through a growing body of experience regarding the behaviour and influence of data cleaning procedures on forecast quality under different environmental and technological influences, further patterns can be identified here which could be related to potential underlying causalities.

However, the initial presentation of these limit values shows that there is the possibility to make later efforts more economically evaluable. Since data quality is a significant barrier for AI implementation projects generally and explicitly in the process industry (see Chapter 2.1) and the creation of suitable data quality takes up a large part of the effort in the implementation process (see Chapter 2.2), both the presentation of solution strategies for the creation of sufficient data quality and the indication of the expected effort and the expected results are important building blocks of an implementation guideline. By integrating this proactive assessment of the potential outcome into the implementation process before the effort is deployed, avoidable costs can be circumvented, and the success of the implementation project can be increased.

The AI Cube research project will develop such guidelines for the process industry based on the experiences and maturity levels of the different sectors and building on existing enabling factors, strategies for overcoming barriers, potential impacts and business models for AI and Big Data solutions. The solutions and effort estimations around data quality presented in this paper provide important parts for these guidelines. Knowledge of the best possible solution to existing barriers such as poor data quality simplifies implementation and makes it easier to plan in terms of capacities, skills, and budgets. This plannability is further supported by the upstream success estimation through the limit value consideration of the error rate. Due to the fundamentally widespread data availability in the process industry through the already existing process control solutions, the further influencing parameters can be particularly well investigated experimentally in this industry in further research. By at least initially fixing the industry focus and thus a potential influencing factor on the correlations further influences can be identified and investigated. However, the objective of the test series presented here does not only influence the process industry from which the data for the test execution originate. Rather, the relationship between the pre-estimation of the forecast quality improvement, the data cleaning methods to be used and the limit values presented here has a generic significance for the preprocessing step of AI implementation processes.

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Workload Forecasting of a Logistic Node Using Bayesian Neural Networks

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Purpose: *Traffic volume in empty container depots has been highly volatile due to external factors. Forecasting the expected container truck traffic along with having a dynamic module to foresee the future workload plays a critical role in improving the work efficiency. This paper studies the relevant literature and designs a forecasting model addressing the aforementioned issues.*

Methodology: *The paper develops a forecasting model to predict hourly work and traffic volume of container trucks in an empty container depot using a Bayesian Neural Network based model. Furthermore, the paper experiments with datasets with different characteristics to assess the model's forecasting range for various data sources.*

Findings: *The real data of an empty container depot is utilized to develop a forecasting model and to later verify the capabilities of the model. The findings show the performance validity of the model and provide the groundwork to build an effective traffic and workload planning system for the empty container depot in question.*

Originality: *This paper proposes a Bayesian deep learning-based forecasting model for traffic and workload of an empty container depot using real-world data. This designed and implemented forecasting model offers a solution with which every actor in the container truck transportation benefits from the optimized workload.*

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1 Introduction

International trade has been one of the key factors in the development of world economies, increasing the need for efficient supply chain mechanisms for product and service distribution in global markets (Rodrigue, 2009). “Although the responsiveness of trade to the Gross Domestic Product (GDP) growth has been moderate over the recent years, demand for maritime transport services and seaborne trade volumes continue to be shaped by global economic growth and the need to carry merchandise trade” (UNCTAD, 2015). In this respect, inland transport of cargo and empty containers plays an essential role in the efficiency of global supply chains.

Empty container depots function as a central place where the shipping and logistics companies can hold their containers until the reuse of containers for the next shipment.

Short term load forecasting which refers to forecasting up to 1 week serves as a practical tool for container terminals and depots to plan the day to day operation (Widhyohadi, 2013). Accurate forecasts of the work or system load on an hourly basis from one day to a week ahead help the container depot operator to accomplish a variety of tasks like economic scheduling of worker capacity, scheduling the necessary handling equipment, etc. In particular, forecasting the peak demand is considered essential as the worker capacity must be adequate in those times to appropriately and efficiently handle the incoming and outgoing traffic of container trucks. Since such forecasting applications lead to increase in the security of operation conditions and cost savings, numerous techniques have been utilized to improve the short-term load forecasting (Hippert, et al., 2001).

Though statistical approaches, such as autoregressive modeling, are a long-time staple and still widely used for forecasting applications (Moghram, and Rahman, 1989), significant advancements in the field of deep learning over the recent years has brought deep learning based forecasting techniques into the spotlight. Today deep learning dominates most forecasting applications and provides state-of-the-art performance (Bim, et al, 2021 and Nassif, et al., 2021).

Although the existing research has successfully demonstrated the superior performance of deep learning on forecasting tasks, inherently, most of the studies are actually based on deterministic models, which lack the ability to capture uncertainty. A new probabilistic deep learning model, the concept of Bayesian deep learning (BDL), which enables a deep learning framework to model uncertainty, is becoming increasingly prevalent in computer vision, natural language processing, medical diagnostics, and autonomous driving (Gal, 2016). BDL exhibits the benefits of uncertainty representation, understanding generalization and reliable prediction; leading to a more interpretable deep neural network through the lens of probability theory. In this paper, a novel probabilistic framework based on BDL for forecasting the workload of an empty container depot is proposed. In order to ascertain whether the forecasting model will help empty container depots improve their current working standards in terms of truck handling operations, the model's performance is examined in different setups and conditions. This approach also captures the aleatoric uncertainty of forecasting data and models. Every hour, the proposed framework automatically produces the hourly workload prediction for the upcoming 5 working days. The primary database for the experimental setup is provided by HCS-Depot which is privately managed specialist company for the repair and stock holding of empty containers in the port of Hamburg. A BDL-based forecasting model is trained using this primary database. In order to examine the capability and forecasting performance of the model, a comparative study between the BDL-based model and another forecasting model is performed. The other model that serves as a benchmark model in this experimental setup was developed by Fraunhofer Center for Maritime Logistics and Services (CML) in the scope of Project LILIE where Fraunhofer CML was partnered up with HCS-Depot to develop a forecasting model by using the multilayer perceptron (MLP) approach (Rendel, John and Karnbach, 2018). Compared with the benchmark model, the proposed approach outperforms the conventional MLP approach and the results show the importance of probabilistic approach over deterministic approach. In addition to this initial comparative study, another performance evaluation between the BDL-based forecasting models which are trained using another complimentary datasets is carried out.

The remainder of this paper is structured as follows; Section 2 introduces current deep learning methods used in the context of short-term load forecasting and provides a brief overview of relevant work as well as detailed insight to Bayesian neural networks. The use case “workload forecasting for an empty container Depot” is covered in Section 3 with individual subsections, giving an overview of the workload at the empty container depot of HCS-Depot and describing every dataset used during the model training, the developed model architecture as well as experimental setup and achieved results. Moreover, the experimental results along with the limitations of the study is discussed in this section. Concluding remarks and possibilities for future research are given in Section 4.

2 Deep Learning for Forecasting

Over the past few years, artificial intelligence and in particular machine learning have seen a significant increase in terms of its usage. Machine learning consists of a number of different algorithms that have been developed to learn correlations through pattern recognition in datasets and use these correlations to make predictions for new, previously unknown data (Nelli, 2018). Today, supervised learning is considered the mainstream subfield of machine learning. Main element of the supervised learning is a large number of labeled data which is a combination of input data and desired output. The labeled data is automatically processed to learn the statistical correlations that encapsulate the relation between input and output. Eventually, these relationships can be used in terms of decision rules when predicting the corresponding output for a given input (Müller and Guido, 2017). More recently, deep learning was introduced as a new subfield in machine learning.

Machine learning algorithms use labeled data to generate predictions. In other words, particular features are defined from the input data for the model and organized into tables, which indicates that input data generally goes through some pre-processing to achieve a structured format. Some of these data pre-processing is eliminated by deep learning algorithms. The main difference with deep learning is that its algorithms are able to ingest and process unstructured data, such as text data and images. Thus, the feature extraction process is automatized and some of the dependency on human experts was removed.

The performance of deep learning models has been significantly exceeding the performance of classical machine learning algorithms in various supervised learning problems. Accelerated by ever-expanding computing power and data volumes, deep learning has therefore enabled notable breakthroughs in applications where text, image or sound data is being processed (Le Cun and Bengio 1995, Goodfellow, et al., 2016 and Le Cun, et al., 2015).

In modern times, forecasting has been a long-time research and application topic among researchers and engineers from different research areas and industries (Goldfarb, et.al, 2005 and The New York Times, 1984). It has a wide range of application areas from time-series forecasting (Lim, et al., 2021 and Deng, et al., 2022) and cloud computing workload forecasting (Masdari and Khoshnevis, 2020) to water quality forecasting for prawn ponds (Dabrowski, et al., 2022) and weather forecasting (Garg, et al., 2022.). As deep learning algorithms and applications started to become readily available and feasible due to worldwide academical and industrial interest along with ever-increasing and affordable computational power getting to a level that is more available for the masses, forecasting has become one of the trendy subfields of machine and deep learning. In the scope of this paper, literature on short-term load forecasting techniques were further investigated and analyzed in detail.

Despite of the increasing trend towards deep learning-based forecasting techniques, there has not been many research studies in the area of short-term load forecasting where the effects of statistical and deterministic approaches were investigated. Cao et al. (2015) adopted an autoregressive integrated moving average (ARIMA) model and similar-day method for intraday load forecasting for electric power companies in China. The study demonstrated that ARIMA performs better in ordinary days while in unordinary days, similar-day yields better results. In another study, Long Short-Term Memory (LSTM) based Recurrent Neural component was used to perform one day ahead hourly load forecasting (He, 2017). The idea explained in the paper was to make use of different types of neural network components to model different types of factors that may impact load consumption. They borrowed the approach in modern image recognition introduced by

Szegedy, et al. (2015) and used multiple Convolutional Neural Network (CNN) components to learn rich feature representation from historical load series. Following that, the variability and dynamics in historical loading were modelled with the LSTM based Recurrent Neural component. For other features such as temperature and holidays, dense (feed-forward) component was employed to project these features into vector representations. As the final step, all learned features were linked together through dense layers to predict load value. Recently, some successful examples on load forecasting were accomplished using k-nearest neighbor (KNN) algorithm whose efficiency was concluded to be the dominant advantage (Zhang, et al., 2016 and Al-Qahtani, et al., 2013)

2.1 Bayesian Neural Networks

Deep learning has demonstrated state-of-the-art performance in a vast number of tasks; however, as Ghahramani (2016) has illustrated in his paper, it still suffers from a series of limitations that need to be investigated and resolved such as requiring vast amount of data, i.e. very data hungry, no representation of uncertainty and compute-intensive training and deployment. The probabilistic approach of Bayesian neural networks (BNNs) addresses these challenges and offers an efficient solution. In this part, the benefits and rationale of employing BNNs to conduct workload forecasting is qualitatively explained along with establishing the mathematical derivation employed during the development of the forecasting model.

BNNs are inherently a probabilistic model which employs a deep learning model to represent uncertainty. Unlike traditional neural networks where their network parameters are fixed once trained, network parameters (weights and biases) in BNNs are expressed as conditional probabilities. To generate its results, the Bayesian model directly samples from its parameters instead of noise addition to the output or setup of multiple input scenarios which are the approaches employed in traditional neural networks. Thus, the Bayesian model is fundamentally probabilistic rather than deterministic in nature.

Contrary to traditional deep learning methods, most of the existing Bayesian deep learning approaches can capture uncertainties that can be observed in the data and also in the model characteristics (Gal, 2016). Uncertainties with which Bayesian models deal can be grouped under two main categories; aleatoric uncertainty (also referred to as stochastic uncertainty) and epistemic uncertainty (also referred to as model uncertainty). Aleatoric uncertainty addresses the noise in the data while uncertainties in model parameters and model structure are examined under epistemic uncertainty. In the proposed Bayesian forecasting model, only aleatoric uncertainty is addressed. This uncertainty is captured by placing a distribution with small variance (Gaussian random noise) over the output, and thus the model is expected to learn the variance in the noise as a function of different inputs (Kendall and Gal , 2017).

Traditional deep neural networks make use of their neurons to memorize the information inside the training data, which signifies that the parameters in traditional neural networks does not possess any physical meaning; thus, their values can be arbitrary. However, BNNs calculate their outputs using Bayesian theory to render the parameters so that the network has the ability to 'feel' certain or uncertain about its result. In particular, the model along with the prediction uncertainty can be calibrated through Bayesian deep learning approach to obtain smart systems that know exactly what they do not know.

The issue of limited amount of data offered by the real-world tasks is another matter that conventional deep learning systems cannot address since the extremely high or low model complexity will lead to the issues of overfitting or poor performance, respectively. However, it was observed that in the case of BNNs, less data is needed to make accurate forecasting (Sun et al., 2019, Kendall and Gal, 2017). BNNs can effectively address the overfitting problem via integrating prior knowledge into learning systems which imposes a prior on hidden units or neural network parameters, even with insufficient datasets. Particularly, BNNs enable the network to gain automatic model complexity control and structure learning through the benefits of the built-in implicit regularization (Wang and Yeung, 2016).

Sun et al. (2019) presented a new probabilistic day-ahead net load forecasting technique which captures both aleatoric uncertainty and epistemic uncertainty using Bayesian deep learning. The performance of the net load forecasting was improved by considering residential rooftop photovoltaic (PV) outputs as the input features and exploiting the clustering in subprofiles. With high PV visibility and subprofile clustering, the proposed scheme proved its efficacy.

The literature research has shown that although there has been a number of research where the performance of BNN based load forecasting models was evaluated and compared to previous methods, developing a BNN based forecasting model that focuses on the workload of an empty container depot or of a similar working environment is yet to be realized.

3 Use Case “Workload Forecasting for an Empty Container Depot”

Container trucks arriving at the empty container depot undergo certain operations, which are referred to as handling process in this paper. Figure 1 illustrates the handling process of the container trucks at the empty container depot. Once a container truck arrives at the gate of the depot, a corresponding gate-in timestamp for the container truck is generated. Following that, trucks awaits until their documents are checked. Depending on the trucks’ main task, they are then moved either to the loading or unloading area. After the loading and unloading operation are complete, the trucks leave the empty container depot as the corresponding gate-out timestamp is generated. The entire process between a truck’s arrival and departure is considered as the handling process and the time spent during this process is referred to as handling time.

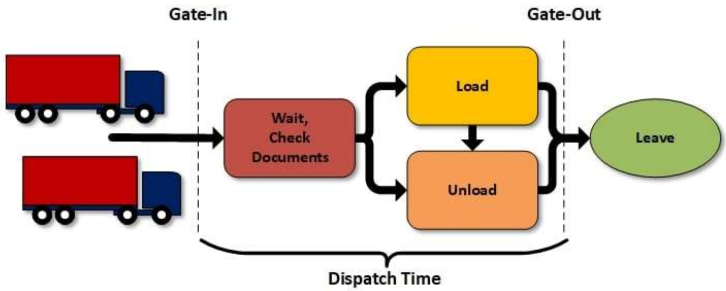

Figure 1: Schematic representation of the workload in the empty container depot

The structure and statistics of the handling process set the framework for developing a hourly forecasting model using Bayesian deep learning approach, as covered in this paper. Accordingly, practical and realistic realization of a forecasting model would require more reliable and stable predictions to be compatible with previously offered solutions. Therefore, the main research question of this paper is whether it is possible to develop a reliable deep learning-based forecasting model which is capable of forecasting the hourly workload of an empty container depot given the recorded data of the depot from the previous years.

The remainder of this section will firstly introduce the datasets utilized throughout the project and then describe the developed and implemented deep learning architecture. Lastly, experimental results of the forecasting model trained with various datasets are presented and discussed along with the study's limitations.

3.1.1 Data

In the scope of the project, we have experimented with datasets from different sources in order to observe the individual effects of these datasets on the prediction model and its performance. In this section, the datasets will be further analyzed and explained in detail.

3.1.2 Base Dataset

The database that acts as the base dataset for the project was provided by HCS-Depot. The database consists of data records regarding every container truck that is part of the traffic in the empty container depot in question. Certain information about every individual container truck that was handled in the container depot between 2017 and 2021 was recorded by HCS-Depot and these records include gate-in & gate-out, loading & dispatch and gate inspection timestamps of each truck along with additional information regarding the containers the trucks carry. In Table 1, every type of data provided in the database is listed as they were originally named in the database along with their corresponding explanations.

Table 1: Data types provided in the HCS-Depot database and their descriptions.

Data Type	**Description**
GateInTime	Timestamp of the truck's arrival at the terminal
GateOutTime	Timestamp of the truck's departure from the terminal
LoadingTime	Timestamp of loading or unloading of the individual container
DispatchTime	Timestamp of dispatch in the interchange
CustomerID	ID of the customer for whom a container is delivered or collected
Is20Feet	Defines whether a container was a 20ft container (represented with '1') or a 40ft container (represented with '0')

Data Type	Description
IsInbound	Defines whether a container was delivered (represented with '1') or picked up (represented with '0')
DepotMoveID	Group key of all containers delivered or picked up on a truck

As mentioned, the main objective of the paper is to develop a forecasting model that predicts the number of trucks and average handling time in minutes for any given working hour of the upcoming week. Thus, an initial preprocessing step was applied on the original database in order to shape the data according to the purpose of the research. The input data which serves as the base input for the experiments consists of every working hour of a day and the corresponding day of the week while the output data contained hourly truck rate and average truck handling time in the container depot for each given working hour of the week. A snippet of the base training data is shown in Table 2.

Table 2: A snippet from the base training dataset

	Input		**Output**	
Date	Hour	Day of the Week	Truck Rate	Handling Time
...	…	…	…	…
2021-06-23 18:00:00	18	2	28	16,76
2021-06-23 19:00:00	19	2	12	17,11

	Input		Output	
2021-06-23 20:00:00	20	2	2	7,41
2021-06-24 05:00:00	5	3	18	40,28
2021-06-24 06:00:00	6	3	41	30,31
...	…	…	…	…

3.1.3 Trucker Appointment Data

HCS-Depot makes use of an appointment system where the truck drivers give their expected arrival time in advance. Hourly expected truck rate was derived from this data and appended onto the base input data in order to observe whether data from the trucker appointment system would have any influence on the model's prediction performance. Since the forecasting model was expected to predict the truck rate and average handling time for the entire upcoming week every day, appointments made within the prediction day would not be implemented in the prediction process. Therefore, only the appointments made one day before or earlier in the trucker appointment system was utilized to derive hourly expected truck rate. Afterwards, this data was added to the base input data as an additional column as displayed in Table 3.

Table 3: A snippet of the input dataset with added expected truck rate values

Date	Hour	Day of the Week	Expected Truck Rate
...	…	…	…
2021-06-23 18:00:00	18	2	5
2021-06-23 19:00:00	19	2	2

Date	Hour	Day of the Week	Expected Truck Rate
2021-06-23 20:00:00	20	2	0
2021-06-23 05:00:00	5	3	17
2021-06-23 06:00:00	6	3	30
…	…	…	…

3.1.4 CAx Data

The Container Availability Index (CAx) is an index that gives information about the import and export moves of full containers around major ports. Interested parties can grab the readily available CAx data to monitor the movement of the containers around provided ports.

CAx values are defined between 0 and 1. A CAx value of 0.5 means that the same number of containers leave and enter a port in the same week. Values greater than 0.5 indicates that more containers have entered the port compared to the containers that have left the same port, whereas values smaller than 0.5 indicate an opposite trend. In addition, 20ft and 40ft containers are represented separately in the CAx data. In Figure 2, a graph corresponding to the CAx values for 40ft containers in the Port of Hamburg between January, 2021 and May, 2022 is shown. The horizontal axis of the graph refers to the weeks of a year, whereas the vertical axis represents the CAx values.

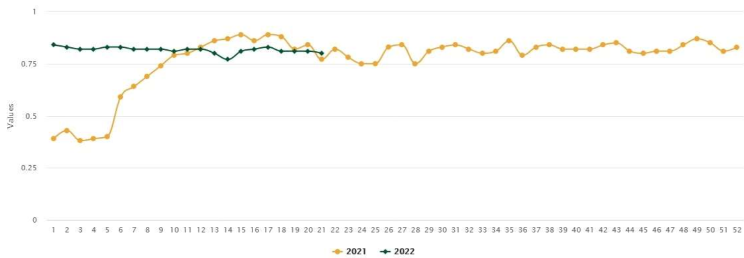

Figure 2: CAx values of 40ft containers in the Port of Hamburg for 2021 and 2022. Source: Container xChange, 2022

Corresponding weekly CAx values were appended to base input data as an additional column.

3.1.5 Sailing List

Another additional data source is the sailing list dataset published online by Hamburger Hafen und Logistik AG (HHLA). The dataset provides information about various data of ships in a predefined period (HHLA, 2021). The sailing list dataset serves as a ground data to calculate the corresponding the twenty-foot equivalent unit (TEU) for every ship in the dataset. TEU is an inexact unit of cargo capacity, often used for container ships and container ports. It is based on the volume of a 20-foot-long (6.1 m) intermodal container, a standard-sized metal box which can be easily transferred between different modes of transportation, such as ships, trains and trucks.

The sailing list data provides information regarding the container traffic at the port of Hamburg. As we were achieving to predict the workload of an empty container depot, the amount of time truck drivers spend on the road between the port and the depot was also included in the calculations regarding the gate-in and & gate-out times. After completing the necessary preprocessing of the data, corresponding hourly TEU values were appended to the base input data.

3.2 Architecture

Bayesian neural network architecture used to train a forecasting model for the use case of “Workload Forecasting for an Empty Container Depot” consists of an input layer followed by the hidden layers and the output layer, also referred to as predictor.

Hidden layers contain two dense layers. Dense layer is a layer that is deeply connected with its previous layer which means the neurons of the dense layer are connected to every neuron of its previous layer (Dillon, et al., 217). To introduce the aleatoric uncertainty, dense layers are combined with probabilistic layers. With that combination, the mean and covariance matrix of the output is modelled as a function of the input and parameter weights. To achieve that, a multivariate normal distribution was introduced to the dense layer. Through this layer, posterior probability distribution structure, which in this case, due to symmetry, is a multivariate normal distribution where only one half of the covariance matrix is estimated, is declared. Lastly, Kullback–Leibler divergence (KL-divergence) regularizer, which is a regularizer that adds a KL-Divergence penalty to the model’s loss function, is added to the output layer (Wang and Ghosh, 2011). The regularizer acts as priori for the output layer.

This novel architecture is developed using TensorFlow which is an interface for expressing machine learning algorithms and an implementation for executing such algorithms (Abadi, et al., 2015). The model also utilized TensorFlow Probability (TFP) library to implement and combine probabilistic models with traditional model components.

3.3 Experimental Results

In this section, the structural plan we have followed during the experimentation is explained and corresponding experimental results are presented.

3.3.1 Structure of the experiments

In the scope of this paper, various experiments were conducted to analyze the performance of the newly developed forecasting model. The initial experiment in this paper aimed to compare the performance of two different forecasters; the prediction model proposed in this paper and the prediction model that was previously developed by Fraunhofer CML (Rendel, John and Karnbach, 2018). Both models were subjected to the same input data which is referred to as base input data in this paper and were expected to predict hourly truck rate and average handling time for 4 weeks of August, 2021. As mentioned in 2.1, BNNs was observed to produce more accurate prediction results when less and current data is introduced. To analyze the influence that the time window of the input data has on the model's prediction performance, the input data was split into 5 different sets where the starting date of the input data was differentiated for each set, as shown in Table 4.

Table 4: Timespan of each input data split

	Starting Date	**End Date**
First Set	January, 2017	July, 2021
Second Set	January, 2018	July, 2021
Third Set	January, 2019	July, 2021
Fourth Set	January, 2020	July, 2021
Fifth Set	January,2021	July, 2021

Following the initial experimental setup, additional experiments with extended input datasets generated by appending the relevant data extracted from new data sources to the base input data were also carried out. In these experiments, the focus was to observe the effect of these relevant data on the model's prediction performance. The additional data sources provide data only for the year 2021. Therefore, in the secondary experimental setup, the timespan of the input dataset was the same as the fifth set of the primary experimental setup; from January, 2021 to July, 2021.

Since our forecasting model is a probabilistic model, a Monte Carlo experiment was performed to provide the predictions. In particular, every prediction of a sample x results in a different output y, which is why the expectation over many individual predictions has to be calculated. After producing a number of the predictions through iterations, the prediction outputs were averaged out and published as the final predictions by the forecasting model.

3.3.2 Results

Two distinct metrics were applied to compare the model's performance with provided datasets; coefficient of determination and mean square error. The coefficient of determination is a statistical measurement that analyses how differences in one variable can be explained by the difference in a secondary variable, when predicting the outcome of a given event. In other words, this coefficient, denoted as R^2, assesses the strength of the linear relationship between two variables.

Given that in a dataset with n samples, $y_1, \dots, y_n$ (collectively known as y_i) represents the true values, whereas $f_1, \dots, f_n$ (known as f_i) being predicted or modeled corresponding values, the residuals can be formulated as in (1).

$$e_i = y_i - f_i \tag{1}$$

The mean of the observed data, denoted with $\bar{y}$, is derived using (2)

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \tag{2}$$

We can measure the variability of the data with two sums of squares formulas;

- The sum of squares of residuals:

$$SS_{res} = \sum_i (y_i - f_i)^2 = \sum e^2 \tag{3}$$

- The total sum of squares (proportional to the variance of the data):

$$SS_{total} = \sum_i (y_i - \bar{y})^2 \tag{4}$$

- Using these two sums of squares formulas, coefficient of determination (R^2) can be calculated as follows,

$$R^2 = 1 - \frac{SS_{res}}{SS_{total}} \tag{5}$$

According to the given formula, the highest possible obtainable R^2 value is 1, which can be interpreted as that the predicted values exactly match the observed values. R^2 value of 0 indicates a baseline model where for each prediction, the mean of observed data ($\bar{y}$) is predicted. As the predictions get worse, R^2 value of the model is expected to obtain negative values.

The mean square error (MSE) is defined as the mean of the square of the difference between actual and predicted values. MSE is a commonly used loss function to assess the quality of a predictor. MSE of a predictor is computed as

$$MSE = \frac{1}{n}\sum_{i=1}^{n} (y_i - f_i)^2 \tag{6}$$

where y_i being the i-th observed value and f_i being the i-th predicted value in a dataset with n samples. An MSE of zero is interpreted as that the predictions are generated with perfect accuracy. As the MSE value increases, the performance of the predictor worsens.

Table 5 shows a performance comparison of prediction model developed in Project LILIE and the Bayesian model in terms their MSE rates. Though the prediction performances for forecasting the number of trucks handled hourly in the empty container depot showed no significant difference between the two forecasting models, the proposed Bayesian model yielded a relatively lower error rate for forecasting the average time spent in a given hour for handling the trucks by the depot workers. Especially for the time windows of 2020 and 2021, the Bayesian model performed significantly superior compared to the benchmark model when predicting the average handling time.

Table 5: MSE Values that LILIE and Bayesian model yielded for base input data with different time windows

	LILIE		Bayesian	
Training Data Start Date	Truck Rate	Handling Time	Truck Rate	Handling Time
2017-01-01	6.73	8.33	6.59	6.40
2018-01-01	6.39	7.68	6.50	6.40
2019-01-01	6.49	8.64	6.48	6.16
2020-01-01	6.51	23.62	6.45	6.21
2021-01-01	6.50	20.43	6.29	6.20

A similar trend was also observed in the coefficient of determination values among the models. Corresponding coefficient of determination comparison is presented in Table 6. Both forecasting models performed similarly in terms of predicting the hourly truck rate. Their coefficient of determination for this prediction laid around 0.7 which is a strong prediction performance, considering that the coefficient of 1 is considered the perfect prediction model. However, the performance difference between the models became highly obvious when predicting the average handling time. Negative coefficient values of the benchmark model indicate poor forecasting performance. On the other hand, a slight increase in forecasting performance of the Bayesian model was observed, as the time window of the input dataset got closer to the present date. These results also support the conclusions regarding the performance of the BNNs when less and more relevant data are fed into the BNNs (Sun et al., 2019, Kendall and Gal, 2017).

Table 6: Coefficient of determination comparison between LILIE-Model and the Bayesian model

	LILIE		**Bayesian**	
Training Data Start Date	Truck Rate	Handling Time	Truck Rate	Handling Time
2017-01-01	0.72	-0.65	0.71	0.29
2018-01-01	0.74	-0.07	0.72	0.29
2019-01-01	0.73	-0.60	0.73	0.35
2020-01-01	0.74	-20.43	0.73	0.33
2021-01-01	0.72	-18.06	0.74	0.32

The error rate of the Bayesian model for each dataset is presented in Table 7. In this experimental setup, the performance of the Bayesian model with the base dataset served as the benchmark performance. While experiments with CAx dataset and sailing dataset resulted in rather similar performance compared to the benchmark model, the forecasting model trained with data containing trucker appointment system data yielded a superior performance for predicting hourly truck rate. Since the trucker appointment system provides additional relevant information to the model about the number of trucks for the given hour, it was expected that the model would generate more accurate results compared to the benchmark model setup. By training the model with this dataset, the lowest error rate which is approximately 25% lower than the benchmark model's was achieved.

Table 7: MSE Rates of Bayesian model with the experimentation of different datasets.

	Truck Rate	Handling Time
KIK-LEE Base Dataset	6.29	6.20
Trucker Appointment	4.74	6.75
CAx Dataset	6.19	6.34
Sailing Dataset	6.42	6.55

Regarding the coefficient of determination, a similar trend was detected as shown in Table 8. When the forecasting model trained using trucker appointment dataset, its performance reached up to the level of 0.85 in terms of its coefficient of determination for truck rate predictions. Though training the model with other datasets resulted in a decrease in the prediction performance for the average handling time, the poorest performance for handling time predictions was achieved by the model trained with trucker appointment dataset. This indicates that the model prioritizes the truck rate correlation during the training.

Table 8: Corresponding coefficient of determination values for different datasets

	Truck Rate	Handling Time
KIK-LEE Base Dataset	0.74	0.32
Trucker Appointment	0.85	0.18
CAx Dataset	0.74	0.27

	Truck Rate	Handling Time
Sailing Dataset	0.68	0.28

3.4 Limitations and Discussion

As mentioned in 2.1, Bayesian neural networks can employ both aleatoric and epistemic uncertainty. In the scope of this study, only aleatoric uncertainty was modelled in the experiments. Another limitation of the study was a dataset limitation regarding the sailing dataset. HHLA, publisher of the sailing dataset, openly publishes data that only dates back to three months from the current date. Thus, the corresponding dataset employed in the study was consisted of only the sailing data between May, 2021 and August, 2021.

During the comparison experiment between the LILIE-Model and the Bayesian Model, instability in the LILIE-Model was observed after the time window of 2020 when generating predictions for average handling time. The same instable results were obtained even after repeating the experiments for a number of times. It was suspected that the benchmark model, i.e. LILIE-Model, could not perform the learning process or could not approximate any appropriate forecasting function when less data was provided. Furthermore, performance of the Bayesian model has gotten slightly better as the time window of the input dataset has gotten closer to the present date. These results also support the conclusions drawn in previous research papers regarding the performance of the BNNs when less and more relevant data are fed into the BNNs (Sun et al., 2019, Kendall and Gal, 2017).

In the secondary experimental setup, the effects of the additional relevant data provided by the trucker appointment system on the prediction performance were highly visible. Nearly 25% lower error rate for predicting hourly truck rate compared to the benchmark model indicates that providing additional relevant information about the number of trucks that are expected to be handled for the given hour helped the forecasting model generate more accurate predictions. Also, examining the results obtained in the experiment with CAX data, it can be seen that influence of CAx data on the prediction performance was rather insignificant. CAx data is a data recorded weekly, whereas the prediction models are expected to provide hourly forecast. As a result, the CAx value of a week was appended to every hour of this particular week as an additional column in the input dataset. Therefore, the repetitive nature of the CAx data added no further context or relevant information to the training.

On the other hand, the sailing dataset caused poorer performance in terms of both truck rate and handling time predictions. The data time window limitation of this dataset has had its effect on the prediction results and the forecasting model has given the worst prediction performance with the sailing dataset. Though BNNs are expected to give superior results with less and more relevant data, the short time span of the data has prevented the prediction model catch or create any relevant context.

The proposed approach shows promising results for offering a reliable forecasting framework for empty container depots which can be used as the groundwork for fully realized real-life applications. The results also demonstrate that shifting to the probabilistic approach can benefit the forecasting models in terms of reliable predictions and prediction stability.

On the basis of the obtained results, a number of interesting findings invokes possible future researches. Since only the aleatoric uncertainty is considered for the experiments, capturing both the epistemic and the aleatoric uncertainty together serves as a promising further research. Another promising topic for a further analysis concerns extracting more relevant information from the databases, as the corresponding results showed that datasets that provide additional context or information layer to the data can help forecasting model improve their performance.

4 Conclusion

Empty container depots play an essential role in the empty container traffic and storage as well as in the inland transportation of goods. Due to unexpected or planned delays at ports or during transportation between port and the depot, certain setbacks can occur for the container transportation. Such incidents can create additional workload for the empty container depot. Future workload forecast promises the potential for work optimization and efficient time management. Receiving the next week's forecast beforehand gives empty container depots the opportunity to preplan the work schedule and man power needed for the next week and enables them to redistribute the workforce of the depot when needed.

This paper has demonstrated that state-of-the-art Bayesian neural networks are capable of forecasting the hourly workload in an empty container depot for upcoming weeks in terms of the number of trucks handled at the depot and average handling time of the trucks.

This corresponds to a well-known problem of unpredictable workload changes at depots and offers a solution that addresses the problem with an automatable system. Moreover, it has shown that the forecasting model produces predictions that has a small error rate when more relevant data was provided, such as data from trucker appointment system of HCS-Depot.

Despite achieving a first step in forecasting hourly workload at empty container depots, it is clear that much remains to be done. Subsequent research will focus on introducing new relevant datasets, that the forecasting model can take advantage of, along with further developing the forecasting model. Accordingly, next steps will involve finding the relevant data sources and gathering the necessary datasets, applying further development work on the forecasting model as well as automatizing the process of publishing the forecast result. Since only aleatoric uncertainty was considered in this paper, including both aleatoric uncertainty and epistemic uncertainty in the model is one of the main milestones for the further development of the forecasting model. Using both uncertainties can help the model reduce predictive uncertainty, which is the confidence that a forecasting model has in a prediction. Moreover, since only certain parts of the databases were taken advantage of during forecasting experiments, it would be worthwhile to examine and work on these databases in detail to find out whether unused parts of the database can provide any further relevant information for better forecasting performance.

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III.
Innovation and Technology Management

Digital transformation of planning in the pharmaceutical sector

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Purpose: *To adjust the inventory supply planning, through digital transformation that allows automation and tracking of demand behavior in real time and with low cost tool.*

Methodology: *The collected database is loaded into an Excel along with the required input variables in each of the inventory policies. The data is processed and imported into Python, the demand forecasting is made and the policies are simulated to choose the one that generates the lowest cost.*

Results: *The algorithm indicates the inventory scheduling to be implemented by the company according to the policy that allows the lowest costs and that supplies the demand of each product.*

Originality: *The design of an original tool, that allows obtaining accuracy of the inventory management, with easy interaction of the user and the algorithm, through the reception of information and output of results in Excel, processed by python, across the synergy between the two programs.*

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1 Introduction

Nowadays, the digital transformation throughout the supply chains forces to immediately improve the response to the demands of essential products (pharmaceuticals, health, beauty, baby, and personal care) required by consumers through quick commerce.

As the third largest market in Latin America, the pharmaceutical sector in Colombia grew exponentially throughout the pandemic, due to a greater demand for generic drugs formulated by public health institutions; manufacturing grew by 6% and sales by 10.1%. Several organizations of these supply chains, as it is the company under study, had to transform, adapting their operation to the needs of the digitization of processes to respond to the increase of quick commerce (SOLUNION, 2022).

For the present study, a pharmaceutical company with almost one hundred years of experience is taken as a reference, which has identified inflection points to improve its supply through digital transformation, reducing costs and increasing the reliability of prediction in the face of the change in consumption behavior. This company has a planning area, which depends on a software that makes suggestions for product supply from the distribution center to its sixty-three stores in the country. Unfortunately, this software is very rigid for the diverse types of demand these products have, which generates a lack of synchronization between demand and supply. Likewise, additional management is performed in loading and updating information, prompting delays and slow response capabilities in the supply chain.

This scenario becomes an opportunity to review inventory planning management. And in this way, the question arises of how to implement an accessible digital transformation in terms of costs and applicability in the supply chain, for this a tool that integrates these characteristics and has a progressive adjustment in inventory planning in a distribution center is proposed.

Real-time automated planning is achieved under an algorithm chained in Python, which provides an assertive response to future demand and the changing market, through a variety of inventory and supply policies, consistent with the behavior of the demand for each SKU (Stock Keeping Unit), maintaining a logistics cost and a controlled inventory for the operation.

This article begins with the introduction and exposes the background. Subsequently, the concepts associated with this investigation are described. In Section number four the methodology is described, followed by the description of the results. In section number six the improvements are identified and finally, the conclusions are presented.

2 Theoretical Background

2.1 Context of the industry

Colombia is the third largest pharmaceutical market in Latin America, accounting for 4.1% of the country's GDP (Rincón, 2021). Given this growth generated by the constant increase in demand for products, the organization under study, in the past, has had to deal with sporadic and immediate growth in its operation, assuming a high logistical cost, influenced by the restrictions of the national panorama.

In Colombia, logistics cost represents 12.6% of sales, highlighting that the highest item focuses on the cost of storage and inventory with 43.2%, followed by the cost of the transport category that occupies 30.7% of the total logistics costs due to inadequate planning of inventories along the supply chain. (DNP, 2020)

In addition to this situation, there are a plethora of situations, such as smuggling, counterfeiting, and unfair competition, which continue to affect market prices. For this reason, this retail sector finds it necessary to explore new tools to connect suppliers with their stores throughout the country, even more so with the emerging growth that was obtained with the pandemic by going from 50 to 63 stores in 3 years. Therefore, a shift in the way of planning and creating sourcing policies for the 14,000 SKUs is proposed (Investincolombia, 2022).

2.2 Literature Review in Inventory Planning

For the development of this project, it was necessary to go deep into research based on the use of Machine Learning and its application in terms of optimal decision-making in product supply.

It can be inferred that the way in which markets operate to make optimal decisions of their supply has come through the implementation of models that use mixed linear programming, which are based on algebraic modeling software (Liliana Delgado Hidalgo, 2020).

Also, there have been project developments based on the use of Machine Learning, more specifically in neural networks, which use algorithms that improve the accuracy of predictions mitigating their errors. The purpose of this research was to predict the inventory supply, considering demand, inventory management, and maintenance costs (He, n.d.).

Lishura Chen explored a forecasting method like the moving average but more advanced, which allows an adjustment to the annual cyclical behavior of demand, through the Python programming tool. (Chen, 2019)

On the other hand, in the article "Predictive Control of Inventory Management in Supply Chain Systems with Uncertain Demands and Time Delays" they consider a predictive control algorithm for uncertain demands and supplier delivery time delays, with the supply strategy of the balance between inventory costs and the level of customer satisfaction. (Yi-yang, 2021)

Currently developed relevant studies were also found, such as the one presented by Danielle Nyakam Nya and Hassane Abouaissa, in which a new way of controlling supply chains is sought, since currently the methods used are control strategies based on models such as stochastic, deterministic, economic and based on simulation, which play an important role, however, due to the increasing complexity of such systems, the modeling of supply chains becomes more difficult and fails to capture all the dynamic behavior of the networks in the chain. This is why a methodology is developed based on the configuration of "Modelless Control (MFC)" and its related intelligent controllers, which is developed through a mathematical description of the supply chain inventory production system in semiconductor manufacturing, which allowed the development of an internal model control design of multiple degrees of freedom and in this way control the inventory so that there is no excess of it even if it is subject to a variable demand. (Abouaissa, 2022)

On the other hand, the study "Proposing Multi-item Replenishment model for an Inventory Management System of Malaysia's SMEs studio" describes an economic modified order quantity (EOQ) for the multiple item replenishment model with the deterministic demand nature of an inventory management for companies in the Malaysian manufacturing sector. This research is developed through a function that is subject to the financial and space constraints available in organizations. If the restrictions are not satisfied under the given conditions, the Lagrange technique is applied to obtain the optimal order quantity of the multiple items. The purpose of this study is to offer a model that controls overproduction and underproduction inventories to satisfy customer demand at the right time. (Irfan ur Rahman, 2022)

Another research is concerned with the importance of available quantities in the inventory for restocking calculations and thus make the decision that the SKUs most in demand are the ones that should constantly be in the inventory. For this, they implemented a Machine Learning algorithm called clustering, which allows them to reduce the size or dimensionality of the data and achieve the classification of urgent products to be ordered more easily (Shoujing Zhang, 2020).

The authors of the article "Inventory management and cost reduction of supply chain processes using AI based time-series forecasting and ANN modeling" had tabulated and structured data, for which they applied models based on decision trees, thus managing to reduce the stock level and the monetary resources allocated for this purpose (Umamaheswaran Praveen, 2019).

Finally, Jaumot (2021) proposes that the prediction should be able to show the optimal stock level and thus offer a good customer service, reducing costs from inventory management. The stock level was obtained from the historical data of demand, without generating forecasts about it. For the execution, the author implemented Gradient Boosting algorithms guaranteeing the timeline of the time series (Jaumot, 2021).

2.3 The process

The distribution center of this organization has five basic operations: product reception, storage, picking, crossdocking, and distribution to stores.

The research focused on the planning of the supply to stores. The distribution of a product is conducted frequently, when the inventory of the references in the store is about to be sold out, due collecting, consolidation, and transport to the store are conducted.

Points of sale send a sales record for each product, the supply request, and the number of SKUs that are required. This data is stored in software that specifies the collectors the product to be supplied and the point of sale to which it must be sent. These products are accumulated in a basket. Once this basket is ready, they proceed to label the information of the products, indicating their destination and then be taken to the loading area, where they are loaded to be transported to the different stores in the country. The process is shown in Figure 1.

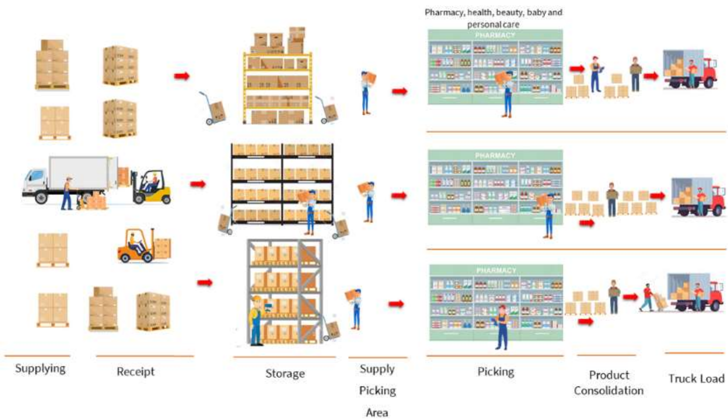

Figure 1: The process

3 Applied concepts

To achieve the construction of this model, it was necessary to understand both supply and demand. For demand, an algorithm is designed that can forecast each product's values. For supply, inventory policies are designed so that they can respond to each demand behavior, specifying shipping frequency and quantities of product to be loaded.

This shows the need to improve planning through a base of parameters designed to efficiently manage the quantity and frequency of orders, with the aim of minimizing costs and ensuring availability of products in stores nationwide.

These parameters define inventory policies, which have been created due to the dynamic environment that simulates different behaviors in demand and allow modifying the efficiency and capacity of a supply chain through the management of its resources to find an optimal solution that balances cost and service (John J. Coyle, 2019).

3.1 Inventory policies

A policy is a rule that a company implements to organize the behavior of some of its elements. The inventory policy involves determining the batch size, which includes the frequency and quantity to be ordered for inventory. Batch Size is the quantity of an item in inventory that management purchases from a supplier or manufactures through an internal process (Sunil Chopra, 2013).

Considering the literature about the existing policies in inventory management, the authors propose four inventory policies for the development of the algorithm to model different behaviors that present the demands of the SKUs that the company deals.

The proposed policies for the development of this work, which involve four variables, are set out below:

- Time(T): It is the period in which an order must be placed.
- Quantity (Q): It is the optimal quantity that must be ordered from the supplier.
- Safety Inventory (S): It is an inventory that is kept in stock used to cushion shortages produced by uncertainty of demand and delivery time.
- Roof (R): It is the possible inventory limit to keep in stock.

TQ Policy: It is a model that consists of ordering a fixed amount whenever required. The optimal quantity of supply Q is ordered each period T calculated according to the demand that in this case presents a behavior of low uncertainty being continuous and constant.

The Figure 2: TQ policy shown below is a simulation of the model with the behavior of some boxes of medicine over time, starting with an inventory of 12 days, which is 220 boxes; its consumption is represented with the red slope until it reaches the 8 days of inventory reorder point established by the company, which is 150 boxes.

To calculate the amount Q, formula 1 is used, and to calculate time T, formula 2 is used:

$$Q = \sqrt{\frac{2 * d * Cp}{Cs}} \tag{1}$$

$$T = \frac{Q}{d} \tag{2}$$

Where:

- d = Average demand over a period.
- Cp= The shipping cost that is generated each time an order is placed.
- Cs= Cost of inventory maintenance per unit.

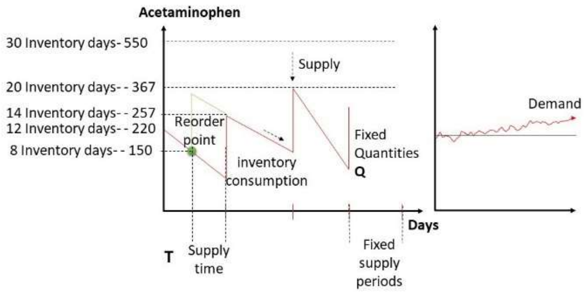

Figure 2: TQ policy

SQ policy: It consists of a model that is responsible for preventing a stock-out, calculating an inventory or safety stock that must be maintained in the face of uncertain conditions that arise when the demand has a dispersed and volatile behavior as can be seen in Figure 3: SQ policy. Under this scenario in which demand and supply times present a high component of uncertainty, the safety inventory "S" depends on the variability of demand and delivery times. In Figure 3Figure 3: SQ policy SQ policy, the first slope illustrates the consumption of the initial inventory up to the safety inventory (the first green point), which is the time at which order of quantity Q is placed. To calculate the quantity Q, Formula 1 is used. Formula 3 is required to calculate the safety stock (Sunil Chopra, 2013).

$$S = d * t + \omega * z * \sqrt{t} \qquad (3)$$

Where,

- d= Demand. Refers to the average demand over a period.
- t= Provisioning. It is the time it takes the supplier to deliver.
- Z=Safety Factor. Adjustment factor that represents the probability of avoiding shortage, according to the normal distribution of demand.
- ω=Sigma. Standard deviation of demand.

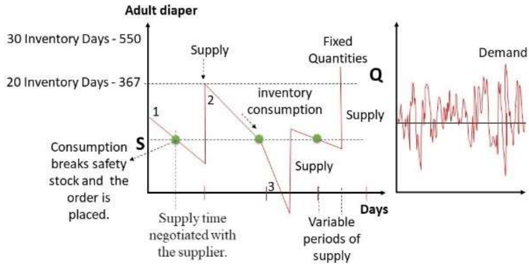

Figure 3: SQ policy

SR Policy: Consists of a model that establishes a maximum fixed inventory called roof (R) and calculates the quantity to be ordered when the current inventory is less than the safety inventory (S). This model is used when the demand has a dispersed behavior, but with a growth trend, being adjustable to any atypical behavior of the demand. The quantity to order is determined by the difference between the roof and the current inventory. Figure 4: SR policy illustrates the decrease in inventory up to the safety inventory in the first green point, in which an order equivalent to the difference between the "R" roof and the safety inventory must be placed. To calculate the safety inventory (S), Formula 3 is used and Formula 4 is required to calculate the roof (R).

$$\mathrm{R} = (D + \omega) * \mathrm{t} + \mathrm{z} * \omega * \sqrt{\mathrm{t}} \tag{4}$$

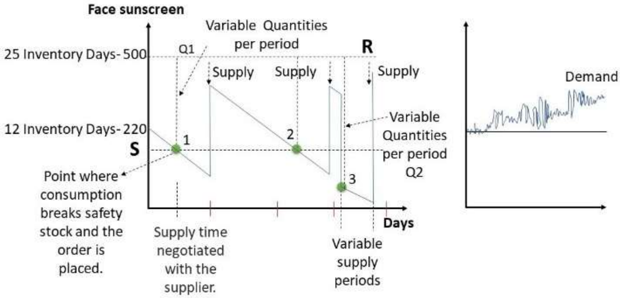

Figure 4: SR policy

TR Policy: Consists of a model that is responsible for requesting product inventory on a periodic basis, calculating the difference between the maximum inventory called roof (R) and the available inventory. It is applied when the demand has a seasonal behavior as seen in Figure 5: TR policy.

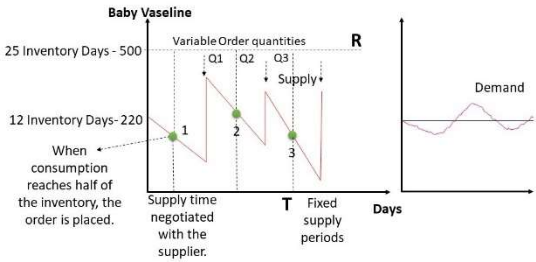

Figure 5: TR policy

Formula 2 is required to calculate the supply time (T), which considers the shipping cost (Cp), the cost of maintenance (Cs), and the average demand (d). Formula 5 is required to calculate the roof (R).

$$R = D * (t + T) + z * \sigma * \sqrt{t + T} \tag{5}$$

The four policies described above were integrated into the programming of the Python algorithm developed in this project, to automate the action for all the requested SKUs and thus optimize the order and storage rate. To do this, artificial intelligence was integrated to obtain the demand forecast that inventory policies require to adapt to the behavior of the expected demand and thus decide on the type of policy to choose.

3.2 Machine Learning

Quick and efficient data analysis is key for operational planning, as it provides support for processing and managing large volumes of information and obtaining data closer to actual market behavior. Based on this trend, it is necessary to apply or implement mathematical analysis tools to obtain accurate data which can help identify failures and opportunities for improvement in all organizational operations.

A branch of artificial intelligence called Machine Learning, allows the use of algorithms that can analyze large volumes of data to generate forecasts that help decision-making, that is, finding hidden patterns from the data, thus creating knowledge that provides increasingly real and accurate information over time, minimizing bias and errors in the quality of the information. This contributes to the minimization of costs, since the information about the operation is available in real time, achieving adequate management (Karagiannakos, 2020).

For the development of Machine Learning algorithms, Python is the programming language with the most growth today, and the one that has allowed competitiveness in companies (Tokio School, 2020), due to its simplicity, ease of machine learning and open source. This makes the Python app ideal for time series forecasting.

The algorithm designed for the research in question uses the following libraries to perform demand forecasting and inventory policy implementation:

- Pandas: Python library specialized in the management and analysis of data structures (Alberca, 2022)
- NumPy: Python library specialized in numerical computing and data analysis, especially for high volume data (Alberca, 2022)
- Statistics: Provides functions for the calculation of statistical values in the field of real numbers (Interactive, s.f.)

- Math: Used for complex mathematical operations that use floating point values, including logarithms and trigonometric operations (Anon., 2022)
- Keras: It is an open-source library of artificial neural networks, it is designed to build each neural network in blocks, which are the ones that allow training deep learning models (Anon., s.f.)

For the execution of the model, the Jupyter Notebook application was used, which allows the deployment of notebooks that support forty programming languages including Python.

4 Methodology

4.1 Stages

The methodology used in this study comprises several stages for treating the data set using Excel and Python, as follows:

Data acquisition: Among the products used to conduct the proposed research, those medicines that do not require a medical prescription, personal care, beauty, and baby care products stand out. The obtained data were the result of the information provided by the planning staff of the company under study, for this it was necessary to hold several meetings with this area in 2021. The products taken are classified into three types of references (A, B, and C), and their mode of operation is cross-docking, that is, none of the references has storage. This indicates that the minimum time it takes for a product to leave the distribution center is 3 days and the maximum is 7 days; for this reason, all products were considered high turnover.

Data upload: the historical demand data obtained from the company is loaded into a base Excel spreadsheet. The demand for each SKU is in a column, organized with its corresponding date as shown in Table 1. Additionally, the input variables that are required to identify the cost of the inventory policy of each product are entered, which are: t (supply time), Cp (shipping cost), Cs (maintenance cost), Cf (missing item cost), Ns (Service level) and Ii (initial inventory) as shown in Table 2.

Table 1: To modify input demand

FECHA	D1	D2	D3	D4	D5
1/01/2017	9	6	3	12	42
2/01/2017	34	7	3	5	10
3/01/2017	89	33	4	40	55
4/01/2017	108	24	27	40	46
5/01/2017	110	41	45	57	64
6/01/2017	93	16	59	29	43
7/01/2017	7	5	59	3	5
8/01/2017	60	18	41	42	101
9/01/2017	42	12	6	15	54
10/01/2017	102	37	29	42	47

Table 2: To modify input variables

Provisioning	Shipping Cost	Cost maintenance	Shortage Cost	Service Level	Initial Inventory
2	150	10	60	0.95	100
4	230	12	60	0.95	200
3	315	14	60	0.95	150
4	400	12	50	0.98	200
5	150	10	55	0.98	170
2	220	12	40	0.98	100
3	320	15	45	0.98	200
4	130	13	80	0.98	350
3	140	14	65	0.98	100
3	260	10	55	0.98	200

Data pre-processing: For the model to be implemented to function properly and yield adequate results, the data needs to have the required quality. Therefore, the outliers and missing values should be treated in Excel, while data is normalized in Python.

Demand projection: for this stage, the data projection model is built with the use of Machine Learning. The model's projection results are used to calculate inventory policies.

Inventory Policy Algorithm: The algorithm that simulates inventory behavior is constructed based on the parameters established in each policy, as described in chapter 3.1. so that the policy that generates a lower cost for each SKU is chosen. The results obtained will be displayed in Excel as shown in table 3

4.2 Model formulation

The model simulates the behavior of inventory policies from the demand forecast, based on the historical data provided by the pharmaceutical distribution center. As a result, the policy that generates a lower cost is determined, according to the desired level of service. The process is shown in Figure 6: Understanding the algorithm.

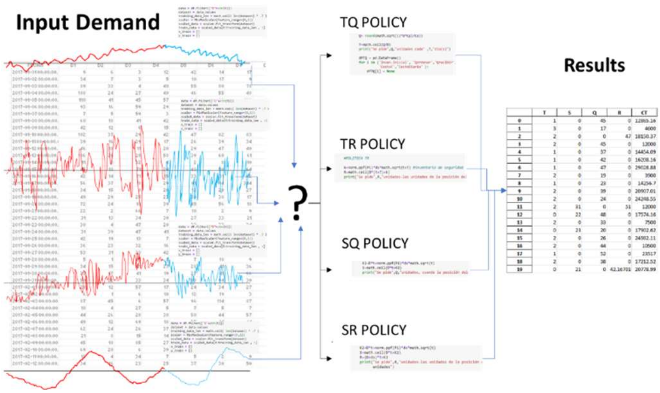

Figure 6: Understanding the algorithm

The projection of historical demand is made based on the artificial intelligence method called neural networks. Artificial neural networks are grouped by layers or neurons that form a neural network. The neurons take a value or weight in each training iteration until they fit with the test dataset. This allows, when the history is entered, to predict the number of values, according to the weights they retain, and the projection is approximate (Anon., 2019).

To make use of neural networks, the training data set corresponding to 70% of the demand history is first obtained and normalized because it is a requirement to use the time series in the neural network. For the above, we have a database provided by the pharmacist for five months.

The model is trained with groups of twenty data points that is updated chronologically and predicts the following position. Figure 7: Algorithm training representation illustrates the training process with six data points and clusters of three. The training begins by predicting the value of the demand on day 4 based on the grouping of the first 3 data points of the time series, then the value of the demand on day 5 is predicted, based on the grouping of days 2 to 4 and so on until an adjustment and creation of the neural network model is generated.

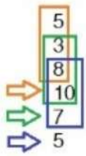

Figure 7: Algorithm training representation

The algorithm uses a neuron that iterates one hundred times, and it adjusts considering the weights of the connections of the neurons of the Adam method, as it has an exceptionally good behavior in forecasting with the time series. (Velasco, 2020)

Once the model has been trained, the demand for the following 60 days is predicted, the inverse of the data normalization is conducted and a Data Frame with sixty positions is created to store the prediction that will support the inventory policies.

The data obtained from the demand prediction are simulated to show the behavior of the inventory in each of the policies according to the input variables mentioned above. Each policy has the order of the structure shown below:

1. The inventory policy is calculated, that is, the quantity to be ordered and how often to order.

2. The projected data are saved in the data frame.
3. The quantity to be ordered and received is assigned in accordance with the inventory policy, as follows:

TQ POLICY: For the quantity to be ordered, if day i is a multiple of the order frequency T i.e., if (i/T -integer (i/T) =0 then on that day Q units are ordered, otherwise it is assigned an amount of 0. For the quantity, it is configured so that the data stay in the data frame on the order day plus the supply time.

TR POLICY: For the quantity to be ordered and the quantity to be received in this policy, it works the same as with the TQ policy, but unlike it, the quantity to be ordered is R (roof) minus the position that the inventory has on day i.

SQ POLICY: For the quantity to be ordered, the entire data frame is traversed, so that if the inventory position is less than the safety stock, Q units are ordered, which would be received in (i + t) days.

SR POLICY: For the quantity to be ordered and the quantity to be received in this policy, it works the same as with the SR policy, with the difference that in this policy, the quantity to be ordered is R (roof) minus the position that the inventory has on day i.

1. The daily costs of shipping, maintenance, and missing item are calculated, and they are totaled at the end. In this way, if at position i of the Quantity to be ordered there is a positive value, the shipping cost will be equal to Cp, otherwise it is 0. If the inventory at the end of the day has a positive value the maintenance cost is Cs by the number of units, otherwise it is 0. If the inventory at the end of the day has a negative value, then a Cf cost is assigned, otherwise it is 0.
2. The costs of all the days projected for each policy are totaled.
3. The policy that generated the lowest total cost is chosen

5 Results

The results are presented in a table from the Excel spreadsheet associated with the algorithm, which indicates the type of policy to be used according to each SKU. SKUs are identified with an integer value of one digit and their results are presented in the same order in which they were entered. Figure 6: Understanding the algorithm shows the process for obtaining the results. In summary, the historical demand data is first inserted in Excel, then the algorithm is executed and finally the results are obtained in Excel. The variables found in the result table are T (supply time), Q (quantity to be ordered), R(Roof) and S (Safety stock). To identify the policy to which each product belongs, it is necessary to verify which cells of the table contain a numerical value and to which column it belongs. For each SKU, two numerical values must appear in the table. For example, in the table 3 for the pilot shows that product 1 has a TQ policy, which means that each frequency(T) of 3 days 200 units of product (Q) must be ordered from the supplier.

Table 3: Results

Time (T)	Safety Inventory(S)	Quantity(Q)	Roof (R)	Total Cost
1	0	45	0	12865.16
3	0	17	0	4600
2	21	0	47	18150.37
2	0	45	0	12000
1	0	37	0	14454.09
1	0	42	0	16208.16
1	0	47	0	29028.88
2	0	19	0	3900
1	0	23	0	14256.7
2	0	39	0	20907.01

Additionally, the table shows an average daily cost that would be incurred to implement the policy according to each product, this cost is unleashed because it is the minimum compared to the cost that would be generated if the other policies were implemented.

The proposed solution is a low-cost tool that allows innovation in the planning of complex operations of small and medium-sized distribution centers. 4.0 technology is used to make the company more competitive by having real-time information and being able to generate an action plan that allows it to predict the future and respond to the behavior of its market. Considering that in Colombia only 78% of companies implement some type of technology such as Excel, QR readers, software, among others, this research has been conducted in the pharmaceutical sector to show that implementing these types of tools is not expensive and allows competitiveness in the sector.

6 Improvements

The fourth industrial revolution has brought about good practices hand in hand with technology, evidenced in applications, software, and robots from another generation. However, the adaptation of PYMES (small and medium enterprises) and even large companies are still in the process of starting this transformation and improvement. One of the objectives of this article pretends to give another meaning to this modernization. The substitution of some software's in the organizations are already possible. Professionals with new skills and knowledge in both logistics and programming are showing it. This stage of the industry is based on solving problems with low budgets, being innovative and creative with accessible resources with minimum cost.

Although the tool designed in this document helps to improve supply planning, as an opportunity for improvement, it is proposed to integrate the use of machine learning not only for the projection of demand but also for the determination of the inventory policy. The objective is that the algorithm acquires the ability to identify patterns in the behavior of the established policies, based on historical predictions and achieve a graphical display of them.

As well, this improvement will help to process a greater amount of data demand for each SKU analyzed. By having the history of the demand of at least one year, it is possible to identify the seasonality in the behavior and with it a better adjustment to the forecast.

On the other hand, it is necessary to look for an alternative that allows obtaining the optimal values of the parameters used in the neural network for the prediction, because the estimates lack well-defined criteria.

Finally, it is proposed that the user interacts only with Excel, or with a dynamic python interface that allows him to enter data easily and intuitively; without the need to open the Jupyter Notebook application, as it is considered more complex.

7 Conclusions

The digitization of planning has become an icon of the supply chain, key for its direction to be consistent with market behavior, managing to maneuver and persuade different demand behaviors.

Optimizing and trying to eliminate the activity from the planning is our proposal. Numerous planning activities that have been managed in the chain, as well as cost overruns generated by lack of forecasting or rapid changes, are some problems faced by several organizations, as they do not have a rapid response model to the uncertainty of the markets.

The model to propose is based on self-planning, which, through four inventory policies (TQ, SQ, SR and RT) responds to a changing demand, where the model learns to project the demand, and, which, according to its behavior, the algorithm locates an optimal sourcing policy for the type of demand it is presenting.

This digital transformation brings many benefits in the sector of this organization, allowing PYMES:

- To optimize the management of inventories, picking, and cross-docking to each store.

- To have information in advance, with greater certainty, to react and cope with the increases or decreases that the market presents; this makes the distribution center react whether to place or not frequent orders, in its supply.
- To reduce both the administrative costs of planning, as well as the errors and impacts that these generate in the chain.
- To substitute storage costs for responsiveness, interpreted with more credible data and synchronized with the market.
- To modernize and learn modern technology, through the use, maturation, and customization of an algorithm that can assertively expedite shipping products to different country stores.

It should be noted that it is not possible to quantify the performance of the model proposed in this article, compared to the implemented models seen in the literature review, since they do not share databases or some quantified result, which allows distinguishing the improvement of the proposed model.

Finally, the proposed improvements allow for greater foresight and identification of the inventory policy to be used, as well as greater practicality in manipulating the model and improving processing times.

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Auction Design in Strategic Freight Procurement

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Purpose: *This article aims to derive options for auction design in strategic freight procurement from the related literature and synthesize them into a design framework.*

Methodology: *The proposed framework is based on a comprehensive literature review on auction design in strategic freight procurement. After conceptualizing the research topic and defining the scope of the review, a broad literature search was conducted. Inclusion and exclusion criteria were applied to select the literature. A coding scheme was used to extract the data.*

Findings: *The literature review reveals design features and associated design options for each feature. This paper additionally identifies shortcomings in the scientific literature for auction design in strategic freight procurement. Based on this, the further need for research is derived.*

Originality: *The literature to date has focused primarily on describing the auction process and solving the Winner Determination Problem as a subset of the auction process. In contrast, the specific auction design (e.g., bid types, lane design, number of auction rounds) is only considered in a fragmented way. The proposed framework fills this research gap by synthesizing design options from the freight procurement literature.*

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1 Introduction

In times of uncertain supply chains and rising costs of transportation services, effective and efficient transportation management is of great importance for shippers to be resilient and keep costs under control (Caplice, 2021).

Strategic Freight Procurement is a core Transportation Management (TM) activity for shippers to establish contractual relationships with carriers for the provision of transportation services (Brilka and Clausen, 2021). In order to establish contractual relationships, reverse auctions (also referred to as freight tender by some authors (Andersson and Norrman, 2002; Guo, et al., 2006; Lim, Xu and Wang, 2008; Wang and Wang, 2015) are utilized. In a reverse auction, the shipper receives bids from selected carriers for lanes that the shipper has bid out and determines the winning bids as the basis of long-term contracts between the shipper and the carriers. An essential function of the contracts is to govern the assignment of carriers to lanes and the prices for transportation services. (Caplice and Sheffi, 2003; Sheffi, 2004; Caplice, 2007; Seiler, 2012; Holcomb, Liao-Troth and Manrodt, 2014)

Despite the relevance of strategic freight auctions, its process design has only been considered in a fragmented way in previous research. A synthesis of the various design approaches has been lacking so far. This paper aims to close this gap. For this purpose, design options are extracted from the existing literature and synthesized into a design framework. In this way, a holistic design framework is created to support shippers in designing freight auctions. Additionally, the literature reviewed provides a comprehensive overview of the freight procurement knowledge base and can be used as a foundation for future explanation-oriented and design-oriented research.

The remainder is structured as follows. The review methodology is described in Chapter 2. In Chapter 3, the review results and the design framework are presented. Finally, in Chapter 4, the research findings are discussed, and further research opportunities are identified.

2 Methodology

This chapter provides an overview of the research methodology used. A systematic literature review was conducted to extract design options from existing literature. The literature review methodology is based on the guidelines for systematic literature reviews by Durach, Kembro and Wieland (2017).

The first step was to conceptualize the research subject and define the scope of the literature review. The next step was to establish inclusion and exclusion criteria for paper selection to ensure that only those that contribute to the design of the strategic freight auction process are selected. The criteria are listed in the following table.

Table 1: Inclusion and Exclusion Criteria

Criteria for inclusion or exclusion	Reasoning
Exclusion: Paper focus on short-term procurement via spot market	Short-term procurement via spot market is not strategic (Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015; Acocella, Caplice and Sheffi, 2020)
Inclusion: Paper focus on shippers and contribute to the design of freight auctions	The design of auctions is done by the shippers
Inclusion: Paper is written in English	English is the prevalent language in supply chain and logisitcs research (Pan, et al., 2019)
Inclusion: Paper only published in journals ranked in the top quartile in at least one category in the Scientific Journal Ranking 2021 of SCImago	The quality of the work is guaranteed by publication in a reputable journal.

An exception to the journal ranking criteria is the monographic publication by Seiler (2012). The publication by Seiler (2012) was initially used to conceptualize the research subject, as it provides a comprehensive overview of TM, including a description of strategic freight procurement and its role in TM. Subsequently, the publication was included in the literature review despite the violation of the defined quality criterion in order not to ignore its contributions to auction design. However, this example illustrates that the quality criterion involves the risk that some high-quality publications were not included. The following shows the inclusion and exclusion criteria.

The Web of Science database was used for the literature search. The search was done using the keywords *freight procurement*, *freight auction,* and *freight tender* in all fields ((ALL=(*freight procurement*)) OR ALL=(*freight auction*) OR ALL=(*freight tender*)).

In the fourth step, the inclusion and exclusion criteria were used to remove irrelevant publications identified by the keyword search. An additional forward and backward search was performed using the same selection criteria for all remaining articles. The paper selection process is shown in Figure 1. The process was carried out jointly by the authors.

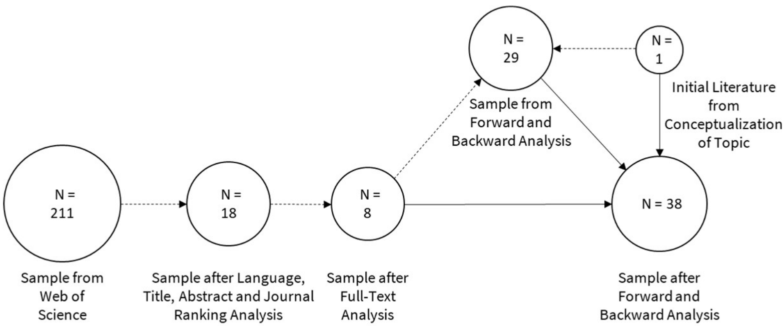

Figure 1: Paper Selection Process

In the next step, the selected literature was fully analyzed and integrated in terms of design options. A predefined coding scheme was used, to extract relevant data. The coding was done by two coders. Fields with discrepancies were resolved through a repeated joint coding of the respective publications. Literature was coded by author, year of publication, title and design options. In order for all coders to have an equal understanding of what a design option is, it was defined as a possibility for action to influence the way the strategic auction process is carried out. After an initial review of the material, the coding category of design options was divided into pre-auction stage design options, auction stage design options, and post-auction stage design options, following Caplice (2007), who divides the strategic auction process into these three stages. Table 2 shows which design options were assigned to which stage based on Caplice's (2007) descriptions.

Table 2: Strategic Auction Process – Stages

Stages	**Explanation**
Pre- Auction Stage Design Options	Design options that influence the way the auction preparation is performed.
Auction Stage Design Options	Design options that influence the way the auction execution is performed starting from the communication of the bid information.
Post-Auction Stage Design Options	Design options that influence the way the bid analysis and carrier assignment is performed.

In addition, each coder iteratively generalized each text passage and representation in the material that contained a design option and iteratively subsumed it under an inductively formed design feature. Inconsistencies were resolved through repeated joint generalization and feature formation.

Once all the design options were identified and grouped under the design features, the auction design framework was developed. For the development of the framework, morphological boxes were used, which according to Zwicky (1967) can be used for solving design problems. According to the process division into three stages, a morphological box is created for each of the process stages. To create a morphological box, a matrix is created in which the design features are arranged in the left column and the individual expressions (design options) are entered in the respective rows of the features (Hetterscheid and Schlüter, 2019). According to Zwicky (1967), the design options assigned to a feature are mutually exclusive. However, this need not always be the case as Hetterscheid and Schlüter (2019) and Pousttchi, Schrödl and Turowski (2009) show. For the design of the morphological boxes in this paper, the second approach is followed, since some identified design options of a feature, as shown in the literature, do not necessarily have to exclude each other.

3 Review Results and Design Framework

Based on 38 selected peer-reviewed journal articles, 38 design features with a total of 220 design options, distributed over three auction stages, were identified and compiled into a design framework. The design framework is shown in Figure 2. The framework consists of three design packages corresponding to the three stages of an auction process: pre-auction stage design, auction stage design, and post-auction stage design. Each design package consists of several design features, each of which includes several design options and is arranged in a morphological box (Figures 3 to 7). For better clarity, the morphological box for pre-auction stage design has been divided into three sub-boxes (Figures 3 to 5). By combining at least one design option per feature of each morphological box, different design variants can be created for the auction process. In the following sections, the morphological boxes are illustrated, and the design options per feature of a box are presented according to the review results.

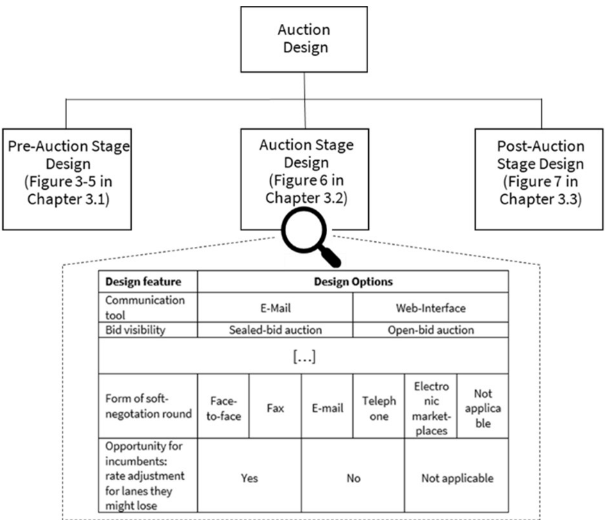

Figure 2: Auction Design Framework for Strategic Freight Procurement

3.1 Pre-Auction Stage Design

In the pre-auction stage, the shipper determines how the network is presented to the carriers, which carriers are to be invited, what information the carriers must submit (Caplice, 2007), and what terms and conditions the carriers must satisfy (Basu, Bai and Palaniappan, 2015). Figures 3 to 5 show the design features and options in the context of these tasks.

<table>
<tr><th>Design feature</th><th colspan="12">Design Options</th></tr>
<tr><td>Classification of lanes</td><td colspan="3">Point-to-point</td><td colspan="3">Zone-to-zone</td><td colspan="3">Zone-to-point</td><td colspan="3">Point-to zone</td></tr>
<tr><td>Lane design approach</td><td colspan="4">Threshold volume approach</td><td colspan="4">Distance classes approach</td><td colspan="4">Origin-destination pairs</td></tr>
<tr><td>Demand forecasting approach</td><td colspan="3">Estimation based on historic demands</td><td colspan="3">Stochastic determination from historical data</td><td colspan="3">Determination from future material flows</td><td colspan="3" rowspan="2">No demand planning</td></tr>
<tr><td>Distribution of forecasted demand</td><td colspan="2">Based on day</td><td colspan="2">Based on week</td><td colspan="2">Based on month</td><td colspan="3">Based on year</td></tr>
<tr><td rowspan="2">Lanes auctioned off</td><td colspan="6">Higher volume lanes</td><td colspan="6">Lower volume lanes</td></tr>
<tr><td colspan="3">With provision of a volume forecast</td><td colspan="3">Without provision of a volume forecast</td><td colspan="3">With provision of a volume forecast</td><td colspan="3">Without provision of a volume forecast</td></tr>
<tr><td>Agreement of back-up rates for lanes not auctioned off</td><td colspan="4">Yes</td><td colspan="4">No</td><td colspan="4">Not applicable</td></tr>
</table>

Figure 3: Pre-Auction Stage Design – Part 1 of 3

The network of a shipper consists of a set of lanes. Lanes are unidirectional arcs between two nodes on which a specific transportation service is to be provided (Caplice and Sheffi, 2003; Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019). According to Caplice (2007), nodes are either points or zones, and lanes can thus be classified as point-to-point, zone-to-zone, zone-to-point, or point-to-zone. Depending on the geographic specificity used, a point is a specific ship-to or ship-from-point, a city, or a postal code area. Anything larger than each is considered a zone (Ledyard, et al., 2002; Caplice, 2007; Lim, Rodrigues and Xu, 2008; Yang and Huang, 2021).

Furthermore, Caplice (2007) outlines an approach to deciding which shipping locations to be treated as a point rather than combined into a zone. The approach can be referred to as “threshold volume approach” (Caplice, 2007). The approach proposes to use volume thresholds that must be reached as a point-to-point, zone-to-zone,

zone-to-point, or point-to-zone lane. The thresholds are defined in such a way that higher volumes travel on point-to-point, zone-to-point and point-to-point lanes, while low volumes travel on zone-to-zone lanes. The objective of the approach is to consider both effectiveness and coverage when establishing the representation of the network. On the one hand, most lanes should be sufficiently specific to allow the carrier to price them accurately; on the other hand, lanes should cover all regions where traffic could occur throughout a contract period. (Caplice, 2007)

A prerequisite for using the threshold volume approach is a forecast of the demand of each origin-destination flow for the transportation service to be procured through the auction process. Several methods for forecasting demand can be found in the literature. The demand can either be estimated based on historical demand data or calculated using stochastic methods (Moore, Warmke and Gorban, 1991; Basu, Subramanian and Cheikhrouhou, 2015; Qian, et al., 2020). In addition, the demand can be determined from future material flow data such as sales forecasts or production plans (Lim, Rodrigues and Xu, 2008; Seiler, 2012). Besides lane design, demand forecasts are also essential information for the price calculations of carriers (Caplice and Sheffi, 2003). Nevertheless shippers occasionally do not provide them at all (Caplice, 2007) or do not provide them in sufficient quality. On the one hand, quality problems arise from inaccurate forecasts (Basu, Subramanian and Cheikhrouhou, 2015) and, on the other hand, from the inaccurate provision of the distribution of expected demands. Caplice and Sheffi (2003) show how the provision of expected demands per year negatively affects shippers' bidding behavior. Alternative time units reported in the literature to indicate demand distributions are day, week, or month (Caplice, 2007; Rekik and Mellouli, 2012; Basu, Bai and Palaniappan, 2015).

An alternative approach for designing lanes is shown in the GVE (Güterfernvekehrentgelte). The GVE is a collection of standard rates for long-haul transportation in Germany (Seiler, 2012). In a GVE rate structure presented by Seiler (2012), lanes are defined in distance bands of 100 km each to a point. It is thus a network representation based exclusively on the point to zone or zone to point scheme, where each zone corresponds to a distance class (e.g., until 100km, until 200km, etc.) from or to a point. A third method simply defines lanes as origin-destination pairs (Ledyard, et al., 2002; de Vries and Vohra, 2003; Basu, Bai and Palaniappan, 2015; Yang and Huang, 2021).

Another design feature of the network representation is to decide which lanes to bid out. Caplice (2007) points out that shippers typically auction off the higher volume lanes with a forecasted volume. The lower volume lanes, however, will not be explicitly auctioned. Instead, shippers typically request back-up rates from carriers for a collectively exhaustive and mutually exclusive set of zones without giving a volume forecast.

In order to determine which carriers to invite to an auction, the first step is to identify potential carriers. On the one hand, potential carriers are carriers that have been used in the past and, on the other hand, carriers that have not been used yet (Caplice and Sheffi, 2003; Caplice, 2007). To identify new carriers, various sources of information are available to shippers, such as carrier websites (Caplice and Sheffi, 2003), public exchanges (Caplice, 2007), trade media, word of mouth, or carrier promotion (Krapfel and Mentzer, 1982). The search for potential carriers can lead to a high number of hits. In addition, especially for potential carriers who are not incumbents, performance data is usually not or hardly available (Caplice and Sheffi, 2003). In order to reduce the number of carriers and thus the complexity as well as costs of the final selection and to ensure a certain level of quality of the carriers, the shipper can perform a pre-selection before inviting carriers to an auction (Coulter, et al., 1989; Moore, Warmke and Gorban, 1991; Ledyard, et al., 2002; Rekik and Mellouli, 2012; Basu, Subramanian and Cheikhrouhou, 2015; Wang and Wang, 2015). However, according to Sheffi (2004), a pre-selection of carriers has the disadvantage that carriers may be excluded prior to an auction based on their performance level, even though their price level would compensate for the deficiency.

Design feature	**Design Options**						
Carriers considered for an auction	Carriers used in the past			New carriers			
Sources of information used for the search of new carriers	Carrier websites	Public exchanges	Trade media	Word of mouth	Carrier promotion	Not applicable	
Carrier pre-selection	Includes incumbent carriers		Includes non-incumbent carriers		No pre-selection		
Evaluation method for pre-selecting non-incumbent carriers	MCDM method: Weighted Sum Model	MCDM method: Analytic Hierarchy Process (AHP)	MCDM method: Other MCDM method	Non-formalized method			Not applicable
Evaluation criteria for pre-selecting non-incumbent carriers	On-time performance	Cut-off times	Reliable pick-up service	Completeness of service offered	Break bulk usage	Direct service points	Not applicable
	Hub locations	Full state coverage	EDI capability	Discount percentage	Barcode tracing	Satellite tracing and communications	
	FAK class rate	Quality/ safety program	Carrier security	Claims ratio	Operating ratio	Claims payment	
	Safety ratings	Insurance coverage	Tranist times (Two-day service)	Service flexibility	Carrier reputation	Familiarity with shipper operations	
	Quality of carrier personnel	Billing service	Service frequency	Rate changes	Loss/ damage history	Financial stability	
	Quality of customer service (e.g., ability to handle special needs and emergencies)	Pricing flexiblity	Handling capabilities	Area coverage			
Numbers of persons and fuctions involved	One person from one business funtion		Multiple persons from one business function		Multiple persons from multiple business functions		

Figure 4: Pre-Auction Stage Design – Part 2 of 3

When a shipper pre-selects carriers, this may include non-incumbents as well as incumbents, although it is rare that incumbent carriers are not invited to an auction, according to Caplice (2007). The pre-selection of carriers is also known as Request for Information (RFI) (Andersson and Norrman, 2002).

As Basu, Subramanian and Cheikhrouhou (2015) show, the decision to invite or not invite incumbents to an auction is made based on the output of the carrier performance review process. Since the process of the performance review is not the subject of this paper, evaluation criteria and methods relevant to the design of this process are not discussed in the following. For non-incumbents, in contrast, carrier evaluation is part of the screening process. How such screening activity can be conducted is demonstrated by the case study of MicroAge Computer Centers Inc. with 300 carriers described by Sheffi (2004). In 1994, the company pre-selected carriers for an auction using a weighted sum model that evaluated carriers based on their responses to 18 evaluation criteria. In addition to these 18 criteria, other criteria can be considered when selecting carriers, as the results of literature reviews on carrier attributes conducted by Meixell and Norbis (2008) and Coulter, et al. (1989) reveal. The individual evaluation criteria presented in both publications are summarized in the morphological box in Figure 4.

Meixell and Norbis (2008) also show that in addition to the Weighted Sum Model, the Analytic Hierarchy Process (AHP) is also used as a multi-criteria decision making (MCDM) method for carrier selection purposes. In addition, they point out that non-formalized methods are also used for carrier selection. Basu, et al. (2016) further show that in addition to the Weighted Sum Model and AHP, there are other MCDM methods such as Data Envelopment Analysis (DEA) or Grey relational analysis. However, their suitability is discussed only in the context of criteria weighting for a final carrier selection method in the post-auction stage.

Another design feature for carrier screening concerns the number of persons and business functions involved in the selection decision. According to Krapfel and Mentzer (1982), selection decisions can be made by one or more persons from one business function or multiple persons from multiple business functions (e.g., Purchasing and Logistics).

Determining what information the carrier must submit back includes the form of the price, service details, and the types of bid allowed (Caplice, 2007). According to Seiler (2012), the price for a lane includes a basic rate structure, optional discounts, and surcharges.

<table>
<tr><th>Design feature</th><th colspan="8">Design Options</th></tr>
<tr><td rowspan="2">Form of basic rate structure</td><td rowspan="2">Per move</td><td rowspan="2">Per distance unit</td><td>Per load size scale</td><td>Per move and per load size scale</td><td colspan="2">Per load size unit / load size scale</td><td colspan="2" rowspan="2">Per weight / weight scale / product class</td></tr>
<tr><td>With dimensional conversion factor</td><td colspan="3">Without dimensional conversion factor</td></tr>
<tr><td>Surcharges and discounts</td><td>Index-based surcharges and discounts (e.g., diesel floater)</td><td>Additional driver surcharges</td><td>Surcharges for unplanned eventualities such as demurrage</td><td>Additional stop costs</td><td>Fees for customs clearance</td><td>Discounts on continuous moves</td><td colspan="2">Discounts on the total trans-portation expenditure with a carrier</td></tr>
<tr><td rowspan="4">Service components (S = specified by shippr; C = specified by carrier)</td><td colspan="2">Transit days</td><td colspan="2">Capacity availability</td><td>Equipment type</td><td>Maximum waiting time free of charge</td><td colspan="2">Latest amendments or cancellations</td></tr>
<tr><td>S</td><td>C</td><td>S</td><td>C</td><td>S C</td><td>S C</td><td>S</td><td>C</td></tr>
<tr><td colspan="2">Weekend Coverage</td><td colspan="2">Brokerage rights</td><td colspan="2">Safety factors</td><td colspan="2">Performance factors</td></tr>
<tr><td>S</td><td>C</td><td>S</td><td>C</td><td>S</td><td>C</td><td>S</td><td>C</td></tr>
<tr><td>Additional terms and conditions</td><td>IT capabilities</td><td>Minimum volume or spend guarantees</td><td>Payment terms</td><td>Penalty rules for service deficiencies</td><td>Required insurance coverage of the carrier</td><td>Contract period</td><td>Working instructions</td><td>Other (eg., from ADSp)</td></tr>
<tr><td rowspan="2">Types of bid allowed</td><td rowspan="2">Simple lane bid</td><td rowspan="2">Simple segment bid</td><td rowspan="2">Simple lane bid with volume con-straints</td><td>Static package bids (And)</td><td>Static either/or package bids (XOR)</td><td>Flexible Package Bids</td><td rowspan="2">Simple reload bids</td><td rowspan="2">Tier Bids</td></tr>
<tr><td colspan="1">Shipper created</td><td colspan="2">Carrier created</td></tr>
<tr><td>Limitation of the number of bids</td><td colspan="4">Yes</td><td colspan="4">No</td></tr>
<tr><td>Back up carrier bids required</td><td colspan="4">Yes</td><td colspan="4">No</td></tr>
</table>

Figure 5: Pre-Auction Stage Design – Part 3 of 3

Depending on the service, there are different ways to represent the basic rate structure, as publications addressing the rate structure of FTL services, LTL services, and parcel services reveal (Lapierre, Ruiz and Soriano, 2004; Caputo, Fratocchi and Pelagagge, 2006; Caplice, 2007; Seiler, 2012; Yang and Huang, 2021). Several options can be derived from these publications to represent the basic rate structure. The price is either given *i)* per move, *ii)* per distance unit, *iii)* per load size scale, *iv)* per move and per load size unit, *v)* per load size unit per load size scale, and *vi)* per weight unit per weight scale per product class. Load size scales and the load size units are commonly given in the dimensions of weight, cube space, or floor space (Seiler, 2012). However, to ensure that carriers are not solely dependent on one dimension when determining prices, a volume/weight ratio is often also specified as a conversion factor. This allows carriers to price a load either by weight or by volume, depending on which dimension utilizes a means of transportation more. (Lapierre, Ruiz and Soriano, 2004; Seiler, 2012) An alternative to using a dimensional conversion factor is followed in alternative *vi)* with pricing by product class. This option is typical for LTL services in North America. There, product classes are formed primarily by weight density in accordance with the National Motor Freight Traffic Association guidelines, which also allow carriers to take volume and weight into account when pricing a load. (Lapierre, Ruiz and Soriano, 2004)

In addition to the multiple ways to determine the basic rate structure, the literature also provides several options regarding surcharges and discounts. Surcharges and discounts that have been identified in the literature are index-based surcharges or discounts (e.g., diesel price floater), additional driver surcharges, surcharges for unplanned eventualities such as demurrage, additional stop costs, fees for customs clearance, discounts on continuous moves and discounts on the total transportation expenditure with a carrier. (Caputo, Fratocchi and Pelagagge, 2006; Caplice, 2007; Seiler, 2012; Turner, et al., 2012; Scott, 2015; Yang and Huang, 2021)

The service details are either provided by the carrier based on requested service information (Caplice, 2007) or provided by the shipper as terms and conditions that the carrier must satisfy (Andersson and Norrman, 2002; Basu, Bai and Palaniappan, 2015). However, service components specified in an auction process have only been considered marginally in the literature. Although some service components are mentioned sporadically (Andersson and Norrman, 2002; Caplice, 2007; Seiler, 2012; Zhang, et al., 2018), a systematic exploration of different possibilities is missing so far. Service components identified in the different publications include the following: transit days, capacity availability, and equipment type, a maximum waiting time free of charge, the latest possible time until which a load tender can still be amended or canceled, weekend coverage, brokerage share, safety factors, performance indicators such as a tender acceptance ratio, service quality.

Besides the service components, the literature mentions additional terms and conditions that the shipper can formulate as the basis of the business relationship with the carrier. These are (Andersson and Norrman, 2002; Caplice and Sheffi, 2003; Lim, Rodrigues and Xu, 2008; Lim, Xu and Wang, 2008; Meixell and Norbis, 2008; Lim, Qin and Xu, 2012; Seiler, 2012; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015; Zhang, et al., 2018): required IT capabilities (e.g., electronic data interchange), minimum volume or spend guarantees, payment terms, working instructions, penalty rules for service deficiencies, required insurance coverage of the carrier, and the contract period, which is usually one to three years (Ledyard, et al., 2002; Caplice and Sheffi, 2003; Caplice, 2007; van Duin, Tavasszy and Taniguchi, 2007; Lim, Qin and Xu, 2012; Seiler, 2012; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015). Furthermore, there are standardized terms and conditions, such as the ADSp in Germany (Allgemeine Deutsche Spediteurbedingungen), which contain additional terms and conditions for defining the business relationship (Seiler, 2012).

Another design feature of the pre-auction phase is the definition of the types of bids allowed (Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015). Basu, Subramanian and Cheikhrouhou (2015) distinguish two bid types, single bids and combinatorial bids, between which a shipper can choose. Single bids, also referred to as simple bids, are the traditional practice in transportation in which carriers bid for individual lanes or segments of the network, regardless of the volume of business they might win (Caplice and Sheffi, 2003; Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015). The advantage of single bids is that finding the lowest cost carrier can be done by simply sorting the lowest rates on a lane-by-lane (segment-by-segment) basis using a database application or spreadsheet (Caplice and Sheffi, 2003). However, a disadvantage of this type is that carriers are incentivized to hedge their bid prices against the possibility that they will not be awarded any supporting business (Caplice, 2007). Another disadvantage of the simple bid type is that system constraints, such as ensuring that a carrier wins at least a certain level of business or needing a minimum number of carriers serving a location, cannot be considered (Caplice and Sheffi, 2003). Combinatorial bids, in contrast, can consider system constraints. In addition, the uncertainty regarding the amount of business to be won can be reduced (Caplice and

Sheffi, 2003; Lafkihi, Pan and Ballot, 2019). However, to find the lowest cost carrier when using combinatorial bids, it is necessary to apply a formal optimization method instead of a simple sorting method (Caplice and Sheffi, 2003). According to Basu, Subramanian and Cheikhrouhou (2015), combinatorial bids are bids where carriers can submit bids on combinations of lanes. A different understanding of combinatorial bids is expressed by Caplice (2007). The author equates combinatorial bids with conditional bids and understands them as the submitting of bids that are conditional on a pre-defined set of actions also taking place. Several forms of conditional bids are presented in the literature (Ledyard, et al., 2002; de Vries and Vohra, 2003; Abrache, et al., 2004; Guo, et al., 2006; Caplice, 2007; Lim, Rodrigues and Xu, 2008; Chen, et al., 2009; Ma, Kwon and Lee, 2010; Ignatius, et al., 2011; Lim, Qin and Xu, 2012; Rekik and Mellouli, 2012; Remli and Rekik, 2013; Zhang, et al., 2014; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015; Wang and Wang, 2015; Basu, et al., 2016; Zhang, et al., 2018; Remli, et al., 2019; Qian, et al., 2020; Yang and Huang, 2021). Caplice (2007) describes six types of bids currently used in transportation practice. These are 1) Simple Lane Bid with Volume Constraints; 2) Static Package Bids (AND); 3) Static Either/Or Package Bids (XOR); 4) Flexible Package Bids; 5) Simple Reload Bids; and 6) Tier Bids. When using package bids, the shipper must additionally decide whether the shipper or the carriers should create the lane packages. While in most auctions, packages are created by the seller (e.g., art, antique, and other “collection-like” auctions), Caplice and Sheffi (2003) have found that in transportation, packages specified by shippers are less successful because carriers are better at identifying valid lane combinations based on their individual networks and perspectives.

Additionally, regardless of allowing a form of simple or conditional bidding, the shipper must decide whether to set an upper bound on the number of lanes or packages that can be bid on or not (de Vries and Vohra, 2003; Wang and Wang, 2015). Furthermore, shippers must decide whether to require carriers to bid only to serve lanes as primary carriers or serve lanes as alternate or back-up carriers (Caplice and Sheffi, 2003).

3.2 Auction Stage Design

In the auction stage, the shipper communicates the bid information to the carriers, and the carriers submit their bid rates (Caplice and Sheffi, 2003; Caplice, 2007; Seiler, 2012; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015). The design features and options of the auction stage are shown in Figure 6.

Communication tools are used to transmit the bid information to carriers and receive their bids. Nowadays, shippers usually use either e-mail or some sort of web interface (Caplice, 2007; Wang and Wang, 2015).

Concerning the design feature of bid visibility, the literature distinguishes between sealed-bid auctions (no real-time visibility of the rates submitted by competitors) and open-bid auctions, also referred to public-bid auctions (real-time visibility of the rates submitted by competitors) (Ledyard, et al., 2002; Caplice and Sheffi, 2003; Lafkihi, Pan and Ballot, 2019). With open-bid auctions, the initial prices paid can often be significantly reduced due to the transparency of competition created. Disadvantages, however, are that conditional bidding is not possible, that performance factors are ignored, and that a "damaging price war between carriers" is promoted, which can lead to a large portion of the network having to be re-sourced later. In addition, the acceptance of open-bid auctions is low among some carriers, increasing the risk that some carriers refuse to participate in an auction. (Caplice and Sheffi, 2003)

In terms of the number of rounds, a distinction is made between single and multiple auction rounds (Ledyard, et al., 2002; Caplice and Sheffi, 2003; de Vries and Vohra, 2003; Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019). Single round auctions can reduce the probability of a "damaging price war between carriers", incentivizing carriers to give accurate prices "without playing games" and causing less effort than multiple rounds. Multiple rounds, in contrast, provide carriers with the opportunity to adjust their bidding strategies and allow the shipper to exert more pressure on the carriers to lower their bids (Caplice and Sheffi, 2003; Rekik and Mellouli, 2012; Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019). Lafkihi, Pan and Ballot (2019) refer to such auctions, where the bidder adjusts their starting bid downwards in the auction as a descending auction.

<table>
<tr><th>Design feature</th><th colspan="10">Design Options</th></tr>
<tr><td>Communication tool</td><td colspan="4">E-Mail</td><td colspan="6">Web-Interface</td></tr>
<tr><td>Bid visibility</td><td colspan="4">Sealed-bid auction</td><td colspan="6">Open-bid auction</td></tr>
<tr><td>Number of rounds</td><td colspan="2">Single round</td><td colspan="8">Multiple rounds</td></tr>
<tr><td>Exclusion of carriers between rounds</td><td colspan="2">Not applicable</td><td colspan="4">Yes</td><td colspan="4">No</td></tr>
<tr><td>Price information for the carriers between rounds</td><td colspan="2">Not applicable</td><td colspan="3">Provision of the current winning bid on each lane between rounds</td><td colspan="3">Provision of a complete distribution of the bids on each lane between rounds</td><td colspan="2">Provision of a partial distribution of the bids on each lane between rounds</td></tr>
<tr><td>Change of bid type between rounds</td><td colspan="2">Not applicable</td><td colspan="4">Yes</td><td colspan="4">No</td></tr>
<tr><td>Withdrawal rule</td><td colspan="5">Withdrawal of bids is allowed</td><td colspan="5">Withdrawal of bids is prohibited</td></tr>
<tr><td>Stopping rule</td><td colspan="2">After a specified time has elapsed</td><td colspan="3">Standing bid is not outbid within a specified time</td><td colspan="3">After the acquisition cost to a previous round did not decline by a specified percentage + a final round</td><td colspan="2">After a defined number of rounds</td></tr>
<tr><td>Final soft-negotiation round</td><td colspan="5">Yes</td><td colspan="5">No</td></tr>
<tr><td>Form of soft-negotation round</td><td>Face-to-face</td><td colspan="2">Fax</td><td colspan="2">E-mail</td><td colspan="2">Telephone</td><td colspan="2">Electronic market-places</td><td>Not applicable</td></tr>
<tr><td>Opportunity for incumbents: rate adjustment for lanes they might lose</td><td colspan="3">Yes</td><td colspan="4">No</td><td colspan="3">Not applicable</td></tr>
</table>

Figure 6: Auction Stage Design

Options for shippers to influence the bidding of carriers in the next round include deciding how to handle non-winning bids and what information to provide to shippers for the next round (Caplice and Sheffi, 2003). To deal with non-winning bids, Basu, Subramanian and Cheikhrouhou (2015) and Wang and Wang (2015) present the option to call each bidder for the next round. The literature does not address the alternative option of carriers being excluded from the bidding process for certain lanes or packages based on one or more criteria.

Information provided to shippers for the next round is not much represented in the literature. Regarding the information provided to carriers for the next round, Wang and

Wang (2015) and Ledyard, et al. (2002) state that reference prices should be shared with carriers to enhance competition. However, the construction or content of reference prices is not defined. According to Caplice and Sheffi (2003), shippers have the options of, among other things, presenting carriers with a complete or partial distribution of the bids on each lane or providing carriers with information on the current winning bid on each lane

Furthermore, Wang and Wang (2015) show that shippers can change the bid type between rounds under certain circumstances and accordingly provide the relevant information to carriers before the next round. In the use case presented by the authors, the carriers are to submit self-created package bids in the first round. Based on the bids, the shipper then creates overlap-free packages covering all lanes, on which the carriers have to bid in the next round. The goal of the approach is to leverage the advantages of carrier-created packages without taking the risk of not finding a solution in carrier assignment that covers all auctioned lanes without overlaps.

Two other design features for the design of the auction stage are the withdrawal rule and stopping. The withdrawal rule is an additional design feature for the design of multi-round auctions. The stopping rule applies to the design of both single and multiple round auctions. Based on Ledyard, et al. (2002), the shipper's decision whether to allow or prohibit the withdrawal of a provisional winning bid is defined as the withdrawal rule. Ledyard, et al. (2002) argue in their paper that shippers should not be allowed to withdraw provisional winning bids as this creates bad incentives and prolongs the auction. The stopping rule is also addressed by Ledyard, et al. (2002). According to the author, the stopping rule specifies when an auction ends. Three stopping rules are presented by the authors: 1) the auction ends after a specified time has elapsed; 2) the auction ends if no one outbids the current standing bid within a specified time; 3) the auction ends after a final round, which is declared if the acquisition cost did not decline by a specified percentage compared from the previous round. Another stopping rule for multi-round auctions is shown by Wang and Wang (2015). The auction presented by the authors ends after a defined number of rounds. In addition, several authors mention stopping rules but do not specify them. (Abrache, et al., 2004; Basu, Subramanian and Cheikhrouhou, 2015; Lafkihi, Pan and Ballot, 2019).

Another design feature for both single and multi-round auctions is the decision whether there should be a final soft-negotiation round (Andersson and Norrman, 2002; Caplice, 2007). If a final soft-negotiation round is to be conducted, there are two further design decisions that apply. The shippers must decide whether incumbent carriers are offered the opportunity to adjust their submitted rates on lanes they stand to lose (Caplice, 2007), and what the form of negotiation will be. The traditional form of negotiation is face-to-face. Other forms include using fax, e-mail, telephone, or electronic marketplaces. (Lafkihi, Pan and Ballot, 2019)

3.3 Post-Auction Stage Design

The post-auction stage includes the analysis of the bids submitted per round, the assignment of the business to specific carriers, and the assembling of the routing guide (Caplice and Sheffi, 2003; Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015). Figure 7 shows the identified design features and options in this stage.

Caplice and Sheffi (2003) distinguish three types of methods used in practice for bid analysis and carrier assignment. These are simple sorting of lowest rates, MCDM, and optimization-based analysis. Simple sorting of the lowest rates is a standard method by shippers running bids in-house. An advantage of the method is that it can be performed with little effort if the network complexity is low. However, the disadvantage of the method is that neither performance and sustainability factors nor conditional bids and business constraints can be considered. Whereas with an MCDM method, it is possible to consider performance factors. (Caplice and Sheffi, 2003)

Design feature	Design Options						
Bid analysis and carrier assignment method	Simple sorting of lowest rates	MCDM method: Weighted Sum Model	MCDM method: Analytic Hierarchy Process (AHP)	MCDM method: Other MCDM method	Non-formalized method	Optimization-based analysis	
Performance factors considered in carrier assignment	On-time performance	Reliable pickup service	Billing service	Claims performance	Refusal rate		
	Transit time	Response time	EDI capability	Surge capacity	Loss/Damage history		
	Area coverage	Insurance coverage	Financial stability of carrier	Route optimization of carrier	Energy efficiency of carrier		
	Carbon foot print of carrier	Electronic documentation	Carrier security	Satellite tracing and communications	Quality of carrier personnel		
	Carrier reputation	Familiarity with shipper's operation	Completeness of service offered	Pricing flexibility	Loading and unloading facilities		
	Handling capabilities	Service frequency	Rate changes	Willingness to focus on continuous improvement	Willingness to meet cost goals		
	Quality of customer service (e.g., ability to handle special needs and emergencies)	Established safety programs	Not applicable				
What-if scenarios with different business considerations	Yes	No					
Business considerations in carrier assignment (to choose for each scenario)	Carrier base size restrictions	Back up carrier bids	Minimum/ Maximum Coverage	Treshold volumes	Service requirement for alternates	Restricting carriers	
	Core carrier guarantees	Favoring of in-cumbents	Penalizing the nomination of additonal carriers	Carriers' disruption risk	Shortages in carriers' required shipment volumes	Valuing per-formance	Not applicable
Numbers of persons and fuctions involved	One person from one business funtion	Multiple persons from one business function	Multiple persons from multiple business functions				
Allocation mechanism	First-price auction	Second-price auction					
Documentation of auction rates and assignment	In paper-based system	In electronic catalog: With integration into an execution software system	In electronic catalog: Without integration into an execution software system				
Documentation of non-winning rates to be used as backup rates	Yes	No					

Figure 7: Post-Auction Stage Design

Yet, only a few studies have addressed the use of MCDM for bid analysis and carrier assignment. Basu, et al. (2016) contrast a weighted sum model with optimization-based analysis. In addition, they show that MCDM methods, such as AHP, Data Envelopment Analysis (DEA), or Grey relational analysis can be used to determine the weights of performance factors in a weighted sum model or an optimization-based analysis. However, the extent to which these MCDM methods are suitable as sole methods for carrier selection is not discussed. Meixell and Norbis (2008) give some examples from literature where carrier selection was made using AHP. Futhermore, Meixell and Norbis (2008) show that carrier selection is also performed by some shippers using non-formalized methods.

When using an MCDM method, a key design feature, in addition to deciding on a specific method, is the selection of performance factors to be evaluated. In the literature review, we found various performance factors that can be considered (Coulter, et al., 1989; Caplice and Sheffi, 2003; Sheffi, 2004; Guo, et al., 2006; Meixell and Norbis, 2008; Rekik and Mellouli, 2012; Basu, Subramanian and Cheikhrouhou, 2015; Basu, et al., 2016; Zhang, et al., 2018). The individual performance factors are shown in the morphological box in Figure 7.

Unlike simple sorting of lowest rates and MCDM methods, the use of optimization-based analysis has been the subject of numerous publications (Ledyard, et al., 2002; de Vries and Vohra, 2003; Abrache, et al., 2004; Guo, et al., 2006; Caplice, 2007; Lim, Rodrigues and Xu, 2008; Chen, et al., 2009; Ma, Kwon and Lee, 2010; Ignatius, et al., 2011; Lim, Qin and Xu, 2012; Rekik and Mellouli, 2012; Remli and Rekik, 2013; Zhang, et al., 2014; Basu, Bai and Palaniappan, 2015; Basu, Subramanian and Cheikhrouhou, 2015; Wang and Wang, 2015; Zhang, et al., 2015; Basu, et al., 2016; Zhang, et al., 2018; Remli, et al., 2019; Qian, et al., 2020; Yang and Huang, 2021). The Optimization-based analysis involves optimization-based approaches for solving the Carrier Assignment Problem (CAP) (Caplice and Sheffi, 2003), also called the Winner Determination Problem (WDP) (Caplice 2007). The CAP is about finding a carrier-lane assignment based on the auction bids that minimizes the shipper's total cost while ensuring that each lane is served and its required capacity is available (Basu, Subramanian and Cheikhrouhou, 2015).

The advantage of optimization-based approaches is the ability to analyze conditional bids and incorporate various business considerations, including performance factors, into the carrier assignment decision (Caplice and Sheffi, 2003). Some shippers even run multiple what-if scenarios with different business considerations to maximize the fit of carriers to their business needs (Caplice and Sheffi, 2003). Several business considerations can be found in carrier assignment models. The following business considerations can be found in carrier assignment models (Caplice and Sheffi, 2003; de Vries and Vohra, 2003; Guo, et al., 2006; Caplice, 2007; Lim, Rodrigues and Xu, 2008; Chen, et al., 2009; Ma, Kwon and Lee, 2010; Lim, Qin and Xu, 2012; Rekik and Mellouli, 2012; Zhang, et al., 2014; Basu, et al., 2016; Zhang, et al., 2018; Qian, et al., 2020):

- Carrier base size restrictions at the system, region, facility, or lane level
- Preventing carriers from being assigned as a primary carrier and alternate or back-up carrier on a lane (back-up carrier bids)
- Ensuring that the amount of traffic assigned to a carrier, or set of carriers across the system, within a region, at the facility level, or on a lane is within a certain bound (Minimum/Maximum Coverage)
- Ensuring that if a carrier is awarded any business on a lane, from or to a facility, or system-wide, it has to be of a certain minimum threshold amount (Threshold volumes)
- Limiting the number of carriers within the system by requiring that all carriers operate as both primary and alternate carriers over different segments of the system (Service requirement for alternates)
- Restricting carriers (e.g., non-incumbents) from serving certain portions of the system
- Guaranteeing that a group of core carriers wins a target level of traffic across the system (Core carrier guarantees)
- Favoring incumbents by penalizing bids of non-incumbents or discounting bids of incumbents
- Penalizing the nomination of additional carriers by imposing a cost on each carrier used
- Valuing performance by allocating penalties or rewards to the bids based on measured performance
- Integrating costs of mitigation strategies to deal with carriers' disruption risk

- Integrating penalty costs for demand uncertainty-related shortages in carriers' required shipment volumes

When valuing performance in a carrier assignment model, the shipper can choose from various performance factors, as shown in Figure 7.

Following Krapfel and Mentzer (1982), for the design feature of the number of persons and business functions involved in the assignment decision, just as in the case of carrier screening described above, a distinction can be made between 1) one person from one business function, 2) multiple persons from one business function, 3) multiple persons from multiple business functions.

With regard to the allocation mechanism, the shipper can choose between first-price auctions and second-price auctions. In first-price auctions, the carrier with the lowest bid wins the auction at the bid price submitted. In second-price auctions, the carrier with the lowest bid wins the auction at the price of the second-lowest bid. Compared to first-price auctions, second-price auctions are rare in transportation literature, although they have proven to be a truthful allocation mechanism. (Lafkihi, Pan and Ballot, 2019)

The assembly of the routing guide is the final step of the post-auction stage from a process perspective (Caplice, 2007). A routing guide is a paper-based system or an electronic catalog in which rates, assignments, and sometimes non-winning rates as back-up rates, are documented (Caplice, 2007; Basu, Subramanian and Cheikhrouhou, 2015). According to Caplice (2007), most shippers today use as a routing guide an electronic relational database that interfaces with an execution software system used to manage the day-to-day transportation operations (e.g., Transportation Management System). Basu, Subramanian and Cheikhrouhou (2015) also indicate that an electronic catalog is either integrated into the execution software system or not.

4 Discussion and Future Research Opportunities

The basis of this paper is that the design of the auction process for strategic freight procurement has so far been treated in research in a fragmentary way. Therefore, a holistic design framework that supports shippers in auction design has been lacking so far. In order to close this gap, first a systematic literature review was conducted to identify the various design fragments. In total, 38 peer-reviewed journal articles from 1982 to 2021 were systematically selected and analyzed. The literature review resulted in 38 design features with a total of 220 design options distributed across a total of three auction stages. Based on this, a design framework was developed which, for each of these stages, presents design features and design options in a structured and clear manner in matrices based on morphological boxes by Zwicky (1967). By combining at least one design option per feature of each morphological box, various of design alternatives can be generated for the auction process. However, the mere combination can also generate a variety of unsuitable or infeasible combinations. This represents a limitation of the design framework that can be addressed in future research by finding feasible and proven combinations. Another limitation of the design framework that should be addressed in future research is the evaluation of practicality and completeness. As the results of the literature review show, there are few or only a few comprehensive contributions to some design features, which creates the risk that not all potential options have been considered in the framework. The risk is further increased because most publications focus on road freight, and there in particular on FTL services.

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Comparing Manual and Automated Production and Picking Systems

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Purpose: *Automated processes play a crucial role, especially when high product quantities are desired. The automation of manufacturing and order picking processes enables companies to reduce the number of manual transports and order fulfillment time. Nevertheless, manual labor remains relevant. This paper analyses the key aspects that define manual and automated labor and their application in manufacturing and order picking systems.*

Methodology: *We conduct a literature review to analyze manual and automated systems in general and for manufacturing and order picking systems. Using field-based research, we provide several real-world use cases where decisions were made in favor of either concept. Finally, we use morphological analysis to distinguish the key elements of both systematics.*

Findings: *Manual labor cannot be substituted when dealing with highly volatile demands or a high variety of products. Moreover, human adaptability and prestidigitation can, thus far, not be automatized. In conclusion, manual as well as automated labor are not always interchangeable. Further, employing manual as well as automated labor is vital to maximize efficiency in manufacturing and order picking.*

Originality: *While studies exist that deal with automated and manual labor, most are directed at automatization of processes, not considering the advantages of manual labor.*

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1 Introduction

This paper aims to compare the processes of manual and automated labor and their application in manufacturing and order picking. Therefore, three research questions (RQ) are proposed: (RQ_1) What are the key elements that define manual and automated labor? (RQ_2) What are the disadvantages of manual labor that drive process planers to favor automated labor and vice versa? Answering these questions provides a framework for the answer of the third research question: (RQ_3) What method can be used to visually compare manual and automated labor? This question is answered using a morphological analysis.

To gain a holistic understanding of both concepts, the following section will be based on a literature review regarding manual and automated labor in general and for manufacturing and order picking systems. Additionally, using field-based research, several real-world examples are presented where decisions were made in favor of each process. In the third section, the literature review and field-based research findings are used in a morphological analysis. The results of review, research, and analysis are presented in the findings section. The paper closes with a conclusion, insights into the limitations of the study and avenues for further research.

2 Literature Review

2.1 Manual Labor

As the name implies, manual labor is physical work done by humans. Characteristics are adaptability and flexibility, dexterity, creativity, and cognitive ability.

- Adaptability is the proficiency to adjust to changes (Ployhart and Bliese, 2006) while flexibility describes the ability to accept changes in tasks, environmental or social features (Tindle and Moustafa, 2021). Although their definition is different, adaptability and flexibility are often used synonymously.
- Dexterity describes the manipulation of the human hand with the goal of manipulating objects. This can be done according to a visual input, also called

eye-hand coordination, or by memory of the desired object's location without visual input (Johansson, et al., 2001).

- Creativity is defined as "the production of novel and useful ideas by an individual or small group of individuals working together". It is described as the "front end of innovation", which can be seen as "the successful implementation of creative ideas within an organization"(Amabile and Pratt, 2016).
- Cognitive ability, often also described as general intelligence, is the capability to "reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience" (Gottfredson, 1997).

Additionally, human labor can be divided into two different forms: physical and mental workload. Physical workload is characterized by tasks that require a person to adapt to energetic, biomechanical or environmental demands (Sluiter, 2006). Mental workload is an individual's capability to provide cognitive capacities towards task demands. Generally, the mental workload increases when the demands of the task are high, e.g., when dealing with high amounts of information, and responding capacities are low. Correspondingly, low task demands, and high capacities lead to low mental workload and therefore underload or inattention (Hwang, et al., 2008).

The downsides of manual work are mental and physical limitations, fatigue, and error. Physical limitations are the limits the human musculoskeletal system can endure. Mental limitation describes the human brain's limited capacity to become aware of, hold in mind, and act upon visual information. Some factors affecting the limits of a human being, physical and mental, are exposure to environmental extremes like heat or cold, sleep deprivation or noise (Sadegh and Worek, 2006).

Fatigue can be categorized into mental and physical fatigue. Physical fatigue, also known as muscle fatigue, is a decline in performance due to exercise-induced reduction of the maximal voluntary muscle force. (Wan, et al., 2017). Mental fatigue describes a state of diminished cognitive performance, caused by prolonged cognitive activity (Marcora, Staiano and Manning, 2009).

Human error is a deviation from intention, expectation or desirability (Senders and Moray, 2020). While fatigue and limitations, mental and physical, contribute towards errors, they are not the only reasons for humans to fail. Distractions from systems or other persons or acute causes like illnesses or injuries also influence human performance and error (Rasmussen, 1982). Human error is responsible for about 80% of total product failures (Di Pasquale, et al., 2015).

2.1.1 Manual labor in manufacturing

Modern companies are subjected to more and more complexity challenging their manufacturing sector. Figure 1 illustrates the drivers of manufacturing complexity.

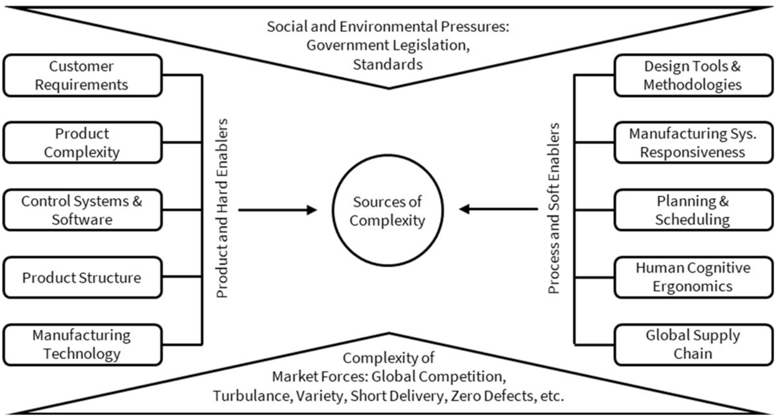

Figure 1: Drivers of Manufacturing Complexity (Elmaraghy, et al., 2012)

Therefore, they rely on manual labor in areas where high flexibility is imperative, or automation is economically unreasonable or technically difficult or impossible. The most typical manual labor tasks are material handling and assembly of products. Manual handling involves the lifting, lowering, pushing, pulling, or carrying loads. Reasons for manual materials handling are the high grade of flexibility and the costs (Lee and Dai, 2011). Characteristic assembly operations consist of joining and handling parts as well as adjusting, controlling and various auxiliary operations (e.g., cleaning, unpacking, printing, oiling). It is estimated that assembly makes up about 45% of the total manufacturing work (Lotter and Wiendahl, 2012).

Manual assembly systems utilize the worker's high flexibility, adaptability and ability to process multiple sources of information and rapidly switch between tasks (Hinrichsen, Riediger and Unrau, 2016).

2.1.2 Manual labor in order picking

Order picking also heavily relies on manual work. As with manufacturing, warehousing is subjected to decreased life cycle and increased product differentiation efforts in industry (Grosse, Glock and Neumann, 2017). Today, warehouses are confronted with

- Small order sizes (Boysen, Stephan and Weidinger, 2018)
- Large assortments, especially in e-commerce (Brynjolfsson and Smith, 2003; Boysen, Koster and Weidinger, 2019)
- Limited delivery time (Yaman, Karasan and Kara, 2012)
- Varying Workload (Boysen, Koster and Weidinger, 2019)

Therefore, warehouses tend to employ manual labor in the order picking process. Companies use the minimum of technological expenditure, the high flexibility in regard of volatile demands and range of goods, the suitability for all kinds of products as well as the possibility of processing rush orders, single orders, partial orders etc. at the same time (Gudehus, 2010).

The most common method is the so-called picker-to-parts system: the requested item, stored in a rack or a bin is manually pulled by a worker travelling along the storage aisles. Estimates show that about 80% of all order processes in warehouses in western Europe are picked manually using the picker-to-parts system (Koster, Tho and Roodbergen, 2007; Grosse, Glock and Neumann, 2017). These systems are able to process a maximum of 10.000 order lines per day (Marchet, Melacini and Perotti, 2015).

The downside of manual order regards the operating expenses of warehouses: picking makes up 55% of the operating cost (Figure 2). Of these 55%, half is used for travel between the aisles and to and from shelves (Tompkins, et al., 2010). As travel is seen as non-value-add labor (Bartholdi and Hackman, 2019), it can be inferred that 27.5% of all costs in warehouses are lost to traveling alone.

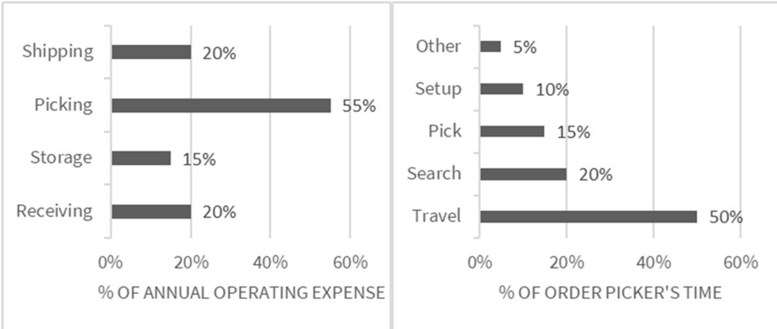

Figure 2: Typical distribution of warehouse operating expenses and order picking time (Tompkins, et al., 2010)

2.2 Automated labor

Automation can be defined as "the technology by which a process or procedure is performed without human assistance" (Groover, 2019b). While humans may observe or participate, the labor in itself is done autonomously and without human intervention (Nof, 2009). Estimates by the World Economic Forum show that by 2025, the share of tasks between humans and machines will be equal (Schwab and Zahidi, 2020).

There are a multitude of reasons to automate labor. These include

- The reduction of labor cost due to reduced cost per unit (Groover, 2019a)
- Increased productivity (Nof, 2009)
- Mitigation of effects of labor shortage (Groover, 2019a)
- Safety, as automation is used in areas either unsafe for human operation (Nof, 2009)
- Improved quality (Groover, 2019a)
- Taking over monotonous or strenuous work (Groover, 2019a)

At the same time, there are different disadvantages of automation. One of the main reasons not to automate a process is that it simply isn't suited for automation, e.g., when the physical access to the work location is limited or the task demands high dexterity. Another main reason is the cost: not only are automated processes linked to high investment costs, but the research and development cost of automating a process is difficult to predict (Lamb, 2013; Groover, 2019a).

2.2.1 Automation in manufacturing

Automation in manufacturing can be subdivided into three different types: fixed, programmable, and flexible automation. Fixed automation is characterized by a fixed sequence of processing operations with specialized equipment. The disadvantages of fixed automation are the high initial investment costs, especially regarding the specialized equipment, and the poor flexibility. In contrast, it can produce very large product quantities, enabling companies to distribute costs over many units, thus minimizing the cost per unit compared to other manufacturing methods (Gupta, Arora and Westcott, 2016; Groover, 2019b).

In programmable automation, the equipment is designed to accommodate changes in the process to allow the manufacturing and assembly of different parts or products. New programs for different parts can be prepared and easily introduced into the control. (Gupta, Arora and Westcott, 2016; Groover, 2019b).

Flexible automation can be seen as an extension or advancement of programmable automation. The equipment is designed to realize quick changes and therefore manufacture a variety of products with little adaption or reprogramming time. Therefore, changes in the product or new product lines can be introduced quickly, and different products can be produced alternately (Gupta, Arora and Westcott, 2016; Groover, 2019b).

There are two fields of application for automation in manufacturing: manufacturing lines and assembly systems. Manufacturing lines consist of multiple workstations that process parts, connected by a transfer system. Automated assembly systems perform a sequence of automated assembly operations to combine multiple components. A typical assembly system consists of one or more workstations, parts feeding devices, handling systems and, in case of multiple workstations, a part transfer system (Groover, 2019a).

2.2.2 Automation in order picking

Figure 3 shows the different picking systems and the corresponding level of automation. Even in manual picker-to-parts systems, automation is used. For example, automated guided vehicles (AGVS) are used to reduce the amount of manual transport (Boysen, Koster and Weidinger, 2019).

In a picker-to-box system, the picking area is divided into zones connected by a conveyor on which boxes with the manually picked items are placed, each corresponding to a customer order. With this system, up to 120.000 order lines per day can be achieved (Marchet, Melacini and Perotti, 2015).

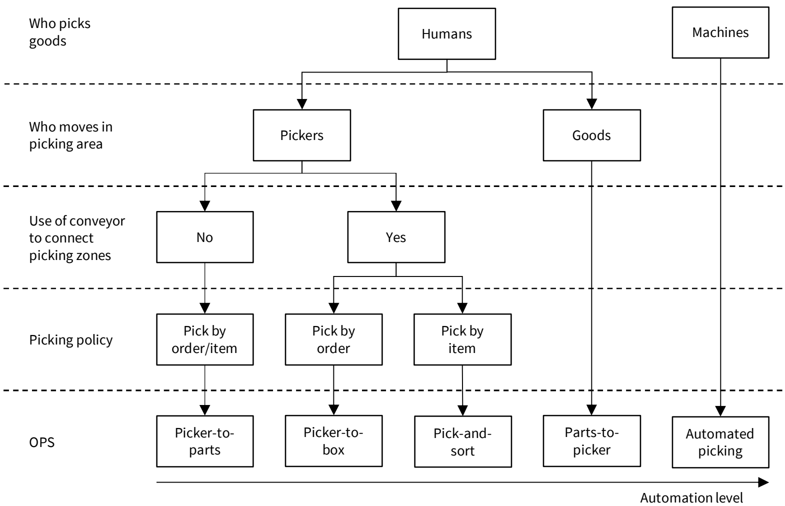

Figure 3: Classification of order picking systems (Dallari, Marchet and Melacini, 2009)

In Pick-and-sort systems, pickers retrieve an amount of a single item resulting from the batching of multiple orders and place them on a takeaway conveyor connected to an automated sorting area, which allots the items to the customer orders. The achievable picking volume can be up to 35.000 order lines per day. Both picker-to-box and pick-and-sort systems are not suitable for bulky, heavy, and fragile items or those with low picking volume (Marchet, Melacini and Perotti, 2015).

In parts-to-picker systems, the items are automatically transported to the human picker from the storage area. The picker selects the required amount of each item and the unit load, if not empty, is transported back to the storage area. Depending on the industry, the picking volume normally reaches a maximum of 10.000 order lines per day (Marchet, Melacini and Perotti, 2015).

Automated order picking systems (AOPS), like the so-called A-frame, completely forgo manual labor in the picking process. Typically, there are four reasons to contemplate the usage of AOPS: high numbers of different items to be picked fast, requirement to pick single pieces, very high flow intensity and minimizing material handling costs (Roodbergen and Vis, 2009).

3 Field-based Research

Additionally, to the literature review, field-based research was conducted. It is a contemporary method in which the researcher has no control, but instead serves as an observer of the phenomena present. This can be achieved by direct or participant observation, interviews of people involved, questionnaire surveys or archival analysis (Snow and Thomas, 1994). Field-based research aims is to gain a holistic overview of real-world events or phenomena. It can either be used to develop theory, e.g., by early exploratory investigations of unknown or little-understood phenomena, or to test and refine existing theories (Yin, 2009), which is used in the paper at hand. Five cases of automation or manual labor decisions are presented. The first four were examined at a company in the electronics industry while the last one was surveyed at a warehouse of a brick-and-mortar business. In all cases, a manual task was studied regarding the potential for automation. The data was acquired through direct observation and archival analysis. As the authors of this paper were directly involved in all projects the cases are based on, they had a holistic insight into all process steps and deliberations that eventually led to the decisions in favor of manual or automated labor.

3.1 Case I

For an injection molding process, several parts must be assembled and the quality controlled. This process was performed manually, which posed capacity problems, as the takt time of the worker (3 minutes) was lower than the mold's closing time (2 minutes) as well as logistics problems, as the manual workstation was spatially disconnected from the molding area and couldn't be moved closer. Using automation, the processing time could be reduced to match the mold's closing time. Further, the automation could directly be added to the molding system, eliminating the transportation need.

3.2 Case II

In this case, the manual completion assembly of the injection molded product of case I was studied. In the process step analyzed, the product is equipped with an actuator. This actuator is manually screwed on and then fastened with a specific torque.

The process poses a few challenges:

- The tip of the actuator, which holds the thread, is spring-loaded and pivoted. Therefore, the torque must be applied to this tip
- The tip is only 6mm long and inserted at least 116.5mm into the casing
- The space between actuator and casing is about 28mm along the entire circumference
- Rework is necessary in 16 percent of all cases

This process was considered for automation. Yet, the expected assembly time was estimated to be higher, with no automated process for disassembly. As the manual process time analyzed yielded ~60 seconds, as well as having the ability for rework, the automation attempt was discarded in favor of manual labor.

3.3 Case III

In this case, the manual final assembly of the switchgears was studied. While the assembly process by itself isn't suited for automation due to order volume, complexity, accessibility, etc., the transport of the switchgears was examined. During assembly, the gear must be subjected to several component tests. For that purpose, it is transported between test stations, buffers, etc. (Figure 4)

		handover station out	buffer 1	test station 1	assembly station	test station 2	test station 3	buffer 2	repair station	handover station out	sum
1	handover station in	0	**6**	0	0	0	0	**6**	0	0	12
2	buffer 1	0	0	**7**	**2**	**6**	0	0	0	**2**	17
3	test station 1	0	**2**	0	**7**	**1**	0	**2**	**1**	0	13
4	assembly station	0	**5**	0	0	**2**	0	**5**	0	0	12
5	test station 2	0	**1**	0	0	0	**10**	**1**	**1**	0	13
6	test station 3	0	**2**	0	0	0	0	**2**	**1**	**8**	13
7	buffer 2	0	0	**7**	**2**	**6**	0	0	0	**2**	17
8	repair station	0	**1**	**1**	0	0	0	**1**	0	0	3
9	handover station out	0	0	0	0	0	0	0	0	0	0
	sum	0	17	15	11	15	10	17	3	12	100

Figure 4: Material flow matrix of the switchgear final assembly for a two-shift day

The evaluation showed that about 100 transports, each lasting up to four minutes, are performed daily. Due to the size of the switchgear and safety regulations, every transport must be conducted by two workers. Considering a two-shift day has about 900 minutes (including breaks), ~44% of the daily working time was lost to transportation. Therefore, AGVs were implemented. With a few layout modifications, these could take over all necessary transports, reducing the number of manual transports to zero.

3.4 Case IV

The outgoing products of the electrical company are either stored in pallet cages or wooden boxes. These boxes were stored in multiple manually operated high racks in the past. Additionally, the material used for manufacturing was also stored in the high racks. Due to high manufacturing rates as well as demands, this resulted in high amounts of transports. Further, the workers needed specific special trainings, for example forklift certifications. Therefore, the materials-handling was automated using a multi-deep automated storage and retrieval system (AS/RS).

3.5 Case V

For the warehouse of brick-and-mortar company, automation was considered for two different areas. In the first area, fruit and vegetables, automation was ruled out. This was due to highly volatile goods issues and demands (+40 percent in demand on 52 days/year) as well as limited keepability of such spoilable wares. In the second area, drugstore goods, automation was implemented, as the number of articles is high while goods issues per article are low, resulting in high amounts of walking time and transports.

4 Morphological Analysis

General morphological analysis describes a heuristic creativity technique developed by Fritz Zwicky. This method aims to gain a holistic understanding of the relationships of multi-dimensional, non-quantifiable, problem complexes (Zwicky, 1967). Each of these problems or complex parameters is then assigned a number of relevant attributes or conditions (Ritchey, 2011). Finally, these parameters and their attributes are then collected in a n-dimensional matrix, also called morphological box. Each cell contains one condition for the parameter, thus visualizing the particular state of the problem complex (Ritchey, 2011). One advantage of the method is the “totality research” (Zwicky, 1967), meaning it provides the means to derive all the solutions of any given problem (Ritchey, 2011). Further, it helps identify relationships and boundary conditions of the given parameters and attributes (Ritchey, 2011). The morphological box finally represents a structured format illustrating all potential solutions to the problems (Kley, Lerch and Dallinger, 2011). Therefore, while historically rooted in engineering and the design of physical products, it is also used in the service design domain, e.g. for business models in the Business to Business context (Lay, Schroeter and Biege, 2009), service for industrial goods (Aurich, Mannweiler and Schweitzer, 2010) or electric vehicle service (Kley, Lerch and Dallinger, 2011).

Based on our findings from field-based research and the literature review, we conducted a morphological analysis to visualize the key elements, or conditions, of manual and automated labor attributes. The performance categories of order picking are time, quality, cost and productivity (Staudt, et al., 2015), as well as flexibility (Koster, Tho and Roodbergen, 2007), operational efficiency (Gu, Goetschalckx and McGinnis, 2010) and human factors (Grosse, Glock and Neumann, 2017). While designed for order picking, the indicators mentioned above are universal. For example, a manufacturing plant aims for high throughput, low cycle or takt times, low cost, high quality etc. Therefore, in the morphological analysis, these categories are used for the comparison.

Figure 5 shows the analysis for labor in the manufacturing area. For manual labor, productivity and quality can be moderate to high, depending on the product and the type of work. This could also be validated in the second case of the field-based research. At the same time, manual labor is the go-to solution when high flexibility is in demand. Further, compared to automated systems, the costs for manual labor are low, especially when the labor is outsourced to low-wage countries. On the downside, manual labor is usually connected to high cycle time and human factors, especially regarding ergonomics.

labor in manufacturing				
performance indicator	manual labor	fixed automation	programmable automation	flexible automation
cycle time	high	low	moderate	moderate
quality	moderate - high	very high	very high	very high
cost	low	moderate – very high	high – very high	very high
productivity	moderate - high	very high	very high	high
flexibility	very high	low	moderate	high
operational efficiency	moderate - high	high – very high	high	moderate - high
human factors	very high	low	low	low - moderate

Figure 5: Morphological Box for labor in manufacturing

Automation is characterized by high productivity and quality, yet at the same time high investment costs. The flexibility of the systems range between low and high. As explained, fixed automations are generally utilized for single products with high demand, and changes in design are difficult and costly to implement. Programmable automation introduces some flexibility by providing the possibility to implement different manufacturing programs and tool changes. The highest, although most expensive, flexibility can be achieved with flexible automation. Yet, all these systems cannot achieve the human flexibility, e.g., dexterity or cognitive flexibility.

The operational efficiency for automation can range between moderate and very high. Due to the very high productivity of fixed systems, the cost per unit usually is very low compared to manual labor. Therefore, the investment cost can be balanced to a certain degree. While programmable and flexible automation are also highly productive, their investment costs dampen the operational efficiency. Human factors normally play a secondary role in automation. Yet, they should at least be considered, e.g., when planning access points or control systems.

In order picking (Figure 6), automated labor is regarded across the whole scope. As can be seen, for picker-to-parts systems, which make up the bulk of OP, order lead time is high and productivity low. This is due to the high amounts of walking and transportation. On the other hand, it is the very high flexibility, e.g., when dealing with highly volatile demands or processing a large variety of products, which makes it the most-popular method of order picking.

With picker-to-box systems, the lead time can be reduced and the productivity drastically increased, due to transportation being taken over by the system. On the downside, the cost is increased as well, due to the investment for the system itself and the needed space. Therefore, these systems are preferred in areas with high number of small-sized items, medium-size flows, and small order sizes. The flexibility is lower, due to the system being unable to process bulky, heavy, or fragile items. As both systems rely on workers moving and picking, as well as high picking quality, they should be laid out as ergonomically as possible.

Pick-and-sort-systems further decrease the order lead times. In addition, they increase the quality of the pick compared to the two systems mentioned so far, as the sorting of items is automated, meaning wrongly picked items are discharged from the conveyor and stored next to the system. The flexibility is moderate, as each new item must be programmed into the system. Additionally, the system isn't suited for bulky, heavy, and fragile items or items with low picking volume. The investment is higher compared to the other systems due to the need for space, conveyors as well as sorting systems, which need mechanical as well as digital (scanners, lasers, cameras etc.) facilities.

Parts-to-picker-systems eliminate the transport part of order lead time by transporting the items directly to the picker. As the system only transports the exact items needed to fulfil the order and the picker only chooses the amount, the picking quality is usually high, with a few errors in counting being a possibility. The worker doesn't have to leave his working area, so the ergonomic design can be restricted to his workspace. As the system is manually loaded and emptied, it can accommodate changes in demands as well as items, therefore working with good flexibility. Downsides are the low productivity, as the picking and sorting is still done manually, and the high investment cost. Therefore, it is only moderately efficient.

labor in order picking					
performance indicator	picker-to-parts	picker-to-box	pick-and-sort	parts-to-picker	automated picking
order lead time	very high	high	moderate	low	very low
quality	moderate - high	moderate - high	very high	high	very high
cost	low	moderate – high	high	very high	very high
productivity (OL/day)	low (10.000)	very high (120.00)	high (35.000)	low (10.000)	very high (750.000)
flexibility	very high	high	moderate	moderate - high	very low
operational efficiency	moderate	high	moderate	moderate	moderate
human factors	very high	very high	high	moderate	very low

level of automation

Figure 6: Morphological Box for labor in order picking

Characteristics for automated systems are very low order lead times as well as very high picking quality and productivity. On the downside, the costs for acquiring and accommodate such a system are very high. The flexibility of such systems is relatively low, so as such systems cannot accommodate changes in unit loads, SKUs, long-lasting changes in order volume, etc., as well as being limited in their ability to pick targets from bins filled with multiple items.

5 Findings

We conducted a literature review to answer the first research question (RQ_1) "what are the key elements that define manual and automated labor?". We found that research on automation, while extensive, rarely discuss the disadvantages. Further, most research is based on automating manual labor processes. This is especially the case for automation in manufacturing. In order picking, the significance and advantages of human labor are better understood, with researchers focusing more on the human factors and elimination of waste potential.

Regarding RQ_2 “what are the disadvantages of manual labor that drive process planers to favor automated labor and vice versa?”, analyzing the literature and the field-based research, we concluded that manual labor is mainly used in areas with high volatility regarding demands or products, where long-term forecasts can’t be ascertained. Automation on the other hand mostly is used for high demands with little to no variation, as the high investment costs must be balanced by driving down the costs per unit. Partial automation, e.g., in order picking, is used to eliminate waste like transport costs.

For the last research question RQ_3 “what method can be used to visually compare manual and automated labor?”, we constructed a morphological box for manufacturing as well as order picking. This visual presentation is based on the findings of the literature review and the field-based research and can be used to comprehend the strengths and weaknesses of the systems. Furthermore, it can be used when dealing with the design of a workspace or procedure.

6 Discussion

Our findings in the field-based research, as well as the morphological analysis correspond to the findings of the examined literature. Case II, which needed a high amount of flexibility and dexterity for the end assembly of electronic products, and Case V, the brick-and-mortar company’s warehouse with high volatility regarding issues and demands, were chosen to remain manual processes. This corresponds with the findings of Hinrichsen, Riediger and Unrau (2016), who name high flexibility, adaptability and ability to process multiple sources of information and rapidly switch between tasks as the main advantages of manual compared to automated labor, or Lee and Dai (2011), who stated the grade of flexibility and lower cost as main reasons for manual labor.

Additionally our research showed limited automation capability for hard-to-reach, high dexterity product designs, which was ascertained by Groover (2019a).

Automated labor is best suited for tasks that demand high quantities, little or no flexibility regarding products or product design or very high product quality. For Case I, where manual pre-assembly of products for injection molding was deemed too slow to keep up with the mold's productivity, as well as the need for further transportation, automation was deemed the best solution. These advantages are for example supported by Groover (2019a), or Gupta, Arora and Westcott (2016). Another reason for automation is the takeover of non-value-add work like transportation. This could, for example be observed in Case III, where a manual, non-automatable assembly process was supported by eliminating the need for manual transportation, thus increasing productivity while also increasing the safety and reducing the physical load on the workers due to transport systems moving the bulky and heavy products. This usage of automated transportation to support normally manual labor, especially heavy and bulky loads, was also studied by Boysen, Koster and Weidinger (2019).

7 Conclusions, limitations, and further research

Manual labor cannot be substituted when dealing with highly volatile demands or a high variety of products. Moreover, human adaptability and prestidigitation can, thus far, not be automatized. Therefore, it is imperative that manual labor not be left out when considering processes. At the same time, companies shouldn't fear or disregard automation of processes. Automation can be used to increase productivity as well as to reduce the mental and physical workload of workers to manageable and acceptable levels. In conclusion, manual as well as automated labor are not always interchangeable. Further, harmonizing manual and automated labor is vital to maximize efficiency in manufacturing and order picking. Therefore, research regarding collaboration should be focused upon, as well as the field-test of collaborating systems, especially in the industry 4.0 era. At the same time, the human factors should always be regarded, as they are key to the highest possible productivity of human workers.

While the study aimed to include the most recent research as well as current field research, the insight into the application of up-and-coming systems, fall short. The reason is that those are still considered to be in the early stages of development, although the development steps and periods between publications are becoming shorter. For example, using hybrid order picking systems could be a means to combine human flexibility with the productivity and quality of automation, as well as liberating humans from strenuous and challenging labor tasks.

Further research is warranted regarding the collaboration of automated systems and humans, human-centric system designs and sustainable engineering of manufacturing and order picking systems.

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Drone based Delivery System: Restrictions and Limitations

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Purpose: *Considering the idea of drone application in last mile delivery, this paper has examined literature studies about the restrictions and pitfalls which the organizations will face with for using drones in the last mile delivery. Moreover, the recent drone tests for commercial purposes in last mile delivery industry and challenges in these practices are investigated.*

Methodology: *A survey-based approach has been applied to both the potential customers of the drone delivery service and also literature review for discovery of latest practices for drone enabled delivery projects has been targeted to identify the limitations and restrictions.*

Findings: *The study demonstrates the problems that arise when the delivery drone crushes while in the air and the approach of self-exploding drones does not seem to make positive effect on this problem. Also, issues like special area for landing, noise of drone activities, safety and security of citizens in urban area are found to be main concerns.*

Originality: *Very few research studies have been conducted in evaluation of using drones for last mile delivery operations focusing on current limitations and forthrightly downsides of drones of current state of the art. Therefore, this paper has tried to elaborate the limitations and restrictions from two perspectives of potential customers and technology developers.*

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1 Introduction

1.1 Motivation

Increase of digitization technologies and their effects for improvements of interactions among computers and automation, reinforced with autonomous and smart systems have faced industries with the opportunity of process improvements (Keliang , et al., 2016; Delaram & Fatahi Valilai, 2019). This has also enhanced the in-store consumer behavior and the way how end users consume the product. According to Federal Reserve Bank's economic data, the E-commerce retail sales as a percent of total sales has increased from 0.8% in Q1 2000 to enormous 16.1% in Q2 2020 (Federal Reserve Bank of St. Louis, 2021). This means that the customers' preferences are changing towards the online shopping and even when they make in-store purchases about 38.5% of them were digitally influenced (Satish & Sanjeev, 2017). Taking the massive adoption of information and communication technologies as the internet into account, many businesses have reorganized the method of how products will be produced, advertised and purchased (Nestor, et al., 2017). Hence, the eagerness of individuals for online shopping channels has resulted in the introduction of businesses offering e-commerce services compared to the traditional one, especially when global pandemic step on, many businesses survived by going online (Montenegro, 2021).

One of the most successful examples of e-commerce business would be Amazon.com Inc., here forth Amazon, which started as an online book-retailing business with a mission to create real value for customers–by making their shopping easier and convenient (Amazon 2018). The online shopping industry is in process of constant growth and Amazon might be considered as one of the key contributors of this growth, increasing its net sales from $1.6 billion to $280.5 billion over the period of two decades between 1999 and 2019 (Amazon, 2020). However, the rapid augmentation in the supply chain of the companies as Amazon, DHL, UPS, etc. and overall consumer consumption rate has come with some challenges in optimization throughout the whole supply chain. For instance, as delivery services become more and more popular, studies showed that the share of last mile service costs accounts for 41% of whole supply chain costs (Capgemini Research Institute, 2018). Additionally, this number is more than two times larger than any other category of costs incurred in supply chain such as sorting, inventory or other remaining supply chain costs. Moreover, naturally last mile delivery cost is defined as variable cost, and it might get larger in case if overall delivery volume increases. Therefore, coming up with a new approach in last mile delivery to cut losses in cost and time was in interest of above-mentioned companies like the application of drone enabled deliver technologies (Farajzadeh, et al., 2020; Moadab, et al., 2022).

1.2 Research aim

The recent legislation of Drones for commercial purposes by governmental authorities has laid the first stone for the large-scale implementation of UAVs (Unmanned Aerial Vehicle) in last mile delivery of products (Andy & Ferek, 2021; Ahmadi, et al., 2021). During the last decade, a tremendous amount of work has been done on optimization of logistics of drones and their applications in parcel delivery along with advantages the drone-based delivery system has compared to traditional truck-based shipping mode in last mile logistics. However, very little amount of research has been conducted in evaluation of employment UAVs considering the current limitations and forthrightly downsides of drones of current state of the art. Therefore, the framework which will contain all the negative side effects UAV deployment in last mile logistics may bring along through the thorough analysis of previous literature. Additionally, a survey to both the potential customers of the drone delivery service and providers of air delivery will be conducted to identify other limitations and restrictions both parties see. Hence, the results will be added to the framework considering the actual weight of the problem. First, getting acquainted with the previous literature and studies about the Unmanned Autonomous Vehicles and their usage in delivery businesses will be on top priority. The literature and studies being examined will be mainly about the restrictions and pitfalls the organizations forcing the massive avail of drones, for example Amazon, are facing in the last mile delivery. however, the drone examinations for commercial purposes and what challenges the drone delivery is facing with will be deeply considered.

In parallel with the research, a survey will be conducted on studying the vision and preferences of customers regarding the drone delivery system. Subsequently, the data obtained will be thoroughly analyzed through data analysis tools. Then, tendencies and trends in customer behavior will be identified and finally the recommendations and advice will be proposed for the future research studies of this topic.

2 Literature review

2.1 Challenges in last mile delivery

Over the last decade, e-commerce business models have shown the increase in the number of on-line orders. Accordingly, vendors have to fulfill the enormous demand from private customers through attaining the lowest delivery time of parcels, mainly low weight and small volume, being shipped while constantly facing the overlap in the time windows of customers (Zeynivand, et al., 2021). Therefore, different players throughout the supply chain are trying to refine their plants by making the production processes available 24 hours a day, reducing the processing time of orders and transportation (Archetti, 2020). Nevertheless, the problems associated with decrease of the costs and resources spent in last mile delivery are still currently challenging (Khaturia, et al., 2022). Examining a closer investigation on the root of the problem, there can be derived that the challenges emerging in the last mile are mostly arose from the fact that shipments are formed from individual customers and from a large scale of diversification of destinations, meaning that each order has to be shipped to different address (Macioszek, 2017).

Additionally, last mile logistics employs the service of freight carriers. Therefore, especially in highly dense areas, freight carrying truck drivers are encountering large deal of problems (Aljohani, 2020). Efficient optimization of urban mobility is a key for the economic success of large metropolitan areas and respectively delivery of parcels on time is also crucial factor for companies to satisfy the customers’ need. Recent studies have shown the increasing demand for express and small size parcels in densely populated areas in Europe and there’s also a tendency of customers preferring same-day delivery (Mazareanu, 2019; European Commission, 2018). Furthermore, couriers have to travel long distances from distribution centers mainly located in suburban areas to satisfy the wants of end-users vastly located in inner-city areas.

One more factor negatively affecting the logistics in last mile stage is the presence of high skyscrapers, each comprising bunch of various business establishments, retail stores, food shops and public areas in city centers of large urban areas. Despite the fact that those commercial city towers do not span large area compared to other retail stores and businesses located in one single block, they do effectuate complexity as they simply engender vast amount of freight movement. For example, it was estimated that around 4% of all truck movements in all districts of Manhattan was mainly triggered by 56 neighboring business towers (Miguel, et al., 2015). Moreover, enterprises located in skyscraper buildings mainly order parcels through express delivery meaning the shipment in the same day at hand. In general, the city center area suffers from great amount of traditional truck movements. Here are the factors negatively causing the last mile delivery:

1. Restricted and inconvenient infrastructure for parking the freight trucks and loading the shipments.
2. Intense traffic movement caused by pedestrians, cyclists and congested with other private vehicle owners.
3. The local streets in city centers accessible only for pedestrians.
4. Deficit of facilities that would allow truck drivers to load packages beyond the street.

In the e-commerce era, businesses getting more and more digitized, and customers' standards being increased, last mile distribution of shipments to end-users appearing to be an issue entangled more than ever. Additionally, the amount of goods to be delivered door-to-door towards the customer living places is increasing the number of trucks needed to be involved in inner-city traffic and CO2 emission (Paul & Benjamin , 2018). Accordingly, the emergence of novel last mile delivery concepts was unsurprising and was just a matter of time.

2.2 Advantages of drone-based delivery system

It is undoubtedly that logistics is a dominant factor in businesses as customer's expectations to have their desired products promptly, and hence, logistics companies try to meet customer's ever raising high standards in the most economically viable way. As discussed earlier, traditional truck-based delivery system has a lot of drawbacks and most importantly it is economically detrimental. Therefore, there are various transportation modes such as vessels, goods trains, trucks, carts, etc. have been invented. One of the most eminent and notorious concepts being actively developed during recent years is the Unmanned Aerial Vehicles or drones.

A drone, UAV or Remotely Piloted Aircraft is a flying robot which can be controlled remotely or can fly autonomously without the assistance of human pilot (Federal Ministry of Transport and Digital Infrastructure, 2021). As there are many ways the drone can be referred to, in this paper, the terminology 'drone' is selected in further deliberation. Back in 2019, analysts have forecasted that drones and UAVs are highly likely to be prominently employed for commercial purposes as shown in Figure 1. The sales and revenues accounted for 392 thousand and 1.6 billion USD back then and these values were projected to reach 12.6 billion USD by 2025. The demand for drones has exceeded all optimistic forecasts until then, for instance, the sales of UAVs in 2020 in US alone outreached $1.25 billion (Insider Intelligence, 2021). Now, Goldman Sachs projecting total market size of drones to hit $100 billion by 2025. Apart from that, analysts at Insider Intelligence strongly believe that global shipments being operated with the aid of UAV services will reach 2.4 million by 2023 taking the 66.8% of annual compound growth rate (Insider Intelligence, 2021). Also, it is projected that drones will mainly be employed by five main industries: Agriculture, construction and mining, insurance, media and telecommunications, and law enforcement (Insider Intelligence, 2021). Recent years have demonstrated that drones have the potential to be one of the most essential technologies of our time, especially it was vivid in 2020 when contactless services were in high demand because of the pandemic. Nevertheless, drones are already in use in some places and big corporations such as Amazon, Google, UPS and DHL have already tested them in various environments. Furthermore, they are now capable of lifting freight weighing up to 2-3 kg (McKinsey & Company, 2016). The parcelcopter 4.0 of DHL in collaboration with the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH under the German Federal Ministry and German manufacturer Wingcopter have performed 60 km flight in 40 minutes to deliver medicines to remote rural areas during the pilot project in East Africa (DHL, 2020).

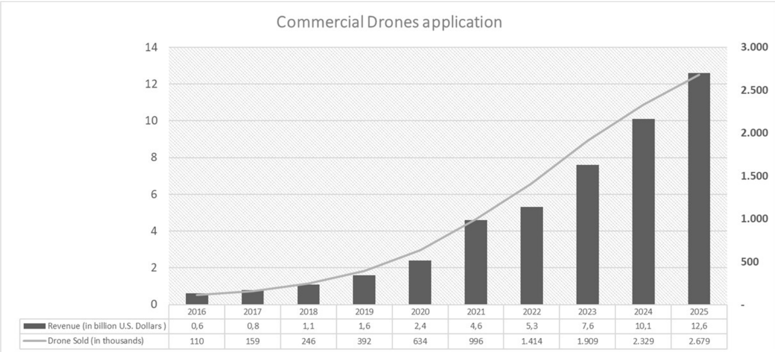

Figure 1: Projected worldwide market growth for commercial drones (Buchholz, 2019)

The fourth generation of parcelcopter is able to speed up to 130 km/h, fly 65 km distance with full battery level and carry up to 4 kg cargo and also have shown that drones can operate in spite of 'natural barriers' and can be a complete game-changer in the areas where the road system is not available (DHL, 2020). Furthermore, partnering with EHang DHL have launched first completely UAV based delivery mode in urban area of China in 2019 (Hartmann, 2019). They highlight the fact that they could reduce cost per delivery by 80%, shorten the 40 minutes lead time to 8 minutes and with significantly less energy consumption and CO2 emission (Hartmann, 2019). As an entirely autonomous solution, drones, can lift packages up to 5 kg per flight and operate being atop of special intelligent cabinets where sender can simply load/unload the shipment (Hartmann, 2019).

Whereas DHL's rival companies as Amazon, UPS, FedEx and Google's sister company Alphabet's Wing are also in process of making drone delivery reality. Amazon's Prime Air service already offers its customers living in 15 miles within the selected areas to get delivered their items weighing less than 5 pounds (2.3 kg) in less than 30 minutes (Wilke, 2019). The drone is equipped with AI system which will help to recognize obstacles, animals, people, etc. and will need a small area around the delivery location to unload the parcel (Wilke, 2019). Plus, Amazon claims the weight limit of 5 pounds covers around 75-90% of purchased items in the platform (Wilke, 2019). While Wing drone has completed hundreds of deliveries to real customers in Australia since 2014 starting from first-aid-kit, candy bars, water to farmers and hot food.

2.3 Challenges and constraints

Generally, drones are naturally very vulnerable to any weather events and wild animal or bird attacks. High speed wind, turbulence, freeze, precipitation, fog and cloud, for instance, might drastically affect travel distance and control system of drone because of their design, dependency on battery level and light weight (Karpowicz, 2018). Any micro-climate contrast, temperature change, or overcoming the physical obstacle as hills will consume the battery; a burst of wind, heavy rain, icing, etc. will not only consume more battery, but will also force the unmanned autonomous aircraft to fall. The safety is the fundamental disturbance for both consumers and regulators and weather are the first danger for drone's safe operation. Furthermore, drones are also prone to be attacked by wild birds. There have been number of incidents detected when birds of prey attack UAVs worldwide, including Australia, Africa, some US states, some areas in Europe and South America (Wade, 2017). One of the drone users in Australia affirms almost 40% of the time he has to perform at least one attacking bird avoidance (Wade, 2017). It might cause serious damage for both the UAVs and birds living around, hence, the surrounding environment and has to be addressed by drone manufacturers, logistics service providers and authorities.

Jeff Wilke, former CEO of Amazon Worldwide Consumer, said to qualify for Amazon Prime Air 30-minute drone delivery, the order has to be less than 5 pounds (2.26 kg) and small enough to fit into the cargo box that the drone will carry (Wilke, 2019). Plus, the recipient must also be located within a 10-mile radius from Amazon's corresponding distributing center, Additionally, in UK, for example, drones are only permitted to fly under 400 feet altitude, during the daytime when there's low wind speed and well visibility (Wilke, 2019). This, undoubtedly, adds up the lifting power issues of drone delivery system which often cuts heavier product categories and adds up to challenges in battery and design.

Moreover, drones are designed to be significantly big, particularly the types that are developed to fly long-distances at lowest cost, and therefore, it may require at least 2 m^2 special area from the recipient to perform landing maneuvers (Yoo, et al., 2018).

Certainly, so-called technology will evolve by time, however, in reality it will be really difficult to provide even smaller drones with proper landing area in densely urban areas. This constraint technically could be surpassed with assigning the smaller and low weight packages that have to be delivered to rural areas, where it might be uncomplicated to find landing space. Nevertheless, if the shipments are also bounded by limited number of time-windows and has to be transported on the same-day, it may take approximately 250,000 pieces of drones in 2025 in US alone to satisfy the demand (McKinsey & Company, 2016). Additionally, one more compelling point is that none of the earlier mentioned enterprises, such as Amazon, does not address the obscurity of the procedures and protocols in reverse logistics, when the customer will need to send the item back. The cost of returning movement of goods away from their actual final destination is estimated to be $642 billion worldwide for Amazon per year (Mazareanu, 2020), for example. Hence, this could be a major pitfall to deploy drone services at full extent for online retailers and logistics companies, also it’s preventing entire last mile logistical operations from becoming fully environmentally sustainable.

Unfortunately, even the most sophisticated Unmanned Aircraft Systems are not completely protected from external events such as weather and wild birds. In 8th of July 2020, there has been a drone incident: a UAV was being operated over the large building in a built-up space for commercial purposes, following the pre-programmed prepared flight path (UK Government, 2020). The chosen drone has passed all the norms and checks before the beginning of the flight, including the assessment of possible wild animal (bird) intervention. However, when the drone entered the autonomous flight mode it was attacked by a gull, which damaged the drone’s front propeller, hence, even the pilot was not able to control it manually. As a result, a drone weighing 6.14 kg fell onto the rooftop (UK Government, 2020). Albeit, even if the drone manufacturers will prepare the Unmanned Aircraft Vehicle to every possible way of danger, there might still be some unseen scenario which could lead to catastrophic outcome (Popper, 2014). Therefore, Amazon have patented a self-destructing drone technology that falls apart in an emergency situation, intending to cause less harm if the crash is inevitable (Vincent, 2017). However, even with the idea of self-exploding drones, the citizens living around are not fully protected from the danger above. In such cases, people might get injured, and properties could be damaged and there emerges the question of who should take the responsibility for the failure and the damage to surrounding people? What will happen to the ordered item? May be there is the intervention of 3rd party insurance company is needed. These questions, of course, remain open to discussion.

3 Methodology and Data Collection

3.1 Survey design

The relationship between the providers of drone delivery and the potential customers of that service will be analyzed in this paper. This section of the paper will explain how this relationship will be tested. As stated in the previous sections of paper, utilization of Unmanned aircrafts has its limitations and restrictions. It is expected that the rapid deployment of so-called technology in last mile logistics is threatened by those negative factors, plus the cultural recognition might take some time so customers would get used to the contact with novel technology. Furthermore, customers will also demand the response from the manufacturers of drones and providers of the service. Therefore, it made a sense to conduct a survey questionnaire among both the potential customers to identify their view on the possible inconveniences the drone technology may bring together and the providers of air delivery service with the reason to determine their vision on the problems and what approaches they are planning to employ to minimize the impact of those negative effects.

First group of respondents will be identified as future clients of UAV shipment option consisting of the residents of different countries, cultures, age groups, genders, etc. and making regular online purchases. Overall, 252 respondents participated in this research survey, and it took place online via Google forms platform. The questionnaire had 13 general questions and was designed to capture the customers' judgement and severity of the limitations from the perspective of customers' experience. The combination of both multiple-choice questions with predefined answer lists and open-ended questions is found to be present in the survey. Moreover, respondents were able to choose and rank among number of variants or to grade on a scale from 1 to 5, where 1 is very bad/strongly disagree/very difficult and 5 is very good/strongly agree. For such questions additional space line was provided to explain and elaborate on the answer. This kind of open-ended questions play a role of great importance in the survey as it helps to properly interpret the obtained data and might shed a light into new unseen valuable material. The multiple choice and ranking questions, in its turn, allows to gather and analyze great amount of data and identify the trends and tendencies in the data.

On the other hand, the second group of respondents are found to be the specialists professionally operating closely to the development of air delivery services. Their visions on the identified issues were recorded online through Google forms platform. In general, experts who are working in the sustainability, mobility & transportation, and supply chain management departments and drone projects of the companies in German and international market participated in the survey. The questions were mix of short & long text answers to pre-described issues and multiple/ranking questions afterwards to rank the severity of each problem.

3.2 Potential customers

From 245 of all respondents, 97.2 %, who participated in the survey were in 18-29 age group and 7 were found to be older than 29. Thus, all the respondents can be stated as the target audience of the providers of drone delivery system with more focus on young generation which are more eager to know more about such technologies and also are more demanding to benefit from shorter lead times of delivery. Also, the first group of respondents were supposed to specify whether they live in Urban area or suburban area. 55.6% of people who participated in the survey as the potential customer are living in urban area or city center were the issues as congestion, GHG emission, and noise pollution are mostly critical. Moreover, 231 out of 252 respondents have confirmed that they have purchased goods on-line within the last 12 months. Furthermore, the ones who have indicated that they shopped online throughout the last year were also asked to describe how often they are likely to place the order and more than third of them order products online once a month on average, 77.8%.

The responders also had an opportunity to pick one or more weight categories out of the given variants to which they feel their average package's weight belongs. The vast portion of the packages ordered are found to be under 2.25 kg (5 pounds) and none of the orders exceeded 5 kg mark. The questionnaire has revealed that 38.9% of all respondents, that is 98 people, lack special place of at least 2 m^2 in open space of their living place for the drones to perform unloading process of packages. Plus, 69.4% of answerers state that they can wait from 2 days to weeks to get their mail delivered, which minimizes the need for quick drone delivery option.

3.2.1 Results and analysis

After the first round of questions clarifying the preferences and details of the responders entitled to be as potential drone delivery service clients, they were given pre-described possible scenarios in the next round. The first case contained the scenario in which drone crashes because of unconditional weather events (e.g. high speed wind, rain, icing, etc.) or wild bird attacks or unseen technical issues onto an innocent resident or their property (e.g. house, car, belongings, etc.). Participants of the survey were given options and space line to describe who they think have to pay the compensation for the injured person and damaged property. As shown in Figure 2, 44.4% of participants reckon that in case of drone crash drone delivery providers such as Amazon, Google, UPS, DHL, and so on has to pay the compensation to injured person and their property. Whereas other half of the respondents deem there should be an insurance company employed for every delivery and they should compensate the damage. In this scenario, the ordered item being delivered by UAV is also likely to be damaged and 44.4% of answerers think the hired insurance company should also cover the cost of the item being delivered. While the same quantity of people feels the carrier has to take the responsibility to cover the cost of spoiled item being shipped and deliver the new item sent to the customer free of cost. Surprisingly, 28 people, that is 11.1% deem that the seller or store has to send a new item or fully refund to the customer.

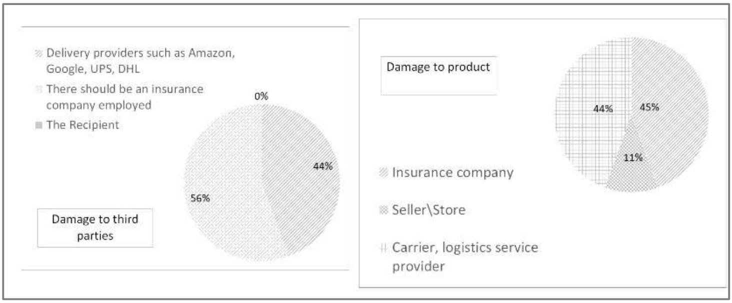

Figure 2: Breakdown of the damage of drone crash (Left)

After the first scenario, the examinees were supposed to rate on a 1-5 scale to which extent they agree/disagree with the drones flying nearby their living places. The vast majority looks neutral to the operation of UAVs nearby residential areas, however the 13.9% of respondents equally agree and disagree with the drones flying around their living place. The next question demonstrated the Amazon inspired city which fully operated with the service of Amazon Air Prime as a visualization of future cities. Afterwards, it was followed up with the question to rate to which extent they are sensitive to noise. More than half of the respondents indicated they are either sensitive or very sensitive to noise which obviously contradicts with the noise level generated by various types of drones.

In the final part of the survey, participants were asked to announce whether they are willing to use drone delivery option as a customer considering all the restrictions and limitations described before. Where 1 is very likely to use, 3 is neutral and 5 is less likely to use. Nevertheless, as illustrated in Figure 3,47.2% of all respondents were found to be prone to be the customer of drone inspired delivery system, while only 27.7% were skeptical to employ drone service. In the end, first group of respondents were given a space line to explain why they support or not UAV based shipment of goods.

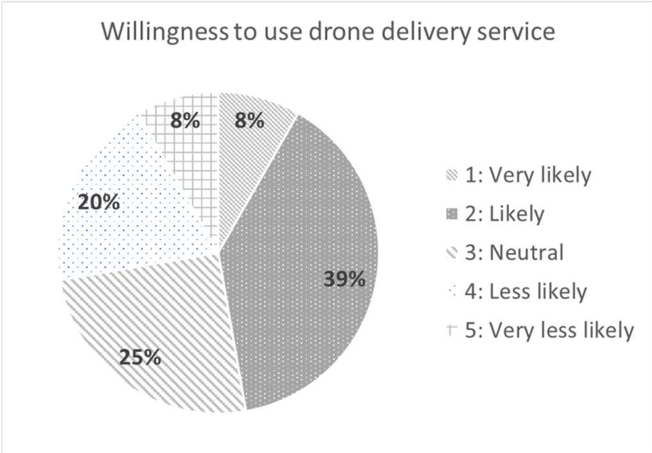

Figure 3: Willingness to use drone delivery service

3.3 Experts

The experts whom were contacted in this survey were working in Sustainability, Mobility, Logistics, and drone projects of various enterprises for more than four years. The questionnaire itself consisted of two parts. The purpose of first part was to obtain the points of view of those specialists on various pre-described restrictions of drone technology. While the second part was generated in order to allow the responders to rank the severity of issue on 1-5 scale, where 5 is very complex, 4 is slightly complex, 3 is neutral, 2 is slightly negligible, 1 is negligible. The first question explained the problem of battery and charging of drones. To address this issue, some adjustments in city infrastructure as charging stations or beehive buildings where drones could be able to stay and charge their batteries is needed. This leads to other problems as city authorities, residents and cultural acceptance. Additionally, flying maneuvers at low battery levels can be catastrophic compared to when traditional truck runs out of fuel. The responders deem that the installment of charging stations where they will not disturb urban traffic at all would minimize the effect of this issue.

The next question raised the issues of unwanted noise amount generated as a result of drone operations. Indeed, this issue can get even more severe when entire cities will employ thousands of drones in last mile logistics. One of the responders mentioned that drones don't cause much noise than cars, trucks, and other urban traffic does, and residents will get used to it by the time passes. While another specialist noted that drone delivery mode should be allowed only for essential deliveries and in restricted amount. As discussed earlier the variability of packages which needs to be delivered by drone is restricted by their weight limit. Amazon air prime, for instance, can ship products below 5 pounds or 2.25 kg at once. One of the specialists said: "Once the drones will be successfully used in everyday delivery services for packages up to 5 kg, and if the clients will be satisfied and demand will be high, then the ways of upgrading the drones could be considered". In case demand is high, there should be enough funding and resources for the upgrade. However, half of the responders consider this issue as slightly complex, one as very complex, and one looks at this neutrally.

Apart from that, in case of emergency, some drones will activate self-explosion mode so smaller pieces will fall down, and less damage will be caused (Vincent, 2017). Responders pointed out that this technology is very dangerous and another approach as the implementation of built-in parachute which will be activated in case of falling should be studied. 75% of specialists considered the problem as either as slightly severe or very difficult. In case of drone accidents, there might be several parties being deteriorated: the shipper who sent the item and lost it; the owner of the property (e.g. house, car, etc.) the drone pieces fell onto; a customer who won't be able to get his item on time. The specialists think the involvement of insurance company in this process would help to distribute the responsibility fairly, saying that if the carrier will have to cover the whole expenses associated with the damage caused due to drone crush the replacement of traditional delivery with drone services won't be possible in near future. Hence, all of the respondents rated this issue as either slightly severe or very complicated.

Some citizens living in residential area where drones were being tested are concerned about their privacy and safety, especially the camera recordings of drones (Cherney, 2018). To mitigate this problem, the organization of educational events raising public awareness would make sense. The answerers reckon the detailed information about navigational purposes should be made public and they all rated this issue as slightly difficult.

3.4 Discussions

The results show that though the 47.2% of respondents are planning to use drone delivery mode regularly, there are number of challenges which needs to be overcame. For example, 38.9% of responders don't have the ability to offer a special area for landing maneuvers of drones. For this issue, respondents in the second group of survey suggested the DHL's approach which involves the installment of intelligent cabinets that were specifically developed for the completely autonomous loading and unloading of the shipments. Another problem is associated with safety and security of the well-being of citizens living around as 19.5%, almost 1 out of 5 people, do not feel safe and protected if drones were flying around. This phenomenon might provoke other issues connected with the mental health of residents. The studies demonstrate that there's a raising tendency that city dwellers are moving to suburbs in search of better quality of life.

Moreover, drone propellers generate great amount of noise which eventually adds up to this problem. Consequently, the challenge gets especially crucial with the 52.8% of respondents identifying themselves as either slightly or very sensitive to noise. Additionally, 69.4% are willing to wait their packages from 2 days to 1 weeks which eliminates the need for instant drone delivery. Furthermore, respondents have noted that they don't feel comfortable living around drone activity areas backing it up with the little development in computer vision and navigation algorithms. It can be concluded that there is a direct relationship between how people feel around drone operating area and their willingness to use the service. On the other hand, some believe that infrastructure and regulations must catch up to drones before wide-scale adoption to prevent violations in privacy and airspace. Plus, the environmentally sustainability of drones also positively influenced the respondents' vision on whether they support the drone delivery adoption or not.

When it comes to the responses of specialists, the most crucial problem was found to be the question of who should take the responsibility if delivery drone crushes in the air. They have mentioned that the involvement of 3rd party insurance company would make the situation easier. However, there emerges another question of who should cover the cost of that insurance company's service? The carrier? The sender, online shop, retailer? Or the recipient? The data protection and privacy of people was happened to be the second most important restriction in deployment of drone technology in last mile logistics. Drones possess a great deal of cameras, LIDAR (Light Detection and Ranging), sensors, and actuators that monitor the real-time surrounding environment and that is essential in drone operation. The selected responders indicated that the detailed information about navigational purposes should be made public and the camera recordings should have an expiration date, meaning the camera footages will be deleted after set time. This period should be discussed with representatives who live in testing area and consent form should be signed. Surprisingly, the solution with self-exploding drones and drone crush while in the air were also occurred to be one of the most severe issues the carriers have to address to execute the massive employment of UAVs in delivery industry. Even though there were number of difficult challenges discussed, responders seem to be optimistic about drone future and think we will see the replacement of traditional truck-based delivery system with UAVs in 2-5 years.

In the very beginning of the paper the majority of challenges that exist in the development of UAV based air delivery were identified. At first, they were discussed with potential customers of the novel technology and the most essential problems were sorted out. In parallel, those issues were also disputed with the specialists professionally working close to this industry. As a result, the possible solutions that might help to mitigate some of those issues were proposed and the most important, hard-to-crack problems were distinguished. Both two survey results illustrate that the availability of special area in the living place of the receiver, limitation in the weight of package the drone is able to deliver, lifting power of drones and installment of charging stations are the challenges that make little sense.

4 Conclusion

This paper has elaborated the limitations and restrictions of drone-based delivery system. This research has discussed the most prominent challenges in the development of UAV based shipment mode have been identified through the study of various scientists' research study, case studies and customers' feedback. The paper has conducted surveys for the representatives of both parties, the specialists, and customers in order to identify the most significant challenges and to disregard the ones that are less important, or the possible solution is available. The paper has examined the respondents' view on the limitations and restrictions in the cultivation of drone delivery method based on the current solutions of Amazon's Prime Air, DHL and EHang's drone delivery service, and Google's sister company Alphabet's Wing. The studies demonstrate the problems that arise when the delivery drone crushes while in the air and the approach of self-exploding drones has not been found to make positive effect on this problem. The interesting area for future studies could be conducting research on introducing another solution for drone crushes while operating in the air.

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Analysis of Potential Benefit and Maturity Level of Digital Procurement

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Purpose: *Procurement departments are facing major challenges of digitalization. To meet future business requirements, managers are forced to arrange investments for the digitalization of procurement processes. Current studies show that the maturity level of procurement digitalization is still lacking due to missing benefit assessments of investments.*

Methodology: *For this purpose, the benefit potentials of digitalized procurement are analyzed based on a systematic literature analysis, followed by qualitative expert interviews to evaluate hypotheses derived from the literature. Moreover, the expert interviews provide information about the current maturity level of digitalization in procurement.*

Findings: *The systematic literature analysis and qualitative expert interviews provide 24 potential benefits, which are summarized in six categories. The expert interviews indicate that increasing of efficiency, process transparency and data quality are seen as the main benefit potentials of digital procurement. In terms of maturity, the experts confirm potentials that need to be exploited to enable future procurement at competitive prices.*

Originality: *Current research on digital procurement is forcing superficial concepts of digitalization measures. A well-founded assessment of potential benefits of the implementation in companies is still missing, which leads to critical barriers in digitalization and missing adaption to rapidly changing market conditions.*

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1 Introduction

Procurement departments are facing many challenges, in particular high process costs due to repetitive activities, long lead times due to complicated approval process across several hierarchical levels and lack of transparency in procurement controlling. In a market economy shaped by globalization and increasing pressure in international competition, the demand for companies to push lean and efficient processes is becoming greater. (Kollmann, 2019)

The digitalization of purchasing processes offers various potentials and is seen as very promising for long-term success. Especially in a VUCA world (Mack et al. 2016), which is a world characterized by *Volatility*, *Uncertainty*, *Complexity* and *Ambiguity*, benefits of digitalization could help to handle supply risks caused by unpredictable events like international conflicts or pandemics.

Nevertheless, the degree of implementation in small and medium-sized companies (SME) is less mature. A survey conducted by BME (2021) in collaboration with ONVENTIS and the ESB BUSINESS SCHOOL among German SME and large mid-sized companies concluded that the maturity level of digitalization in purchasing is still insufficient. There is no discernable trend of an upturn, as the results have hardly changed compared to the same survey of the previous year. The core message is that smaller companies make regression in automation of operative processes, in general the main potential is seen in supplier management due to the implementation of sustainability goals.

Therefore, the objective of this research paper is to find out which barriers inhibit companies' digitalization, although digitalization promises many potential benefits in purchasing. To conduct this research, it is necessary to deal with the topic of digitalized procurement first. *Digitalization*, *Digital Transformation,* or *Industry 4.0* have a huge impact on industrial production processes. It is obvious that traditional procurement will be also influenced by the technological development in future. Another survey shows that the targeted application of technology in procurement helps to save 20 % of staff and 30 % of process costs in best-in-class companies. (Deloitte 2021a)

A further survey of DELOITTE (2021b) asked 400 Chief Procurement Officers (CPOs) in 40 countries about their top priorities. While in 2019 digital transformation was mentioned by 63 % of the participants, in 2021 digital transformation was voted as top-3 priority with 76 % beside cost reduction (76 %) and driving operational efficiency (78 %).

Digital procurement itself is defined as a concept to create a holistic digital transformation of purchasing departments. The term is defined by many authors and shows substantial differences in selected instruments and technologies. The following Table 1 helps to identify the most common technologies mentioned in the context of digital procurement. The literature used for the comparison is part of the screening process in Section 2.1. Beside the potential benefits, they also mention relevant technologies in digitalized procurement.

Table 1: Technologies in Digital Procurement

Authors	**Big Data**	**Cloud Computing**	**Digital Reporting**	**IoT**	**AI**	**Mobile Devices**	**Self Service**	**Social Media**
Bienhaus/Haddud (2018)	X			X	X			
Kleemann/Glas (2017)	X	X		X	X			
Nicoletti (2018)	X	X		X		X		
Reinhardt (2020)	X	X		X	X	X		X
Sendler (2016)	X	X			X			
Tschandl et. al (2016)	X	X	X			X	X	X
Number of mentions	**6**	**5**	**1**	**4**	**4**	**3**	**1**	**2**

Big Data, *Cloud Computing* as well as *Internet of Things (IoT)* and *Artificial Intelligence (AI)* are seen as the main technologies for digital procurement. The analyzed literature sources are an essential element of the research design described in the following section of this research paper.

2 Research Design

The following section describes the research design including the general research process and provides an overview of both research steps and phases. A detailed description of the individual elements follows in section 2.2.

2.1 Research Procedure

Since this research paper deals with answering two research questions, (a) *"Which potential benefits of implementing digitalized procurement are observed by the scientific literature?"* and (b) *"Which potential benefits do procurement managers see in digitalized procurement and how do they evaluate their maturity of digitalized procurement?"*, the methodology is divided into two steps, each consisting of three phases (P).

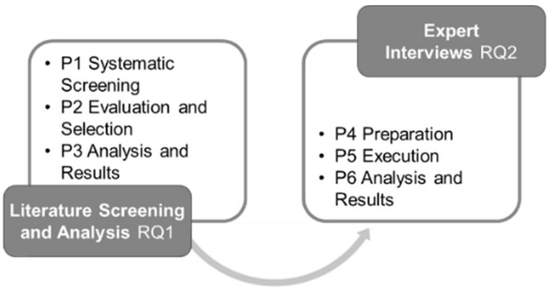

Figure 1: Overall Research Procedure

As shown in Figure 1, two different methods are used to address the two research questions. The first research question (RQ1) is answered by means of a systematic literature screening and analysis. Based on these results, the second research question (RQ2) is investigated through expert interviews, which also requires three phases. The following subsections describe the respective research methods.

2.1.1 Systematic Literature Analysis

To answer the first research question, a comprehensive literature analysis is conducted. Phase 1 starts with the definition of the research question. After that, the databases are determined, which are used for the literature screening. In the next phase the key words are defined, which are used to search for topic-related literature sources in selected databases. After all, parameters must be defined, the last step of this phase is the execution of the systematic screening.

In the second phase, the screened literature is evaluated and ranked according to the relevance for the research question. For this purpose, evaluation criteria are defined. These are presented in an evaluation matrix to ensure objectivity. For the evaluation, the criteria are weighted, and the selected sources are evaluated with a scoring model. The last phase includes the analysis of the selected literature sources to identify the most common potential benefits of digitalized procurement. For this purpose, a content analysis of the research papers is carried out and the results are summarized. The research procedure is shown in Figure 2. The research design is based on different methods of literature (Seuring/Gold 2012) (Hochrein et al. 2015) which are explaining the process of systematic literature reviews, especially for tertiary studies. Since this paper is concentrating on primary studies on the specific topic of digitalization benefits in procurement, the research design is accordingly adapted.

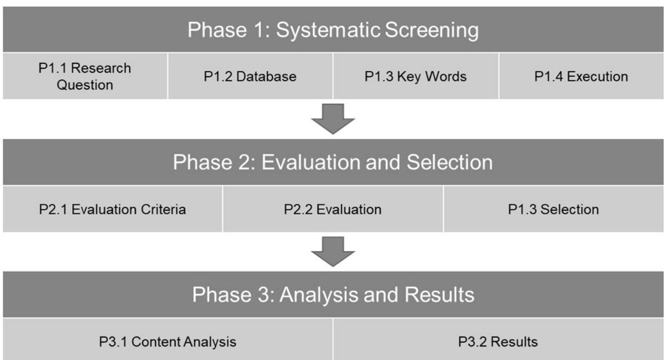

Figure 2: Detailed Research Procedure of Step 1

2.1.2 Expert Interviews

The second step of the research is about the enrichment of the derived results of Step 1 with more practical expert input. Therefore, expert interviews were prepared, and the results analyzed. The target is to find out which potential benefits Austrian industry procurement managers identified. Moreover, they give an insight into the current maturity level of digitalization in the respective procurement department. The interview guide consists of four thematic blocks: (1) *company-specific information* (2) individual *understanding of digitalized procurement and its technologies* (3) *potential benefits of digitalized procurement applications* and (4) *maturity level of digitalized procurement in Austrian industry*. The sampling procedure follows several limitations to ensure well-founded expert interviews, whereby the sample is limited on 4 procurement managers. In a further research step, the number of conducted interviews could be increased or expanded to a quantitative survey by convert the existing interview guide for large-scaled research. The procurement managers are employed in medium-sized companies which are allocated to the manufacturing industry in Austria by using the national classification ÖNACE which is based on the European NACE (Nomenclature européenne des activités économiques) classification. The advantage of ÖNACE is seen in the additional sublevels of the classification, which is not given in NACE. Therefore, a more detailed classification of economical activities is possible. To analyze the expert interviews, a qualitative content analysis is conducted to ensure a qualitative text interpretation (Mayring 2002).

3 Research Execution

After defining the general procedure of the research, the following section shows the execution of the research. The sources identified in this way are evaluated based on predefined criteria, allowing the most suitable literature sources to be selected. These are analyzed in the final phase and provide the potential benefits of digitalized procurement as a result, with which the first research question can be answered.

3.1 Execution of Systematic Literature Screening

After the definition of the research question, the next step is to define which database will be used for the literature screening. For this purpose, three databases were selected for the research since they have a high scientific standard and are assigned to the field of economics.

1. EBSCO
2. Emerald Insights
3. WISO

Furthermore, *Google Scholar* is also used for the research, as it allows further scientific documents to be found that do not appear in three databases mentioned above. After a first general screening about *Digital Procurement* following terms are identified and displayed in the Table 2:

Table 2: Key Words for Literature Screening of Digital Procurement

Key Words (English/German)		
Procurement 4.0 *Beschaffung 4.0*	Purchasing 4.0 *Einkauf 4.0*	Supply Management 4.0 *Supply-Management 4.0*
Supply Chain 4.0 *Supply-Chain 4.0*	Digital Procurement *Digitale Beschaffung*	Digital Purchasing *Digitaler Einkauf*
in combination with … (AND statement)		
Digitalization *Digitalisierung*	Digitalisation -	Digitization -
Digitisation -	Digital Transformation *Digitale Transformation*	Industry 4.0 *Industrie 4.0*

The search terms that fall within the scope of digitalized procurement are now used in a first search run. To ensure the highest possible coverage, the terms above are searched firstly and then in combination with the terms of digitalization.

The second part is to analyze which literature is about potential benefits for digital procurement. For this purpose, synonyms were defined and shown in Table 3.

Table 3: Key Words for Literature Screening of Potential Benefits

Key Words (English/German)		
Potential *Nutzenpotential*	Benefit *Nutzenpotenzial*	Profit *Nutzen*
Return *Potential/Potenzial*	Chance *Chance*	Improvement *Verbesserung*
Expectation *Erwartung*	Advantage *Vorteil*	Goal/Target *Ziel*
Opportunities *Möglichkeiten*		

The first search run offered approximately 11.000 hits. Therefore, the search run is limited on title and abstract. This measure offers 575 hits released since 2015. After deleting duplicates and research papers without full text available, the amount of research papers is decreased to 53. For the second search run, the sources identified in the first search run are now searched for terms from the area of potential benefits. Thus, only those research papers that deal with both digitalized procurement and its potential benefits will be further considered.

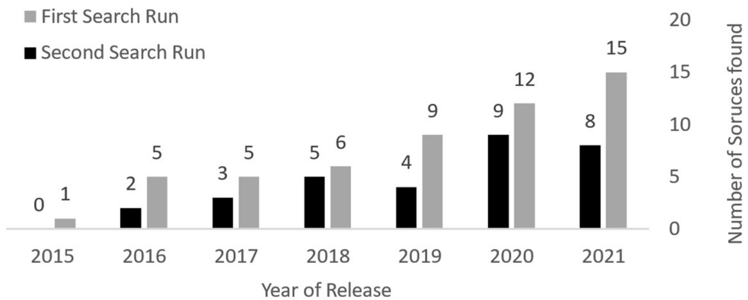

Figure 3: Distribution based on Year of Release after the first search run

As depicted in Figure 3, 53 sources are identified in the first run. The second run offers 31 research papers (8 in German and 23 in English language) which are evaluated using the criteria defined in Table 4.

Table 4: Evaluation Criteria

	Points				
Criteria	**1**	**2**	**3**	**4**	**5**
a) Actuality	2012 or older	2013-2014	2015-2016	2017-2018	2019 - 2021
b) Information content toward Procurement 4.0	rarely addressed	less addressed	mid addressed	highly addressed	main focus
c) Information content toward potential benefits	rarely addressed	less addressed	mid addressed	highly addressed	main focus
d) Procurement-specific or supply-chain (SC)-specific	mainly on SC	mainly on SC, hardly on procurement	balanced focus	Mainly on procurement, hardly on SC	mainly on procurement

After defining the evaluation criteria and the scale, the screened literature is evaluated. Table 5 shows the final rating of the literature.

Table 5: Evaluation of screened literature based on the defined criteria

	Author	**a) 35 %**		**b) 30 %**		**c) 30 %**		**d) 5 %**		**Evaluation**
1	BME et al. (2020)	5	**1,75**	5	**1,50**	4	**1,20**	5	**0,25**	4,70
2	Bienhaus/ Haddud (2018)	4	**1,40**	5	**1,50**	5	**1,50**	5	**0,25**	4,65
3	Globality (2019)	5	**1,75**	4	**1,20**	5	**1,50**	4	**0,20**	4,65
4	Bag et al. (2021)	5	**1,75**	5	**1,50**	3	**0,90**	5	**0,25**	4,40
5	Bag et al. (2020)	5	**1,75**	5	**1,50**	3	**0,90**	5	**0,25**	4,40
6	Högel et al. (2018)	4	**1,40**	5	**1,50**	4	**1,20**	5	**0,25**	4,35
7	Jerome et al. (2021)	5	**1,75**	5	**1,50**	3	**0,90**	4	**0,20**	4,35
8	Nicoletti (2018)	4	**1,40**	5	**1,50**	4	**1,20**	5	**0,25**	4,35
9	Radell/ Schannon (2019)	5	**1,75**	4	**1,20**	4	**1,20**	4	**0,20**	4,35
10	Glas/ Kleemann (2016)	3	**1,05**	5	**1,50**	5	**1,50**	5	**0,25**	4,30
11	Hallikas et al. (2021)	5	**1,75**	4	**1,20**	4	**1,20**	3	**0,15**	4,30

	Author	a) 35 %		b) 30 %		c) 30 %		d) 5 %		Evaluation
12	Efficio (2018)	4	**1,40**	5	**1,50**	3	**0,90**	5	**0,25**	4,05
13	Tripathi/ Gupta (2021)	5	**1,75**	4	**1,20**	3	**0,90**	4	**0,20**	4,05
14	Schlünsen/ Schentler (2016)	3	**1,05**	5	**1,50**	4	**1,20**	5	**0,25**	4,00
15	Von Eiff (2018)	4	**1,40**	4	**1,20**	4	**1,20**	4	**0,20**	4,00
16	Haddud/ Khare (2020)	5	**1,75**	2	**0,60**	5	**1,50**	2	**0,10**	3,95
17	Haddud et al. (2017)	4	**1,40**	3	**0,90**	5	**1,50**	2	**0,10**	3,90
18	Gottge et al. (2020)	5	**1,75**	4	**1,20**	2	**0,60**	5	**0,25**	3,80
19	Sánchez-Rodríguez (2020)	5	**1,75**	2	**0,60**	4	**1,20**	5	**0,25**	3,80
20	Muñoz-Garcia/ Vila (2019)	5	**1,75**	3	**0,90**	3	**0,90**	4	**0,20**	3,75
21	Pattanayak/ Punyatoya (2020)	5	**1,75**	2	**0,60**	4	**1,20**	4	**0,20**	3,75

	Author	a) 35 %		b) 30 %		c) 30 %		d) 5 %		Evaluation	
22	Müller/ Bollini (2017)	4	**1,40**	2	**0,60**	5	**1,50**	4	**0,20**	3,70	
23	Zekhnini et al. (2021)	5	**1,75**	3	**0,90**	3	**0,90**	2	**0,10**	3,65	
24	Kleemann/ Glas (2017)	4	**1,40**	5	**1,50**	1	**0,30**	5	**0,25**	3,45	
25	Chauhan/ Singh (2020)	5	**1,75**	2	**0,60**	3	**0,90**	1	**0,05**	3,30	
26	Koh et al. (2019)	5	**1,75**	2	**0,60**	3	**0,90**	1	**0,05**	3,30	
27	Patrucco et al. (2020)	5	**1,75**	2	**0,60**	3	**0,90**	1	**0,05**	3,30	
28	Becker/ Röper (2021)	5	**1,75**	1	**0,30**	3	**0,90**	4	**0,20**	3,15	
29	Yevu/Yu (2020)	5	**1,75**	2	**0,60**	2	**0,60**	4	**0,20**	3,15	
30	Meitinger (2021)	5	**1,75**	3	**0,90**	1	**0,30**	3	**0,15**	3,10	
31	Mastos et al. (2021)	5	**1,75**	1	**0,30**	3	**0,90**	1	**0,05**	3,00	

3.2 Content Analysis and Results

To focus on the most relevant literature in the content analysis, literature with a rating greater or equal than 4 are selected. This cut-off is based on the fact, that following publications are evaluated at least once with a score of “2”. This measure is needed to ensure high quality in literature selection based on the defined criteria above. At the end 15 sources meet this criterion and are analysed in detail regarding benefits of digitalized procurement. The most important outcomes are described in this section.

Bag et al. (2021) and Bag et al. (2020) refer to increased profit margins and productivity, 30 to 50 % reduction of transaction costs, shortening of delivery times, higher flexibility, and transparency due to data availability. Moreover Bienhaus/Haddud (2018) identified potentials in profitability, shortening of lead times and better transparency and decision-making.

Different studies of BME (2020) and EFFICIO (2018) show significant potentials of digitalized procurement. While BME identified optimization in process costs and an increase of transparency and supply reliability, EFFICIO predict doubling of operational process effectivity by digital solutions. This increase is caused by high and sustained cost reductions, improved decision-making, and risk-reduction along the supply chain.

Glas/Kleemann (2016) expect a cost reduction by digitalized procurement of 7.5 up to 40 %. Högel et al (2021) estimate cost reduction by 5 to 10 %. Beside a reduced coordination effort, product and process quality could be improved and stock levels optimized. Hallikas et al. (2021) defined high transparency and efficiency, shortening of lead times and minimization of supply risks as the highest benefits of digitalized procurement. Concerning lead times, Högel et al (2021) estimate a reduction from 10 to 3 days. Moreover, Nicoletti (2018) defines process costs as potential benefit of digitalized procurement. Furthermore, Jerome et al. (2021) also mentioned a high level of customer satisfaction, reduction of insecurities and improvement of supplier management processes especially in supplier scouting and onboarding. Radell/Schannon (2019) and Tripathi/Gupta (2021) see potentials through real-time data availability and increase of innovation level. Digital technologies in procurement offer new competitive advantages through velocity and quality of data.

In the following step, the results of the qualitative analysis are clustered and assigned to six categories. The main category is defined as *“costs/earnings”*, the other categories are *“time”*, *“quality”*, *“risk”*, *“efficiency/effectivity”* as well as *“others”*. 24 benefits could be identified as depicted in the following Table 6.

Table 6: Frequency Analysis of Potential Benefits in Literature

Potential benefits	**Frequency**	**Share [%]**
Costs/Earnings	23	**21,5**
Decrease Purchase Costs	11	
Decrease Process Costs	5	
Increase Productivity	4	
Improve Profitability/Margins	2	
Reduce Quality Costs	1	
Time	20	**18,7**
Reduce lead and transaction time	15	
Shortening delivery times	2	
Increase time for strategic issues	2	
Reduction of coordination effort	1	
Quality	29	**27,5**
Increase Transparency/Data Quality and Availability	15	
Improve decision quality	7	

Potential benefits	**Frequency**	**Share [%]**
Improve product and process quality	4	
Increase customer satisfaction	2	
Improve integration with LOB/divisions	1	
Risk	10	**9,3**
Minimize purchase risks	7	
Increase security of supply	2	
Improve risk evaluation of suppliers	1	
Efficiency/Effectivity	14	**13,1**
Increase Efficiency/Effectivity in general	11	
Increase level of automation	2	
Reduce Waste	1	
Others	11	**10,3**
Increase Flexibility/Agility	4	
Deny Maverick Buying	2	
Increase level of innovation	2	
Improve stock levels	2	
Improve supplier scouting and onboarding	1	
Number of Mentions	**107**	**100 %**

3.3 Potential Benefits in Practice

The second step of the research is about the enrichment of the results of step 1 with more practical expert input. This part of the research offers a first insight into the practical benefits from the industry's point of view. After a roll out of the expert interviews and transformation into a survey, the current interview guide can be used for a quantitative analysis on the topic in a further step.

The experts were asked about their opinion about which technologies are relevant for digitalized procurement. The outcome of this question shows a heterogeneous picture, as just *Big Data* and *Artificial Intelligence* are mentioned of the technologies of the introduction. Talking about technologies, *e-Procurement*, *ERP-systems*, *supplier portals*, *SRM-systems* and *advanced reporting tools* are mentioned by the experts as the key applications for digitalized procurement. *Cloud Computing* and *Internet of Things* are not mentioned in that context. In a next step, they evaluated the technologies mentioned in the previous question on the relevance using the following rating scale:

- 1 … highly relevant
- 2 … rather relevant
- 3 … rather not relevant
- 4 … not relevant

Table 7 shows the result of the evaluation, summarized into the categories

Table 7: Evaluation of technologies mentioned by the experts (A to D)

Ranking	**Technology**	**Classification**
1	ERP-systems	Highly relevant
2	Artificial Intelligence	

Ranking	Technology	Classification
3	Robotic Process Automation	Very relevant
4	Big Data	
5	Power BI	
6	Supplier Portals	Relevant
7	Advanced Reporting Tools	
8	SRM-systems/e-Procurement	Rather not relevant

Except for *SRM-system/e-Procurement*, experts evaluated the technologies with highly or rather relevant. A possible explanation for the evaluation of *SRM-system/e-Procurement* could be the fact that it is seen as a development step of IT employment to digitalized procurement. Glas/Kleemann (2017) describe this development, starting with *MRP (Material Requirement Planning)* to ERP (Enterprise Resource Planning), over *eProcurement* to *Procurement 4.0* with increasing operative relief and strategic influence from step to step. Therefore, ERP-systems as well as SRM-systems and e-Procurement offer the basis for digitalized procurement. Otherwise, ERP-systems are classified as very relevant technology and is seen as a minimum requirement for efficient collaboration and processes within an organization.

Especially *Robotic Process Automation* in combination with *Big Data* and *Artificial Intelligence* to automate operational purchasing processes like purchase orders or master data management are seen as the core technologies. This estimate is congruent with literature. (Nicoletti 2018) (Tripathi/Gupta 2020) (Bag et al. 2021)

In the next step open questions about the estimation of potential benefits of digitalized procurement are asked to the experts. The results were analyzed by assignment to the categories of Section 3.2. Additionally, experts were asked to evaluate the benefits of the literature based on the scale of Section 3.3, whereby the evaluation is done for benefit categories *Time*, *Quality*, *Risk*, *Efficiency/Effectivity* and *Others*. The benefits of the category *Costs/Earnings* are seen as product of the realization of benefits from other categories.

The most important benefits according to experts' opinion are assigned to the categories *Time*, *Quality* and *Efficiency/Effectivity*. Increasing transparency as well as data quality and availability is evaluated as highly relevant and is mentioned in each screened literature source. Reduction of lead and transaction times, better integration with LOB/divisions, increase of efficiency/effectivity and improvement of automation levels are evaluated with 1,25 in average. Worth mentioning is that the improvement of the integration with LOB/divisions is not mentioned by experts before. Furthermore, the reduction of coordination effort, improvement of decision quality and prevention of Maverick Buying are evaluated with an average under 2, though not mentioned before by the experts.

This result underlines the missing understanding of benefits as well as a lack of known applications to realize them in the industrial environment.

Table 8: Expert Opinion on analyzed Benefits of digitalized procurement

Potential benefits	**Literature Frequency**	**Literature Share [%]**	**Expert Opinion**	**Average Evaluation**
Costs/Earnings	**23**	**21,5**		
Decrease Purchase Costs	11		Mentioned	
Decrease Process Costs	5		Not mentioned	
Increase Productivity	4		Not mentioned	
Improve Profitability/Margins	2		Not mentioned	
Reduce Quality Costs	1		Not mentioned	

Potential benefits	Literature Frequency	Literature Share [%]	Expert Opinion	Average Evaluation
Time	**20**	**18,7**		**1,81**
Reduce lead and transaction time	15		Mentioned	1,25
Shortening delivery times	2		Not mentioned	2,75
Increase time for strategic issues	2		Mentioned	1,50
Reduction of coordination effort	1		Not mentioned	1,75
Quality	**29**	**27,5**		**1,8**
Increase Transparency/Data Quality and Availability	15		Mentioned	1,00
Improve decision quality	7		Not mentioned	1,50
Improve product and process quality	4		Not mentioned	2,75
Increase customer satisfaction	2		Not mentioned	2,50
Improve integration with LOB/divisions	1		Not mentioned	1,25
Risk	**10**	**9,3**		**2,58**
Minimize purchase risks	7		Mentioned	3,00
Increase security of supply	2		Mentioned	2,50
Improve risk evaluation of suppliers	1		Mentioned	2,25

Analysis of Potential Benefit and Maturity Level of Digital Procurement

Potential benefits	Literature Frequency	Literature Share [%]	Expert Opinion	Average Evaluation
Efficiency/Effectivity	**14**	**13,1**	**3**	**1,33**
Increase Efficiency/Effectivity in general	11		Mentioned	1,25
Increase level of automation	2		Mentioned	1,25
Reduce Waste	1		Mentioned	1,50
Others	**11**	**10,3**		**2,35**
Increase Flexibility/Agility	4		Not mentioned	2,50
Deny Maverick Buying	2		Not mentioned	1,75
Increase level of innovation	2		Not mentioned	2,75
Improve stock levels	2		Not mentioned	2,00
Improve supplier scouting and onboarding	1		Mentioned	2,75
Number of Mentions	**107**	**100 %**	**16**	

Another part of the expert interview is to analyze the maturity level of digitalized procurement. The evaluation is based on already realized applications of technologies. The evaluation of the maturity level is based on the framework of Pellengahr et al. (2016) in which the maturity level is separated into 7 levels, with level 1 indicating the lowest level of maturity:

1) No activities
2) Recognized potentials / first observations
3) Concrete observations for realization
4) First application in realization
5) First application near realization
6) 1 to 2 applications realized
7) 3 or more applications realized

The survey of Pellengahr et al. (2016) delivers a similar result as the expert interviews. The perception of benefits through digitalized procurement as well as the maturity level is high, while the definition of *Procurement 4.0* is highly divergent from expert to expert. They mention technologies, which are not seen as pioneer technologies of Procurement 4.0. The knowledge about so-called 4.0-technologies is insufficient. Table 9, in which the planned or realized applications of the experts are illustrated, underlines this statement.

Table 9: Planned or realized applications in practice

Application	**Status**
Robotic Process Automation	In Use
Artificial Intelligence for evaluation of pandemic development	In Use
Artificial Intelligence for global risk management	In Use
Implementation of global ERP-system	In Development

Application	Status
Implementation of WMS (Warehouse Management System)	In Development
Semi-automated invoice verification	In Use
Implementation of ERP-system	In Development
Implementation of SRM-system	In Development
Implementation of commodity management system	In Use
Implementation of Power BI solution	In Use

4 Summary

Digital procurement is not just a trend, it is a necessary step for future competitiveness. Typical 4.0-technologies will help to transform traditional purchasing sustainably. Procurement must react in real-time, which requires fully digitalized processes. Therefore, structural and processual adaptions are necessary. Not only processes will be digitalized, also supplied products and materials undermine digital changes. Digital procurement will help to handle a digitalized supply portfolio while operative purchasing processes can be executed nearly automatically by using f.e. robotic process automation. Therefore, operative purchasing and the role of purchaser will change to more strategic-oriented roles working together in groups of with changing qualification profiles. In future, data science, management of interfaces as well as coordination and controlling will be focused in smaller and strategic-oriented purchasing teams. (Pellengahr et al. 2016)

To start the transformation, procurement managers must be familiar with the most valuable benefits of digitalized procurement. As the result of this research shows, there is less common understanding between the scientific and practical opinion. Especially in Table 9 experts are reporting about technologies in their sense of digitalized procurement, while most of these applications and technologies do not fit to the idea of Procurement 4.0 and should already be state-of-the-art since years.

By evaluating the statements of the experts, many variations are recognizable. Therefore, the research questions should be analyzed in detail by drawing up further research in the form of a quantitative survey to get more and detailed information about the expert's knowledge and understanding about digital procurement and the maturity level of industry as well as how to make the next step of development or even to start the development in digitalization of procurement. This and further surveys should help to understand the need for digitalization in procurement to face future challenges.

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Digitalization of Rail Freight Transport

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Purpose: *Increasing demand for freight transport is in direct contrast to climate policy goals. Rail freight can reduce overall emissions if it builds up more market share. To achieve this, the rail sector needs to increase its competitiveness with other modes of transport using digitalization. Thus, the aim of this work is to analyze digitalization measures in rail freight transport.*

Methodology: *As we consider our problem as a multi-attribute decision problem, we measured the importance of different digitalization measures regarding its contribution to improve the overall competitiveness of rail freight transport based on an AHP-approach.*

Findings: *Based on a systematic literature review we identified 17 digitalization measures, which we grouped into four categories: automated train operation, digital maintenance, automated marshalling, and digital access to rail transport services.*

Out of those categories, automated train operation should be more focused on, followed by digital maintenance. Competitiveness is based on quality improvement, cost reduction and performance improvement out of which quality improvement was considered most important. Thereby reliability as well as time flexibility were considered as equally important by the experts.

Originality: *The paper gives a detailed overview of the status of digitalization measures available in rail freight.*

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1 Problem Background and Research Question

Freight transport is an essential prerequisite for the economy in Germany. In addition to the increasing volume of traffic, transport routes are also becoming longer and longer as a result of advancing globalization (Destatis, 2021). The current trend of increasing freight traffic in Germany is also supported by forecasts, as transport performance is expected to increase by around 40% by 2030 in relation to 2010. These developments in freight traffic are causing significant transport and environmental policy problems, as traffic is increasingly emitting greenhouse gases that are harmful to the climate (BMVI, 2017). However, looking at the modal split, we see that road freight transport is the dominant mode of transport in Germany, accounting for 70.2% of total transport performance, while rail freight achieves a market share of just under 19% (BMVI, 2021c).

To reduce greenhouse gas emissions and energy demand in the transport sector, a modal shift towards more environmentally friendly modes of transport is necessary in addition to a reduction in traffic. Shifting traffic from road to rail is therefore a viable strategy to mitigate the impact of freight transport on climate change, as rail transport (or intermodal transport) is more environmentally friendly than road freight transport only (Pinto et al., 2018). This modal shift can contribute to a more environmentally friendly freight sector (Rickenberg, von Mettenheim and Breitner, 2012; Lobig, Liedtke and Knörr, 2017). Accordingly, strengthening rail freight transport and increasing rail's share of the modal split is an integral part of meeting climate targets (Kagermann, 2021). However, rail's share of freight traffic increased by only 2.8% between 2000 and 2017 (Allianz pro Schiene, 2020). The targets set by the German government in 2002 regarding its sustainability strategy for 2015 have been missed. These targets envisaged an increase in the share of rail in the modal split to 25 % (UBA, 2021). Thus, to cope with the increasing freight traffic and to avoid bottlenecks in the rail freight infrastructure, significant investments in the infrastructure are necessary. Another approach to making better use of the existing rail freight infrastructure can be *digitalization* (Böttger, 2020).

The use of digital technologies offers the opportunity to increase efficiency and safety while reducing environmental impact without limiting mobility (Nemtanu and Marinov, 2019; Kagermann, 2021). Current developments show that road freight transport is benefiting from the increase in freight traffic demand and can further expand its share in terms of the modal split (Zanker, 2018). In this context, it is particularly relevant to consider digitalization, which can play a key role in increasing rail efficiency (Kagermann, 2021).

The focus of this work is the collection, presentation, and structured analysis of current digitalization measures that increase the competitiveness of rail freight transport compared to road freight transport. Increasing the competitiveness of rail should lead to an increase in market share in the freight market and thus support the desired modal shift. The research question is defined as:

Which digitalization measures should be prioritized in rail freight transport to increase the competitiveness of rail as a mode of transport compared to road?

Answering the research question is of theoretical relevance to gain an overview of current digitalization measures in rail freight. A summary of current measures also contributes to a new understanding of the topic in the literature. By identifying these very digitalization measures, future research can examine individual measures more thoroughly based on the overview to be compiled. Furthermore, by prioritizing the digitalization measures, conclusions can be drawn for practical application.

The remainder of the paper is as follows: After having presented the problem background and the research question, section 2 provides the conceptual background which includes digitalization in general as well as in logistics and in rail freight. Furthermore, benefits and drawbacks of digitalization are presented as well as the notions of competitiveness are understood in this paper. Section 3 introduces the methodological approach, which is based on a systematic literature review for identifying the digitalization measures and the Analytical Hierarchy Process (AHP) for the systematic comparison of those. The results of our analysis are shown in section 4 and discussed in section 5. Section 6 provides a critical reflection and answers to the research question, limitations as well as an outlook for future research.

2 Conceptual Background

This chapter defines the term digitalization and addresses its impact on logistics and rail freight. Based on the main advantages and weaknesses of rail freight, a framework for its competitiveness is developed.

2.1 Digitalization

Due to the vagueness of the concept of "digitalization", the term is predominantly not precisely defined in the literature (Srai and Lorentz, 2019). To understand digitalization in a general context, it is helpful to also look at the terms "digitization" and "digital transformation" (see also Figure 1). This is of particular importance in a German context, since "Digitalisierung" is used here as a term for all three concepts. These terms can also be understood as steps that build on each other and are each used according to their scope of application.

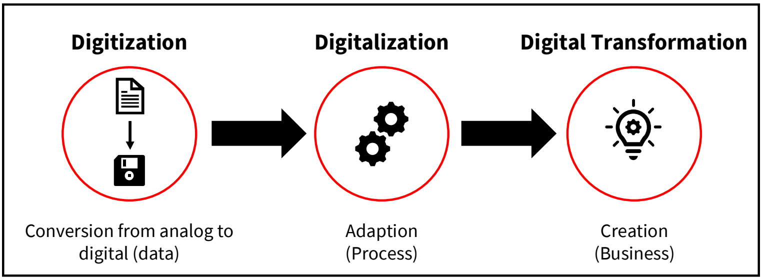

Figure 1: Digitization, Digitalization and Digital Transformation (own representation based on (Maltaverne, 2017; Bumann and Peter, 2019))

The first step "digitization" is limited in its scope of application, as it focuses on the conversion of analog to digital data. The second step "digitalization" then describes the use of digital technologies and thus, for example, the digitalization of a process. In terms of its scope, the third step "digital transformation" is the most encompassing since it affects not only a single process but the entire company or even industry. In digital transformation, previously performed activities are rethought to create new sources of value (Bumann and Peter, 2019).

2.2 Digitalization in Logistics and Rail Freight

Digitalization in the context of logistics is known as "Logistics 4.0", which describes the full availability of digital information on objects and actors in the logistics industry. With the help of digitalization, established logistics companies have the opportunity to realize various opportunities and potential for success (Becker et al., 2019). However, there are certain requirements that digital logistics must fulfill, such as increasing security, reliability, or even speed (Heistermann, ten Hompel and Mallée, 2017). In summary, logistics can be understood as one of application field of digitalization that has great potential. Many digitalization concepts such as Internet of Things (IoT) or autonomous driving are strongly linked to logistics, which is why it plays a central role in the implementation, but also in the design of digital methods and concepts (Wei and Noche, 2020).

Rail freight transport is only on the threshold of the first phase of digitalization, which is the introduction of new technologies. This situation can be explained by the poor economic conditions of rail freight transport, structurally expensive innovations and strategic advantages of other modes of transport (Müller, 2021). The digitalization of rail freight offers advantages such as the reduction of costs, transport times as well as the ecological footprint. On the other hand, the already existing network capacity of rail freight can be expected to increase reliability and flexibility (Enning and Pfaff, 2017; Zapp, 2018; Müller, 2021). Rail freight transport has lower emissions per tonne-kilometer compared to other modes of transportation, and increasing the competitiveness of rail would help reduce emissions in freight transport making it more sustainable (BMVI, 2017; DLR, 2017). The underlying definition of digitalization in this thesis includes the transformation of data as well as the design of processes with the help of the use of digital technologies in rail freight transport in order to achieve an increase in efficiency (Maltaverne, 2017; Bumann and Peter, 2019; Müller, 2021). Step 3 is not included in the definition because the area of digital transformation goes beyond the area of individual digitalization measures.

2.3 Benefits and Drawbacks of Rail Freight

An important advantage of rail freight transport is the low rolling resistance between the rail and the wheel (Meier, Sender and Voll, 2013). This results in the special suitability of rail for transporting large quantities and masses over long distances (Wannenwetsch, 2014). This energy efficiency also results in relatively low pollutant emissions in relation to the transport performance (Meier, Sender and Voll, 2013). A key weakness is the tie to the rail infrastructure, which very cost-intensive to build and maintain (Meier, Sender and Voll, 2013). Another disadvantage of rail freight is its strong dependence on predefined schedules. This leads to a further reduction in flexibility. In addition, the different requirements of the individual national railroads within Europe make for long border stops when transporting goods by rail (Gleißner and Femerling, 2012).

2.4 Competitiveness

We understand in this competitiveness as *“the sustainable and thus long-term ability of a sector to secure or expand market share through simultaneous attention to price and non-price factors”* (Martin, Westgren and van Duren, 1991; Bräkling, Lux and Oidtmann, 2020).

Market share in this context means the share of rail in relation to the total freight transport volume. According to Lee and Karpova, competitiveness consists of three parts: the goal(s), the method(s), i.e. how these goals can be achieved, and the framework conditions under which this process takes place (Lee and Karpova, 2018). Since this abstraction takes a national economic perspective which is not concrete enough for the rail freight industry examined in this work, it needs to be adapted. The three parts addressed plus the introduction of digitalization measures into the concept can be seen in Figure 2.

The framework conditions are to be omitted, as they are not relevant to the core of the study, since they are not influenced by digitalization measures and play a subordinate role in this paper. In the further course of the work, the methods will be referred to as criteria to avoid possible confusion during the implementation of the Analytical Hierarchy Process (AHP).

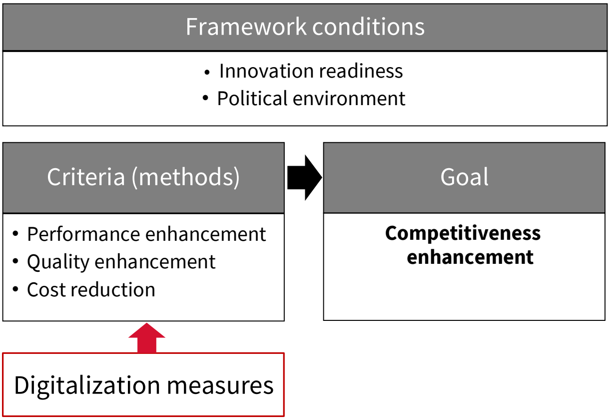

Figure 2: Representation of competitiveness (own representation based on (Gudehus, 2010; Lee and Karpova, 2018; Bräkling, Lux and Oidtmann, 2020)

Since the assessment of competitiveness, or the attractiveness of the offer, ultimately lies in the eye of the user or customer, the criteria will not be omitted (Feurer and Chaharbaghi, 1994). These represent the logistical factors used to decide which mode of transport provides the most utility (Gudehus, 2010; Bräkling, Lux and Oidtmann, 2020). However, it would not make sense to consider all criteria equally, since rail freight already has some advantages over road freight. For example, further emission reductions would not be particularly effective, as marginal returns would be low in terms of offer evaluation. Therefore, only those factors where rail is inferior to road transport will be examined (see 4.2).

3 Methods

This chapter presents the methodological approach consisting of a Systematic Literature Review to identify digitalization measures and an Analytical Hierarchy Process to evaluate those.

3.1 Systematic Literature Review

The methodological concept of the systematic literature review (SLR) aims at the compilation of a comprehensive literature review on a predefined topic by means of a suitable selection strategy (Carnwell and Daly, 2001; Kemmler et al., 2020). In the literature search, the keyword search is the most common method in practice, which is also followed in this work (Ely and Scott, 2007; Kemmler et al., 2020). The literature search is used to identify relevant secondary literature on the topic of "Digitalization measures in rail freight transport". This includes book chapters, journal articles, magazine articles, reports, and contents of websites. A total of five databases are used for the research work. These are Google Scholar, WISO-Net, Scopus, Web of Science, and the Bremen State and University Library. In addition to these databases, simple Google searches are also performed to extract relevant digitalization measures from Internet pages. To ensure a further high quality and reliability of the data, only those websites are used that originate from governmental institutions, represent corporate websites of actors in rail freight transport or are frequently cited in renowned scientific papers. Another step of the selection strategy is the definition of keywords. The search terms „digital*“, „Digitalisierung*“, „Automatisier*“, „Technologi*“, „Schiene*“, „Deutsche Bahn“, „DB Cargo“ were combined in different ways. Particularly with regard to such current and rapidly changing content of a subject area as digitalization measures, it is extremely important to ensure that the information to be procured is up to date (Brink, 2013). Therefore, only literature that is not older than 15 years is used in this work. Furthermore, the selection is made to exclusively German and English language works. For a classification of the relevance of the viewed sources for this scientific work, first the abstracts and conclusions are read. If a positive evaluation results from this consideration, a skimming of the complete contents follows. If another positive assessment for relevance is made after this step, the available literature is subsequently read in detail and the full information on the research objective is extracted. In the last step of the selection strategy, sources are to be included based on appropriate cross-references within the already identified literature. We identified 27 relevant sources in total, most of which were German.

3.2 Analytical Hierarchy Process

The digitalization measures which we identified in the literature (see 3.1) are evaluated with the help of the AHP by Saaty (1977) regarding their ability to increase the competitiveness of rail freight transport. The application of the AHP takes place in five successive steps (Saaty, 1977; 1980; Riedl, 2006; Goodwin and Wright, 2014), which are outlined Figure 3. In this paper, all five steps are applied chronologically to the decision problem.

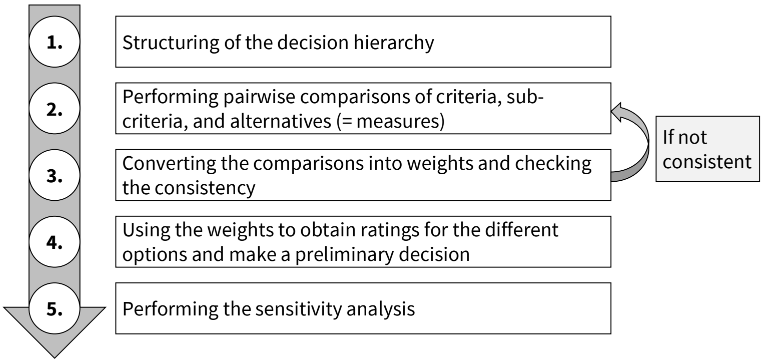

Figure 3: Flow chart of the steps of the AHP (own representation based on (Goodwin and Wright, 2014))

All steps of the AHP were carried out by the authors of this work, except for step two. For this purpose, two experts in the field of rail freight transport were interviewed, who will be referred to as Expert A and Expert B in the following. Expert A works for a company that develops transshipment systems in intermodal transport and Expert B works in the field of digitalization and automation for a large logistics service provider in rail freight transport. All steps from step two onwards are carried out in this work with the help of the online tool AHP-OS by Goepel (2018). For this purpose, the developed decision hierarchy is transferred to the tool, which then guides the user through all subsequent steps. To counteract a certain complexity of the handling with the AHP-OS tool during the pairwise comparisons, the experts were accompanied by the authors during this step in an online meeting. The tool offers the advantage that all calculations, such as the overall result with its intermediate results at the various levels, the consistencies, and the sensitivity, can be performed automatically and displayed clearly.

The experts first compare the criteria with each other in pairs and then the sub-criteria. Finally, the digitalization measures (= alternatives) are compared in pairs regarding their influence on the respective sub-criteria. For each comparison, the experts assign a score between 1 (=equal importance) and 9 (=the first object is absolutely dominant). The comparison results are transferred to matrices and then converted to weights, where the sum of the weights is 1 and the individual weights can be represented as percentages. The mathematical approach is based on eigenvalues (Saaty, 1987). The weights are calculated by dividing each value of the matrix by the corresponding column vector. The rows of the resulting matrix are added and divided by the column sums. The result of this calculation is a weight vector (Riedl, 2006). See Goepel (2018) for additional details.

4 Results

This chapter presents the results of the Systematic Literature Review - the digitization measures - in a structured way and presents the outcomes of the AHP.

4.1 Digitalization Measures

The SLR on digitalization measures in rail freight transport has revealed a large number of different measures. From a total of 27 identified measures, 17 were selected for further analysis. To be selected, the measure must a) conform to the stipulated digitalization definition (see chapter 2.2); b) have a sufficiently strong connection to rail freight transport and c) not be too similar to an already selected measure. The selected measures are assigned to 4 categories, which are based on a DB Cargo whitepaper on the topic of digitalization and automation of logistics in rail freight transport (DB Cargo, 2021b). Table 1 offers a clear representation of the selected measures and categories.

Table 1: Selected digitalization measures and categories

Categories	Digitalization Measure
Digital Access	Track and Trace
(see 4.1.1)	Geofence Control
	Wagon Data
	Modility
Automated Marshalling	Digital Automatic Coupler
(see 4.1.2)	Fully Automatic Bead Breaking Locomotive
	Yard Management Tool
	Automated Brake Test
Automated Train Control	European Train Control System
(see 4.1.3)	Fiber Optic Sensing
	Future Railway Mobile Communication System
	Digital Interlockings
Digital Maintenance	Camera Bridge
(see 4.1.4)	Wheelset Diagnosis
	Brake Sole Diagnosis
	Automated Switch Inspection
	Digital Fleet Management

4.1.1 Digital Access

The category of digital access can generally be understood as the provision of data and information. This provision can take place with the aid of platforms along the value chain and thus support companies in planning and controlling within rail freight transport (DB Cargo, 2021b). This information may include, for instance, the loading condition, temperature or humidity during transport (Meitinger, 2020). In the following, the services included in the digital access category will be discussed.

Track and Trace comprises the acquisition and transmission of location data and the recording of the cargo and wagon condition (Bruckmann, Fumasoli and Mancera, 2014). For this function, the freight cars must be equipped with GPS and telematics (Bosch, 2021; DB Cargo, 2021b). With the help of the GPS sensor and telematics, data on the position and condition of the freight car is transmitted every 10 minutes (DB Cargo, 2021b). This enables remote monitoring of the transport progress and thus better planning of the arrival of the freight car. In the future, other sensors can be installed to provide additional data. These sensors include temperature sensors, humidity sensors and sensors that monitor the status of the doors. All of these sensors enable even more comprehensive monitoring of the cargo and its condition (Meitinger, 2020; Bosch, 2021; DB Cargo, 2021b). Another measure is the service of **Geofence Control**. Here, the technology of geofencing is used. The principle of geofencing is that a virtual fence is drawn around a certain area (Reclus and Drouard, 2009). The freight cars are also equipped with GPS and telematics for this purpose (Verkehrsrundschau, 2021). As soon as the freight car enters the virtual fenced area, it is registered. This enables rail transport companies and customers to have an accurate overview of the number of freight cars within the fenced area (DB Cargo, 2021a). **Wagon Data** is a digitalization measure of DB Cargo AG. The freight cars are equipped with radio frequency identification (RFID) and near field communication (NFC) (DB Cargo, 2021). RFID technology offers the possibility of contactless and automated transmission of information and identification of objects using radio waves (Rosová, Balog and Šimeková, 2013). RFID and NFC thus make it possible to quickly identify a wagon, check the wagon number at loading points and track wagons, and record the wagon sequence of a freight train. These processes can run fully automatically thanks to the technologies used (DB Cargo, 2021). **Modility** is a German platform that is designed to facilitate bookings and intermediation for Combined Transport (CT). Access to intermodal transport is not just intended to strengthen CT, but above all to focus on rail as a mode of transport and thus make it more accessible (Kossik, 2021). By providing necessary information, the platform links two different groups of actors. Operators can market their transport capacities and freight forwarders can find and subsequently book them. Finally, it should be emphasized that Modility does not have any own transport responsibility, as this is passed on to the customers (Kossik, 2021).

4.1.2 Automated Marshalling

Automated marshalling with its automation and digitalization measures represents an important step in the advance of rail freight transport. Through a combination of the Train Formation System 4.0 and the development of the Freight Car 4.0, time-saving and more efficient shunting processes will enable optimization (Enning and Pfaff, 2017; Jäger, 2020).

The **Digital Automatic Coupler** (DAC) is a solution for moving the previously exclusively manual coupling process to the automatic coupling of freight cars (Borghini, Topal-Goekceli and Engelmann, 2021). Compared to the manual screw coupling, the DAC also connects the power, data and main air lines of the freight cars, thus ensuring important prerequisites for digitalization and automation in train formation (BMVI, 2021b). These features can lead to increased efficiency, time savings, increased productivity and safety, and an increase in the overall rail freight modal split (BMVI, 2021b). In addition, the DAC will enable an increase in capacity and performance in terms of the length of freight trains. In the future, the **Fully Automatic Bead Breaking Locomotive** (FABBL) will ensure a fully automatic bead breaking process in the train formation facilities. With the development and introduction, a completely driverless bead breaking operation should eventually be made possible (Eisenbahn-Bundesamt, 2021). The bead breaking process begins when the FABBL is attached to the freight car. This is followed by the release of the wagon securing device by the FABBL. After the removal of the wagon safety device, the FABBL is then ready to press the freight wagon over the hump (TH Nürnberg, 2017). The **YAMATO** decision support system, which is intended to facilitate the work of dispatchers in the train formation system with the aid of real-time data, information, forecasts, decision support and other analyses, can also generate a sustainable increase in efficiency through automated train formation. The digital evaluation of information in the planning cycle of the dispatchers in the train formation system ultimately enables an increase in productivity, quality, and punctuality of the operation. Other features that will bring benefits in the future include ensuring the stability of the entire transport network and minimizing the risk of additional costs incurred by previously manual errors (Nguyen et al., 2020). A digital brake display on the freight car and the associated digitalization measure of the **Automated Brake Test** offer potential for efficiency improvements in the train formation process. The brake checks that have been carried out manually in the past, could be bundled by digital control devices on both sides of the freight cars with the help of sensor technology and telematics information from the brakes and enable the wheeltapper to save physical and time brake checks (DB Cargo and VTG AG, 2019).

4.1.3 Automatic Train Control (ATC)

ATC offers several advantages over the conventional train control currently in use. The automated train monitoring can increase capacity on the tracks, as the technology allows trains to be spaced closer together. Another advantage is the reduction in the number of signaling systems and other trackside elements, which would reduce corresponding maintenance costs. In addition - depending on the degree of automation - personnel and energy costs can be saved (Schnieder, 2021a). Furthermore, computer-controlled driving is expected to reduce noise and mitigate wear and tear. The latter would reduce maintenance and repair costs for the drive and braking systems (Tasler and Knollmann, 2018). Higher levels of automation also require the appropriate infrastructure and technology. In Germany and Europe, these are to be provided by the **European Train Control System** (ETCS). Germany has been investing in ETCS since 2015 (BMVI, 2021a). However, only 320 km of German rail lines had been equipped with ETCS by 2019, with a further 1800 km of rail track to follow by 2023 (Eisenbahn-Bundesamt, 2017; DB Netz AG, 2020). In terms of track monitoring, Deutsche Bahn is currently testing **Fiber Optic Sensing**. This involves fiber optic cables that can measure changes in various properties, such as pressure or temperature. The sound patterns typical of certain events (moving train, running animals, tree breakage, etc.) are stored in a database, and when an incident occurs, the sound waves generated can be compared with those in the database. The localization is accurate to within five meters and can, for example, enable a timely warning in the event of an animal on the tracks (Pohl, 2018; Vidovic and Marschnig, 2020). For communication, the throughput rates of the current, 2G-based radio traffic are too low for the required data volumes and the latency times cause too great delays in interface communication. Therefore, as a measure in this area, a switch from GSM-R to the **Future Railway Mobile Communication System** (FRMCS) is supposed to be implemented. This standard is 5G-based and offers the correspondingly necessary performance in the areas of latency and throughput (Enning and Fratscher, 2017; Nitzschke, Wübbena and Rahmig, 2020; Schnieder, 2021b).

4.1.4 Digital Maintenance

Digital maintenance describes an area of digitalization in rail freight transport in which the reliability and resource efficiency of maintenance processes can be increased through the further development of procedures and the use of data with the help of certain technologies. In addition, the ability to generate forecasts can be enabled (Biedermann, 2019). As part of its Asset & Maintenance Digitalization program, DB Cargo is pursuing a four-stage model for the digital maintenance of its wagon fleet. The first stage describes the modular inspection. The second stage is condition monitoring. The third stage describes condition-based maintenance. The last stage involves predictive maintenance.

The first two digitalization measures within the Digital Maintenance category are **Wheelset and Brake Sole Diagnostics** using suitable technology. Specifically, **Camera Bridges** for external damage detection and transmission computers on the locomotives are used here. The camera sensor bridge can detect damage. The transmission computers are installed on the locomotives and transmit the necessary signals to the wayside. With the help of this data, an early assessment of the condition of a locomotive and an effective adjustment of the maintenance strategy with regard to the brake pads and wheelsets is possible (Müllerschön and Niggemann, 2018; Jäger, 2020; DB Cargo, 2021b). Another digitalization measure in this category is **Automated Switch Inspection**. Currently, switches are responsible for around 50% of disruptions in train operations. Seven cameras are used in this process, which are capable of synchronously recording the switches. The various laser measuring systems can measure the rail cross-sections as well as all guiding distances in the switches. As a result, there is no obstruction of other train traffic and timetables are hardly affected. The images and measurement results obtained are subsequently sorted with the aid of intelligent software and are then available to analysts for assessing the condition. The different angles of the images reveal all the details about the actual condition of the switches. The most striking advantages of this technology are on the one hand the increase of safety aspects in work processes and on the other hand an increased track availability (Eurailscout, 2021). Furthermore, a software solution for fleet control can be used within the framework of digital maintenance. **Digital Fleet Management** digitalizes the maintenance and maintenance order process in rail freight transport. The software solution enables around 3,000 locomotives and their individual components to be mapped digitally. In addition to this mapping, the software is then able to identify the nearest workshop for routine checks as well as potential malfunctions, which also has the necessary resources required for the repair (Boom, 2021). The last digitalization measure is the already mentioned **Camera Bridge** used for the detection and reporting of damages of freight cars. In this measure, the use of AI enables automated maintenance checks of freight fleets. The use of algorithms in AI image sensor data analysis makes it possible to deploy camera sensor bridges that automatically detect and report damage to freight cars (Jäger, 2020; DB Cargo, 2021b).

4.2 AHP Decision Hierarchy

The overall goal of the AHP methodology is to evaluate the selected digitalization measures in terms of their potential to increase the competitiveness of rail freight. We derived three top level criteria from competitiveness definition (see chapter 2.4) and from the logistics objectives as suggested by Gudehus and Kotzab (2012). The criteria include performance improvement, quality improvement and cost reduction. Each criterion is influenced by sub-criteria. These are only those criteria in which rail freight is currently inferior to road freight. Examples of such are transport time and time flexibility. The weakness of rail freight transport compared with road freight transport lies primarily in the long train formation times. This means that the expectations placed on rail freight with regard to transport times can often not be met (BVU, 2016; Stoll, Schüttert and Nießen, 2017). In rail freight transport, time flexibility is characterized by the fixed commitment to predefined timetables (Wannenwetsch, 2014) and the commitment to fixed travel times on the pre-selected train paths (Muschkiet and Ebel, 2013). This results in a certain limitation of rail freight, whereas road freight can act faster except in the case of congestion. Due to the large number of sub-criteria in combination with the pairwise comparisons, a single analysis of all 17 measures is too complex. For this reason, the previously established categories form the alternatives of the AHP.

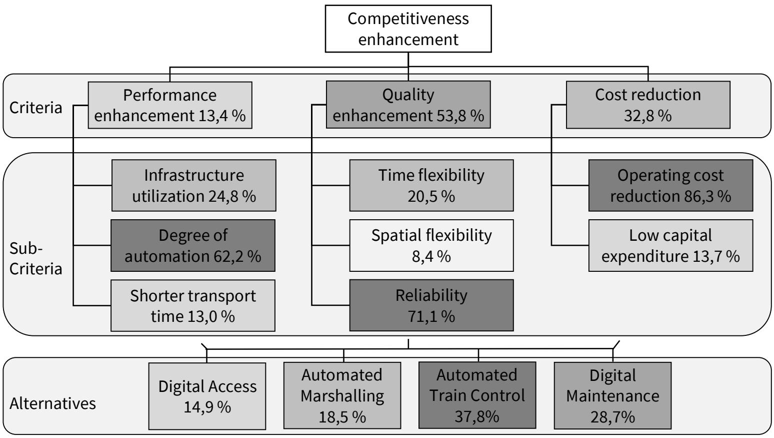

Figure 4: Result representation in the decision hierarchy (own representation according to (Gudehus, 2010; UBA, 2010; Meier, Sender and Voll, 2013; Muschkiet and Ebel, 2013; Sauerbrey and Mahler, 2014; Wannenwetsch, 2014; Breuer and Lieder, 2017; Enning and Pfaff, 2017; Stoll, Schüttert and Nießen, 2017; Schmidt, Enning and Pfaff, 2018; Zapp, 2018; Lutz, 2019; Europäisches Parlament, 2021; Müller, 2021))

Figure 4 shows the entire decision hierarchy and the results of the pairwise comparisons (see 3.2 for details on how the percentages are calculated).

Performing the pairwise comparisons shows that Automated Train Operation has the highest priority (37.8%), closely followed by Digital Maintenance (28.7%). Automated Marshalling (18.5%) and Digital Access (14.9%) have a rather low relevance.

The Consistency Index - i.e., the value indicating whether the experts' assessments are consistent within themselves - is below the recommended value of 10% in the overall result at 6.3% and thus in the optimum range. The sensitivity analysis, also provided by the AHP-OS tool, shows a robust result, i.e., the ATC would lose its first place only if large changes in the ratings were to occur at the decision alternative level. Incidentally, the same is true for the second place of Digital Maintenance. At the sub-criterion level, the model is even more stable; here, the tool sees only one change in the ratings within the realm of possibility. However, this would also only result in Digital Access and Automated Marshaling swapping places.

5 Discussion

This chapter discusses the results of the AHP, addressing the different preferences of the experts. The consensus score given is calculated by the AHP-OS tool and uses the weighted geometric mean aggregation of the experts' judgements (Goepel, 2018).

At the **criteria** level (Table 2), the result of the pairwise comparisons show quality improvement as the most important attribute. It should be noted that the experts are by no means in agreement here, even though the consensus of nearly 54 % is significantly higher than the approx. 33 % for cost reduction. Expert B prefers quality improvement more strongly than expert A prefers cost reduction, which is why the overall results appear clearer than they are.

Table 2: Results matrix for competitiveness

Participant	Performance enhancement	Quality enhancement	Cost reduction
Consensus	13,4 %	53,8 %	32,8 %
Expert A	7,5 %	18,3 %	74,2 %
Expert B	12,2 %	80,4 %	7,4 %

Expert A identified cost reduction as the most important criterion because he describes rail freight as a low-margin business that can offer price advantages to customers with cost reductions in operations and thus make itself more attractive. Expert B argued in favor of quality enhancement, as in his view the mass performance of block train transport, i.e., the bulk of the rail freight business, leaves little room for significant cost savings, but can still make significant gains in the area of service and offer advantages in this way. Support can be found in the literature for both views, both that cost reductions must counteract declining productivity (Doborjginidze, 2005), and that transport quality is a decisive factor in the choice of transport mode (Muschkiet and Ebel, 2013). Both experts agree on the quality enhancement sub-criteria (Table 2). Reliability is the decisive factor here. This is because rail freight transport is inferior to road freight transport in terms of reliability (Schmidt, Enning and Pfaff, 2018), although catch-up potential is still seen here in this context. Flexibility, on the other hand, plays a rather subordinate role in this area. Here, the initial situation is the same (poorer flexibility of rail freight), but road has such an advantage qua natura that an attempt to catch up and the corresponding result would not justify the resource input required for it (Muschkiet and Ebel, 2013).

Table 3: Results matrix regarding quality enhancement

Participant	Time flexibility	Spatial flexibility	Reliability
Consensus	20,5 %	8,4 %	71,1 %
Expert A	28,5 %	6,2 %	65,3 %
Expert B	14,3 %	10,9 %	74,8 %

In the area of **decision alternatives**, the consensus for the strongest decision alternative in percentage terms, Automatic Train Control, is moderate. The ultimately decisive factors here are the sub-criteria reliability and operating cost reduction, which account for just under two-thirds of the overall relevance.

As can be seen in Table 4, the alternatives ATC and Digital Maintenance are practically on a par for the reliability sub-attribute with 0.370 and 0.373 respectively. Here, Expert B argues in favor of ATC, which should enable smoother travel (e.g., through the elimination of signaling systems), especially through the introduction of ETCS, and can thus achieve improvements in punctuality. Expert A favors digital maintenance. Unforeseen disruptions are to be prevented by closer-meshed and more efficient monitoring of the infrastructure and vehicles. Above all, the fact that 50% of all disruptions occur in the area of switches lends weight to this view (Eurailscout, 2021). The fact that Expert B gave digital maintenance a relatively good rating here means that it is still just ahead of ATC overall. The significant difference, however, comes in the reduction of operating costs. Here, both experts grant a high relevance to ATC. While Expert A considers Digital Maintenance to be the most important category, Expert B sees more advantages in ATC. The unanimity with regard to ATC can also be underlined by other sources (Hagenlocher and Wittenbrink, 2015; McKinsey&Company, 2018).

Table 4: Overall results of the decision hierarchy

Criteria	Sub-Criteria	Global Priority	Digital Access	Automated Marshalling	Automated Train Control	Digital Maintenance
Performance enhancement 0,134	Infrastructure utilization 0,248	3,3%	0,427	0,102	0,351	0,120
	Degree of automation 0,622	8,3%	0,249	0,252	0,399	0,100
	Shorter transport time 0,130	1,7%	0,308	0,217	0,377	0,099
Quality enhancement 0,538	Time flexibility 0,205	11,0%	0,198	0,186	0,352	0,264
	Spatial flexibility 0,084	4,5%	0,127	0,151	0,557	0,166
	Reliability 0,711	38,2%	0,130	0,127	0,370	0,373
Cost reduction 0,328	Operating cost reduction 0,863	28,3%	0,060	0,261	0,415	0,264
	Low capital expenditure 0,137	4,5%	0,329	0,163	0,071	0,437
	Sum	1,0	**14,9%**	**18,5%**	**37,8%**	**28,7%**

6 Conclusion, Limitations and Further Research

The overall result indicates that a smooth-running transport process through improved train routing as well as a rail network as free of disruptions as possible through fewer unforeseen failures of switches or trains should be the focus for future digitalization measures in rail freight. Therefore, the digitalization measures are to be prioritized primarily from the category Automated Train Operation and secondarily from the category Digital Maintenance. In addition to prioritizing the measures, it is clear that effective digitalization in rail freight must be holistic (Lotz et al., 2020). However, individual components such as the implementation of ETCS will cost around 32 billion euros, making comprehensive rail digitalization a cost-intensive project (Schmitz, 2021). Expert B mentioned that about 52 billion euros are needed to reach 25% of the modal split for rail freight transport (Schlesiger, 2021). Financing such projects also requires additional policy measures that not only provide the financial resources but also increase investment incentives in rail freight.

Expert A pointed to CO_2 compensation costs as the strongest lever to make rail more competitive with road. In addition to the prioritization of digitalization measures, the present research work has thus also revealed that rail freight transport has a problem regarding transport costs. Operating costs must not be allowed to rise any further, as this would make rail less competitive (Weser-Ems-Wirtschaft, 2021). Thus, a digitalization strategy cannot be considered in isolation from other factors such as implementation costs and operating costs. In addition, potential threats, such as the risk of cyberattacks, should also be considered when introducing digitalization measures, and a comprehensive strategy for the security of digital systems in rail transport should be established. In this way, rail systems can be made not only digital but also secure (European Union, 2019). In conclusion, the research question can be answered as follows: To increase the competitiveness of rail freight transport compared to road freight transport, automated train operation should be prioritized over digital maintenance. However, digitalization per se can only represent one building block for increasing competitiveness (Lotz et al., 2020), and thus a holistic perspective is of particular importance.

The limitations are due to the selected temporal and spatial perspective since this study examines current digitalization measures in Germany. Even if the digitalization measures presented were to be introduced across the board, road freight transport would also continue to develop, which means that increased market shares for rail cannot be guaranteed. Furthermore, freight trains are only economically viable from a distance of over 300 km and for transported goods volumes of 30 - 35 truckloads and above, and therefore a comparison between rail and road is only possible to a limited extent, as a limiting factor in the profitability becomes apparent here (Pfohl, 2018). Another limitation is that only 2 experts participated in the AHP and the customer perspective was not considered. Kinra and Kotzab (2008) highlighted three general limitations of the AHP. The methodology is a quantitative approach that makes it difficult for outsiders to understand individual decisions. In addition, the decisions are, at their core, based on the subjective choices of the experts. Finally, it should be mentioned that the ratio scale of 1 - 9 can represent technical inadequacies (Kinra and Kotzab, 2008).

Future research work could identify further measures that also increase the competitiveness of rail. Here, the focus could be on measures such as the revision of existing regulatory standards, for example regarding CO_2 pricing, or further network expansion, which do not fall directly into the area of digitalization. In this way, further recommendations for action can be made for policymakers by prioritizing the packages of measures as well as individual measures to provide a more targeted overview for increasing the competitiveness of rail freight transport. After all, politics ultimately has an enormous influence on the development of rail freight transport as a whole (VDV, 2015; Enning and Pfaff, 2017). Another way of examining digitalization in rail freight would be to take an even broader look at the concept of digitalization regarding digital transformation. Here it would be of interest whether there is a need in rail freight sector to digitalize not only train operations, but also corporate structures and processes.

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IV.
Supply Chain Risk and Security Management

Supply Chain Risk Management in Crisis Situations

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Purpose: *The aim of the paper is to develop a concept for implementing supply chain risk management (SCRM) in crisis situations based on recommendations for action.*

Methodology: *The paper utilizes a mixed-method approach based on a systematic literature review and an interview study to analyze the state of research and practice in order to extract the recommendations for action.*

Findings: *The insights gained from the analysis of existing approaches and the findings from the expert interviews are incorporated into the development of the concept. This includes general recommendations for implementing a SCRM as well as specific measures for preparing for and managing crisis situations.*

Originality: *The concept is intended to support companies in implementing a suitable SCRM system that supports a systematic improvement in the resilience of companies with regard to risks and crises and forms the bases for effective crisis management.*

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1 Introduction

Companies have been facing various megatrends for more than a decade: Globalized markets, rapidly changing technologies, shorter product life cycles, and the shift from a seller's market to a buyer's market are creating more volatility and uncertainty in the marketplace (cf. Abele and Reinhart, 2011, 10ff.). For years, these trends have been causing companies to rethink their operations and to join forces in supply chains. As a result, it is no longer individual companies that compete with each other, but entire supply chains (cf. Christopher, 2011, pp. 15–16). The task of supply chain management in this context is to achieve the most cost- and time-optimized cooperation possible between the companies involved.

Interruptions and disruptions in the supply chain not only affect the acutely affected organization due to the close interconnectedness of the companies, but can also result in financial losses and reputational damage for other organizations in the value network (cf. Jüttner, 2005, pp. 120–121). The strong focus on efficiency in the context of supply chain management, which goes hand in hand with the reduction of buffer stocks in line with the lean philosophy, is increasingly making supply chains more vulnerable (cf. Kersten, et al., 2011, p. 153). An amplification of the risk of potential supply chain failure or breakdown is evident at the global level, as global supply chains are influenced by a variety of country-specific factors. In this context, the effort and difficulty of management increases enormously, however, this can be justified by access to cheaper labor, raw materials as well as other incentives of different locations (cf. Manuj and Mentzer, 2008a, p. 134).

Due to the high level of uncertainty and associated risks in global supply chains, it is of paramount importance for companies to understand the range of potential risks and their interconnectivity in order to establish appropriate risk mitigation strategies (cf. Manuj and Mentzer, 2008b, pp. 192–193). The volatile market situation prevailing today justifies the classification of supply chain risk management as a discipline of very high priority for both practitioners and academics.

Nevertheless, risk management is not or not sufficiently practiced in many companies. A study by management consultants INVERTO shows that only 38% of the companies surveyed systematically record and assess risks (cf. Jüttner and Maklan, 2011, p. 246; INVERTO GmbH, 2020, p. 5). Crisis situations in particular, such as the current global COVID-19 pandemic, clearly show the vulnerability of companies and their supply chains (cf. Kersten, Schröder and Nagi, 2022, p. 744). For example, in June 2021, 38% of respondents to a survey by the Austrian Association of Materials Management, Logistics and Purchasing perceived supply chain disruptions as an impact of the Corona crisis, and 19% spoke of a disrupted supply chain (cf. BMÖ, STÖHR FAKTOR Unternehmensberatung GmbH and ISM, 2021, p. 6).

The aim of this paper is to develop a concept for implementing supply chain risk management in crisis situations based on recommendations for action. The concept is intended to support companies in implementing a suitable supply chain risk management system that supports a systematic improvement in the resilience of companies with regard to risks and crises and consequently forms the basis for effective crisis management.

To achieve the defined objective, the following research question will be answered: How can supply chains be prepared for and successfully managed in the context of crisis situations?

The structure of the paper is as follows: Section 2 first reviews the general theoretical background of supply chain risk management (SCRM), supply chain resilience (SCRES), and crisis management. Then, Section 3 presents the methodological approaches for the literature review and analysis and the interview study. Afterwards, in Section 4, the core findings of the literature review and analysis and the interview study are brought together to present the developed concept based on them. Section 5 summarizes the findings and offers an outlook on possible areas for further research.

2 Background

2.1 SCRM

Supply chain risk management (SCRM) represents a combination of the classic approaches to risk management with supply chain management (cf. Kersten, Schröder and Indorf, 2017, p. 53). Compared to the classic company-based risk management approach, SCRM as an interorganizational approach differs primarily in its cooperative risk handling with the participation of several supply chain members (cf. Jüttner, Peck and Christopher, 2003, pp. 200–201; Kajüter, 2003, p. 111; Tang, 2006, p. 453; Rao and Goldsby, 2009, p. 101). According to Kajüter (2003, p. 111), interorganizational risk handling entails the following special features for risk management in the supply chain context:

- Two levels of action exist with the companies and the supply chain.
- There are information asymmetries with regard to risks between the individual companies and the supply chain.
- The individual organizations usually pursue different risk strategies.
- Companies are often involved in several supply chains and are therefore limited in their willingness to adapt to individual supply chain standards.
- International supply chains must meet different national regulatory requirements for risk management.

A large number of definitions for the term SCRM can be found in the business management literature, which differ in terms of the scope and objective of the concept (cf. Sodhi, Son and Tang, 2012, p. 8). This paper is based on the definition of Kersten, et al. (2007, p. 1171) according to which SCRM is defined as a "*[...] a building block within supply chain management that encompasses all strategies and measures, all knowledge, all institutions, all processes, and all technologies that are suitable at the technical, personnel, and organisational levels for reducing risk within the supply chain*" (Kersten, et al., 2007, p. 1171).

Collaboration in the context of SCRM is based on two different endeavors: The sharing of risk-related information between supply chain partners and the collaborative management of supply chain risks (see Jüttner, 2005, p. 132; Kleindorfer and Saad, 2005,

p. 66; Li, et al., 2015, p. 84). Sharing information between supply chain partners reduces uncertainty in supply chain management and leads to improved visibility within the supply chain (cf. Chen, Sohal and Prajogo, 2013, p. 2195). The improved visibility and reduced uncertainties also allow companies to stockpile lower safety stocks (cf. Christopher and Lee, 2004, p. 391). The effectiveness of sharing risk-related information is significantly influenced by the duration of the relationship and the level of trust between the supply chain partners involved (cf. Li, et al., 2015, p. 89). Supply chain risks usually result from common processes or the relationship between companies or affect multiple companies in the supply chain (cf. Jüttner, 2005, p. 132). Based on this, these risks are classified as joint risks and risk handling is coordinated accordingly using the capabilities of multiple supply chain partners (cf. Chen, Sohal and Prajogo, 2013, p. 2195). The goal of collaborative risk handling is to make SCRM as effective as possible, but also efficient, in order to maximize and fairly share the value and benefits generated in the supply chain (cf. Kleindorfer and Saad, 2005, p. 66).

The selection of the approach to be followed depends to a large extent on the type of business relationship between the companies in the supply chain. The importance of the business relationship and the phase of network formation are determining factors. In early phases of the network formation the close and trusting co-operation necessary for an enterprise-spreading SCRM is often not yet given, so that in such situations a risk management in the procurement can prove quite effective. With increasing intensity and experience in co-operation this beginning can be developed then further. The parallel pursuit of the approaches within a supply chain is possible, since the decision of the approach is always based on the individual business relation between the partners (see Kajüter, 2003, pp. 116–117).

Nevertheless, companies should aim to design the SCRM process cooperatively with their supply chain partners and thus extend risk identification, analysis and evaluation as well as risk management to the entire supply chain.

In addition to SCRM, the concept of supply chain resilience has also been increasingly discussed and researched in the literature for several years in connection with risks in value networks (cf. Pettit, Croxton and Fiksel, 2019, pp. 57–58).

2.2 Crisis Management

The term crisis is frequently used in everyday language as well as in science, but the ambivalent character of the term is often neglected, especially in the context of non-scientific use (cf. Radowski, 2007, p. 13). In science, on the other hand, the term is interpreted interdisciplinarily as a threat to existence with the possibility of positive as well as negative development (cf. Krystek and Lentz, 2014, p. 33). The term crisis can be generally defined as "*a serious threat to the basic structures or the fundamental values and norms of a system, which under time pressure and highly uncertain circumstances necessitates making vital decisions*" (Rosenthal, Charles and ’t Hart, 1989, p. 10). A variety of causes can bring about crises (see Grewal and Tansuhaj, 2001, p. 68; Krystek, Moldenhauer and Angster, 2007, p. 24). A distinction is often made between system-internal and system-external, but also between natural and man-made causes of crises (cf. Rosenthal and Kouzmin, 1997, p. 280; Krystek, Moldenhauer and Angster, 2007, p. 24).

According to the definition by Rosenthal, Charles and ’t Hart (1989, p. 10), uncertainty, urgency, and danger are central properties of crisis situations. According to Krystek and Lentz (2014, pp. 33–34), crises can also be characterized by the following properties (see also Krystek, Moldenhauer and Angster, 2007, pp. 26–27):

- Threat to existence
- Ambivalence of the outcome (annihilation or coping)
- Temporal limitation
- Limited ability to influence
- Progressive loss of possibilities for action

Accordingly, crisis management can be understood as a systematic approach to the prevention of crises and the effective handling of crises that do occur (cf. Pearson and Clair, 1998, p. 61). This definition suggests an active or preventive approach and a reactive approach to handling crises (see Figure 1). In this context, crises can be seen as the occurrence of risks that threaten the existence of the company, so that the identification, assessment and avoidance of potential crises and thus active crisis management are largely covered by risk management (see Fiege, 2006, pp. 194–196). Preventive crisis management also carries out planning and preparations in the event that a risk cannot be controlled within the framework of risk management (cf. Töpfer, 2006, pp. 377–378). Reactive crisis management (also crisis management in the narrow sense) acts on a case-by-case basis when risks occur that could not be controlled within the framework of risk management and have an impact on the company's objectives that threatens its existence (cf. Fiege, 2006, p. 194). In response to an event occurring, individual and organizational readjustments of basic assumptions as well as recovery and readjustment reactions are required for effective crisis management (cf. Pearson and Clair, 1998, p. 66).

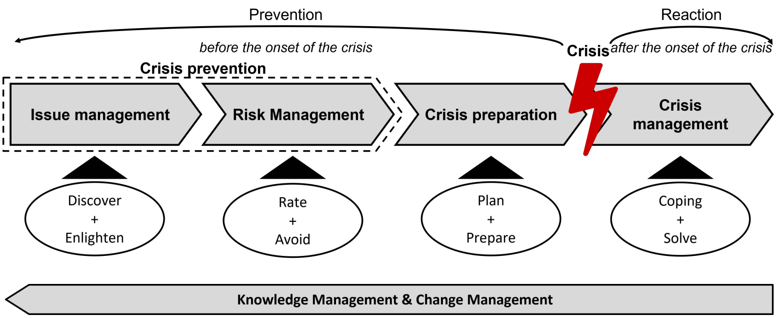


Figure 1: Process diagram of crisis management (own representation based on Töpfer (2006, p. 378))

3 Methodology

In order to answer the underlying question, the authors conducted a literature review and analysis with the aim of systematically collecting and presenting a comprehensive overview of the relevant scientific approaches to crisis management in supply chains. At the same time, however, approaches located in the practice of companies are also to be considered in order to identify the current state of knowledge both in the field of research and in corporate practice.

In the following step, the influence of the integration of SCRM on the resilience of companies and the role of digital tools as well as collaboration in industrial practice will be discussed in this context within the framework of an interview study.

3.1 Systematic Literature Review

In phase 1, starting from the research question, an unstructured online search is first conducted using broad search terms to find important literature in the topic area under investigation (see Figure 2). The aim of this procedure is to compile an initial set of relevant literature for the field of investigation. For this purpose, the works identified as relevant are examined for references to further relevant literature. Based on this compilation, important keywords and formulations in the considered field of investigation can be derived subsequently.

Phase 2 focuses on the selection of databases. Here, a distinction is made between the selection of databases for scientifically published literature and databases for grey literature. The identification of suitable databases for scientific literature is mainly based on the initial literature, on the basis of which different databases are tested for the availability of relevant literature. As a result of this step, the electronic databases SCOPUS (www.scopus.com) and Web of Science (www.webofknowledge.com) are selected, which in combination offer a broad coverage of the potentially relevant literature and also allow a tabular export of the data. For the identification of relevant grey literature, the Google search engine (www.google.com) is selected, since due to the topicality of the research field in the context of the pandemic, the broadest possible base of grey literature should be searched.

In phase 3, a list of search terms is derived based on the keywords and formulations obtained from the initial literature. First, possible terms are collected and supplemented with alternative spellings and potential synonyms. Subsequently, the collected terms are divided into thematic groups, so that from now on combinations of term blocks can be tested as search queries on the selected databases. When testing the potential queries on the SCOPUS and Web of Science databases, two primary criteria are used to evaluate the search queries: The number of hits and the ratio of relevant to irrelevant hits. A very large number of hits may indicate that the search request is too broad and that further processing is very time-consuming. If, on the other hand, the number of hits is rather small, it may be that the search request is too specific and that complete coverage of the relevant literature is not achieved. The ratio of relevant to irrelevant hits for the field of investigation can be tested on a sample basis. However, both evaluation criteria leave some discretion, so testing is an iterative process. This approach applies to scientific databases.

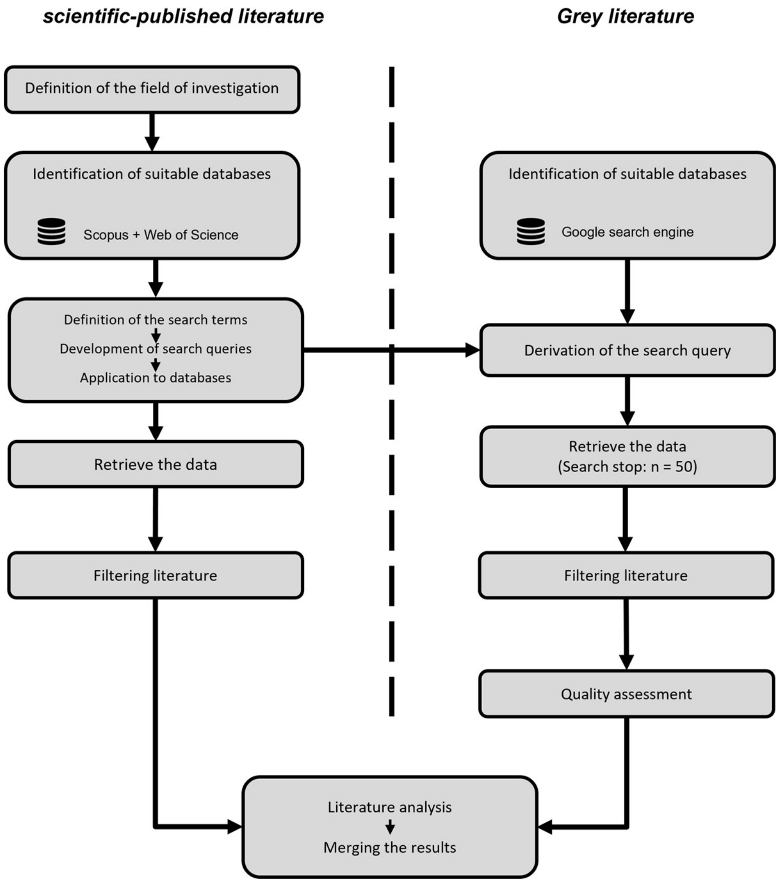


Figure 2: Flow of structured literature review and analysis (own representation; phases based on Fink (2014, pp. 3–5) and Garousi, Felderer and Mäntylä (2019, p. 108)).

For the search request for data collection of grey literature by means of a search in the Google search engine, the search requests of the scientific databases are used and reduced accordingly to the most concise and most frequently used search terms. The individual search queries in the respective syntax of the databases are shown below.

Table 1: Search queries in the respective databases (own representation)

SCOPUS	TITLE-ABS-KEY ((crisis OR disaster) AND ("supply chain" OR "supply network" OR "SCM" OR "SCRM") AND "risk management") AND (LIMIT-TO (LANGUAGE, "English") OR LIMIT-TO (LANGUAGE, "German"))
Web of Science	(TS=((crisis OR disaster) AND (“supply chain” OR “supply network” OR “SCM” OR “SCRM”) AND “risk management”)) AND LA=(English OR German)
Google-search engine	supply chain risk management crisis

In the search queries of the databases SCOPUS and Web Science, synonyms or terms of a topic group are linked with the logical operator "OR" and different topic groups with the operator "AND". The search is applied to title, abstract and keywords and limited to German and English language literature. In the context of the search for grey literature, the use of logical operators is avoided. The searches were applied to the previously selected databases and resulted in 319 hits in the SCOPUS database and 136 hits in the Web of Science database. The search for grey literature is limited to 50 results declared as the most relevant hits by the Google search engine algorithm. Thus, the three databases provide a cumulative total of 505 hits, whereby in the subsequent filtering (phase 4), due to the special handling of grey literature, the hits from the scientific databases (SCOPUS and Web of Science) are considered separately from the hits from the Google search.

In phase 4, the literature lists generated from the queries of the databases are filtered for scientific and for grey literature. The order of the filtering stages is largely identical, apart from the fact that the assessment of the relevance of grey literature can in part only take place in the context of a full text analysis due to the lack of a standardized form (cf. Adams, Smart and Huff, 2017, p. 434). In the first filtering stage, duplicate and incomplete hits are obviously sorted out. Subsequently, in filtering stage 2, duplicates are identified that are in the hit list due to partial overlaps of SCOPUS and Web of Science. Subsequently, in filter stages 3 and 4, hits relevant to the field of investigation are filtered out using filter criteria in the context of title and abstract screening. In order to be considered in the literature analysis, the works must firstly have a reference to supply chains and secondly address the management of crises in the broadest sense. Furthermore, articles are excluded in this step which, in the context of the title or abstract screening, show a very strong specialization with regard to the industry or risk type under consideration, so that the results obtained do not have any general validity. The resulting list of relevant literature is subjected to a full text analysis in step 5 in order to finally filter out the relevant approaches to the management of supply chains in crisis situations.

The peculiarities in the handling of grey literature are, in the context of filtering the literature list, on the one hand, the compulsory full text analysis for some works due to the lack of meaningfulness of the titles or abstracts, if abstracts are available. On the other hand, the literature identified as relevant cannot be included in the literature analysis (phase 5) without prior quality assessment. For this reason, the identified works are examined with regard to their quality using an evaluation form based on Garousi, Felderer and Mäntylä (2019). For this purpose, each work is evaluated with regard to 19 criteria/questions. If the evaluation is positive in terms of quality with regard to the respective criterion/question, the work receives one point. For the inclusion of grey literature in the literature analysis, a minimum score of ten out of 19 possible points is required. The approved works, as well as the identified relevant works from the defined scientific databases, are subsequently analyzed in more detail in phase 5.

In phase 5, both scientific works and works that can be classified as grey literature are analyzed and processed in order to reflect the state of research, but also current practice.

For this purpose, the identified works were examined in terms of content and qualitatively systematized.

3.2 Interview study

In addition to the systematic literature review, expert interviews were conducted to answer the research question. In the interviews, in addition to the handling of the SCRM process in practice, collaboration and digital tools and, finally, SCRM in the Corona pandemic were discussed.

For the evaluation of the expert interviews, content-structuring qualitative content analysis was carried out according to the approach of Mayring (2015). The focus of content analysis according to Mayring is a system of categories derived from theoretical assumptions and developed on the material, which determines the aspects to be filtered out of the materials (cf. Mayring, 2016, p. 114). For this purpose, categories were determined deductively from the research question and the interview guide in the present research project, which were supplemented by categories derived inductively from the material. In the context of interpreting the data, Mayring (2015, p. 67) distinguishes between three different basic forms: Summary, Explication, and Structuring. This article is based on a structuring summary of the content of the data collected in the course of the expert interviews (cf. Mayring, 2015, p. 103).

The data collection of the nine expert interviews took place in May 2021. Prior to this, contact was made by e-mail or LinkedIn and, if necessary, subsequently by telephone. The vast majority of the interviews took place via online video telephony using the Zoom software tool, and one interview was conducted by telephone. The duration of the interviews ranged from 31 to 60 minutes, and on average an interview lasted approximately 45 minutes. To prevent loss of information, the interviews were allowed to be digitally recorded, with the exception of the telephone interview. During the telephone interview, a transcript of the interview was made by the interviewer.

The transcription of the interviews is indispensable for a detailed analysis of the data (cf. Gläser and Laudel, 2006, p. 193; Meuser and Nagel, 2009, p. 476; Mayring, 2016, p. 89). For this reason, verbatim transcripts were created using the audio recordings of the interviews.

Table 2: Overview of interview participants (own representation)

Interview	Position	Industry
1	Head of Logistics Controlling	Heating Systems
2	Supply Chain Manager	Aircraft
3	Head of Sales	Software/IT
4	Head of Supplier Risk Management	Automotive
5	Solutions Design Manager	Logistics
6	Head of Advanced Purchasing	Mechanical Engineering
7	Senior Vice President – Strategic Procurement & SCM	Mechanical Engineering
8	Partner	(IT-) Consulting
9	Procurement – Head of Strategic Projects	Heating Systems

The evaluation is based on a category system whose categories were determined deductively from the question and the topics of the interview guide as well as inductively by reading the interview texts. In the context of this evaluation, individual sentences are used as the smallest material components for category assignment and paragraphs as the largest material components for category assignment. The individual interviews each represent a unit of evaluation. The evaluation is first conducted using the deductively derived initial evaluation grid and structures the content by assigning it to main categories. Based on the text work, the evaluation grid is extended and refined by further (main) categories. The final analysis process is carried out with the final evaluation pattern/category system. The main categories considered are the following: SCRM in Practice, Collaboration, Digital Tools, Crisis Situations, and Corona Pandemic.

4 Concept Development

In the following section, the findings obtained in the course of the structured literature review and analysis as well as the expert interviews and the qualitative content analysis are combined and transferred into a concept for SCRM in crisis situations. Within the framework of the concept, recommendations for companies on how to prepare supply chains for crisis situations and how to manage them when such situations arise will be presented in line with the underlying research question. For this purpose, the identified state of practice will first be briefly summarized in order to then present the concept with recommendations for action on the basis of the core findings obtained.

In practice, the integration of SCRM often takes place in the individual departments of companies, such as logistics, purchasing, production, etc., and focuses the risk assessment on the respective department (Interview 1, 2, 6, 7, 9). A consolidation of the different information and perspectives on the risk situation in the supply chain is rarely part of the implemented SCRM (Interview 3, 8). SCRM tasks are mostly the responsibility of employees who perform these tasks only as a limited part of their role in the company. These employees are thus often experts in the respective field, but in some cases have only limited expertise and experience in the area of risk management (Interview 4, 6, 9). Based on this, many companies lack a systematic process approach to SCRM (Interview 3, 4, 6, 8). The lack of interdepartmental information exchange and a non-systematic approach can result in limited visibility of risks in the supply chain in companies, which can lead to late detection of risk-related crisis situations. Similarly, due to the lack of systematization of the SCRM process, manual updating of risk data is often irregular (Interview 6, 9). In addition, the existing supply chain structures are often designed to achieve efficiency goals, so that single-source solutions are also often implemented to achieve volume effects, which, depending on the type of crisis situation, harbor particularly large risk potentials with regard to the company's security of supply (Interview 3, 5, 9). Crisis situations in companies, and particularly in the area of supply chain management, are often not considered by means of proactive measures, but only reactive ones (interview 3, 5, 8). One measure primarily used in this context in practice is the buildup of buffer stocks to secure supplies (interview 1, 7, 9).

There are considerable differences between the state of practice identified and the information obtained on approaches and options for SCRM in crisis situations. However, using the example of the corona-pandemic, it can also be noted that general recommendations for action of specific measures to address crisis impacts are not possible. The impact of the coronal pandemic on companies is highly dependent on the company's industry and the products or services it sells, as well as the company and supply chain structure. Thus, some companies may benefit from the same crisis events that threaten the existence of other companies. Furthermore, no "classic" crisis situation can be characterized, as the influences can be multidimensional and affect companies in a wide variety of ways. Nevertheless, on the basis of the core findings (CF) presented below from the structured literature review of scientific and grey literature as well as the analyzed expert interviews, various recommendations for action can be derived for corporate practice. These reflect general strategies and measures for strengthening the company's resilience with regard to crisis situations.

CF 1	SCRM forms the basis for SCM in crisis situations; however, it is not possible to fully capture crisis situations within the framework of the classic SCRM process.
CF 2	Building flexibility and redundancy is a critical element of supply chain resilience to crisis situations.
CF 3	Supply chain collaboration is a helpful element for both crisis identification and crisis management.
CF 4	Modern technologies offer companies the opportunity to manage crisis situations faster and more effectively, especially through monitoring processes and simulations.
CF 5	Integrating a systematic SCRM approach into corporate structures allows for building increased organizational resilience.
CF 6	Transparency, flexibility and a risk-conscious culture are elementary factors of corporate resilience.
CF 7	Digital tools have the potential to enhance the positive effects of SCRM and allow for simplified handling of the process.
CF 8	Collaborative SCRM takes place in industrial applications only to a very limited extent, but it offers the potential to function as a key factor and competitive advantage with regard to crisis situations as well as in the context of normal competition.

Figure 3: Core findings of the preceding research methods (own representation)

Due to the fact that crises, as already described, can occur for companies in a variety of characteristics and can influence the supply chain, the recommendations for action are based primarily on preparatory activities in the area of SCRM. For this reason, the recommendations for action largely present generally applicable measures and strategies for preparing for crisis situations and largely dispense with specific approaches to specific risk situations. These must be adapted to the structure, risk strategy and type of risk in the respective company. Furthermore, approaches and options are presented within the framework of reactive crisis management, which take into account adjustments within the framework of this special situation for SCRM. Again, specific recommendations for action are not provided.

The recommendations for action described below are aimed at strengthening the resilience of the respective company and implementing strategically important factors for managing crisis situations. In essence, the concept aims to achieve the following goals in the course of crisis management:

- Avoidance of crises if possible
- Early identification of crisis situations
- Detailed view of the supply chain and its structures (visibility)

- Flexible options for action
- High reaction speed

The recommendations for action described below are therefore not only suitable for crisis situations, but also represent generally applicable measures for implementing effective SCRM. The concept describes five interlocking sub-areas that enable adequate crisis management of supply chains: SCRM, digitalization, SCRES, collaboration and reactive crisis management (see Figure 4). While reactive crisis management addresses the actual crisis situation, the other four areas act in preparation for the avoidance, limitation or management of crisis situations.

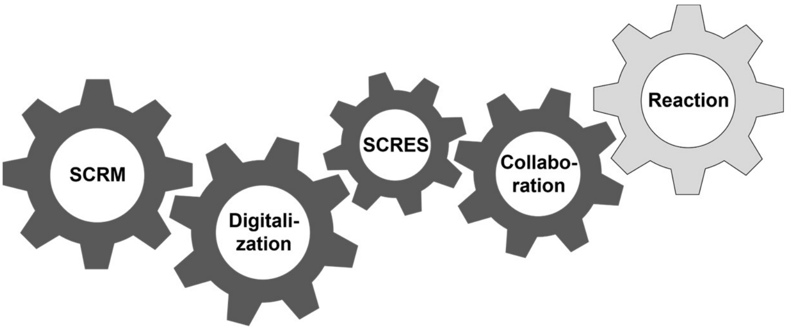


Figure 4: The five sub-areas of effective supply chain crisis management (own illustration)

The recommendations for action within the framework of the preparatory sub-areas of supply chain crisis management are presented below (see Figure 5). It should be noted here that the first three areas in particular build on each other and are interwoven, so that the greatest possible effects for companies can only be achieved by implementing all areas. For this reason, the recommendations for action presented in the concept are based on the interaction and use of SCRM, digitization and SCRES. Collaborative SCRM (presented as Collaboration) once again occupies a certain special position here, since the internal mastery of SCRM in the form of the aforementioned areas should in principle be regarded as a prerequisite for the application of this cross-company approach.

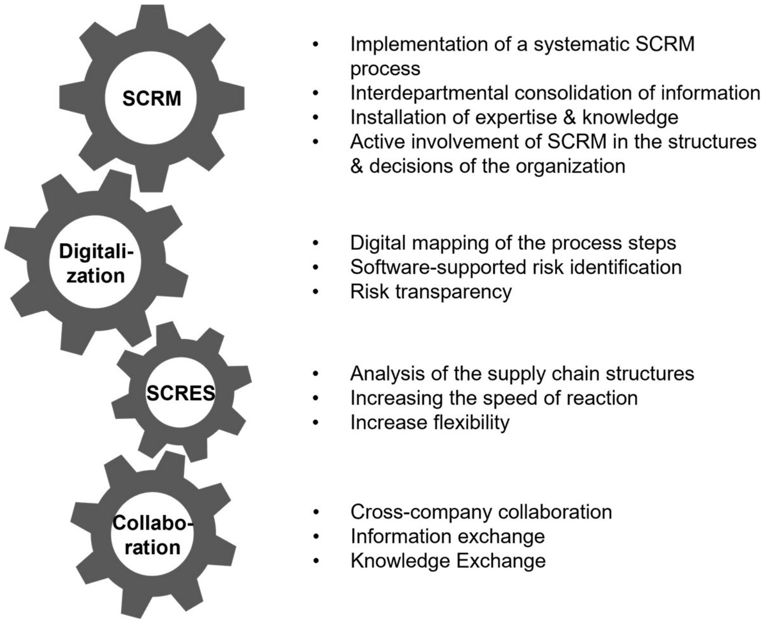


Figure 5: Preparatory measures (own representation)

The basis of the concept is SCRM and its organizational integration. To this end, companies should implement a systematic SCRM process in the specialist departments of the supply chain (e.g. purchasing, logistics, production, quality management, sales, etc.). The information from these processes should be combined across departments in order to exploit synergy effects and possibly implement measures jointly. The goal is to increase the effectiveness and efficiency of the processes by allowing all departments to benefit from a better information situation and to avoid measures with negative effects on other departments of the company. For this purpose, the digital mapping of process steps is advantageous, as this allows all information to be brought together digitally and made accessible to the relevant persons or employees. In this way, the company actively promotes the internal exchange of information and ensures transparent documentation of the risks and measures as well as the underlying processes. With the help of these measures, SCRM or risk management in general should be actively integrated into the structures and decisions of the company in the next step in order to establish a risk-conscious culture among all employees of the company. In the course of this, it is of great importance, especially with regard to crisis situations, to implement clear structures for decision-making as well as an awareness of the need for fast decision-making processes in crises within the company

In order to install the SCRM process in the individual departments and bring it together effectively at the corporate level, companies need to establish knowledge and expertise in the necessary places. This means that it is necessary to train and educate the respective employees with regard to risk management, as they are mostly experts in the relevant area of the specialist department. Here, if available, the company's risk management departments can provide support in terms of methods and processes and define cross-departmental risk management standards. The expertise of the relevant employees supports the effective implementation of the systematic process and also promotes its continuous improvement. The process itself is classically divided into the phases of risk identification, risk analysis and assessment, and risk monitoring

In the context of risk identification, risk scenarios should be considered, which can be discussed with the help of creative techniques, such as brainstorming, and discussed in teams. Here, schemas with risk categories and potential risk events can serve as input to support the process. On the other hand, the structures of the supply chain should also be analyzed for potential vulnerabilities and the individual supply chain links for their stability. In this case, too, the use of schemas of possible loss events can be helpful. External data, such as that from insurance companies or credit institutions, should also be used to identify possible vulnerable or unstable links in the supply chain. In the course of digitization, this process step can be simplified and made clearer for companies by digitally mapping the supply chain. In addition, AI-supported tools offer the possibility of automatically merging large amounts of data from external sources, making it clearly accessible to employees and updating it on a regular basis. Especially in the case of complex global supply chains, which are to be mapped beyond Tier 1 partners, this type of tool offers an enormous simplification of the process and has a strong positive impact on transparency and visibility.

The assessment of risks should consider on the one hand the probability of the risk event, but also the impact of the event occurring. The probability can be determined by external data or by expert estimates within the team. When determining the impact of the risk event, companies should avoid using only the damage caused by the event. Rather, the assessment should consider both quantitative and qualitative factors. A quantitative factor could be, for example, the impact on sales or on the operating result of the company, which in the case of supplier failures can be calculated with the help of bill of materials data, but also automatically using digital tools. These quantitative metrics may be more suitable than the loss amount for certain risks, as they already take into account possible coverages of the risk event by insurance companies. Other factors that can be considered include, for example, the detection period of the risk occurrence, the duration of the risk event, or the time it takes to restore full performance. As part of a qualitative consideration, the company's affected products can be analyzed (Is the core business negatively impacted or is it a niche business?) and in the case of supplier risks, it may be advisable to consider the relationship with the supplier (Is it a strategic partner of the company?). These assessments should be based on the expertise of the respective specialist department and allow partial inclusion of non-monetary damage components (e.g., reputational damage). The assessment should always take into account measures already implemented and be based on data and company-specific expertise. In the case of risk impacts that are difficult to derive, the use of scenario analysis can be helpful as part of the assessment and provide valuable information for risk treatment.

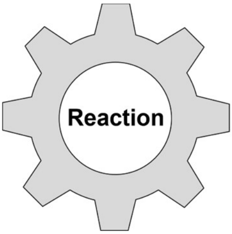
Risk treatment is based in part on the application of the five classic strategies: avoidance, mitigation, limitation, pass-through, and acceptance. Furthermore, however, it should also focus on strengthening resilience (SCRES) and explicitly building flexible capacity to limit or reduce the impact of unpredictable risk events. The goal of this is to safeguard potentially vulnerable points in the supply chain. Potential measures in this area include the qualification of personnel for various activities, the establishment of second-source suppliers with contractually defined flexible capacities, short-term contract terms, flexible capacities at logistics service providers, and the differentiation of supplier locations to limit the influence of local risks or crises. In addition, reducing the complexity of supply chain structures can be considered to increase the visibility of the company.

For specifically defined risk scenarios, it is a good idea to develop business continuity plans so that pre-planned measures can be initiated in the event of occurrence. A strategy that aims to build up redundancies can also be implemented, but this must be analyzed and assessed in detail beforehand in terms of its impact on the company's liquidity, especially with regard to crisis situations. In addition, it should be taken into account that strategies such as the classic range increase through buffer stocks may be subject to a time limit in terms of their effect.

The measures implemented as well as the assessment of risks should be reviewed on a regular basis. To this end, it is necessary to carry out a cyclical update of the data on which the risk assessment and thus also the strategy derived from it are based, and to make a new assessment of the situation. A need for action is then derived on the basis of the results. For example, a visualization based on the traffic light colors is suitable for displaying the current status of the respective risks and the urgency of possible actions in a simplified manner. As already mentioned, updating the data can be facilitated by the use of digital tools.

Once the recommendations for action described above have been successfully implemented and consolidated in the company, an expansion of SCRM to the cross-company level can be considered. For this, however, it is necessary to first define the relationship with the respective partner, as companies should assess the type of cooperation with other companies based on the trust placed in them, the underlying dependency and possibly different business strategies. Companies can and should cooperate with different companies within their supply chain in different ways and with different intensity. Once the type and intensity of collaboration is determined, cross-company SCRM initiatives can be launched. In its simplest form, this can take place in the context of knowledge exchange, for example in the course of supplier development programs. The goal of this is to benefit from the different expertise in the partner companies in order to increase the profitability of the individual companies. A further step could be the implementation of a formal process of information exchange between the companies in order to improve the information base and thus also the basis for the companies' decision-making. The final step of collaborative SCRM also includes the joint development and implementation of risk treatment measures. The basis for all forms of collaborative SCRM is the general cooperation and mutual trust of the partners.

In the event of a crisis occurring, only a few general recommendations for action can be derived due to the diversity of characteristics of such situations. Important elements of successful management of supply chains in crisis situations are shown below (see Figure 6).



- Generation of maximum risk transparency
- Monitoring the liquidity situation
- Demand - Supply - Synchronization
- Acceleration of decision making
- Initiation of specific measures
- Planning of the post-crisis state

Figure 6: Reactive crisis management (own representation)

The basis for all action in such situations is a solid information situation across all departments of the company, as crises can have a wide range of effects on different areas of the company. For example, supply chains and thus supply can be threatened, but at the same time demand can also fluctuate extremely. The effects of the crisis as well as the implemented measures should therefore always be considered with regard to the entire company. In addition, crises can bring about rapid changes in situations and thus also in the requirements for SCRM, so that it may be necessary to shorten the update cycle in order to create risk transparency. In the best case, companies act on the basis of daily updated data, which underlines the advantages of digital tools. Due to the threat to the company's existence associated with the crisis, an assessment of the measures to be implemented in terms of their impact on the company's liquidity is imperative. In this case, scenario analyses are recommended as appropriate tools due to the uncertainty that often prevails. In addition, in order to maintain the company's liquidity, the company's demand and supply should always be considered in combination and reconciled. As a negative example, the classic reaction of many companies to uncertainties in the supply chain is to increase the range of coverage through buffer stocks, which can contribute to a significant deterioration of the company's liquidity situation in the event of a simultaneous slump in demand. This emphasizes the relevance of overall corporate action in the context of crises. However, the short-term changes in the situation in the context of crises also require companies to react quickly. In this case, the installation of a crisis team with the aim of accelerating decision-making can be expedient. In addition to rapid decision-making, the recognition of certain crisis effects and the implementation of specific measures can also influence the speed of the crisis process for the company. In the course of this, business continuity plans with pre-planned measures can bring about a higher speed. In addition to measures to mitigate the crises, strategies and measures to restore full performance should also be developed at the same time as part of ramp-up plans. These serve to plan the resumption of regular business activities after the crisis has been overcome. Observing the recommendations for action described above can enable companies to achieve greater resilience in the face of supply chain-induced crises, as the vulnerability of the supply chain is considered and analyzed as part of the preparatory measures in order to subsequently justify a continuous reduction in the risk level of the supply chain through individually developed measures. In the event of a crisis, companies are prepared in terms of their options for action, speed of action and information base through the described implementation of SCRM to the extent that they can develop their full entrepreneurial potential. The recommendations for action in the event of a crisis make decision-makers aware of the special aspects of a crisis and support the selection of measures or strategies by focusing on elementary crisis characteristics.

5 Conclusion and Outlook

Within the scope of the contribution, a concept for implementing SCRM in crisis situations was developed on the basis of recommendations for action. The insights gained from the analysis of existing approaches and the findings from the expert interviews were finally incorporated into the development of the concept. This includes general recommendations for action to implement an SCRM as well as specific measures to prepare for and manage crisis situations. The primary areas addressed are the integration of SCRM into the organization, the systematic design of the SCRM process, the digitization of the area, and building resilience through more flexible structures and collaboration within the value network. In addition, explicit guidance on how to handle crises in the SCRM domain is presented. The paper explicitly places the needs and requirements of the practical application of SCRM in the foreground of the concept and presents elements of crisis management in the context of SCRM that build on each other.

Despite a carefully chosen approach and methodological fidelity, this paper is subject to limitations. For example, the results of the structured literature analysis are partly subject to a web search limited by search stop (n = 50), which is why a completeness of the obtained data cannot be guaranteed. Furthermore, the qualitative analysis of the existing approaches is subject to a subjective influence with regard to addressing the relevant disciplines

Due to the implementation of the small number of nine expert interviews, the interview study is only a section of the basic population and cannot claim to represent it completely. With regard to the analysis of the corona pandemic and the discussion of this crisis situation in the course of the expert interviews, it must be taken into account that at the time the interview study was conducted, the crisis had not been concluded and it was therefore not possible to take a fully comprehensive view. Furthermore, for the most part, industry-specific factors are not taken into account when considering the crisis example.

In the context of further research projects, other cases of the practical application of SCRM should be considered in order to explore the requirements of practice in even greater detail. This could provide further insights into the successful implementation of SCRM in general and also into the addressing of crises in this context. In addition, an industry-specific analysis may be useful to identify special aspects of the respective industry in the area of SCRM and to use these for the development of concrete recommendations for measures. The level of detail of such considerations can exceed that of the present work and thus make an important contribution to practical application. Furthermore, a consideration of crisis management in the field of SCRM during the corona pandemic with some distance after the pandemic seems to make sense, as this would allow a full consideration of the crisis period as well as the knowledge gained from research and practice. The present contribution already provides a considerable benefit in this regard, so that further work can build on it. Likewise, building on the findings of this work, the long-term changes in the practical application of SCRM should be considered on the basis of the events in the context of the corona pandemic.

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Structured Literature Review of Transport Networks and Supply Chain Resilience

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Purpose: *The literature on Supply Chain Resilience faces a steep and significant interest in recent years owing to the pandemic and disruptions in global trade. As the literature amplifies due, this paper aims to provide transparency about the intersection of Supply Chain Resilience and transport networks. Existing literature reviews do not consider this aspect.*

Methodology: *This paper conducts a Systematic Literature Review using the keywords "Supply Chain Resilience" combined with "Transport/Infrastructure networks" to identify the relationship between transport networks and Supply Chain Resilience. The method, as a result, identifies about 251 articles from 2004 to 2022, of which 36 relevant papers are included.*

Findings: *Excluded overview papers address Supply Chain Resilience and transport independently. As a result of the full-text screening, a shift to quantitative methods can be observed. Network theory and mathematical programming models stick out. However, a list of specific research gaps for future research proposed in the literature remains. In particular, a dedicated transport network like highways is seldomly considered.*

Originality: *This research improves the understanding of the relationship between Supply Chain Resilience and transport networks with the interrelation of transport and supply chain disruptions.*

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1 Introduction

Supply Chain Resilience (SCRe) has gotten soaring attention recently. The Covid19-pandemic has disrupted Supply Chains (SCs) and compelled them to adapt to ongoing threats, e.g., stockouts and lockdowns (Sodhi, Tang and Willenson, 2021). An out-of-sync global trade with container vessels queueing at ports for dozens of days further exacerbates the situation (e.g., see Xiao and Bai, 2022). Meanwhile, sea freight rates surge to historic levels, questioning the economic viability of certain transport. Failure of logistics infrastructure like canals contributes its share: reshoring and nearshoring become a consideration of "changing network design and resulting in overall less transport" that can be disrupted (van Hoek and Dobrzykowski, 2021). SCs must adapt to this *new, never normal*.

The literature on SCRe attempts to gauge the *new, never normal* by describing and deriving models to assess its effects. The literature review by Farooq et al. (2021) and further findings of supply chain disruptions during the Covid19-pandemic (see Hobbs, 2020; Xu et al., 2020; Fu et al., 2022) suggest that understanding the interrelationship between SCRe and transport networks provides benefits. Moreover, Kiani Mavi et al. (2022) identify resilience management as one of five emerging topics in transport logistics. Still, main literature reviews on SCRe don’t consider networks of transport or infrastructure distinctively (see, e.g., Hosseini, Ivanov and Dolgui, 2019) but as different aspects of Supply Chain Management (SCM). Henceforth, aspects of transportation in the scope of SCRe occur without explicit reference to the existing literature on either transportation science (see, e.g., Wan et al., 2018) or transport logistics (Kiani Mavi et al., 2022).

The role of transport is acknowledged in the SC Risks Management literature and has been worked on ever since (among others, see Ho et al., 2015; Bak, 2018; Bier, Lange and Glock, 2020). The literature suggests that transportation and infrastructure could significantly impact the vulnerability of SCs (Pettit, Croxton and Fiksel, 2019; Bak, 2018). However, the literature remains vague about the effect of a disrupted transport network on capacities of SCRe and which paths exist to recover SC operations if affected, as previous literature reviews don't consider both.

The main objective of the research paper is to reveal and categorise the link between the relationship of a transportation network and SCRe to give researchers an overview of the intersection between the fields. A Systematic Literature Review (SLR) identifies relevant research that considers the role of transportation and infrastructure networks in SCRe considerations (and potentially vice versa). The objective is met by answering the following aspects via the SLR:

1. What is the relationship between SCRe due to transportation and infrastructure network disruptions? How are SC disruptions and transport disruptions linked?
2. What are managerial implications and available risk mitigation decisions considering the role of transportation and SCRe?
3. What potential has future research based on the literature gaps?

Figure 1 outlines the objective of the SLR and the potential contribution: understanding the relationship between transportation and SCRe. Whereas a solid body of literature exists for the black arrows, the green arrows highlight the aim of the first and second research aspects of the SLR. The main objective, the red arrow, elaborates the link between the transportation network layer and SCRe – be it via the route of supply chain disruption or transportation disruption.

The research objective is achieved by, firstly, outlining recent literature about SCRe and literature on transport networks with their terminology to establish common ground and demarcate this research from other research disciplines. Secondly, this paper performs a SLR of the intersection between SCRe, transport, and infrastructure networks. Relevant papers are screened to derive common findings. Managerial implications on the role of transport networks in SCRe are also outlined. Thirdly, this paper discusses the results. Eventually, this paper concludes with the revealed SLR-based understanding of the relationship between transportation networks and SCRe.

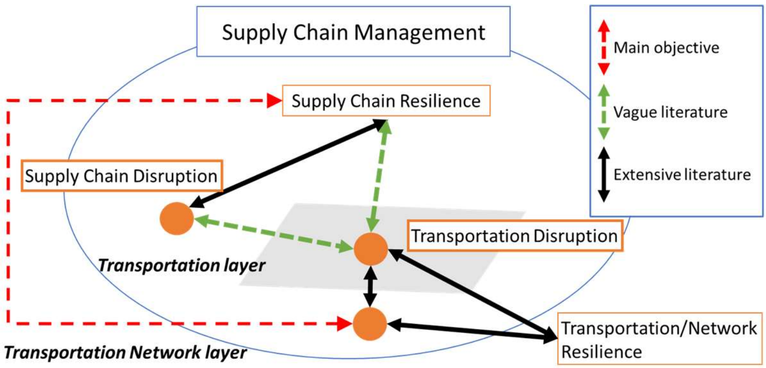

Figure 1: Schema of the objective of the Systematic Literature Review

2 Terminology and differentiating remarks

Due to the interdisciplinarity and vastness of SCM, this section carves out the necessary definitions for the research scope while also displaying ideas around resilience in transportation science, infrastructure networks (civil engineering), and network theory as opposed to SCRe.

2.1 Terminology

Starting with “building the resilient supply chain” (Christopher and Peck, 2004), the field of SCRe has ever extended since. In short, SCRe is viewed from different perspectives, e.g., the SC capability to recover from a disruption to a desired state. Please refer to Hosseini, Ivanov and Dolgui (2019) for an extensive list of SCRe definitions. Section 4.1 describes the definitions of SCRe found in the body of literature via the SLR.

Transport plays an essential role in SC Risk Management (see Bak, 2018), where disrupted transports impact operations and threaten performance. SC Risk Management methods often are qualitative or static and neglect the recovery aspect (Bak, 2018); here, SCRe enters the limelight. However, SCRe literature lacks the consideration of transport and infrastructure networks, as described before. Contrary, "SC Design decisions consider the environment and access logistics infrastructure in the network planning stage while also emphasising disruption risks"; the optimisation of network configuration shares methods to transport network resilience (see Esmizadeh and Mellat Parast, 2021). Transport networks are highly relevant in humanitarian relief logistics, which considers SCRe aspects (Thompson and Anderson, 2021). Thus, there could be an exciting field of study to transfer methods to SCRe and transportation networks of general SCs.

2.2 Differentiation between Network Resilience and Supply Chain Resilience and Transportation Networks

SCs rely on transport infrastructure (transhipment nodes like ports and intermodal hubs), and multiple stakeholders interact with it. Network resilience is well explored and finds application in transportation science, among others, in terms of transportation resilience. Albeit, network and transportation resilience do not consider SCM dimensions like stakeholder interaction and communication between SC agents (see Chen, Lam and Liu, 2018; Wan et al., 2018).

"Research analysing the relationship between transportation performance and their respective infrastructure networks is common, but the aspect of resilience is just emerging from a SCM perspective" (Kiani Mavi et al., 2022). Yet, combining SCRe and transportation provides benefits. For example, "effective transportation planning can reduce costs and shortages in medicine and vaccine procurement and distribution" (Farooq et al., 2021).

In addition, network resilience theory offers various methods to explore the resilience of networks (Smith et al., 2011), albeit the theory omits the linkage to SC agents or dedicated features of SCM (see Sharkey et al., 2021). Hence, this paper takes a SCRe perspective to incorporate SCM practices regarding transportation networks.

3 Method

This section describes the SLR approach to meet the research goal of deepening the understanding between SCRe and transportation. Multiple authors (i.e., Durach, Kembro and Wieland, 2017; Farooq et al., 2021) inspire this methodological approach.

3.1 SLR Methodology

A baseline sample of relevant papers is retrieved from a first scan of the literature revealing a connection between infrastructure and transport and from the authors' previous works. The SLR uses the Kühne Logistics University's main library database tool to search. The database includes publications from several databases like Scopus, Web of Science, and Wiley, and logistics journals. The earliest year of publication was set in 2004, when the discipline of SCRe got kicked off by Christopher and Peck (2004).

As directing features, the search strings in titles, abstracts, keywords, and texts are ("Supply Chain Resilience" AND "transport* network*") and ("Supply Chain Resilience" AND "transport infrastructure"). "Transport* network*" is inclusive to the similar used term "transportation" while including "infrastructure" captures other papers dealing with, e.g., road and rail networks and transport that do not use "Transport* network*". Both search strings have an overlap of 25 abstracts. See Figure 2 below.

The papers are included based on their presented topics in their abstracts: they must address SCRe by dealing with a – preferably transportation-heavy - Supply Chain Network (SCN) rather than only considering transportation network or transport infrastructure. Hence, the presence of interactions between stakeholders or SC agents is an inclusion criterion.

Generally, only papers in the English language are considered. Solely peer-reviewed articles are included. Two authors conducted the review: Based on abstract screening, the papers that only consider either SCRe or transport networks are also excluded because this research is interested in the connection of both. Several papers mentioning the search terms in the full text didn't demonstrate their relationship in the abstract and were subsequently eliminated. The described steps above are summarized in Figure 2.

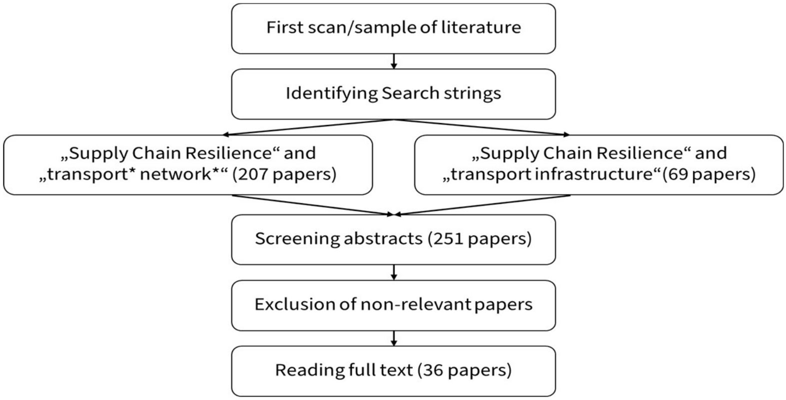

Figure 2: Step of the Systematic Literature Review

3.2 A structural and methodological analysis

Figure 3 below, created with the tool VOSviewer (2022), shows the keywords occurring with the default minimum of at least five times in the literature body of the rejected abstracts. Multiple topics around SCM are present and common methods in the field like literature reviews. The tool allows the clustering of keywords provided by the publisher/authors and colours papers regarding prominent keywords and co-occurring keywords like the colour red for general SCM topics in Figure 3. In contrast, the obtained body of literature consists of 36 relevant papers. The keyword analysis in Figure 4 remarkably shows only the keywords associated with the SLR research objective because they occur more than five times and are thus visualised: "*Transportation*", "*Supply Chain disruptions*", "SCs", "*SCRe*", and "*resilience*". As these keywords associated with the main research objective are not present in Figure 3 of the excluded papers but in Figure 4 of the included papers, this supports the validity of the abstract screening to an extent.

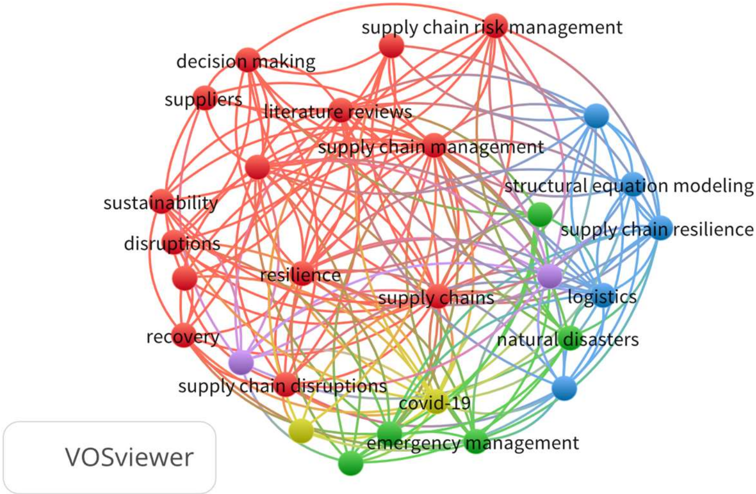

Figure 3: Co-occurrence of keywords in excluded papers

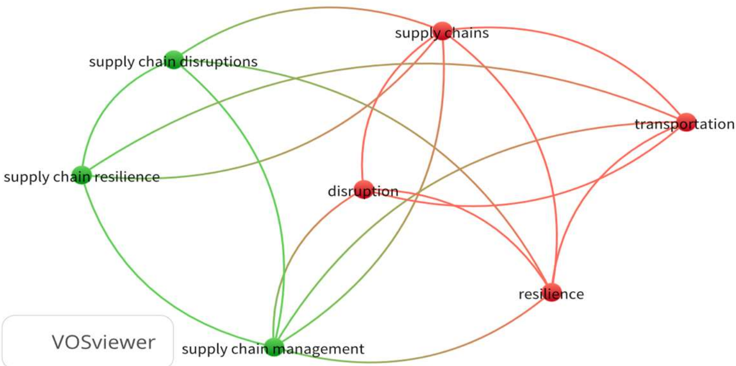

Figure 4: Co-occurrence of keywords in relevant papers

Most of the 36 papers were published just recently, as Figure 5 above shows. Note the gap between 2005–2011. Forestalling the discussion section, Peck (2005) identified the relevancy of transportation infrastructure for stakeholders in a forward-looking survey building on studies issued by the UK government. The academic interest continued from 2011 onwards. Even though Figure 5 pictures a trend that potentially is related to the pandemic or general rising interest in SCRe, the statistical trend is not yet significant due to the low number of publications per year. The relevant papers were read thoroughgoingly to derive findings on the relationship between SCRe and transport.

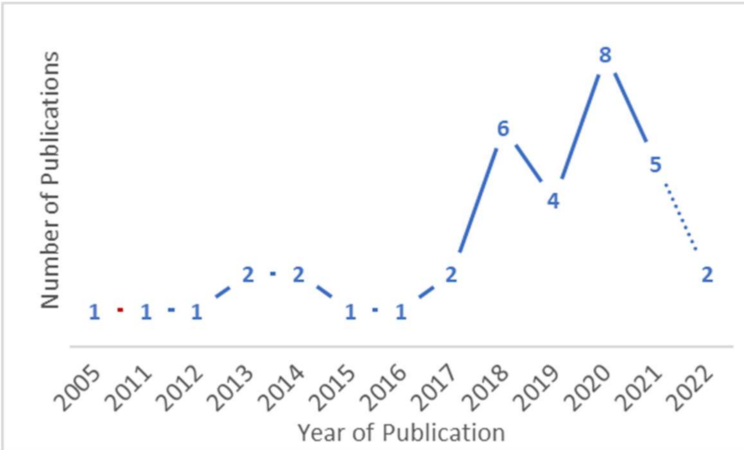

Figure 5: Year distribution of publications

Table 1 below shows the relevant papers clustered according to their methods while also listing the scope of their transport networks. Some mixed-method approaches are occasionally present, where: qualitative connections between SCRe and operational SC elements are identified through literature or workshops followed by quantitative analysis to determine the dependency metrics. Most papers did not define the transport mode of their SC. Instead, transportation is an undefined graph or flow network with links between origin and destination and nodes representing warehouses, suppliers, or production sites. Therefore, they are classified as “unspecified” in Table 1. Only around 10% of the papers did specify road, maritime or multimodal transport networks and subsequently address specific network infrastructure characteristics, for example, how a city's access to a highway impacts delivery.

Table 1: Paper overview according to methods

Method	**The transport network in the scope of the research papers**
Graph theory	*Unspecified*: Hearnshaw and Wilson (2013); Zhang, Dadkhah and Ekwall (2011). *Maritime*: Gong and Liu (2020). *General Infrastructure*: Kayikci (2021); Yi-Zhu Su and Wei-Chang Yeh (2022)
Mixed Linear Programming (or similar optimisation)	*Unspecified*: Behzadi et al. (2018); Adenso-Díaz; Mar-Ortiz and Lozano (2018); Wang, Herty and Zhao (2016); Guan et al. (2020); Zhang and Yu (2021); Zhao and You (2019); Mari, Young Hae Lee and Memon (2014). *Road*: Ishfaq (2012). *Multimode*: Ehlen et al. (2014); Mousavi Ahranjani et al. (2020); Kabadurmus and Erdogan (2020)
Simulation/ Heuristics	*Unspecified*: Paul et al. (2019); Mao et al. (2020). *Road*: Viljoen and Joubert (2018). *Maritime*: Yuan, Hsieh and Su (2020). *Multimode*: Chen, Lam and Liu (2018); Beheshtian et al. (2019)
Qualitative Research	*Unspecified*: Bhattacharya et al. (2013); Singh et al. (2019); Fu et al. (2022). *Road*: Singh-Peterson and Lawrence (2015). *Multimode*: Xu et al. (2020). *General Infrastructure including Transportation*: Peck (2005)
Mixed method	*Unspecified*: Forbes and Wilson (2018); Xia (2021); Oluwole, Odehairo and Oladokun (2021). *Road*: Costa et al. (2020); Sharma and George (2018)
Empirical studies	*Unspecified*: Tukamuhabwa, Stevenson and Busby (2017); Xing Liu et al. (2017);

4 Findings

The obtained body of literature reveals insights presented in this section. This section starts with some general observations before structurally clustering the insights regarding the main research objective, the link between SCRe and transportation networks: The first aspect, “the relationship”, is deduced in section 4.2. Based on the established relationship clusters, the second aspect, “managerial implications”, are presented in section 4.3. The third aspect, “future research avenue”, is highlighted in section 4.4.

4.1 General findings

SCRe and sustainability are conjointly present in eight papers (Beheshtian et al., 2019; Behzadi et al., 2018; Zhang and Yu, 2021; Mousavi Ahranjani et al., 2020; Kayikci, 2021; Mari, Young Hae Lee and Memon, 2014; Kabadurmus and Erdogan, 2020; Yi-Zhu Su and Wei-Chang Yeh, 2022). Though there is evidence that the pandemic incited research on SCRe (see Farooq et al., 2021), only two relevant papers dealt with the subject (Xu et al., 2020; Fu et al., 2022); that subject felt more present in the excluded abstracts.

Surprisingly, no author of the relevant papers has a (co-)authorship of any other papers, which is opposite to literature identified by major SCRe reviews like Hosseini, Ivanov and Dolgui (2019). Presumably, no overlapping authorships indicate that the research discipline is not yet established. Moreover, no case studies have been conducted in Europe or North America but mainly in the Southern Hemisphere (e.g., Tukamuhabwa, Stevenson and Busby, 2017; Costa et al., 2020; Oluwole, Odehairo and Oladokun, 2021).

Many papers discuss transport networks implicitly as an element of SCRe or enablers of risk mitigation strategies like rerouting (see Table 2 below). However, contrary views are not present claiming transport is part of the SCRe principles (according to Christopher and Peck, 2004) or linking transportation to SCRe capabilities (according to Pettit, Croxton and Fiksel, 2019) are not present.

4.2 Relationship between transport networks and SCRe

Undoubtedly, the method used influences the findings of the relevant papers. Table 1 above already shows the high amount of used quantitative methods stemming from Operations Research. Nevertheless, there exist significantly distinctive definitions of SCRe in the papers' models that affect the parametrisation and thus potentially lead to different outcomes in the relationship between SCRe and transportation networks. Nearly all follow the principles outlined by Christopher and Peck (2004), which get extended in two distinctive ways: the cross path between SCRe as a "cost/resilience enhancement trade-off" (Tang, 2006) – respectively an efficiency/resilience tradeoff. Or "SCRe describes the recovery of SC performance to a preferably better state" (Tukamuhabwa et al., 2015).

Papers following the first way are present in the second and third clusters in Table 2; the ones following the second way are present in the first cluster in Table 2. Moreover, the following definitions exist in addition to the ones above: Some papers adopt a view from SC Risk Management rather than SCRe (Behzadi et al., 2018; Xu et al., 2020), dealing with probabilistic occurrences. Unfortunately, the definitions used are not always explicitly stated; Ehlen et al. (2014) reveal not even an implicit view on SCRe. Nevertheless, a clear definition gets fully incorporated into the papers' models by Mao et al. (2020) and Hearnshaw and Wilson (2013). Their definitions are used with a graph-based method focusing on the mathematical relationship between recovery and relevant network configurations (i.e., node criticality and the redundancy of links). An odd way is setting SCRe equal to delivery reliability by Paul et al. (2019). Finally, Guan et al. (2020) define SCRe from a disaster relief management perspective.

To sum up, available characteristics or managerial choices in transportation networks are a contributing factor to building up or enhancing SCRe. Besides, no authors undertake to add their own research findings to phrase a new definition of SCRe for a specific context. Eventually, six distinct ways to describe the relationship of aspect 1 of the main objective are presented in the following:

Structured Literature Review of Transport Networks and SC Resilience

(1) Transport networks are part of SCN and contributing factor to SCRe

Where transport is part of the SCN, the relationship between transport and SCRe is parametrised with qualitative and quantitative identified key mechanisms. SCRe can be built and enhanced with transport network considerations.

(2) Transport disruptions equal SC disruptions that are part of SCRe

Moreover, suppose transportation disruptions due to node/link failure in the SC are also analysed. In that case, the relationship between SCRe and transport gets quantifiable regarding the impact of disruptions on operations in the SC network.

(3) The resilience of transport networks affects SC performance

Considering the role of transport on SC performance under disruption scenarios allows one to calculate an optimal network design with an efficiency/resilience trade-off.

(4) Decision-makers have choices in SCRe relying on transportation networks

Considering specific choices of SCM decision-makers even enhances the optimal planned network as literature considers further dimensions like time and CO_2 emission costs. Hence, available choices in transportation networks are a contributing factor to building up or enhancing SCRe.

(5) Transport is disrupted by infrastructure failure affecting SCs

These papers look closely on the relationship between transport and the required infrastructure, which public stakeholders run. From the infrastructure perspective, implications on the resilience of potentially affected SCs are discussed.

(6) Empirical studies about SCRe identify a relationship

Empirical studies and mixed-method approaches identify a link between SCRe and transportation networks without prior assumption of such a connection. As transportation networks were not the objective, a comparison between other factors next to transportation networks affecting SCRe is presented.

Table 2: The various relationships between SCRe and transportation networks

Cluster	Authors	Implication and Findings regarding supply chain resilience
(1)	Bhattacharya et al. (2013); Singh et al. (2019); Zhang, Dadkhah and Ekwall, (2011); Xing Liu et al. (2017); Forbes and Wilson (2018); Mao et al. (2020); ZHANG and YU (2021); Xia (2021); Mousavi Ahranjani et al. (2020); Neboh and Mbhele (2021); Mari, Young Hae Lee and Memon (2014); Sharma and George (2018); Hearnshaw and Wilson (2013)	Transportation and underlying networks allow to build and enhance SCRe with managerial practices and restoration strategies. Key mechanisms are identified or derived from graph theory that can already be incorporated into the planning and design stage.
(2)	Adenso-Díaz, Mar-Ortiz and Lozano (2018); Ehlen et al. (2014); Paul et al. (2019)	By assessing transport disruptions, SCRe gets also quantified and assessed.
(3)	Beheshtian et al. (2019); Yuan, Hsieh and Su (2020); Ishfaq (2012); Lam and Liu (2018); Fu et al. (2022); Xu et al. (2020); Kayikci (2021); Zhao and You (2019)	Resilience is measured in terms of performance impact and cost trade-off. Private investments mitigate risks.
(4)	Behzadi et al. (2018); Wang, Herty and Zhao (2016); Kabadurmus and Erdogan (2020)	The focused topic is *rerouting*, leading to optimal performance but lower costs with multimode and CO_2 prices.
(5)	Peck (2005), OLUWOLE, ODEDAIRO and OLADOKUN (2021); Gong and Liu (2020); Yi-Zhu Su and Wei-Chang Yeh (2022); Viljoen and Joubert (2018); Chen, Lam and Liu (2018)	Public investments in the design and state of infrastructure have to account for a trade-off between cost and resilience.

Cluster	Authors	Implication and Findings regarding supply chain resilience
(6)	Tukamuhabwa, Stevenson and Busby (2017); Singh-Peterson and Lawrence (2015); Costa et al. (2020)	Transportation is of relevance for SCRe, depending on the context.

4.3 Decision to mitigate risks and future research avenue

Papers analysing the impact of disruptions on transport networks often highlight ways to mitigate risks and thereby enhance SCRe: Costa et al. (2019) reveal that transport, in fact, is an element of resilience which leads to significant managerial implications, for example, that the use of telematic systems mitigates the impact of disrupted road transport networks, see (1) of Table 1. Reliability of supply in a SC network is relevant: Ensuring delivery reliability increases SCRe (Ehlen et al., 2014; Adenso-Díaz, Mar-Ortiz and Lozano, 2018), see (2). "Rising the awareness of SCM about the transport network" by increasing the transparency about available routes and their redundancies enhances SCRe (Xu et al., 2020), see (3). Utilising modal shifts (Wang, Herty and Zhao, 2016) and rerouting then also becomes more viable with network redundancies. Moreover, rerouting is the prominent strategy (Behzadi et al., 2018; Wang, Herty and Zhao, 2016), see (4). Private investments into the logistics infrastructure (Ishfaq, 2012) or public investments (Chen, Lam and Liu, 2018) into transport networks enhance SCRe and prevent the infrastructure from degradation, see (5). Regarding (5) and (6), there is no evidence that a good state of the infrastructure enhances resilience. However, there is evidence that badly maintained infrastructure has a negative effect on SCRe (Tukamuhabwa, Stevenson and Busby, 2017; Oluwole, Odedairo and Oladokun, 2021).

4.4 Future research avenue

Most papers provide suggestions for the extension of their developed models. For example, Yuan, Hsieh and Su (2020) suggest that external macroeconomic factors, such as the global economic outlook, facilitate resource allocation on existing and new shipping routes. Zhang, Dadkhah and Ekwall (2011) propose to consider risk prevention and mitigation strategies targeted to infrastructure. Paul et al. (2019) suggest that researching the disruption effect on lead-time and recovery plans is a future research step. Finally, Mao et al. (2020) suggest considering varying demand during recovery.

Several researchers recommend validating their findings: For example, Costa et al. (2020) propose to validate findings by employing more quantitative studies in various industries to identify their SCs' elements of resilience and interactions among them. Kabadurmus and Erdogan (2020) suggest applying their model to a real-life case study to validate the current results and discover new relationships. Saliently, Bhattacharya et al. (2013) argue that "future research should be directed towards building an SCN with the concepts of econophysics adapted from statistical physics and quantum physics, thereby providing a resilient and more robust SCN mode". However, econophysics have not been pursued further yet. Neboh and Mbhele (2021) recommended that future researchers adopt a longitudinal approach to test the relationships between SC Design and Resilience.

5 Discussion

This paper presented a SLR to reveal the link between transportation and infrastructure networks and SCRe considerations. The main objective of the research paper is achieved in section 4.2. Most papers, except for the empirical and qualitative research, view this link primarily bottom up, meaning that transportation networks influence the outcome of SCRe. The other view that the management of SCRe can impact the configuration of transportation and infrastructure networks is not present. Likely, this requires communication and collaboration with infrastructure operators, often public stakeholders, which was not in the scope of the relevant papers.

5.1 Discussion of findings in the academic context

Six different views on the link have been identified and presented in section 4.2 since the link gets acknowledged multiple times (see Costa et al., 2020). Although the direct link between the transportation network layer and SCRe often isn't explicitly stated, the formulisation of the models of the relevant papers embeds this link implicitly by, e.g., setting up an optimisation model with a SCRe objective that also considers characteristics of the transportation networks.

Operation Research methods (i.e., graph theory and linear optimisation) are most common to analyze transportation networks and the tradeoff between performance and resilience. This finding is in line with Ivanov and Dolgui (2021). Besides, the authors (2021) point out the problematic nature of not precisely defining a specific setting for the research objective – in their case, the pandemic. Because this way, findings would always be transferrable into the general pandemic context. Their observation finds evidence for this research as only around 10% of the relevant papers specify road, maritime or multimodal transport networks and subsequently don't address specific network infrastructure characteristics or vulnerability towards certain events. For example, inland waterway transportation networks that rely heavily on infrastructure are entirely missing and easily disrupted by extreme weather effects.

Hosseini, Ivanov and Dolgui (2019) pointed to the lack of quantitative and mathematical methods back then. This seems addressed as most relevant papers apply quantitative and mathematical methods. The relevant papers benefit from Operation Research methods as these are capable to capture the network characteristics of … the transportation and infrastructure networks. Furthermore, (intermodal) rerouting facilitated by “redundancy within the transportation network” is a common consideration (Hosseini, Ivanov and Dolgui, 2019). In fact, there is an overlap of identified papers between the SLRs, i.e Tukamuhabwa et al. (2015) and Behzadi et al. (2018). However, this SLR missed out on Khaled et al. (2015) analysing SCRe and the criticality of railroad networks. The missing out can be explained due to the narrowly defined two keywords in this paper, which contrasts with Hosseini, Ivanov and Dolgui (2019), who use 12 keywords to get a holistic overview of SCRe, for example including “resilient supply”. Transportation networks in context of SCM could benefit from precise definitions incorporating SCRe.

The influence of transportation and infrastructure networks gets more attention due to disruptions affecting SCs globally; for example, the pandemic, the blockage of the Suez Canal, and queues at the port of Los Angeles incited discussion on SCRe and require SC decision-makers to act upon. Adding characteristics of intertwined transportation networks and sustainability considerations (e.g., emission pricing) connects this paper’s output to the relatively new field of SC Viability research (see Ivanov, 2020): whether SCs in their current design can operate in the future, or a reconfiguration becomes necessary — and that infrastructure investments by the public heavily influence that design. Multiple available decisions for SC decision-makers are listed in 4.3 and briefly discussed in the following.

5.2 Discussion of managerial insights

The derived managerial implications mainly have three streams of impact.

1. Most papers propose that their methods are used to prepare, assess, alleviate, and manage the consequences of transportation disruptions by intensifying SCR investments. Public stakeholders can facilitate this to at least prevent the degradation of the current state of infrastructure.

2. Papers provide decision-making tools containing strategies like rerouting considering SCRe and transportation.
3. There Is an optimum of investment, resource allocation, and risk based on quantifiable SCRe. However, the applicability of most of the proposed managerial implications is not tested in empirical studies. Thus, section 4.4. shows many instances where validating the model is presented as a future research opportunity.

Hosseini, Ivanov and Dolgui (2019) name three potential assets enhancing SCRe for decision-makers to obtain: "(i) redundancies such as risk mitigation inventories, subcontracting capacities, backup supply and transportation infrastructures, (ii) data-driven, real-time monitoring and visibility systems, and (iii) contingent recovery plans." All assets are present in the relevant. Next, the authors also point out the cost associated with these resilience assets. However, as transportation infrastructures are often run by public authorities or at least multi-user systems, costs are optimized against the requirements of multiple affected SCs. Finding the right balance between public and private investments enhancing one's SC is highlighted as an addition to the findings in section 4.2.

6 Conclusion

This paper establishes a link between transportation network and Supply Chain Resilience by conducting a Systematic Literature Review of 36 relevant academic journal papers. The review identifies six distinct categories describing various characteristics of said link with their managerial implications. In short: transport networks are an element of resilience and contribute to building resilience capabilities, whereas network disruptions affect supply chain performance and require decision-making in mitigating risks. The findings emphasise the benefit of considering networks for resilience considerations by, e.g., applying appropriate mitigation strategies for transportation as this also enhances Supply Chain Resilience.

This paper contributes to the rising field of Supply Chain Resilience literature by structuring existing research from the perspective of transportation and infrastructure networks. Researchers can use this foundation and take into consideration the extracted directions of future research; for example, specifying the mode of a transportation network provides further insights that is not present in most of current research.

The review method is subject to the authors' bias. Still, the figures from VOSviewer indicate a sound result as "transportation" is highlighted in the relevant papers but not present in the excluded abstract. Applying such a toolkit could bear fruit for the Systematic Literature Review method in general because statistics are computed algorithmically immediately. The overall amount of contained, peer-reviewed papers is around 4,200 for "Supply Chain Resilience" and 98,000 for "Transport* network*" indicating that future SCRe research could build upon the understanding and methods used to analyse transportation networks and link these to SCM.

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V.
Maritime Logistics

Assessing Offshore Wind Farm Collision Risks using AIS data: An Overview

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Purpose: *Currently offshore wind farms are built in areas with high vessel traffic like the German Economic Exclusive Zone (EEZ). During the building phase and the operational phase a high amount of vessels will pass these offshore wind farms in close proximity and thus there is a risk of collision of a vessel with other vessels in the wind farms, e.g. installation vessels or service vessels or with objects like the wind turbines or the substation of an offshore wind farm.*

Methodology: *In this paper relevant publications over the last ten years with a focus on the use of AIS (Automated Identification System) in regard to the collision risks of offshore wind farms will be investigated and sorted in a structured way. The publications will then be listed and classified into six sub groups.*

Findings: *This analysis will show an overview of the current state of the art in using AIS data to determine the collision risks for offshore wind farms and the proposed methods to reduce these risks.*

Originality: *The paper is original because there is currently no complete and up-to-date overview for the use of AIS-data to mitigate the collision risks of vessels with offshore wind farms.*

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1 Introduction

Offshore Wind is becoming more feasible over time and due to technical advances as well as political decisions the amount of offshore wind turbines in the Exclusive Economic Zones (EEZ) in the North and the Baltic Seas of the Federal Republic of Germany will increase from 1.469 turbines with 7.5 GW in 2019 to 30 GW by 2030. Due to recent political events it is possible that the as of today announced numbers will even increase more.

But not only the number of offshore wind turbines will increase in German territorial waters but also the amount of vessels which will be traversing the German EEZ. The German Bight for example is already one of the most frequented water areas in the world.

The constant increase of offshore wind farms in the German EEZ and a simultaneous expansive increase of European maritime traffic and ship size developments in recent years lead to an increasing safety risk due to limited available fairways. Last but not least, these increasing frequencies can lead to direct collisions between offshore wind turbines and ships or other accidents. As an example, in the area of the southwestern Baltic Sea, 1520 reported shipping accidents occurred in the period 2011-2015 with a level of about 300 accidents per year. The German Bight of the North Sea is one of the most frequented maritime sea routes in the world.

Human error is responsible for most collision accidents. 95% off all accidents between 2015 and 2020 in Korean waters for example were caused by human error (Park et al. 2021).

(Copping et al. 2016) states that because of "[…] the development of offshore wind farms, fixed structures will begin to appear in and around historical shipping lanes." This shows the importance of the topic and thus the relevance to investigate this topic further.

2 Problem description

Since these conditions are very complex and thus can lead to accidents between ships and offshore wind structures like substations or the offshore wind turbines or to accidents between two ships in the wind farm or close to the wind farm with adverse effects on human lives, the environment or high financial losses it is necessary to mitigate these risks.

In this paper the authors will give an overview over the current scientific literature in regard to the use of AIS-data to access and mitigate collision risks for offshore wind farms.

Due to the new and applied nature of this topic a lot of the literature is “grey literature” from companies as well as internet sources by companies. Additionally standards and guidelines are also present, e.g. (Wasserstraßen- und Schifffahrtsverwaltung des Bundes 2021). Additional basic literature like books are also sources which will not be considered in this paper.

2.1 Navigational Safety / Collision Risks

In the German EEZ in the North Sea and Baltic Sea and thus also in German shipping lanes, offshore wind farms and offshore platforms have been already constructed and in the foreseeable future even more will be built. From the point of view of nautical traffic and maritime policy, such installations constitute artificially created obstacles to navigation, which restricts the free sea space and thus creates new hazards for the safety and ease of shipping traffic. These risks have to be mitigated by appropriate measures. This also applies to the laying and operation of submarine cables and comparable submarine installations in traffic-relevant areas.

Ensuring the safety and ease of shipping traffic is governed by international and national regulations and is an explicit part of the "Strategy of the Federal Government for the Utilization of Wind Energy at Sea" from 2002.

The responsibility for both the prevention of dangers to the safety and ease of shipping lies with the Federal Maritime Administration pursuant to § 1(2) in conjunction with §3(1) of the Seeaufgabengesetz - SeeAufgG (Wasserstraßen- und Schifffahrtsverwaltung des Bundes 2021). Offshore windfarms have to be equipped with AIS-transponders in the German EEZ meaning that at least all of the outer wind turbines have to be fitted with AIS-transponders (Wasserstraßen- und Schifffahrtsverwaltung des Bundes 2021).

Additionally in the planning phase of an offshore wind farm there is the obligation to do an NRA (Navigational Risk Assessment) by the developer to be aware of potential nautical risks and thus mitigate the risks of collisions. This NRA is not standardized so that there are different approaches.

The following overview shows what are the influencing factors on navigational risks in offshore wind parks:

(Lv et al. 2021) give a very good overview over these influencing factors. They divide them into "natural conditions" and "navigational environment". Whereas in the first, visibility, wind speed and wind direction, current speed and current direction are the determining factors. The factors in the "navigational environment" are distance between navigational routes and the wind farm. Additionally the amount of traffic as well as the number of encounter areas are of importance, too.

2.2 Automated Identification AIS

„The AIS (Automated Identification System) is a real-time network of transmitters and receivers that allow vessel movements to be broadcast, tracked, and recorded." (Wright et al. 2019).

The International Maritime Organization (IMO) requires since 31 December 2004 in SOLAS (Safety on Life at Sea) regulation V/19 that all vessels of 300 gross tonnage and above in international voyages and all vessels above 500 gross tonnage in non-international voyages as well as all passenger vessels to be equipped with AIS (IMO 2022).

Additionally to its traditional role use of mitigating collisions by keeping track of vessels, AIS is also used for maritime safety planning (Wright et al. 2019). This could be for example, the planning to reduce accidents between vessels and offshore structures (like offshore wind farms) before they are build.

By using AIS heat maps, historical AIS data is used to determine where ships in general travel (Wright et al. 2019). This information can be used in the planning process of the construction of an offshore wind farm. Additionally real-time AIS data can be used to determine the behavior of a ship (Wright et al. 2019) and thus to mitigate the collision risk on an operative level. Interestingly only 75% of all commercial vessels are fitted with AIS (Natale et al. 2015). Since it is only mandatory for vessels over 15m in length.

The following table 1 gives an overview over the information which are send by AIS systems.

Table 1: AIS Information Source (IALA 2014)

Static information	**Dynamic Information**	**Voyage related information**
MMSI (Maritime Mobile Service Identity)	Ships's position	Ships's draught
Call Sign and ship name	Position time stamp in UTC	Hazardous cargo (type)
IMO Number	Course over ground (COG)	Destination ETA (Estimated time of Arrival)
Length and beam	Speed over ground (SOG)	
Type of vessel	Navigational status (underway, at anchor, moored)	
Location of position fixing antenna	Rate of turn (ROT)	

(Wawruch and Stupak 2011) give a good overview in their paper which input data from AIS-sources can and should be used to construct a model (see table 2).

Table 2: AIS input data for a model (Wawruch and Stupak 2011)

Wind farm data	**Wind turbine positions, distances between the wind turbines, tower dimensions**
Data wind farm location	Shape of the coast line, water depths, ground, sea level changes (e.g. tides)
Information about ship movements	Ship routes, density of traffic, vessel types, changes in vessel traffic based on season or day
Wind and waves	Speed and direction of wind, wave height, wave direction, speed of current, visibility, ice conditions
Technical vessel data	e.g. frequency of engine damage, possible tug assistance
Additional information	Probabilities of human error during planning of voyage, possible navigational errors

(Wawruch and Stupak 2011) additionally name models which were developed by organizations dealing with shipping safety: COLLIDE by Safetec Nordic AS, the models by the Dutch Maritime Research Institute MARIN (SOCRA – Ship Offshore platform Collision Risk Assesment and SAMSON – Safety Assessment Models for Shipping and Offshore in the North Sea); CRASH (Computerized Risk Assessment and MARCS (Marine Accident Risk Calculation System) by Det Norske Veritas; COLWT by Germanischer Lloyd; COLLRISK by Anatec UK Ltd. and DYMITRI by British Maritime Technology (BMT).

According to the UN Convention of the Law of the Sea (UNCLOS) vessels which are restricted in their maneuvering by obstacles like an offshore wind farm have a mandatory safety zone of 500 m around them (United Nations 1982).

3 Research Methodology

3.1 Literature Review

In this chapter a structured literature review for AIS as a tool to mitigate the collision risks for offshore wind turbines was conducted. The goal is to give a concise overview over the relevant publications.

In this paper the emphasis lies on peer reviewed scientific papers . In addition books and book chapters were not included in this paper. Grey literature and internet sources were also not taken into account. Thus only peer-reviewed articles from journals and conference proceedings were considered for this paper. Only publications in English were reviewed. To not miss relevant publications the snowballing was used (Wohlin 2014).

The databases used for the search were: Google Scholar, Scopus and Web of Science. The time frame were the publications were considered was January 2010 till March 2022.

The following keyword / terms were used in the search: AIS, Offshore Wind, Collision Model.

The search string: “AIS”, “Offshore Wind”, “Collison Model” returned 489 publications in Google Scholar. The next step was reading the titles if they fit the scope of this literature research. After this step 158 papers came into deeper consideration. Then the abstracts of these papers were read and the papers which were deemed useful after this step were investigated further. Thus the final sample of 23 were archived for Google Scholar. The procedure was then repeated for the other two databases. After analyzing the three databases and elimination of duplicates a total of 25 relevant papers were the result. These publications are shown in Tab. 3.

3.2 Classification of the literature

The following classification was used to systematically structure the particular literature.

A high number of papers were just taking into account the mitigation of collision risks in a very general way, if there was no connection to offshore wind structures like offshore wind farms and the use of AIS in a some way the papers were not used in this paper. Also papers which were not using AIS were discarded for the sample. Some nevertheless useful publications which did not made the cut are still noteworthy and are mentioned here.

(Xiao et al. 2022) give a very good overview as they compare models for the risk assessment of vessels with structures in a general way. They however do not concentrate on offshore wind turbines and thus are here just mentioned for reference. (Kao et al. 2021) also published a general model to prevent collisions using a fuzzy logic approach. (Mujeeb-Ahmed et al. 2018) were conducting a probabilistic approach to collision risks with offshore platforms. Since they were looking at oil and gas platform the paper will not be discussed into detail in this review in detail but the findings can be used to transfer findings to offshore wind farm collision risks.

The topic of this paper is not widely discussed in the scientific community at this point. But seeing the increase in the use of large data sets by machine learning approaches, simulation or other means like neural networks because of more relevant data and also more powerful information technology this topics will increase in use over the next years.

In the reviewed papers the following six groups were identified and the papers were structured into these groups:

- Mathematical Models / Numerical Models
- Detection / Near Miss / Prediction Models
- General Models / Risk Assessment Models
- Simulation Models
- Machine Learning / Deep Learning Models

- Trajectory Models

Table 3 shows this in a structured way.

Table 3: Classification of the literature (Own representation)

Authors	Mathe-matical	Detection	General	Simu-lation	Machine Learning	Trajec-tory
(Borkowski 2017)						**X**
(Chang et al. 2014)			X			
(Copping et al. 2016)	X					
(Lv et al. 2021)	X					
(Ma et al. 2022)				X		
(Mehdi et al. 2020)						**X**
(Mou et al. 2010)		X				

Authors	Mathe-matical	Detection	General	Simu-lation	Machine Learning	Trajec-tory
(Murray and Perera 2021)					X	
(Naus et al. 2021)			X			
(Park et al. 2021)					X	
(Rawson and Brito 2022)			X			
(Rawson and Rogers 2015)		X				
(Suzuki et al. 2013)	X					
(Scheidweiler and Jahn 2019)			X			

Authors	Mathe-matical	Detection	General	Simu-lation	Machine Learning	Trajec-tory
(Tabi Fouda et al. 2019)		X				
(Tranberg et al. 2019)					X	
(Tsai and Lin 2021)			X			
(Wawruch and Stupak 2011)			X			
(Yoo and Jeong 2017)			X			
(Yu et al. 2020a)						**X**
(Yu et al. 2020b)			X			
(Zhang et al. 2015)		X				

Authors	Mathe-matical	Detection	General	Simu-lation	Machine Learning	Trajec-tory
(Zhang et al. 2016)	X					
(Zhang et al. 2018)						**X**

4 Findings

The following paragraphs will show the findings after the mentioned papers were thoroughly examined.

4.1 Mathematical Models / Numerical Models

The following chapter shows the use of mathematical or numerical models for the AIS models. Four papers have this as a focus.

(Copping et al. 2016) did a numerical model using AIS-data as input for a simulation typical movements of e.g. cargo ships, tanker, etc. along typical used sea lanes of the Atlantic coast of the United States. The authors are only concerned with the long term effects of navigational safety during the operation phase of an offshore wind farm. They took AIS-data from 2010-2012 and filtered to one minutes intervals and thus vessel tracks were generated which were used as input into the numerical model to determine the likelihood of the accident between a commercial vessel and an offshore wind farm off the Atlantic coast of the United States (Copping et al. 2016). In contrast to similar studies for Europe there is no before / after effect observable in real live because there are not commercial offshore wind farm projects of the Atlantic coast of the US compared to projects in the German or British North Sea. (Copping et al. 2016) model shows after the run of 17 simulation that there is no “statistically significant increase in the mean frequency of collisions for the wind farm scenario […]” (Copping et al. 2016).

(Zhang et al. 2016) proposed an advanced method for the detection of near miss ship collisions using AIS-Data by developing a mathematical model. They develop a conceptual framework whereas they use the AIS data to determine the spatial characteristics of the traffic in a particular area. They calculate a "Vessel Conflict Ranking Operator (VCRO) to evaluate how grave a navigation conflict is by determining the safety distance between ships incorporating AIS data, ship size and the ship domain.

(Suzuki et al. 2013) were formulating a mathematical model with deals with the impact of an accidentally drifting vessel into an offshore wind farm.

(Lv et al. 2021) use a Fuzzy Inference System to conduct a navigational risk assessment for offshore wind farms. "By extracting visibility, the number of traffic flows, the number of meeting areas, and distance between sailing routes and wind farms, the risk of natural condition and navigational environment operation in the navigational system of ships in the wind farm area is, respectively, evaluated."

It can be seen that mathematical models are used in a very theoretical way and the value to apply these models to real life has to be considered. The use of a mathematical model is quite static and it is to be valued if these models give a valuable answer to the problem that there are multi dependent inputs into these models.

4.2 Detection / Near Miss / Prediction Models

The following chapter deals with the findings of publications which deal with the detection and prediction of vessel behavior by analyzing AIS-Data. The analysis of near misses is also in this category.

(Rawson and Rogers 2015) did a study to assess the impacts to vessel traffic from offshore wind farms in the Thames Estuary by using a predictive analysis. They looked at five windfarms of the coast of the UK in the Thames estuary and the vessel movements recorded using AIS before the windfarms were build and after the windfarms were build. These datasets were then analyzed and presented in a Geographic Information System (GIS) (Rawson and Rogers 2015). The shortcomings of the study were that (Rawson and Rogers 2015) only focused on ships passing by the windfarms and vessels which were involved in construction or the Operation and Maintenance of the offshore windfarms were discarded. Additionally no fishing vessels or sailing boats were taking into account (Rawson and Rogers 2015).

(Tabi Fouda et al. 2019) developed a software model to control the movements of ships in an offshore area so that actions can be done before accidents happen and to visualize this using a GIS.

(Mou et al. 2010) uses the aforementioned SAMSON model to analyze AIS-data in linear regression model for the area around the busiest port in Europe, the port of Rotterdam. They used a timeframe of 62 days in Sommer of 2007. The port of Rotterdam was chosen because the AIS-data for this area is available and the model can be easily transferred to other busy area with a high traffic density. The study also revealed that in that part of the North Sea tankers have the highest risk profile for a collision (Mou et al. 2010).

(Zhang et al. 2015) developed the “Vessel Conflict Ranking Operator” which is a new method to detect near miss ship-ship collision and was used on data from the Northern Baltic Sea.

The strength of the aforementioned models is that they use real AIS-data and take into account the multiple influences of the behavior of vessels in or near offshore wind farms and thus try to predict possible accidents before they happen and to mitigate the risks of these accidents to happen. It is also useful that (Rogers et al. 2015) and (Mou et al. 2010) did their studies in areas where there will be a lot of offshore wind activity, like the Thames Estuary were a lot of offshore wind farms are already been built and even more will be built in the future or the approach to the port of Rotterdam which is the port in Europe with the most traffic.

4.3 General Models / Risk Assessment Models

(Rawson and Brito 2022) did a study to assess the validity of navigational risks assessments for the United Kingdom. In this study they compared the made predictions to the real historic incident record in regard to offshore wind farms in British Waters. Nevertheless they state that: “[…] it is difficult to access the validity of the underlying models and their applicability to OWFs given the sparsity of historical accident data” (Rawson and Brito 2022). Because there is not particular database of accidents in particular regard to only accidents with offshore wind farms (Rawson and Brito 2022) did review five general British accident databases and used additionally secondary resources for the years 2010-2019. In total they identified six collisions between vessels, 29 incidents involving a vessel and a fixed offshore structure (e.g. offshore wind turbine or substation), as well as 21 groundings and 13 near misses for a total of 69 incidents (Rawson and Brito 2022). Of these incidents interestingly 36% were occurring within the wind farm and 20% outside of the windfarm. The rest was happening within O&M ports. (Rawson and Brito 2022). Additional noteworthy is that 82% percent of the involved vessels are vessels working in the particular offshore wind farm (e.g. Crew Transfer Vessels (CTV) and Offshore Supply Vessels) and just the rest of 18% were commercial vessels or leisure vessels. The split of incidents between the construction phase and operational phase is 50%:50% thus leading to the conclusion that the shorter construction phase is much more prone to collision incidents. (Rawson and Brito 2022).

(Naus et al. 2021) did a study as a posteriori vessel traffic analysis for offshore wind farms in Polish waters using historical AIS-data. The study showed that the “research results confirm the hypothesis that it is possible to use historical AIS data during the implantation of the spatial planning process aimed at optimizing the location of marine renewable energy installations.” (Naus et al. 2021).

(Chang et al. 2014) were assessing the navigational risks of the development of Offshore Wind Farms off the coast of Taiwan using AIS-data. Chang et al. used this data among others research questions to estimate the frequency of possible collisions between ships and an offshore wind farm.

(Wawruch and Stupak 2011) show in their paper which input of AIS-data is necessary for an analysis and then they discuss current used collision models by research institutions and private companies and compare these models by calculating the probability of a collision between a ship and a wind farm.

(Yoo and Jeong 2017) were doing a research study regarding the risks offshore wind farms pose for fishing vessels and vice versa. They conclude that September is the riskiest month and that there should be a least a safety zone of 0.3 NM around offshore wind farms to mitigate the collision risks for fishing vessels with offshore wind structures (Yoo and Jeong 2017).

(Yu et al. 2020b) conducted an assessment of the “Influence of offshore wind farms on ship traffic flow based on AIS data”. Here they used AIS data of two years with 26,645 ships in a particular area in Chinese Waters in 2014 before the wind farm was built and this number was reduced to 17,444 vessels after the wind farm was built meaning that a high number of vessels had to change their trajectories because of the new situation. (Yu et al. 2020b)

(Tsai and Lin 2021) used AIS-data to improve the navigational safety in regard to offshore wind farms in the Taiwan Strait. There were also looking at the impact of fishing vessels and especially at the bottlenecks in the shipping lanes created by the development of offshore wind farms (Tsai and Lin 2021).

It is not a surprise that there are a lot of general models / Risk Assessment models in the literature since before an offshore wind farm can be built a navigational risk assessment has be done. Since these risk assessments are in general done by commercial companies these are normally not of a scientific nature like the aforementioned publications. Nevertheless these approach is of interest for researchers too, and since it is not that particular complicated to analyze historical AIS-data the publications above did exactly that. This approach is very useful but should be combined with further methods to return more robust results.

4.4 Simulation Models

(Ma et al. 2022) papers takes into account a evaluation of the risk of a vessel to collide with a structure (the Jiantian Bridge in China) by combining AIS-data and Bayesian Networks in a Monte Carlo Simulation. Even though this model is not geared at offshore wind structures the authors of this paper believe that it can be transferred to be used for other offshore structures like offshore wind turbines or offshore substation as well.

Rather surprising is that there is only one publication which explicitly uses simulation to determine the collisions risks using AIS-data and Bayesian networks between offshore structures (in this case a bridge) and vessels. Even though the number of publications is insufficient for this group it can be assumed that in the future more publications with the use of AIS data in a simulation will be published.

4.5 Machine Learning / Deep Learning Models

(Park et al. 2021) developed a model to predict the trajectory of vessels using a machine learning based approach using collected AIS-Data of 14 days in the waters close to South Koreas biggest port, Busan. The dataset included 1351 vessels and 2816 trajectories and was divided into four types of vessels: cargo, passenger, oil tanker and dangerous cargo ship.

(Murray and Perera 2021) developed a deep learning framework for the prediction of ship behavior based on historical AIS-data. The investigated area will be divided into clusters and each cluster contains trajectories with similar behavior characteristics. In each of these clusters a local model will be generated to describe the local behavior in the cluster. The authors propose to: “[…] to cluster historical trajectories using a variational recurrent autoencoder and the Hierarchical Density-Based Spatial Clustering of Applications with Noise Algorithm.” (Murray and Perera 2021). (Scheidweiler and Jahn 2019) did a paper on the use of AIS data in business analytics and their potentials and limits. They show what potential uses and opportunities can be achieved by using AIS-data in machine learning approaches.

(Tranberg et al. 2019) used k-means clustering, an Machine Learning approach to identify the time and processes of offshore installation processes using AIS-data. Even though (Tranberg et al. 2019) did not use their model specifically to determine or mitigate the collision risks of offshore wind farm projects the authors of this paper are confident that the model by (Tranberg et al. 2019) could be also used for this research question.

Machine Learning models are very useful for the prediction of collisions of vessels with offshore wind farms. Since there is a lot of data generated by AIS, machine learning algorithms can be useful employed to filter, clean, group and analyze the large amounts of data to determine patters and thus help to generate models to for prediction of collision risks and to mitigate these risks. Since over time even more AIS data will be created and computer power is also increasing the robustness of these models will also increase.

4.6 Trajectory Models

(Zhang et al. 2018) suggest a "[…] multi-regime vessel trajectory reconstruction model through three-steps processing, including (i) outliers removal, (ii) ship navigational state estimation and (iii) vessel trajectory fitting". The AIS-dataset consisted of 500 ships which used the port of Singapore. (Zhang et al. 2018) state that their model can decrease the errors like abnormal rate of speed (from 43,42% to 0.00%), acceleration (from 10.65% to 0.00%), ROT (Rate of Turn) (from 50.33% to 15.81%) and jerk (from 59.25% to 17.82%) and is thus much better than other models , e.g. linear regression models, polynomial regression model or the weighted regression model.

(Mehdi et al. 2020) developed a deterministic method which can either be used operational by seafarers or strategically in the planning stages of an offshore wind farm project by the project developers.

(Borkowski 2017) e.g. proposed a trajectory prediction model which used several neural networks which were learning from maritime data.

(Yu et al. 2020a) use a semi-qualitative risk model using Bayesian networks to do the risk assessment of ship flows close to offshore wind farms. Here the Bayesian network is trained on available AIS data sets so it is able to describe actual traffic flows. Then the authors use expert opinions using evidential reasoning to identify the most important risk factors.

Trajectory models are another approach. These models seem also to be very useful in analyzing historical data and training to predict the behavior of vessels near or in offshore wind farms. Here the researchers looked mainly at the real traffic flows and the trajectory of the vessels to determine the environment and the movements of the vessels and based on that they determine not normal behavior to access the risk of a collision.

5 Conclusions

This overview can only show the current state of research and is also very focused on a narrow part, the analysis of mitigating collision of vessels with offshore wind structures by using AIS data. Currently mathematical models are used to a high degree but since these are very theoretical and do not take into account the multi interdependency of inputs into the collision models between vessels and offshore wind farms it can be assumed that the use of these models will decline in the future.

Surprisingly traditional simulation approaches are only used to a small degree.

Risk assessment models using historical AIS data are very widely used and are definitely useful in the analysis of collision risks. Additionally they are relatively easily to conduct. The same holds true for trajectory models.

However the authors determine that the biggest improvement will be the greater use of machine learning models to determine the collision risks between vessels and offshore wind farms.

The use of machine learning models will likely increase in the future because the conclusions drawn from these models will be more thorough and useful than from other methods. There is a high amount of AIS-data generated and by using the appropriate algorithms machine learning will be very useful in predicting collisions of vessels with offshore wind farms.

The topic of this paper will definitely become more important over the next years because there will be more projects in the North Sea but also off the Atlantic Coast in the USA and in China. All this three areas are heavily traversed by commercial shipping and will also likely see even more vessel movements over the next years.

There are a lot of research questions still open and answers to these can be given by developing novel and innovative approaches. Especially the advances in handling of large datasets by new approaches using machine learning will lead to improvements in this area.

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Marine Communication for Shipping: Using Ad-Hoc Networks at Sea

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Purpose: *Oceans are a dominant means for transport of goods, which in turn has caused a boom in data volumes exchanged at sea. Internet connectivity at sea is heavily reliant on satellites, but it suffers from high cost, low bandwidth and complex regulatory requirements. This acts as an impetus to find alternative means of connection to ease marine communication.*

Methodology: *A literature review related to SANET, followed by an analytical and simulation model-based evaluation, along with real-life trace analysis were performed. Three routing protocols (namely, ER, RRS, and S&W) and three communication technologies (VHF, LR-WiFi and WiMax) were inspected based on three use-cases: sending small data in emergency, large data sharing route information, and very large data for insurance purpose.*

Findings: *The evaluation shows that VHF is suitable for distant communication of small data files, whereas WiMax works better for faster transmission of large data files. The performance of the routing protocols is heavily dependent on the deployed scenarios.*

Originality: *To the best of our knowledge, this study is the first to compare the combination of the three communication technologies and routing protocols. The study paves the path for choosing appropriate technologies and routing protocols for the deployment of SANET in maritime logistics.*

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1 Introduction

The world is made up of one portion of land, and three portions of water. Eighty percent of the world's goods are transported through the marine way [42], which is the primary reason for gradual increase of ship traffic at sea with each passing year (ALPHALINER, 2021). In the year 2011, the number of container ships worldwide was 4966, which increased to 5434 by 2021 (Statista, 2021). The sea-based shipping process requires reliable means of communication at sea. Impervious to the growth in market, the communication process at sea has not improved significantly over the years. From ship-to-ship or ship-to-shore, communication has its application province in the maritime logistics sphere varied from exchanging data regarding Search and Rescue (SAR) operations, to business objectives. The communication process at sea is predominantly dependent on using satellites for distant communication and Very High Frequency (VHF) signal for short direct data exchange. High traffic volumes are causing an overload in the connection lines and disrupting communication (Spire, 2020). Over time, satellite communication technologies have been updated but this comes with a massive cost. Satellite-based communication lacks coverage in some places, having the problem of blind spots near high latitude areas, leaving people in undeniable distress, disconnected from the rest of the world during emergency situations (Yau, et al., 2019). Facing these challenges over and over again, the need to find an alternative that could work in time of need, even in the absence of proper infrastructure, has become an unavoidable task. Ad-hoc communication has the potential to be a suitable option to alleviate the above-mentioned problems, while offering additional advantages.

Ad-hoc communication is when two communicating partners come inside each other’s connection range and they exchange information. The information moves around the ad-hoc network based on the mobility of the ships in marine communication, making them the carrier of the data. Because of its infrastructure-less structure, Sea Ad-Hoc Network (SANET) is also suitable to be used in regions where even satellites are unable to provide coverage. In the case of a natural or manmade calamity too, when the existing infrastructure breaks down, it has proven its viability (Dattana, et al., 2020). While being able to work in an adverse situation, and being around for quite some time, SANET is still a relatively unexplored approach. This paper is targeted at providing evidence regarding the feasibility of SANET under different circumstances, and comparing three routing protocols, namely Epidemic Routing Protocol (ER), Randomized Rumor Spreading (RRS) and Spray and Wait (S&W) and three connecting technologies, namely Worldwide Interoperability for Microwave Access (WiMax), VHF and Long Range Wireless Fidelity (LR WiFi). From hereafter, Section 2 explains the state of the art and related terms, Section 3 has methodology explained, Sections 4 and 5 focus on explaining the results and Section 6 concludes the paper.

2 Related work and Literature Background

This section explains the concepts of the terms associated with the marine communication processes and SANET. Searching for the literature focusing on SANET is difficult as compared to the publications available for other ad-hoc processes, for example for Vehicular Ad-Hoc Network (VANET). The scarcity of papers for SANET is evident across various databases, as it can be seen in the following Table 1.

Table 1: Quantitative comparison of publication numbers between SANET and VANET, (without any time limit, in total number) [as accessed on 06.12.2021]

Website name	Number of Hits	
	“Sea Ad-Hoc Network”	“Vehicular Ad-Hoc Network”
Web of Science	85	4651
Scopus	182	15198
Google Scholar	194	56900
Microsoft Academic	44	32738

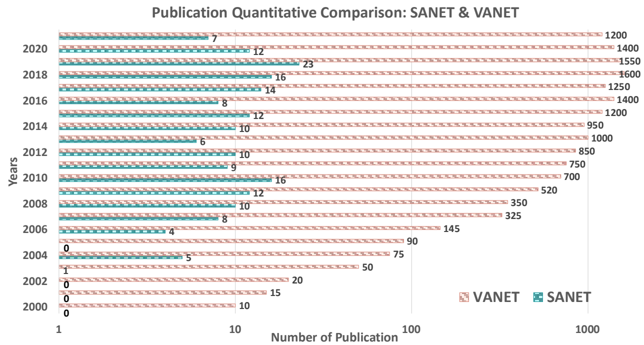

Figure 1: Number of Publication comparison between SANET and VANET in Scopus

The shortage of the papers concerning SANET, in comparison to VANET (Table 1) shows the limited amount of work done in the field, though recently there is a growth in the number of publications for SANET too, as it is in VANET, accessing the growth in publication number focusing only from the year 2000 onwards in Scopus (Figure 1). Starting from the beginning on how SANET is established at sea and how the communication process can take place (Laarhuis, 2010; Zhou & Harada, 2012), the work moves forward to explore how advantageous the infrastructure independence is for data transmission from remote offshore areas (Xu, et al., 2019). Some papers focuses on the prospects and the problems associated with SANET from a general perspective (Taher, 2018), while some explained SANET along with the other types of ad-hoc networks, describing its functionality and the application areas (Al-Absi, et al., 2021; Chauhan, et al., 2020; Yau, et al., 2019). Work has been done to explore the usability of SANET in various fields, such as, for real-time Voice over Internet Protocol functions (Lambrinos & Djouvas, 2011), or for marine data acquisition and cartography (Al-Zaidi, et al., 2017). Publications are also exploring the effect of parameters on the efficiency of the communication process (Mohsin, et al., 2015). Different routing protocol performances are also evaluated in this regard (Mohsin & Woods, 2014), some proposing new routing protocols to be explored and explaining their advantages over the available ones (Yun, et al., 2012). Few of the publications focuses on exploring SANET on the basis of case studies (Xin, et al., 2015), investigating the utilization of SANET for the underwater data exchange process (Garcia-Pineda, et al., 2011; Kong, et al., 2005). Work is also in progress to increase the efficiency of the communication process following the principles of SANET (Shi, et al., 2016).

Due to the insufficiency of available papers associated with the topic of SANET (see Table 1), information is also extracted from the published papers on the topics of communication over other types of ad-hoc networks, as VANET, Mobile Ad-Hoc Network (MANET), to develop the literature background for the paper, as explained below.

2.1 Satellite Communication (SATCOM)

The marine communication in the process of transferring goods through the sea way, includes communication between the ships, as well as with the shore. The main requirement is to ensure a proper uninterrupted communication system between the ships for tracking or monitoring, updating information when on route, and providing safety or security alerts. Establishing communication and entertainment for the crew members is another requirement for communication at sea. Since 1964, satellites are being used as the medium of communication for marine purposes (Ilcev, 2019). To communicate with a ship from the shore, the data is sent to the satellite, which then forwards the data to the intended ship. The opposite way communication too happens the same way, having the satellite in between to forward the information back to shore (Figure 2). With time, the number of satellites have increased, starting from geosynchronous equatorial orbit, then including highly elliptical orbit, low earth orbit satellites in the process, to ensure better efficiency in the data exchanging process.

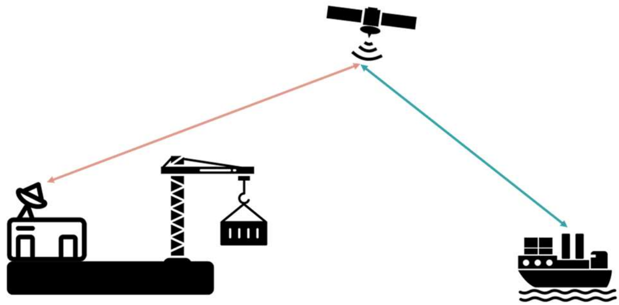

Figure 2: Satellite Communication process (Own work)

2.2 Ad-Hoc Networks

Ad-hoc networks are opportunistic, dynamic, wireless, infrastructure-less network with unavoidable delays associated with the process (Kaur & Mathur, 2016). The connection between nodes is limited by their range of communication, and their movement, which occurs in irregular intervals. The process can be described as “store-move-forward” (Nguyen, et al., 2015). A node receives information, stores it within, moves from place to place, finds another node inside its range to communicate, and forwards the message. In ad-hoc communication, there remains a possibility that the source and destination might never come directly into contact (Kaur & Mathur, 2016), the source tries to find out the shortest path and either sends copies of messages to all its neighbors or directly transmits the message itself forward, depending on the requirement. By choosing the hop count, memory allocation, and routing protocols appropriately, the efficiency of the ad-hoc networks can be increased.

2.3 Routing Protocols

The nature of the routing protocol being used for communication, decides the delay and resource consumption in the network. They can be divided broadly into two categories based on the data transmission characteristics (Figure 3), namely *forwarding-based approach* and *flooding-based approach*. For this paper, protocols are chosen from both flooding-based (ER & RRS) and forwarding-based (S&W) types, respectively following the principle of *epidemic* and *direct transmission*. Their performance and the effect of data dissemination principle on the efficiency of SANET are evaluated based on the chosen routing protocol under similar circumstances.

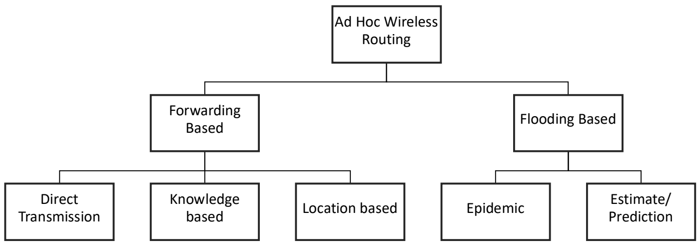

Figure 3: Classification of Routing Protocols based on data dissemination [adapted from (Kaur & Mathur, 2016)]

2.3.1 Epidemic Routing Protocol

ER is a type of flooding-based, direction-less approach (Kuppusamy, et al., 2019), so it forwards the message to every node coming inside its range, and before sending the information, it creates an *anti-entropy session* between the node pair and after that only data sending takes place as shown in Figure 4.a. It does not keep track of meeting nodes after a certain period of time, if all messages are found to be the same for both nodes, no data transmission takes place. So there is always some overhead present, however, the data is never sent twice to the same node. There are two factors deciding the performance efficiency of the routing protocol- *hop count and buffer size*, which control the data delivery process and the communication in ER (Amin & Becker, 2000).

2.3.2 Randomized Rumor Spreading

RRS is an existing, gossip-spread-based algorithm used to disseminate data in a large network. The algorithm is used to distribute copies of a recent update or the *hot rumor* among the nodes of the network (Karp, et al., 2000). It uses simple and random communication for robustness, without creating any anti-entropy session (Figure 4.b).

When a node receives any new update, it becomes the hot rumor for that specific node. Until it receives any new update, it keeps on spreading the update among its neighbors, calling them randomly, to spread the message in the whole network. RRS offers the advantage of spreading the news in the whole network with a minimum amount of rounds. The key advantage of this algorithm is its simplicity and robustness as it can be seen in Figure 4.b, its self-organizing nature and its scalability (Doerr, et al., 2014).

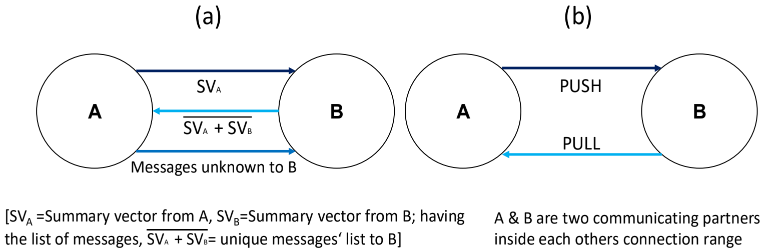

Figure 4: Data transfer process through ER (a) and RRS (b)

2.3.3 Spray and Wait Routing Protocol

S&W is a direction oriented forwarding routing protocol that follows two phases in the data exchange process, as:

- Spray phase: The originating node produces L copies of the message and sprays the message to $L-1$ nodes coming to contact.
- Wait phase: After spreading the message, and having left with only one copy of the message, the source goes into the wait phase for a certain amount of time, while the nodes that received the message copies in spray phase, does direct transmission to the destination.

The S&W routing protocol follows the principle of the ER protocol, being similar with the speed and simplicity for direct transmission, while differing in keeping a limit on the number of copies of the message being available in the network, thus being better on the basis of the number of transmissions (Dhurandher, et al., 2015).

2.4 OMNET++ and OPS simulator

OMNET++ is an expandable, modular, well structured, C++ simulation framework, referred to as the 'Objective Modular NETwork testbed', offering flexibility for parallel execution of simulation, large ranged library for various modules, graphical representation of results and support for both event and process based simulations (Dorathy & Chandrasekaran, 2018).

Utilizing the advantages offered by OMNET++, the Opportunistic Protocol Simulator (OPS) is built on its framework, which is the used simulator in the scope of this paper (ComNets, 2017).

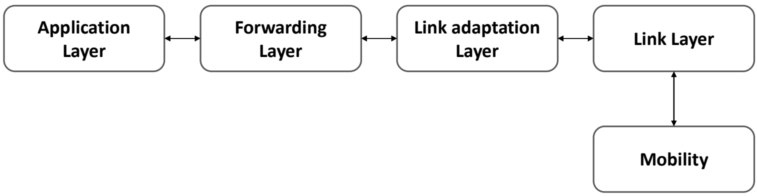

Figure 5: Opportunistic Protocol Simulation (OPS) [adapted from (Udugama, et al., 2019)]

OPS is a set of simulation models having its own grouped forwarding protocols, where the opportunistic network is implemented through the following layers, as explained in Figure 5 (Udugama, et al., 2019):

- Application layer, responsible for generating data, the amount of data to be sent and traffic data in the simulator, to evaluate the network with different traffic generation patterns.
- Forwarding layer, responsible to decide the forwarding routing protocol to disseminate the data in the network.
- Link adaptation layer, responsible to transform messages from one form to another, to be sent to other nodes.
- Link layer, here the characteristics of the connecting medium is defined. Wired or wireless, the range, data rate these parameters are explained here.

- Mobility model, that controls the mobility in the network, based on either real-life traces or already available mobility models from INET. This an input provided to the link layer (INET Framework, 2003).

3 Methodology

To check the merit of an undertaking to be used for real-life applications, and to ensure its feasibility for a specific purpose, an evaluation is needed to be performed. The operations to perform such evaluations are depicted in Figure 6, there are few options available, as Dede, et al., 2018 explained:

- Analytical model: The evaluation process follows mathematical calculation with simpler assumptions for faster evaluation, offering lesser accuracy.
- Simulation: The evaluation process prepares Software models, offering scalability to the network design. Simulators allow to have a pretty accurate result, replicating the real-world scenarios in software.
- Emulation: This process combines both the hardware and software part, so for the evaluation process some parts are implemented in real life, while some are done in the simulators.
- Real-life deployment: The evaluation does experiments done in real life, having maximum accuracy. Large scale experiments are costly and complex but smaller scaled ones offer most precise and dependable results.

In the scope of the paper, analytical and simulation modelling are chosen to be the evaluation processes to obtain the desired results, as described below.

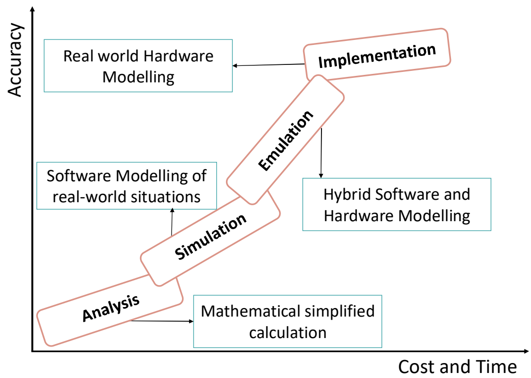

Figure 6: Available processes for evaluation

3.1 Literature study

To understand the SANET communication process, its usability, the correlated routing protocols and other corresponding terms, the first step to begin with the work is the literature review section, which explains the concepts associated with the process. The following evaluation process is then broadly divided into two sections.

1. Analytical calculation, is done to estimate the data efficiency in SANET varying different parameters for a communication situation considering two ships meeting each other.
2. Simulation of a real-life replicated scenario, considering varying network traffic congestion, is done to calculate data efficiency in SANET varying different parameters.

The literature study helps to identify and decide on the connecting technologies and the routing protocols to compare. The reason to opt for ER, RRS and S&W, namely MANET's routing protocols instead of the available SANET's ones is to inspect if the widely used and already available routing protocols are equipped to be used at sea as they are in land, even when the network structure and the communicating partners' nature changes. The three connecting technologies are chosen from the ongoing projects in the field of SANET to have a realistic comparison altogether, between the connecting technologies already being looked into, as listed below:

- WiMax: Project TRITON, which was an approach to develop low cost and high speed connection using WiMax, for ship-to-ship and ship-to-shore mesh network. It was designed to accompany or replace SATCOM in narrow water channels closer to shorelines in Singapore (Shankar, et al., 2008).
- LR WiFi: Project MICRONET, which was an approach to develop an affordable mobile LR WiFi based infrastructure for the fishermen community in India to enable ad-hoc communication (Reddy, et al., 2017).
- VHF: Project NORCOM, which was an approach to develop a single hop ad-hoc network to communicate deep in the sea using VHF, almost hundred kilometers away from the shores of Norway (Yau, et al., 2019).

To check the suitability of SANET under different surroundings, three use cases are chosen, reproducing events that happen in real life.

- Search and Rescue: The use case takes into account a SAR situation where the ships need to communicate and inform the whole network as soon as possible, the data amount is very low to be sent as it is just a notification, stating the emergency, but the main deciding factor here is the time to inform, as people's lives are at stake.
- Route information: This use case considers sharing nautical charts to the ships from the central provider, which happens at regular intervals. This is a time relaxed information to share, but the file size is high.
- Insurance video: This use case considers the data transmission for insurance obligation. As there is a requirement of providing proof to demand the insurance amount, the use case considers that proof to be a high quality video message, which can be transmitted in a time-relaxed manner.

A variety of scenarios can be simulated via the analytical and simulation models, by setting different parameters, such as:

- The number of ships (number of nodes) that creates the traffic for the simulation,
- Speed of the ships, used to create the mobility model, defining how the ships move, along with their direction of movement,
- Data amount, decides the size of message to be sent, which is chosen based on the use cases considered,

- Connecting technology, acts as the medium of communication between the ships offering various data rates and covering ranges,
- Routing protocols, which are the deciding factor of how the ships will communicate in a multi-hop network, under different circumstances.

Additionally, for the simulation model, the area and time of simulations are also added as the input parameters, as the boundary conditions.

3.2 Analytical Modelling

To look over the credibility of SANET theoretically, based on the above explained use cases, some real-life meeting situations are considered where two ships move towards each other, cross and move away from each other in either parallel or angular paths. The speed of the ships along with their directions are taken as the parameters to compare the concerned connecting technologies and the routing protocols. By changing the parameters, different scenarios are created for the two ships to meet each other. The first step in this section is to calculate the Time of Contact (TOC). TOC is the time until when the ships stay inside each other's communication range to convey information. When the TOCs are known, the next step is to calculate the data amount and the overhead amount for all the occurrences, varying the connecting technologies as well as the routing protocols. From the maximum transmittable amount and the total transmitted data amount and duplicate or summary vector amount, the percentages are calculated respectively for both data amount and overhead and they are compared. As the result, the values are plotted in graphs to show the comparison and based on them the conclusions are obtained and analyzed. To dig deeper, the influence of the direction of movement and the separation distance between the ships along with the message's nature is explained in the results section of the paper (4.1 Analytical Modelling). As for unicast communication, S&W performs similar to ER, thus the analytical section considers only RRS and ER.

3.3 Simulation Modelling

This segment focuses on replicating a real-life marine outline in OMNET++ and OPS (Udugama, et al., 2019; Kuppusamy, et al., 2019). To serve this purpose, the simulation models are made following two principles, as:

- Model 1: Synthetic data model, where the data associated to create the model is based on different considerations, assumptions and practical data sources, which allows the model to be scalable and flexible to create various conditions for the analysis of the communication process under different amount of ship traffic on the sea.
- Model 2: Real-life trace analysis, where the model is created based on real-life traffic details, recorded AIS data, accessible and available online publicly. This model provides an opportunity to analyze the effectiveness of the communication technique, on the foundation of a real-life marine traffic.

3.3.1 Synthetic Model

The synthetic model is a mobility model that is produced by recreating a real-life open sea situation, where the number of ships is gradually increased, to enable communication between them.

To create the mobility of the ships to be used for simulation, a python script is written, which takes the following inputs:

- Number of ships: 10, 50 and 100
- Speed of ships: randomly chosen between 13.5 knots to 21.5 knots
- Simulated area and simulation time
- Ships moving from east to west or vice versa in parallel way
- Ships moving from east to west or vice versa with an angle
- Minimum separation distance between the ships: 2.7 knots

Accumulating all this information the collision-free mobility model is prepared for the ship network.

3.3.2 AIS Model

For the AIS data model, the first step is to download an AIS data log file that had the information of all the ships travelled in a single day. For the purpose of this paper the AIS data file of the date 31.12.2020, having the details of the ships for that particular day (NOAA Office for Coastal Management, 2021). The area chosen is near Miami Port having the longitude under the boundary of -79° to -82° and the latitude of the focus area was between 25° to 26°. For the chosen time and area, 175 ships are available in the downloaded AIS data set. The obtained data was transformed into a mobility model file using a python script, translating it to a Bonn motion file (OMNET++, 2020), readable by the simulator, which identifies that for every time instance t there is a corresponding value to X and Y. As the AIS data contains the latitude and longitude data for the ships for a given timestamp, the transformation to the Bonn motion file starts with identifying the minimum values for the timestamps, latitude and longitude as the base values, and then calculating other values from their distance to the base values. The ships containing data for only 1 entry are ignored in the beginning as they are to be depicted as stationary ships. The Bonn motion file is prepared having 150 ships' data to be used as for the real-life trace analysis, developing a network using SANET for communication.

The main contrast from the analytical model to the simulated models is the change in the amount of traffic in the network, which allows to evaluate the viability of the process, while reproducing the real-life traffic at sea. The simulation model offers the possibility of modelling, varying congestion that in turn affects the time of contact among ships. These variations cannot be captured effectively in the analytic model. Out of all the inputs considered, the number of ships, speed of each ship, area, and time of simulation are considered to be as fixed inputs to the simulations. Based on all these situations produced by varying the input parameters different real-life scenarios are modelled to inspect the viability of SANET.

Each simulation model provides their own sets of advantages. As the scalability offered by the synthetic model allows to change the network size and number of ships to evaluate its effect on the communication process, while the real-life trace analysis gives the chance to simulate a real-life scenario to examine the process. Both the simulation models provide the opportunity to evaluate the efficiency over a range of situations.

For both the simulation representations, the process of developing the underlying mobility models are different, for the rest of the situation similar circumstances are to be examined for the SANET process, as explained below in Table 2.

Table 2: List of simulations for Synthetic and AIS data model

	Case Study Setup		Routing protocols	Connecting Technology
Situation	Data type	Data size		
SAR	Image	2 MB	ER	WiMax
Route information	Nautical charts	660 MB	RRS	LR WiFi
Insurance proof	Video message	1050 MB	S&W	VHF

To explain the simulation setups in details, three examples are described below:

1. In a network, one of the ships has time-critical information, as an image, to share with other ships and the shore. The situation considers the sending of small data (2 MB) in an emergency, from one to all.
2. The central provider from the shore transmits the nautical chart to the ships, updating them in a timely regular manner. The situation considers a one to all transmission, where the source is stationary, and the destinations are dynamic in nature, for a large file (660 MB) in a time-relaxed manner.
3. In compliance with the insurance policies, a ship has proof of a broken part in the form of a large-sized video. It needs to send the video to another ship, for further transmission. The situation considers unicast communication between two ships sharing a very large file (1050 MB) in a time-relaxed manner.

Each of the simulations for both models is repeated 30 times to account for stochasticity. To make the results more realistic, it is considered that the communication range of the ships follows free space path loss policy (Christian Wolff, 2021), so with the distance the strength of the connection reduces.

The obtained results are evaluated based on the following performance metrics, as:

1. Delivery ratio: Calculated by dividing the total data bytes received (a) by the total data bytes maximum receivable (b), as:

$$Delivery\ ratio = {}^{a}/_{b} \quad (1)$$

2. Overhead amount: Calculated by subtracting the total data bytes received (a) from the total bytes received (c), as:

$$Overhead\ amount = (c - a) \quad (2)$$

3. Average delay: Average time taken to disseminate the data in the whole network or to send to a particular destination

4 Results

The following section is focused on explaining the obtained results from the analytical and simulation modelling sections as explained above.

4.1 Analytical Modelling

Due to the change in direction, the delivery ratio changes. For two ships moving in the same direction, the TOC stays higher, allowing the ships to communicate longer, while the opposite direction movement restricts the TOC and the data transmission (Figure 8.b). Similar to the effect of the free space path loss policy, when the separation distance between the ships is increased, the delivery ratio decreases (Figure 8.a). Based on the connecting technology, WiMax sends most amount of data in comparison to the other alternatives. VHF has the highest range thus it is able to communicate even when WiMax and LR WiFi fail to establish a contact, but having the lowest data rate VHF shows decreased delivery ratio in comparison. ER and RRS achieve comparable delivery ratio when the message is unique in the network, but as the messages become seen in the network, RRS performs poorly as the whole amount is transmitted as duplicate, while ER stops the transmission after exchanging the summary vectors, having a comparably negligible amount of overhead, thus showing better performance (Figure 7).

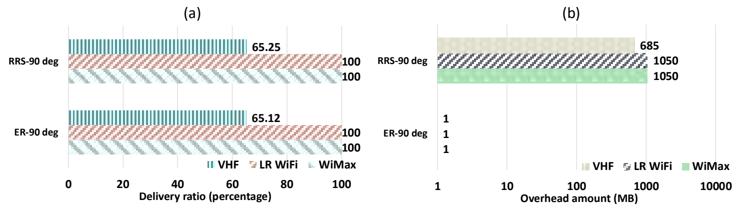

Figure 7: Delivery ratio (a) and Overhead (b) comparison between ER & RRS, effect of Seen and Unique video message in the network; meeting situation between Bulk carrier and RORO carrier

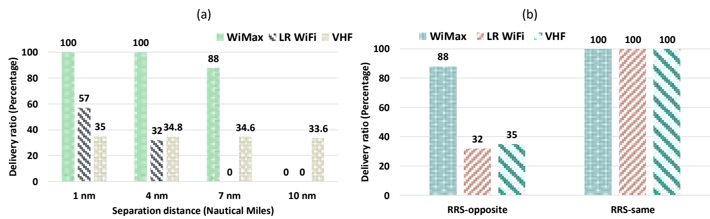

Figure 8: Delivery ratio comparison for effect of Separation Distance (a) and Direction of Movement (b) between two Cargo ships sharing 660 MB sized large file through RRS

4.2 Simulation Modelling

4.2.1 Image

For the synthetic simulation, as the traffic is varied from 10 ships to 50 ships to 100 ships, the effect of it on the delivery ratio becomes evident. The results are explained for VHF only for the following situations, as it showcases superior performance covering the largest area of communication. The delivery ratio of the data decreases with the increase of traffic in the network for ER and S&W, but for RRS, it is able to broadcast the whole data for any number of ships being present in the network (Figure 9).

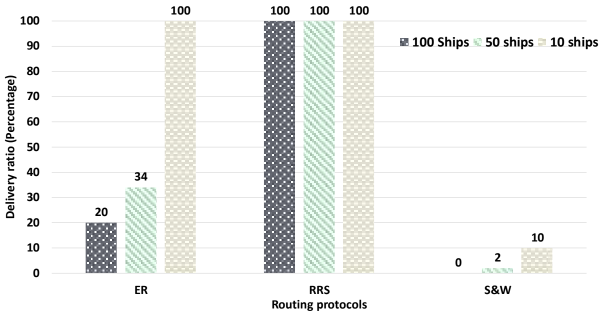

Figure 9: Delivery Ratio comparison for Synthetic model simulation

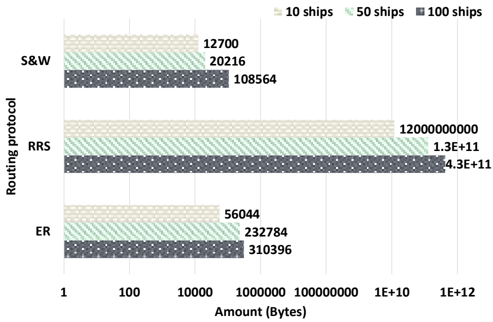

Figure 10: Overhead amount comparison for Synthetic model simulation

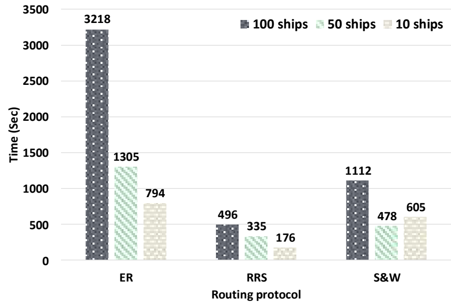

Figure 11: Average Delay comparison for Synthetic model simulation

Even though the problem of having the huge amount of overhead (Figure 10) is associated, along with the time advantage, RRS comes ahead as a better alternative for the considered situation of transmitting time critical information (Figure 11).

The AIS simulation with 150 ships too shows that to send a small sized data VHF works better. It is able to communicate with the ships far away due to its wide range and send the complete data within the stipulated time. Comparing the routing protocols, RRS is able to broadcast more data in every situation (Figure 12), but with the presence of a humungous amount of overhead, as it keeps on sending the data over and over again (Figure 13).

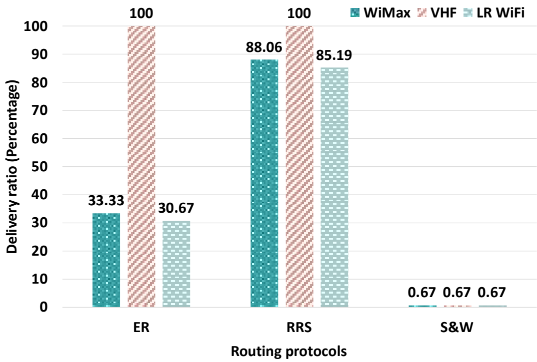

Figure 12: Delivery ratio comparison for AIS model simulation

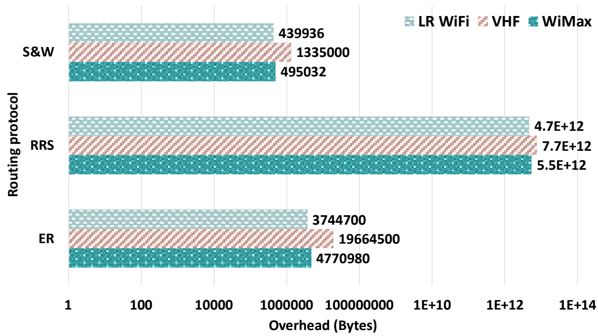

Figure 13: Overhead amount comparison for AIS model simulation

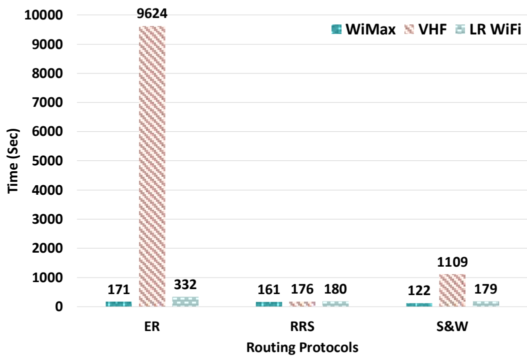

Figure 14: Average Delay comparison for AIS model simulation

ER works in a standard way, with VHF it is also able to send the whole amount of data, while producing considerably less amount of overhead compared to RRS. The S&W routing protocol performs poorly, being limited by the amount of copies of the data available to it. RRS also shows a better timely delivery of the image, when compared to the other two alternatives (Figure 14). As the situation considered, is a time-critical emergency scenario, RRS proves to be a better option, checking off all the requirements. If the situation is considered to be a time-relaxed scenario, ER having better overhead management, demonstrates its efficiency.

4.2.2 Nautical Charts

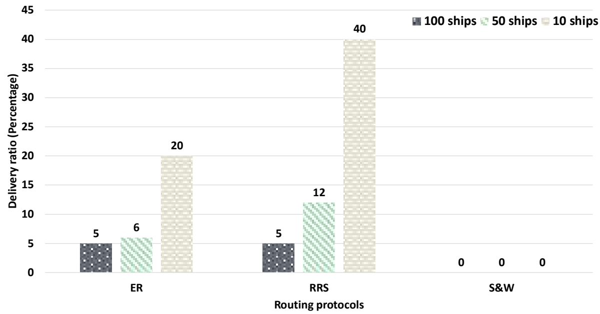

Figure 15: Delivery Ratio comparison for Synthetic model simulation

With the increase in data size, VHF becomes unable to send the data and WiMax becomes a better alternative. For the synthetic model simulation, due to the increased traffic the delivery ratio of the nautical chart decreases from a 10 ship network towards the 100 ship network. RRS offers better delivery ratio than the other two alternatives in all the situations (Figure 15), but still struggles with the enormous amount of overhead (Figure 16). The limitation on the copies of messages and the hop count deteriorates the performance of the S&W routing protocol and it remains unable to send the data under any circumstances.

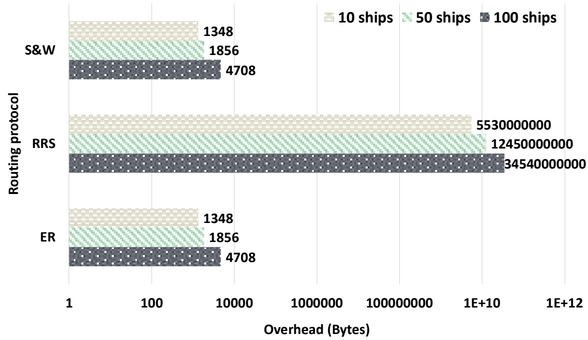

Figure 16: Overhead amount comparison for Synthetic model simulation

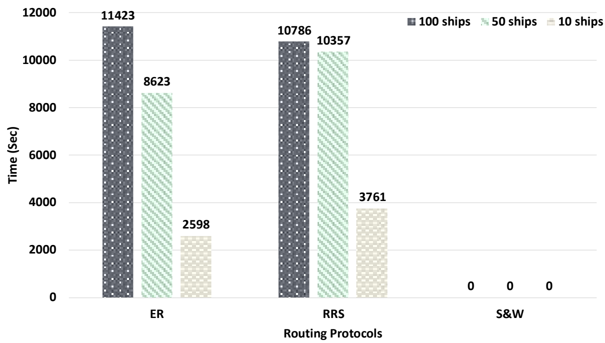

Figure 17: Average Delay comparison for Synthetic model simulation

The AIS-based model simulation also shows similar results, even though the ER protocol transmits data in a standard way, RRS broadcasts with more delivery ratio in every case (Figure 18), except transmission of data with VHF. RRS delivers data with time advantage but in the presence of huge duplicate transmission. But even though ER and S&W too are unable to send any data while using VHF, they still produce a certain amount of overhead due to the exchange of summary vectors, in case of RRS the overhead amount in the VHF situation remains zero (Figure 19).

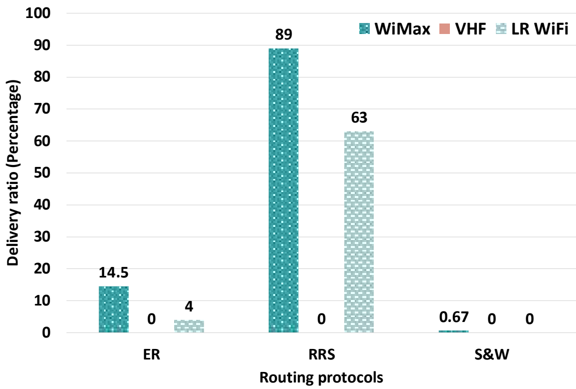

Figure 18: Delivery Ratio comparison for AIS model simulation

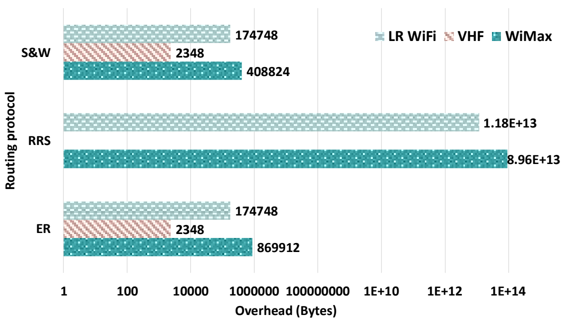

Figure 19: Overhead amount comparison for AIS model simulation

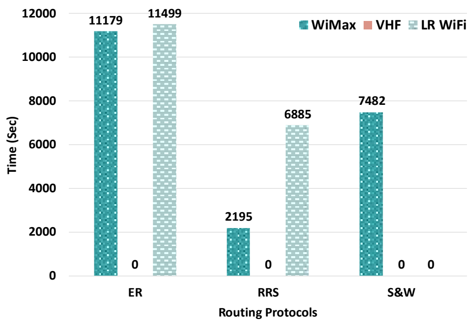

Figure 20: Average Delay comparison for AIS model simulation

Even though the image and nautical chart sending scenarios consider a similar network setup where a single source sends the data, and the rest of the network acts as the destination, the dissimilarities in the delivery ratio is a result of the change in the process parameters and it showcases the effect of them on the communication process following SANET. As the delivery ratio reduces while transmitting nautical charts in the network, it depends on the increase of the data size from image to the charts, along with the effect of the mobility of the source, which is changed from a moving ship to a stationary shore station, which circulates the nautical chart in the network. This provides evident of the dependency of SANET on the mobility of the nodes in the network to have better communication.

4.2.3 Video Message

For the synthetic modelling, all the routing protocols are able to send the data to the destination, even when the network size changes. But in this case, RRS produces no overhead, as while staying connected, the source utilizes all the time to deliver the huge amount of data (Figure 21). For ER and S&W, the overhead is the summary vector, exchanged for the anti-entropy session, which is produced whenever two ships meet. Thus having least overhead and comparable time management (Figure 22), with similar delivery ratio, RRS broadcasting becomes a preferable option in this situation.

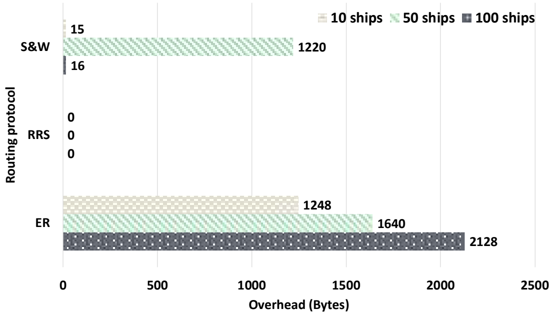

Figure 21: Overhead amount comparison for Synthetic model simulation

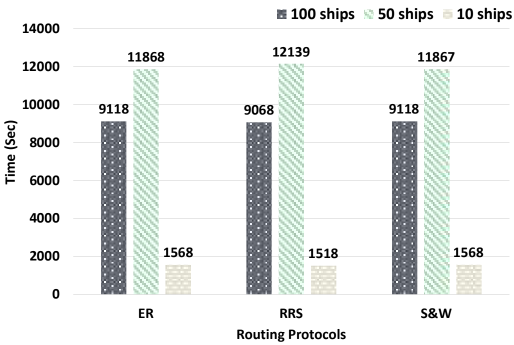

Figure 22: Average Delay comparison for Synthetic model simulation

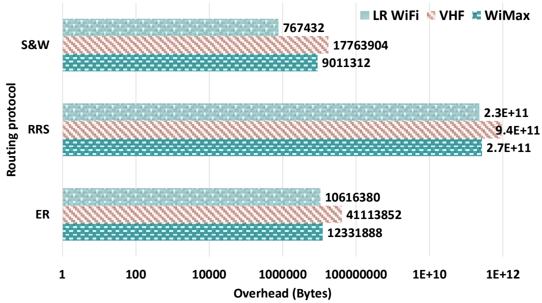

Figure 23: Overhead amount comparison for AIS model simulation

For AIS based model too, similar to the previous scenarios, RRS produces a lot of overhead (Figure 23), but it's the only option where the data reaches its destination. Even though ER and S&W are not able to send the complete data to the destination, as they keep on meeting other ships, they keep on producing summary vectors too, creating overhead in the network for zero delivery ratio.

5 Discussion

The results explained above, obtained through the calculation processes and observed as graphs, show that no routing protocol and connecting technology individually or even as a particular combination can be named as the most preferable option to go for in every situation. It is always dependent on the fixed and variable inputs that decide the characteristics of the situations, as it is seen in the simulation modelling. Because it considers the effect of having increased network traffic, when the number of sources and destinations are varied in the network for sending different amount of data.

The synthetic model network shows the effect of gradually increasing the traffic. So for the network with a small number of ships, it is possible for all the connecting technologies to have higher delivery ratio, but as the number of ships increases, the ratio keeps on decreasing. The same effect is observed for increasing data amount, so even for a large network with 100 ships, the efficiency is 100% mostly, when the data being exchanged are small in size as the image, and it reduces by a large amount when the amount of data to be exchanged is changed to video messages. The AIS-based simulation model validates these results on the basis of real-life trace analysis.

The dissimilarities in the performance of the routing protocols and the connecting technologies when simulated against the AIS data and the synthetic model can be described by the difference in their underlying mobility models, as the difference in the movement of the ships, having different speeds, different directions, holds a very large influence on the process. As from the findings of the analytical estimation section it is seen that the changes in these process parameters actually decides how efficient the communication will be.

Accumulating all the data from the graphs explained above the conclusions can be drawn that:

1. ER offers a standard performance in all scenarios,
2. RRS with broadcasting works better when there is a single source.
3. S&W protocol works better when there is a single destination.

While VHF performs better for transmitting smaller data files for distant communication and WiMax performs better for the transmission scenarios involving faster communication and sharing larger data files.

Also, the disparity between the analytical and simulation's outcome can be explained by the way the message is considered for estimation. The analytical section takes the data by their size, so it even considers the data is being sent when even only 1 MB has reached the destination, thus showing delivery ratio based on that. The simulation section takes the data as a whole packet, so when the complete amount is not received by the destination, it takes no data has been transferred and approximates the efficiency accordingly.

From all these above discussions it could be said that even though using SANET for the marine communication purpose cannot solve the problem of having delays to deliver messages to their destination, for certain protocols under certain situations, as it was visible in SATCOM too, but it is able to provide solution to the following problems, as:

- It is a solution to the problem of having higher cost associated with SATCOM, as SANET utilizes the already available technologies, to share data with each other, avoiding the huge capital and operational cost.
- It provides a solution from having the complex regulations (Ilcev, 2019) associated with SATCOM to be used.
- It also provides a solution to the problem of SATCOM usually offering a low data rate (Yau, et al., 2019), as with WiMax the maximum achievable data rate was 6 Mbps.
- SANET being able to communicate locally, also provides a solution for the blind spot problem in SATCOM. When in certain regions SATCOM is not able to communicate due to the coverage breakage, SANET, with the availability of ships in the proximity, can create contact and share information.

6 Conclusion and Future Scope

The paper considers three routing protocols that showcase different characteristics and three connecting technologies that are already being inspected for ongoing projects based on SANET. All the components are compared under the same umbrella - having the same circumstances around them, facing the same changes in the basis of case study simulation. To the best of our knowledge, this is the first time where all these factors are examined all together.

The flow of the paper also allows to find the solution of SANET being evaluated over a wide range of spectrums, covering multiple possible scenarios. The change in the situations to evaluate SANET's feasibility also proved that the efficiency is highly dependent on the situation established, along with showing the effect of the mobility pattern that the ships follow. As the route information of the ships is mostly known beforehand, utilizing the information, SANET could be used in real-life scenarios more efficiently.

The paper has its own limitations, as it considers only three available protocols and connecting technologies. There are other options available, out of which some might work in a more efficient way, for the situations taken into account. The paper opens up multiple research opportunities to be explored in the future, as:

- Look-up based optimization: A database prepared and made available to the ships containing a range of varied situations and the solutions, based on the situation which routing protocol to be used. Thus, when the circumstance changes, based on the available list, the routing protocol is chosen automatically.
- Parameter control: An option to prepare a system that allows the ships to choose their destination for a specific data file, based on the requirement, pointed by their GPS location, to avoid unnecessary hopping of the message, or to customize the network based on the time and place of implementation.
- Security aspect: If any ship is eavesdropping or changing the data being sent, or even stopping the dissemination process by not forwarding the data anymore to create problems, future work can focus on solving these problems to make SANET a much more secure network to opt for.

As for the maritime shipping operators, along with the timely delivery of the information, it is also important to have a lower cost of operation, and a simplified communication process equipped with a higher rate for data transferring. It could be said that even though having SANET as the only option for communication might not be the ultimate choice to be used right away, the process holds its merits to be integrated into the ships and used together with SATCOM, complementing each other's deficiencies, to provide an efficient medium to exchange data at the sea in real-life and gradually increase its application area in the shipping process.

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Prevailing Technologies and Adoption Obstacles in Maritime Logistics

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Purpose: *Digital technologies (DTs) are transforming logistics operations in the shipping industry. Yet, the industry is only in the early stages of digitalization. Consequently, there is a lack of empirical evidence on applied DTs and related obstacles for DT adoption.*

Methodology: *A multiple case study was conducted comprising ports, freight forwarders, and carriers. Based on 18 expert interviews and additional data sources, differences and similarities concerning currently applied DTs and associated obstacles to DT adoption were examined.*

Findings: *Presented findings indicate comprehensive efforts toward a paperless and digitalized way of operating within maritime container logistics (MCL) by using DTs such as blockchain, cloud solutions, and artificial intelligence. Especially ports strive to achieve collaborative data usage but are frequently hindered by a lack of inter-organizational data sharing. Furthermore, the inherent complexity of the MCL chain and employees' and managers' defensiveness toward technological change needs to be overcome by applying suitable measures for DT adoption.*

Originality: *The research contributes to the scarce literature of DT adoption within MCL by providing empirical insights into the state-of-the-art of DTs for ports, freight forwarders, and carriers. Additionally, this research is the first to address implications for tackling existing obstacles for successful DT adoption in MCL.*

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1 Introduction

Maritime logistics is of outstanding importance for global supply chains, being responsible for the majority of overall freight logistics (OECD, 2022). In 2020, maritime container logistics (MCL) was in charge of the shipment of approximately 20% of tons loaded in overall international maritime logistics (UNCTAD, 2021). From 2022 to 2026, MCL is expected to grow 4.6% annually – thus exceeding the growth expectation of overall maritime logistics of 2.4% annually (UNCTAD, 2021), emphasizing its current and future significance for global supply chains. However, the container shortage, starting in 2020, negatively influenced the reliability and increased costs in MCL (UNCTAD, 2021), displaying the need to incorporate digital technologies (DTs) in MCL to compensate for the negative effects on global supply chains (Panwar, Pinkse and Marchi, 2022). Emerging DTs, such as artificial intelligence (AI), machine learning (ML), blockchain, or the Internet of things (IoT), are characterized by not merely digitizing products and processes of organizations, but beyond being responsible for the digitalization of organizations, radically modifying logistics chains, renewing business models, and affecting the logistics industry's structures (Ceipek, et al., 2021). Also before the COVID-19-crisis, the significance of emerging DTs in MCL was highlighted (Fruth and Teuteberg, 2017), as the following examples illustrate: (1) DTs, such as the Internet of Things (IoT), are applied to allow seamless tracking and tracing of containers (Sanchez-Gonzalez, et al., 2019); (2) blockchain technology is used for the standardization and digitization of paper-based processes (Yang, 2019); (3) sensors, among other things, support monitoring activities within ports (Fruth and Teuteberg, 2017); and (4) artificial intelligence (AI) was found to optimize routing problems (Jurdana, Krylov and Yamnenko, 2020) or to monitor and predict weather and ice conditions (Benz, Münch and Hartmann, 2021). These examples display that DTs have a huge potential for transforming MCL towards increased transparency and real-time information availability (Bathke, et al., 2022). However, Munim, et al. (2020) indicated that the mere existence of DTs is not efficient until it is widely adopted in overall MCL.

Regarding appropriate DT adoption, the research in MCL is still in its infancy (Fruth and Teuteberg, 2017; Tijan, et al., 2021a). Although the adoption of specific DTs such as blockchain (Yang, 2019) or AI (Jurdana, Krylov and Yamnenko, 2020) have already been examined, no differences between incumbent actors in MCL were elaborated. However, as MCL is moving towards digitalization at different speeds in different domains (Sanchez-Gonzalez, et al., 2019), the behavior of organizations regarding DT adoption may differ (Fruth and Teuteberg, 2017). Additionally, emerging DT adoption was found to be one of the biggest challenges that organizations in logistics currently face (Mathauer and Hofmann, 2019; Karakas, Acar and Kucukaltan, 2021), and thus, several obstacles need to be overcome for successful DT adoption (Cichosz, Wallenburg and Knemeyer, 2020; Tijan, et al., 2021a; Yang, Fu and Zhang, 2021). These potential obstacles to DT adoption are currently lacking research in MCL. Referring to potential inherent differences between the main incumbent actors of MCL—ports, freight forwarders, and carriers (Talley and Ng, 2013), this research aims to answer the following research questions (RQs):

> *RQ1: What is the state-of-the-art of DT adoption comparing ports, freight forwarders, and carriers?*
>
> *RQ2: What are the obstacles that need to be overcome for successful DT adoption for ports, freight forwarders, and carriers?*

To answer the RQs, an empirical case study is conducted. Thereby, the study is structured as follows: After providing theoretical background information about the topic, the underlying methodology is explained. Next, a cross-case analysis is conducted, discussing the findings gathered from the case study. Lastly, managerial and theoretical implications, limitations, and paths for future research are displayed.

2 Theoretical background

The objective of this paper is to demonstrate the current DT adoption status and obstacles to DT adoption in MCL. Therefore, first, theoretical information regarding DT adoption is provided, followed by an analysis of obstacles to DT adoption in general.

2.1 Adopting digital technologies

DTs have significant impacts on different levels of logistics organizations: (1) within logistics organizations regarding a change in business models and processes; (2) between logistics organizations considering governance and relational configurations; and (3) at the level of the logistics industry regarding disruptions to the status quo and the emergence of new product or service providers (Wang and Sarkis, 2021). In particular, in MCL, DTs enable standardization, digitization, and easing of paperwork (Yang, 2019). Additionally, DTs may minimize the employee role in MCL organizations to that of a system observer, as DTs have the potential to self-optimize processes (Jurdana, Krylov and Yamnenko, 2020) and to take over error-prone tasks (Bălan, 2020). This results in a simplification of freight calculations, and a decrease in the costs of fuels and human resources (Bălan, 2020; Jurdana, Krylov and Yamnenko, 2020).

When adopting DTs, the study by Yang, Fu and Zhang (2021) stated that organizations go through several stages depending on their level of technological intelligence and supply chain collaboration. The authors' developed matrix can be adapted to MCL, as presented in Figure 1. The first axis, *technological intelligence*, is defined as the degree of intelligence to which DTs are adopted in MCL (Schoenherr and Swink, 2015). Little technological intelligence means that traditional DTs, such as enterprise resource planning (ERP), transportation management systems (TMS), application programming interfaces (API), robotics process automation (RPA), data collection and visualization, or data processing technologies, are used in MCL (Munim, et al., 2020; Núñez-Merino, et al., 2020; Yang, Fu and Zhang, 2021), thus representing digitized solutions that merely convert analog into digital information. On contrary, high technological intelligence implies that real-time data can be processed by applying smart sensors, and predictive analyses are applied for forecasting and real-time planning (Yang, Fu and Zhang, 2021), consequently being related to digitalization. High technological intelligence is represented by IoT, augmented and virtual reality (AR/VR), additive manufacturing, blockchain, cloud and edge computing (Sanchez-Gonzalez, et al., 2019), as well as AI and machine learning (ML) (Sanchez-Gonzalez, et al., 2019; Jurdana, Krylov and Yamnenko, 2020; Munim, et al., 2020). The second axis represents the *level of collaboration* between MCL organizations (Cloutier, Oktaei and Lehoux, 2020). By inter-organizational application, DTs are considered to lead to intelligent supply chains and involve connections between different actors within supply chains (Núñez-Merino, et al., 2020). Low collaboration means that DTs are solely applied intra-organizational, whereby high collaboration refers to the application of DTs and data sharing across several organizations (Cloutier, Oktaei and Lehoux, 2020; Yang, Fu and Zhang, 2021).

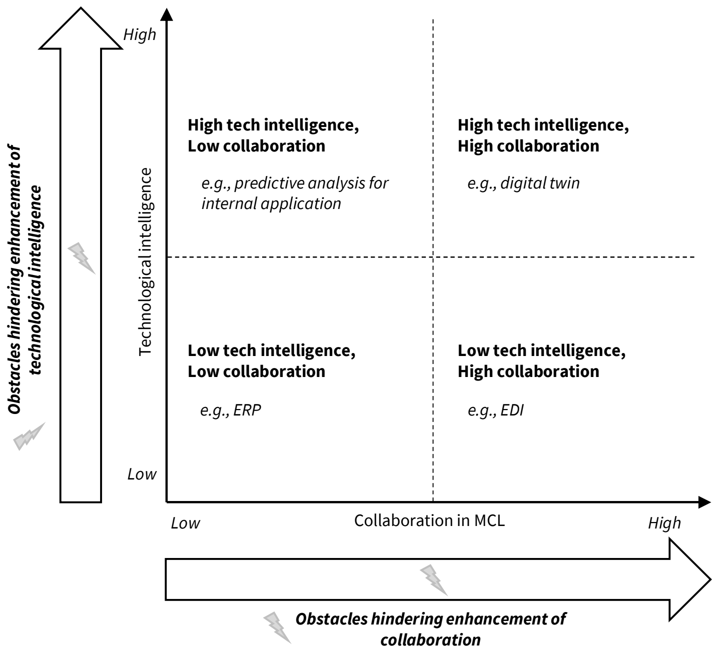

Figure 1: Research framework, adapted from Yang, Fu and Zhang (2021)

2.2 Obstacles to successful DT adoption in logistics

The mere existence of DTs has no impact until they are adopted in the whole MCL industry (Munim, et al., 2020). However, the inappropriate DT adoption potentially results in a disruptive change that leads to high risk and uncertainty (Yang, Fu and Zhang, 2021). Thus, DT adoption is referred to several potential disadvantages, such as cyber risks (Hofmann, et al., 2019), or the high potential volatility (Büyüközkan and Göçer, 2018). In addition, the uncertainty dilemma, stating that timely and accurate data is an arduous task and often not completely achievable in a volatile, uncertain, complex, and ambiguous environment, is a challenge regarding the usage of DTs (Lechler, Canzaniello and Hartmann, 2019). Consequently, obstacles inherent to DT adoption must be overcome to succeed in DT adoption (Yang, Fu and Zhang, 2021), as represented in the research framework in Figure 1. Potential general obstacles to DT adoption in logistics, found by screening respective literature, are summarized in Table 1. The results of Table 1 result from a desk research, using the databases Scopus and Google Scholar and applying the keyword sequence “digital technology” OR "digital technologies" AND "adoption" OR "implementation" AND "logistics" OR “supply chain” and additional relevant sources. The table serves as a basis for the analysis of the case study results regarding DT adoption obstacles in MCL.

Table 1: Obstacles to DT adoption according to literature

Obstacles to DT adoption	Reference(s)
Heterogeneous information systems and lack of standards	*Cichosz, Wallenburg and Knemeyer (2020), Inkinen, Helminen and Saarikoski (2019), Tijan, et al. (2021a), Yang (2019)*
Heterogeneous organizational structures or cultures	*Harris, Wang and Wang (2015), Tijan, et al. (2021a)*
High implementation costs and risks	*Harris, Wang and Wang (2015), Tijan, et al. (2021a)*
Lack of capabilities to change	*Balci and Surucu-Balci (2021), Tijan, et al. (2021a)*

Obstacles to DT adoption	Reference(s)
Lack of coordination and collaboration	*Tijan, et al. (2021a), Yang (2019)*
Lack of early adopters	*Balci and Surucu-Balci (2021)*
Lack of investments in DTs	*Harris, Wang and Wang (2015), Tijan, et al. (2021a)*
Lack of knowledge about DTs	*Balci and Surucu-Balci (2021), Tijan, et al. (2021a)*
Lack of regulation	*Balci and Surucu-Balci (2021), Harris, Wang and Wang (2015), Tijan, et al. (2021a), Yang (2019)*
Lack of skills	*Cichosz, Wallenburg and Knemeyer (2020),Tijan, et al. (2021a)*
Lack of support from stakeholders	*Balci and Surucu-Balci (2021), Harris, Wang and Wang (2015)*
Lack of trust in DTs	*Balci and Surucu-Balci (2021)*
Lack of urgency to adopt DTs	*Tijan, et al. (2021a)*
Privacy concerns/no cyber security	*Balci and Surucu-Balci (2021), Cichosz, Wallenburg and Knemeyer (2020), Harris, Wang and Wang (2015), Kala and Balakrishnan (2019), Tijan, et al. (2021a)*

Obstacles to DT adoption	Reference(s)
Resistance of stakeholders (e.g., employees) to adopt	*Balci and Surucu-Balci (2021), Cichosz, Wallenburg and Knemeyer (2020), Tijan, et al. (2021a)*

3 Methodology

The methodology applied to answer the RQs is a multiple-case design, collecting empirical data (Yin, 2018). Thereby, the following chapter is structured as follows: first, a short background about the case study design is provided. Afterward, the sample and data collection are presented in detail, followed by a description of the data handling.

3.1 Case study design

The case study approach is considered appropriate for our research for several reasons: (1) research regarding DT adoption in MCL is still at the beginning and existing knowledge regarding DT adoption is not sufficient (Fruth and Teuteberg, 2017); (2) the case study helps to widely evaluate the research problem and observe it within its actual practice (Yin, 2018); (3) the case study allows the close investigation of Yang, Fu and Zhang's (2021) DT adoption framework and expanding it based on the insights gathered from the interviews (Siggelkow, 2007); and (4) by using at least three sources of evidence per case, required triangulation is ensured (Eisenhardt and Graebner, 2007).

While executing the case study, construct validity, internal and external validity, and reliability need to be ensured to allow high-quality results (Yin, 2018). Construct validity is enabled by developing and adapting the questionnaire based on an extensive literature review and collecting multiple sources of data (Yin, 2018). Internal validity is allowed by analyzing existing literature regarding DT adoption and conducting interviews with a heterogeneous group of experts (Yin, 2018). External validity is ensured by conducting a multiple instead of a single case study; and reliability relies on the selection based on predefined criteria, the sharing of the questionnaire in advance, and support by another researcher while analyzing the results (Yin, 2018).

3.2 Sample and data

We aimed to evaluate the differences between the three incumbent MCL actors "ports," "freight forwarders," and "carriers" (Talley and Ng, 2013). Thereby, the experts were selected according to the following, predefined criteria (Eisenhardt, 1989):

- Ports were required to be among the top 15 largest container ports around the world according to the handled volume. Experts from port authorities were chosen as interview partners in this category, as recent literature emphasized the significant role of port authorities regarding DT adoption in MCL, potentially becoming digital hubs in the future (Tijan, et al., 2021b);
- Freight forwarders needed to ship a volume of 500,000 twenty-foot-equivalent units per year by vessel; and
- Carriers were supposed to possess over 5% market share.

The literature provides several recommendations regarding the number of cases that seem appropriate for a multiple-case study. While some authors suggest that no more than 15 cases shall not be included (Perry, 1998), others propose that four to ten cases are sufficient (Eisenhardt, 1989). According to Corbin and Strauss (1990), additional cases shall be incorporated until saturation is achieved. They consider that any further cases would merely provide little variation compared to the already gathered data, marginally new insights, and no further relevant managerial and theoretical implications (Corbin and Strauss, 1990). Information regarding the final set of interview participants can be found in Table 2. The final set consists of nine cases and 18 interview participants. According to anonymization reasons, the size of the organizations is shown as an incremental range.

Table 2: Overview of cases

Case	Current position of the contact person	Organizational type	Number of employees
Alpha $_1$	Port Representative (Digital products)	Port authority	50,000–100,000
Alpha $_2$	Chief Digital & Innovation officer		
Beta $_1$	Project Manager for Digital Projects	Port authority	10,000–50,000
Beta $_2$	Consultant for Digital and Business Transformation		
Gamma $_1$	Proposition Manager Digital Business Solutions	Port authority	>100,000
Gamma $_2$	Product Lead Digital Products		
Delta $_1$	Vice President and Global Head Ocean freight processes	Freight forwarder	>100,000
Delta $_2$	Head of International Supply Chain		
Epsilon $_1$	Vice President Global IT	Freight forwarder	50,000–100,000
Epsilon $_2$	Senior Product Manager for Digital Innovation		
Zeta $_1$	Vice President Global Sea freight Processes and Systems	Freight forwarder	50,000–100,000
Zeta $_2$	Vice President Global Sea Logistics Operations		

Case	Current position of the contact person	Organizational type	Number of employees
Eta_1	Member of the strategy office	Carrier	10,000–50,000
Eta_2	Digitalization Manager		
$Theta_1$	Deployment Lead (Transformation and Change Management)	Carrier	50,000–100,000
$Theta_2$	Investment Advisor Digital Products		
$Iota_1$	Global Chief Digital & Information Officer	Carrier	50,000–100,000
$Iota_2$	Projects Manager for Digital & Innovation		

3.3 Data handling

High construct validity was ensured by an extensive review of respective literature and discussions within the research team (Eisenhardt, 1989). This allowed the development of an interview guideline with a semi-structured design, using open questions, to react flexibly during the interviews (Yin, 2018). In addition, the interview questions were adapted during the conduction of the interviews. Before conducting the interviews, the potential experts were made familiar with the DT adoption framework by Yang, Fu and Zhang (2021) to understand the process of DT adoption. Furthermore, they were asked to classify their organization in this matrix.

All 18 interviews were conducted by two researchers of the research team. The interviewees had on average 14 years of experience in MCL. Data gathered from the semi-structured interviews served as the primary and most valuable data source (Yin, 2018). By additionally using secondary data besides the interview material, a potential social desirability bias can be reduced (Crane, 1999). The interviews were then transcribed. Subsequently, the transcript and a summary of the interview were sent to each interviewee with the confirmation request to avoid misunderstandings and to guarantee the accuracy of the information supplied (Yin, 2018).

The data was analyzed by revealing common patterns and differences regarding DT adoption across the nine cases by a cross-case analysis. The identification of structures and patterns in the unstructured qualitative interview data and secondary data was allowed by a systematic coding process (Corbin and Strauss, 1990). Subsequently, categories were built on the identified codes. To allow inter-rater reliability and a high-qualitative analysis, an iterative coding approach was applied (Pagell and Krause, 2005). Consequently, another researcher of the research team revised and verified the identified codes and patterns during each coding step. Thereby, deviating results were iteratively approximated in three research meetings, leading to an agreement regarding the codes and patterns. Using the same categories for all interview transcripts allowed to efficiently compare the different case organizations (Eisenhardt, 1989). To facilitate the handling of the large amount of data, the categorization of the data was supported by computer-aided qualitative data analysis software (Yin, 2018).

4 Cross-case analysis

4.1 Digital technologies currently applied in maritime container logistics

According to the classification of the case organizations in Yang, Fu and Zhang’s (2021) DT adoption matrix, Table 3 displays the level of technological intelligence and level of collaboration of the different case organizations.

Table 3: Current level of DT adoption of the nine cases

Case	Classification in DT adoption matrix	DTs applied in case organizations
Alpha	*High tech intelligence/high collaboration*	APIs, Autonomous shipping, Blockchain, Digital twin, Drones, ERP, IoT, Sensors
Beta	*High tech intelligence/low collaboration*	3D printing, Digital twin, Drones, ERP, ML, RPA, VR/AR
Gamma	*High tech intelligence/low collaboration*	AI, Autonomous shipping, Blockchain, Cloud computing, Drones, ERP, IoT, ML, RPA
Delta	*Low tech intelligence/low collaboration*	APIs, Chatbot, EDI, ERP, ML, Process mining
Epsilon	*Low tech intelligence/high collaboration*	APIs, AI, Chatbot, Cloud computing, Drones, ERP, IoT, ML, Quantum computing, RPA
Zeta	*Low tech intelligence/high collaboration*	APIs, AI, Blockchain, EDI, ERP, Predictive analytics, RPA
Eta	*Medium tech intelligence/low collaboration*	APIs, Blockchain, Cloud computing, ERP, RPA
Theta	*Medium tech intelligence/medium collaboration*	AI, Blockchain, Control tower solutions, ERP, IoT, ML, Process mining, RPA

Case	Classification in DT adoption matrix	DTs applied in case organizations
Iota	*Low tech intelligence/medium collaboration*	APIs, AI, Blockchain, Cloud computing, ERP, IoT, Predictive analytics

All ports state that they hold a high technological intelligence. However, the level of collaboration differs among the interviewed experts. Whereas Alpha displays a high level of collaboration, Beta and Gamma do not show high collaboration efforts. Alpha strives toward establishing a *"digital nervous system on top of the physical ports […] to focus on safety and security in the port area "(*$Alpha_1$), therefore testing the application of digital twins. This DT is also applied by Beta. However, Beta still displays silo-thinking and thus hinders collaboration efforts to some extent. All ports apply drones to *"detect oil spills"* ($Alpha_1$) or to *"inspect buildings"* ($Beta_2$). Blockchain is furthermore adopted by the ports for the transfer of documents. Additionally, Beta enhances its monitoring efforts by using sensors and AR.

Freight forwarders, on contrary, all display a low level of technological intelligence. While Delta further emphasizes its low level of collaboration, Zeta and Epsilon strive toward high collaboration with their MCL partners. Consequently, DTs to enhance data sharing are highly relevant for these two organizations. They adopted several cloud solutions to interact with their customers and manage their end-to-end logistics chain. Furthermore, AI simplifies their interaction with customers: *"With AI, we have the repository, where we have a lot of replies to a lot of questions collected over time"* ($Epsilon_2$) which can then be used for automated chatbots. Moreover, optical character recognition helps to scan physical documents that are arriving at the organizations: *"We had a lot of business inquiries from potential customers: Can you fulfill this requirement? Or do you have this standard? […] Now, we can do it in an hour instead, because we OCR scan these documents from the customers"* ($Epsilon_1$).

The carriers are all located in the lower left-hand corner of the DT adoption matrix, having low to medium technological intelligence and low to medium collaboration. Two out of three carriers apply IoT in their organization. For example, Iota uses IoT for *"the* *monitoring of containers"* and the establishment of smart containers. In addition, the application of AI, ML, or predictive analytics was emphasized by the experts. ML can help *"analyzing all data that could eventually become […] a new product that we could bring as part of our digital offering to our customers"* ($Iota_1$). Some carriers strive towards establishing new services for their customers and therefore need to analyze data. Moreover, the experts mentioned that currently paper-heavy solutions are being replaced by digitized ones, such as electronic solutions for the bill of lading, and *"many of the traditional paper-based architectures are or will be paperless"* (Eta_2). Tracking and tracing efforts by the application of blockchain and IoT are essential for the interviewed experts of the carriers. For Theta, it is not only relevant where the container is on the vessel, but beyond that *"getting real-time visibility when your container is moving on a truck, where that truck is right now"* ($Theta_1$) to enable *"new potential different products and services along that end-to-end journey"* ($Theta_1$).

The DTs adopted by the different case organizations are summarized in the following graph, presented in Figure 2.

	Ports			Freight forwarders			Carriers		
	Alpha	Beta	Gamma	Delta	Epsilon	Zeta	Eta	Theta	Iota
3D printing		x							
AI			x		x	x		x	x
APIs	x			x	x	x	x		x
Autonomous shipping	x		x						
Blockchain	x		x			x	x	x	x
Chatbot				x	x				
Cloud computing			x		x		x		x
Control tower solutions								x	
Digital twin	x	x							
Drones	x	x	x	x	x				
EDI						x			
ERP	x	x	x	x	x	x	x	x	x
IoT	x		x		x			x	x
ML		x	x	x	x			x	
Predictive analytics						x			x
Process mining				x				x	
Quantum computing					x				
RPA		x	x		x	x	x	x	
Sensors	x								
VR/AR		x							

Figure 2: DTs adopted by different stakeholders in MCL

4.2 Obstacles to digital technology adoption in maritime container logistics

The obstacles to DT adoption in MCL can be classified into obstacles that hinder the enhancement of technological intelligence, obstacles that impede the enhancement of collaboration, as well as obstacles that hinder both. In this context, the obstacles mentioned during the interviews are displayed in Table 4. Table 1 in chapter 2.2 served as a basis for the analysis of the following results.

Table 4: Obstacles hindering DT adoption in MCL

No.	**Obstacles to DT adoption**	**Examples**	**Barrier to technological intelligence**	**Barrier to collaboration**
O1	Competitors and external stakeholders *Alpha, Delta, Eta*	*Market power of carriers; freight forwarders hindering DT adoption*	No	Yes
O2	Complexity of MCL network *Alpha, Gamma, Delta, Epsilon, Zeta, Eta*	*Volatility of the market; involvement of many parties*	Yes	Yes
O3	Customers *Alpha, Delta, Eta*	*Smaller customers; customers in specific countries*	Yes	No
O4	Heterogenous organizational structures *Beta, Delta, Epsilon, Zeta, Theta, Iota*	*Size of the organizations; working in silos*	Yes	No
O5	Heterogenous systems/lack of standards *Alpha, Delta, Epsilon, Eta, Theta, Iota*	*Plenty of different systems and interfaces; lack of standardization*	No	Yes

No.	Obstacles to DT adoption	Examples	Barrier to technological intelligence	Barrier to collaboration
O6	Internal bureaucracy *Beta, Gamma, Delta, Epsilon, Zeta, Theta, Iota*	*Strong hierarchical structures; long decision processes*	Yes	No
O7	Lack of collaboration *Alpha, Beta, Gamma, Delta, Zeta, Eta, Theta, Iota*	*No willingness to share data; lack of finding adequate partnerships*	No	Yes
O8	Lack of adequate government regulations *Gamma, Delta, Epsilon, Zeta, Iota*	*No clear "digital" laws; plenty of different laws and regulations in different countries*	Yes	Yes
O9	Lack of necessary resources *Alpha, Gamma, Delta, Epsilon, Eta, Theta, Iota*	*No employee capacity; lack of IT skills; lack of financial resources*	Yes	No
O10	Lack of strategy/urgency Alpha, Gamma, Eta, Theta, Iota	*No clear vision; no shared business and technology strategy*	Yes	Yes

No.	Obstacles to DT adoption	Examples	Barrier to technological intelligence	Barrier to collaboration
O11	Lack of support from managers/C-level *Beta, Gamma, Epsilon, Eta, Theta*	*Lack of management attention; lack of C-level attention*	Yes	Yes
O12	Lack of trust *Alpha, Epsilon, Eta, Iota*	*No trust in systems or numbers; fear of losing competitive advantage*	Yes	Yes
O13	Legacy of old systems *Alpha, Beta, Gamma, Delta, Epsilon, Zeta, Eta, Theta, Iota*	*Running costs for old systems; no innovation focus on internal processes*	Yes	No
O14	Old-fashioned industry *Beta, Gamma, Delta, Epsilon, Zeta, Eta, Theta, Iota*	*No job rotation; predominant incumbent organizations*	Yes	Yes
O15	Privacy concerns/no data security *Alpha, Beta, Epsilon, Iota*	*Fear of too much transparency of the organization; lack of data security*	Yes	Yes

No.	Obstacles to DT adoption	Examples	Barrier to technological intelligence	Barrier to collaboration
O16	Resistance of employees *Beta, Gamma, Delta, Epsilon, Zeta, Eta, Iota*	*Older employees; employees hindering DT adoption*	Yes	No

All experts mentioned that the legacy of old systems, such as *"the amount of investments and support that we need to still do and have in regards of the legacy systems"* ($Zeta_1$), hinders the investments and the available capacity for the adoption of emerging DTs. In this regard, the experts further emphasized that the maritime industry itself is old-fashioned with an antiquated culture and that *"people in our industry generally are not quickly changing jobs. So, […] our staff works at least 10 years in the company"* (Eta_1). The missing collaboration is mentioned by 8 out of 9 organizations. However, especially within ports, many actors need to collaborate to guarantee efficient and disruption-free processes in the ports: *"There is still a certain degree of competition among the port players and actually we should position ourselves more strongly as a closed port"* ($Beta_1$).

Regarding the obstacle of the lacking resources, the organizations emphasize the challenge of *"investments and a proper budget to be spent on something that we know that we may fail"* ($Iota_1$). Besides *"the competence of the workforce"* ($Gamma_2$), the challenge to attract the right "digital" skills to be able to cope with the respective DTs often hinders the adoption of emerging DTs. This is fueled by internal bureaucracy, as emphasized by all experts working in freight forwarding: *"If something has to be researched, then you need a certain budget for it, then it has to be approved, and then […] ten committees have to be passed"* ($Delta_1$). This is closely related to the resistance of employees. As several experts mentioned, especially older employees delay the DT adoption as they refuse to learn and adapt to new circumstances. Some employees fear being replaced by DTs. The employees further often lack trust in the systems and numbers: "*They do not always trust the numbers, and they do not trust the AI results"*

(Iota$_1$), sticking to Excel sheets and thus hindering appropriate communication and analysis enabled DTs. This is related to privacy concerns between the different organizations, as mentioned by some experts: *“Digitalization is one thing, but it has a flip side”* (Alpha$_2$). Some organizations are worried about cyber risks resulting from emerging DTs.

In particular for carriers, both internal and external, heterogeneous systems and lacking standardization impede DT adoption. There is not*“ a unique platform, a unique standard that allows everyone to talk the same language when it comes to data”* (Iota$_1$). The experts of freight forwarders emphasized the heterogeneous structures in MCL. Often, these organizations have *“many siloed approaches between several teams”* (Delta$_1$), leading to a strategy for DT adoption that is rather organized in silos. This is related to the complexity of the MCL network, as for *“a container of food shipped from Africa to Europe, 30 parties [are] involved and 200 data transactions [are necessary]”* (Alpha$_1$). Furthermore, several different laws and regulations exist on different continents and countries, being an obstacle to enhancing both collaboration and technological intelligence.

Additionally, the missing support by managers slows down DT adoption by being closely related to manager’s priorities and alignment (Theta$_2$). In this context, several experts emphasized that a shared business and technology strategy is relevant to appropriate DT adoption: There is *“a barrier between the business strategy and the technology strategy. So there are two different processes, […] and there is always a bit of discrepancy that is a problem for implementing a common strategy and reinterpreting it with technology”* (Theta$_2$). As further opined by several experts, some customers hinder the advancement of technological intelligence. *“Many boxes continue to be booked by small customers. Small producers in China, small forwarders, and in many cases, they are still manual themselves”* (Eta$_1$). Besides smaller customers in general that are less digitized, customers in specific regions impede DT adoption: *“There are still a few small two-man companies in China that want to [communicate] by fax”* (Delta$_1$). Competitors, in particular carriers, were identified as barriers by the other stakeholders as “*there is a relatively small market of large carriers that cover the market and at the moment everyone is happy to get any capacity at all”* (Delta$_2$).

The findings of the analyses in chapter 4.1 and chapter 4.2 are summarized in Figure 3, complementing the presented research framework.

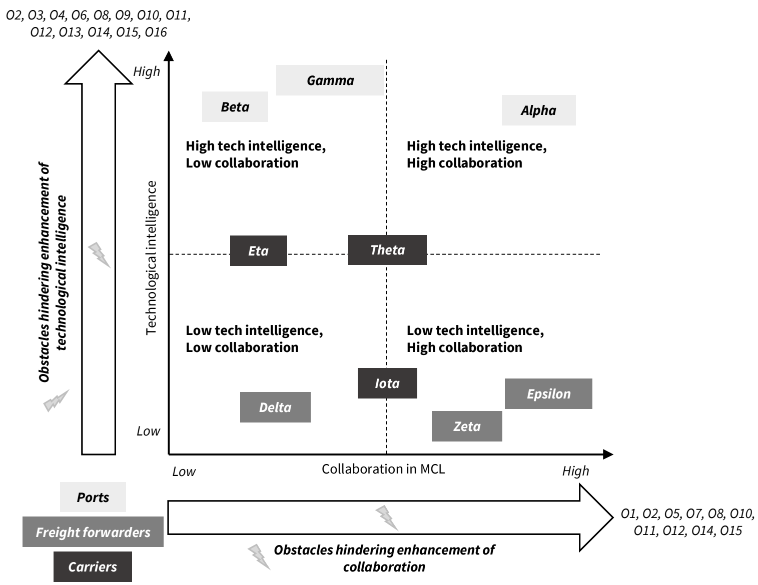

Figure 3: Expanded research framework, adapted according to Yang, Fu and Zhang (2021)

5 Discussion

Merely Alpha assessed themselves as being at a high level of both technological intelligence and collaboration. Beta, Gamma, Eta, Theta, Iota, and Delta need to overcome several obstacles hindering collaboration. As collaboration was found to have a positive impact on the competitive advantage of ports (Seo, Dinwoodie and Roe, 2016), also Beta and Gamma need to strive toward the upper-left-hand corner of the matrix. Zeta displays a high level of collaboration, but mentioned that it is difficult to find adequate partners for collaboration and ecosystems: *“In South America, […] Africa and* *some areas in Asia, it is very difficult to find partners that would say let's see what we can do in terms of blockchain"* (Zeta$_2$). The collaboration is hindered by trust, as one expert opined: *"We make a decision only after we do all the steps that we used to do 15 years ago and a good feeling, […], not looking in the numbers."* (Eta$_1$) Furthermore, lacking data security is impeding the enhancement of trust: *"We have massive problems driving digital projects forward because our lawyers and IT architects say, […] before we do anything with the data, we have to make sure that it is protected, that it is secure."* (Epsilon$_1$) In general, DTs, such as blockchain, were found to enhance trust by enabling cyber security, thus leading to increasing collaboration (Dubey, et al., 2020). Moreover, according to some experts, support from business associations, such as the digital container shipping association (DCSA), is necessary to develop and successfully implement standards regarding DT adoption. This is especially relevant due to the complexity of the MCL network (Jensen, Vatrapu and Bjørn-Andersen, 2018). Standardization is further emphasized regarding the *"very different customs rules and customs processes in different countries"* (Delta$_2$). Consequently, government support is essential. Nevertheless, in case blockchain is already adopted (Yang, 2019), standardization efforts can be advanced and thus other obstacles removed.

The obstacles hindering the enhancement of technological intelligence are mostly related to intra-organizational challenges. Maritime organizations mainly consist of old-fashioned people: *"So, […] our staff works at least 10 years in the company"* (Eta$_1$), which impedes bringing new insights regarding the usefulness of several DTs in the organization (Yang, 2019) because *"traditional values are still predominant"* (Beta$_2$). As *"there is a lot of demand for digital experts in various areas"* (Epsilon$_2$), MCL is having a problem attracting the right skills (Canepa, et al., 2021), for example in *"software development and hardware engineering talent, to get enough people"* (Theta$_2$). The commitment of the management- and C-level is relevant for DT adoption (Ko, et al., 2022). As one expert aptly opined, *"Our CEO once said, we are not Google. We are not an internet company. He is right, we are not, but the future is"* (Eta$_2$). This requires an adequate strategy for DT adoption. As mentioned by several experts, they often have a strategy regarding DT adoption, but they are *"struggling with making the strategy a bit more tangible for the various subdivisions in the company and cascading it down to* *management in a coherent way"* (Theta$_1$). Thus, the strategy of DT adoption should be shared across organizational units, as there is an *"enormous divergence in maturity, in understanding what digital is all about"* (Alpha$_1$), dissolving silo approaches in the maritime organizations.

6 Conclusion, implications, and further research

As far as known by the authors, this research is the first to address the state-of-the-art of DT adoption and obstacles to further DT adoption in MCL by elaborating on similarities and differences between ports, freight forwarders, and carriers.

By applying a multiple-case approach, we identified that ports already display high levels of technological intelligence, but that collaboration efforts can be enhanced between the ports and external stakeholders with the support of governments and business associations such as the DCSA. DT adoption in ports is currently hindered by a legacy of old systems and ways of working within their organizations. The freight forwarders all display low levels of technological intelligence, but their collaboration level differs. They strive toward the application of DTs but are hindered by their silo approach. Their DT adoption is further impeded by the market power of the carriers. The carriers, however, are located in the midfield of the DT adoption matrix. Therefore, for carriers, obstacles for both leveraging the level of collaboration, such as heterogeneous systems, and the level of technological intelligence, such as their old-fashioned ways of working, need to be overcome. To summarize, our developed framework helps MCL organizations to derive implications for tackling the existing obstacles for successful DT adoption and to adapt their DT adoption strategy accordingly.

Theoretically, our research contributes by providing a detailed DT adoption framework for MCL, displaying the levels of DT adoption of the different incumbent maritime organizations based on the research of Yang, Fu and Zhang (2021). Our adapted framework highlights the obstacles that need to be overcome to further enhance the level of DT adoption in maritime organizations. Thereby, our research is the first to empirically provide such a framework in the context of MCL and supports incumbent maritime organizations in benchmarking themselves with other organizations.

The research exposes certain limitations that, in turn, reveal potential avenues for further research. One limitation regards the selection of the cases. Even though the number of cases seems sufficient according to Eisenhardt (1989), more research including smaller stakeholders in MCL may help to enhance the generalizability of the results, referring to required standardization efforts of the whole MCL industry. Additionally, merely organizations in MCL are considered for the research. In this context, further research needs to elaborate on whether the findings of this research are also applicable to other types of maritime logistics. Lastly, as MCL is inherently multimodal, especially the collaboration obstacles need to be regarded from an angle of collaboration with actors outside of MCL, incorporating other modes of freight transportation.

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VI.
Port Logistics

Potential of Container Terminal Operations for RoRo Terminals

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Purpose: *With the increasing environmental pollution due to the growing freight transportation, the roll-on roll-off (RoRo) transport is considered one of the most promising alternatives in short sea shipping to the dominant pure road transport. The interruption of the transport chain by freight handling represents a potential for improvement. Therefore, the handling processes at the RoRo terminals, in particular, must be optimized to increase competitiveness.*

Methodology: *A systematic literature review is applied to identify innovative approaches for container terminals to increase terminal efficiency. Gained insights will be examined concerning their transferability to RoRo terminal processes.*

Findings: *The research identified various novel optimization approaches for the functional areas of truck operations, gate-system, storage, transportation, and quay operations. The gate system is the most critical functional area with tremendous potential for improvement; measures based on the optimization approaches are developed.*

Originality: *Based on highly efficient container terminals, optimization potentials for RoRo terminals are identified. This approach has not been pursued before and offers many research opportunities.*

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1 Introduction

Short sea shipping plays a vital role in achieving the EU transport target of reducing 55 % of transport-related greenhouse gas emissions by 2030 (European Commission, 2020) and shifting 30% of road freight transport over 300 km to other modes by 2030 (European Commission, 2016).

A shift of freight transport from road to short sea shipping requires frequent and reliable maritime transport, combined with a fast and straightforward transshipment system. Short sea shipping competes directly with road transport on many routes, and the obstacles to shifting back to pure road transport are small, shipping companies and terminal operators, in particular, must strive to meet customer requirements and offer a high-quality transport service (Notteboom, 2020; Christodoulou, Raza and Woxenius, 2019). Intermodal transport chains, such as RoRo, suffer from inevitable interruptions during transshipment between the port's land and seasides. The terminals are the weak link in the entire RoRo transport process in terms of lack of resilience and vulnerability to problems ((Balaban and Mastaglio, 2013). Delays in vessel handling can lead to delays in vessel schedules, terminal operations, and, ultimately, the entire transportation chain (Maksimavičius, 2004; Saurí, et al., 2012).

For this reason, efficient and well-connected RoRo terminals are an essential prerequisite for shifting freight traffic from road to sea (Sambracos and Maniati, 2012). Due to the increase in traffic volumes and larger ships, RoRo terminals face major challenges that require increasing terminal capacity through possible terminal expansions or performance improvements (Eckert, Fliege and Steinhauer, 2008; Morales-Fusco, Saurí and Spuch, 2010). The transport of general cargo by container has developed into one of the most efficient transport systems, so container terminals are a suitable subject of investigation. Therefore, the focus of the present work is to examine container terminals concerning their transferability to the structures and processes of RoRo terminals. The research questions are, therefore, as follows:

1. Which characteristics of container terminals offer the potential for transfer to the processes of RoRo terminals?

2. Which identified measures offer the most excellent opportunities for optimization to increase overall terminal efficiency?

A systematic literature review methodology is used to answer the first research question. The second research question investigates the highlighted results on question one about their transferability in RoRo terminals. The paper is organized as follows. The following section presents the theoretical background of RoRo terminals. The subsequent section shows the methodology of the systematic literature review and describes the results of this paper, including possible approaches to optimize RoRo terminals based on approaches from container terminals. Many of the identified publications focus on handling automotive vehicles, which likewise functions under the wording RoRo. This framing of the literature is not part of the underlying publication. The results are then analyzed in a benchmark study for selected approaches. Finally, the benefits of the presented solutions for implementation in RoRo Terminals are evaluated, and our conclusion and outlook are presented.

2 Theoretical Background

The following chapter provides an insight into the state of research regarding RoRo terminals showing the structure and processes.

2.1 RoRo Traffic

Horizontal transshipment in RoRo Terminals places lower infrastructural demands on the storage and transhipment areas, requiring a smaller investment outlay than container transhipment (Schieck 2009). These characteristics give the RoRo system certain flexibility, allowing lines to be established at short notice, and discontinued when demand stagnates (Brinkmann 2005). Pure road transport and container transport in terms of short sea shipping are among the main competitors of RoRo transport (Jia et al. 2019). However, RoRo transport offers more competitive total costs than pure road freight transport. Furthermore, external costs can be significantly lowered by reducing congestion and increasing road safety (Deutsch, 2013; Fancello, Serra and Mancini, 2019).

Efficient, fast, and well-connected ports are necessary for shifting freight transport from road to sea (Casaca and Marlow, 2007; Medda and Trujillo, 2010). In RoRo traffic, the ratio of sea time to port laytime is much lower, and thus ships and port facilities are more closely interrelated, special attention must be paid to the design and operation of RoRo terminals ((Lüsch, 2005; Balaban and Mastaglio, 2013). Terminals must allow for rapid cargo handling so that the total transit time of the supply chain is not longer than for a purely road-based alternative ((Santos and Soares, 2020). Both RoRo and roll-on/roll-off passenger (RoPax) ferry terminals handle rolling cargo, with unaccompanied transports dominating at RoRo terminals, while accompanied transports were more common at ferry terminals. In accompanied transport, self-propelled loading units, such as trucks, are loaded onto RoRo vessels. If the drivers do not remain with the cargo during the main run, it is called unaccompanied transport, which includes trailers or semitrailers next to roll trailers, cassettes, and containers. (Santos and Soares, 2020) In these cases, the loading units are parked at the terminal after the initial run. New drivers take over the loading units at the destination port and take over the loading units to transport them on the onward leg (Schieck, 2009; Daduna, 2007; Deutsch, 2013). Due to the increasing number of large RoPax vessels, which in addition to classic passenger transport, carry out accompanied and unaccompanied transports, the former boundaries between the two terminal types are becoming blurred (Lüsch, 2005). Since this scientific paper focuses exclusively on handling unaccompanied transports, the structure and processes of classic RoRo terminals are explained below. However, most of these explanations can also be transferred to (RoPax) ferry terminals, whereby structural facilities that would be necessary for passenger transfer and the handling of accompanied transports are omitted. In addition, only facilities that cover the transfer between road and ship will be considered.

2.1.1 Layout and structure of RoRo terminals

While the operations at RoRo terminals are relatively uniform worldwide, there are often significant discrepancies in layout or equipment used (Muravev, et al., 2016).

A RoRo terminal can be viewed as a continuous system (Mhand, Boulmakoul and Badir, 2019). This system consists of several subsystems and functional units, which are further explained below.

Gate system

The terminal gate system includes check-in and check-out counters, gate entry and gate exit buffers, scanning facilities, and border control and customs clearance, where applicable. The gate system, therefore, acts as an interface between the terminal site and the hinterland and is one of the most important facilities of a RoRo terminal (Moszyk, Deja and Dobrzynski, 2021). The number of gates and the optimal scheduling of the gate system are composed of the critical indicators for managing traffic flow during peak hours at the RoRo terminal.

Storage area

In the storage area of the RoRo terminal, loading units are temporarily parked. The parameters of the storage area include the total area, the number, the area of parking spaces, and the type of parking system. The number of parking spaces is closely related to the traffic volume and the dwell times of the loading units. The higher the traffic volume and average dwell times, the more storage space is needed for the loading units (Santos and Soares, 2020). The parking spaces at RoRo terminals are often arranged at an angle, which allows for better space utilization. In general, storage areas can be subdivided into import and export areas. Berth-related slots are used for intermediate storage of cargo units, which are usually assigned to a direct ship berth.

Cargo handling area

Non-rolling cargo units, such as containers and swap bodies delivered to the RoRo terminal without semitrailers, must first be lifted onto cassettes or terminal trailers for transport on the premises and onto the ship (Muravev, et al., 2016).

Ship berths

RoRo terminals have one or more ship berths. Since most RoRo vessels are equipped with a bow or stern ramps, the vessel must moor in a corner of the quay for loading and unloading (Ventura et al. 2020, p. 49).

The ship's ramp connects to the shore ramp to provide vehicle access.

Stevedoring

Seaward cargo handling is carried out by stevedores, who are usually employed by the terminal operator. They are organized in groups and tow the unaccompanied cargo units to or from the RoRo vessel in a predetermined sequence using terminal tractors (Santos and Soares, 2020).

2.1.2 Processing in RoRo Operations

This subchapter will describe the handling processes at RoRo terminals in more detail.

Export case

A driver from the shipping company brings the loading unit to the RoRo terminal. If the forwarder has yet made no pre-booking, this process must occur before entry. The gate personnel then check the booking documents and announce the slot number for the loading unit. For temporary storage, self-rolling loading units are usually parked on the terminal premises. If the unit is already booked for a specific ship, it is assigned to a corresponding berth-related export slot. In case of multiple bookings or inaccurate data, loading units are taken to an export consolidation yard until the situation is clarified. In all cases, the driver drives to the designated berth and uncouples the trailer or chassis (Muravev, et al., 2016). To ensure that the actual transshipment runs as smoothly as possible, precautions are taken by the terminal operator. Firstly, loading units that have previously been parked at the export staging area are brought to the berth-related bays by the tractor units after successful booking (Muravev, et al., 2016). Second, semitrailers and chassis can be jacked up for the subsequent loading process ((Saurí, et al., 2012; Paternina-Arboleda, 2019).

Import case

The processes for picking up an unaccompanied loading unit are similar to those for delivery. The tractor unit appears at the terminal for the pick-up of a loading unit. All required documents are checked by gate personnel at the check-in counter, and the data is matched. A preliminary check of the security code entered by the carrier on the check-in slip is already carried out to avoid disruptions during check-in. If all the data is correct, the driver receives the number of the parking space where the loading unit to be picked up is located. The driver then picks up the loading unit (Muravev, et al., 2016).

3 Systematic Literature Analysis

To investigate possible shift opportunities from container terminals to RoRo terminals, a systematic literature review is conducted according to Fink (2014). For this purpose, the literature databases Scopus and Web of Sciences are used, which contain the research output from the fields of natural sciences, technology, medicine, social sciences, and the humanities. To have a sufficient database synonyms and extensions of the term ‘container terminal’ are used. Therefore, the search query in both Scopus and Web of Science databases is as follows:

(("container terminal*" OR "container terminal*" OR "container port*" OR "container-port*") NOT ("crane"))

3.1 General Results

The source search in the two databases resulted in a hit count of 6.251 (Figure 1). Due to many hits, the search result was further specified according to various criteria. The period of publication was set from the years 2017 to 2021. Furthermore, the literature selection was limited exclusively to journal articles. Studies are examined that relate to specific functional areas, processes, or subject areas (summarized below as functional areas) of a container terminal and contain innovations or approaches that can generate optimization potential. The focus should be on landside processes. Studies that do not meet these criteria will be excluded from further investigation. These include economic studies, analyses, comparisons, evaluations of different container terminals, and various financing approaches. In addition, topics related to vessel-based applications, such as congestion planning, berth allocation, or liner planning, are treated as further exclusion criteria.

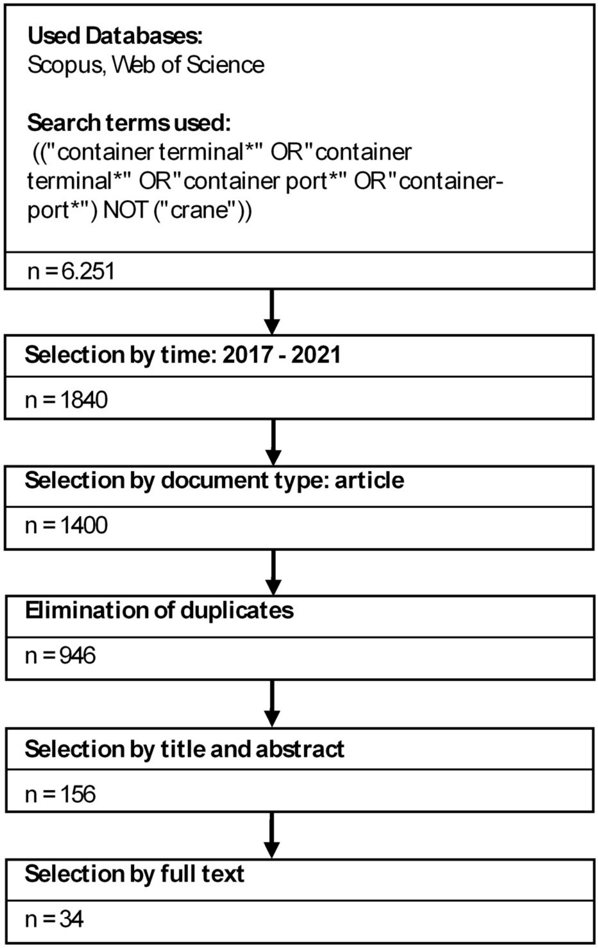

Figure 1: Documentation of conducted systematic literature research

156 sources can be identified, after initial consideration, as potentially relevant for answering the research question. These are subjected to an analysis of approaches with transfer potential. On the one hand, the transferability of each approach applied at container terminals to the processes of RoRo terminals and, on the other hand, the similarity of the problem definition of both terminal types are examined. The latter is whether the problem to be addressed and the set objective of the respective approach match those of a functional area or process in the RoRo terminal. If these properties are not fulfilled, the source is excluded.

The performed literature analysis has identified 34 sources, which show in their problem definitions extensive overlapping amounts with structure and processes in functional areas of general RoRo terminals.

3.2 Identified relevant function areas

This subsection shows the most promising relevant functional areas to optimize different aspects of RoRo terminal processes. Table 1 shows a literature classification of the relevant functional areas where transfer potential from container terminals to RoRo terminals exists.

Table 1: Literature Classification for relevant functional areas of container terminals

Author	Gate	Truck Operations	Quay	Storage	Transport
Azab et al. (2020)		x			
Caballini et al. (2020)		x			
Chamchang and	x				
Chao and Lin (2017)	x				
Deng et al. (2021)					x
Díaz-Ruiz-Navamuel			x		
Fan et al. (2019)		x			

Author	Gate	Truck Operations	Quay	Storage	Transport
Fu and Sun (2020)	x				
Gharehgozli et al.				x	
Hill and Böse (2017)		x			
Jacobsson et al. (2018)		x			
Jin et al. (2021)	x				
Kadir (2017)	x				
Karam and Attia (2019)					x
Kim et al. (2021)				x	
Li et al. (2020)		x			
López-Plata et al.					x
López-Plata et al.					x
Man et al. (2021)				x	
Minh and Huynh (2017)	x				
Moszyk et al. (2021)	x				
Nadi et al. (2021)		x			
Peng (2021)			x		
Peng et al. (2019)			x		
Radwan (2019)			x		
Torkjazi and Huynh		x			
Torkjazi et al. (2018)		x			
Wang et al. (2018)	x				
Wu and Wang (2020)			x		
Xu et al. (2021)		x			
Yang et al. (2019)			x		
Yi et al. (2019)		x			
Zaerpour et al. (2019)				x	

In summary, discrepancies between terminal types exist and prevent the transferability of the identified innovation and optimization approaches. The differing handling characteristics of the loading unit can be seen as a significant factor influencing the terminal handling processes. Whereas container terminals use standardized containers as the central loading unit, which are stackable and easy to handle, unrollable and rollable goods, which are not stackable, are handled at RoRo terminals. Their properties require different handling processes, limiting the transfer potential of functional areas of storage and intra-terminal transport. Since containers and semitrailers are moved similarly by a tractor unit in the hinterland, more transferable optimization approaches can be identified. Another reason for the inhibition of knowledge transfer is the varying complexity of terminal processes. Many problem areas within a container terminal, such as the stacking problem in the yard, the complex stowage planning, or simply the higher handling volume, require solutions that do not offer a transfer requirement for RoRo processes. The distribution of sources for the various functional areas is shown in Figure 2 below.

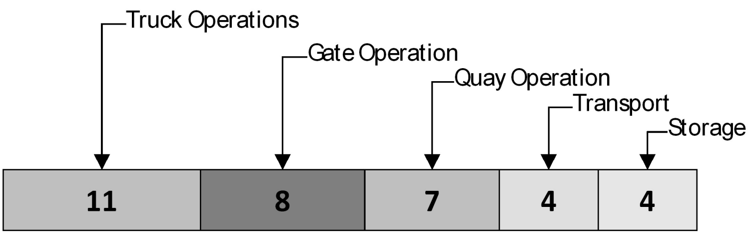

Figure 2: Number of publications according to the different functional areas

In the following, the focus will be on functional area and discussed in terms of transfer to RoRo terminals.

4 Findings

Our study has contributed that the gate processes of RoRo and container terminals, based on the conducted analysis. are characterized by a strong similarity regarding the handling processes in im- and export of loading units at container terminals and RoRo terminals. Therefore, the focus of this chapter will be exclusively on the gate system based on identified characteristics at container terminals. A detailed exposition of the gate systems as the transfer object is carried out.

According to the analysis of the literature, for both terminal types, the gate turns out to be a critical point in terms of terminal performance. As a challenge, the high vulnerability of gate processes at peak times can be mentioned, which manifests itself in congested gate lanes and long queues. In the context of performance evaluation, no exact comparisons based on KPIs due to the lack of data, but estimations based on relevant sources are done. In the simulation model developed by Keceli, Aksoy and Aydogdu (2013), which was tested using data from a RoRo terminal in Turkey, the average utilization of the terminal gate was found to be less than 25%. RoRo terminals are used particularly frequently during peak hours, but hardly at all outside these hours. Due to the high volume of trucks during peak hours, the risk of truck queues increases given the insufficient entry capacities. The forwarders carry out the deliveries in advance and the collections in the aftermath transporting unaccompanied loading units at their discretion, irrespective of the traffic situation. Peak times in the export process, i.e. for accompanied loading units arriving on land at the terminal entrance, can be defined as the period of two to three hours before the arrival of the respective ship. At this time, about 80% of loading units arrive at the gate of a RoRo terminal (Maksimavičius, 2004). In the case of imports, the immediate time after a vessel's arrival can be defined as the peak time for gate exit (Keceli, Aksoy and Aydogdu, 2013). Accompanied units leave the terminal area immediately after the vessel docks. In addition, the aim is to collect unaccompanied loading units as soon as possible after they have been staged at the terminal area. The loading principle by which stowage occurs on a RoRo vessel, which must necessarily follow the last-in-first-out (LIFO) procedure, can further exacerbate the formation of these peak periods (Saurí, et al., 2012). Loading units arriving late at the terminal are often the last to be loaded, allowing them to be the first to leave the ship at the destination port. In addition to the high gate loads during peak hours each truck's extended gate handling time, especially for export, leads to queues. One reason can be seen in the overbooking by the shipping company and the unannounced arrival of unaccompanied or accompanied units, which increases the handling time at the gate due to the manually booking of slots ((Saurí, et al., 2012; Keceli, Aksoy and Aydogdu, 2013).

In addition, deficiencies in terminal layout and gate management can also lead to congestion in the entry and exit lanes. Insufficient handling space and undersized entry and exit lanes and poor performance of check-in and check-out counters, lead to problems and can thus exacerbate congestion situations (Saurí, et al., 2012).

5 Development of Measures

In the following section, four measures are introduced in terms of transfers from gates of Container terminals to gates of RoRo terminals. The measures proposed are then compared and evaluated. Then the overall efficiency of the terminal gate is evaluated.

5.1 Presentation of Measures

The inefficiencies highlighted cannot be addressed by one measure alone. Nevertheless, solving one problem has positive implications for other performance gaps. The most appropriate measures adapted from the analyzed papers dedicated to gate function area for RoRo terminals are presented below.

Introduction of a Truck Appointment System

Using a Truck Appointment System (TAS), which acts as a communicative interface between shipping companies, terminals, and freight forwarding companies, a reduction of the landside transport volume and the equalization of truck arrivals at the terminal can be achieved. The TAS allocates a defined number of handling slots per time window. This procedure allows the capacity of the gate to be regulated. The notification of the pick-up of an unaccompanied unit by the terminal operator can be seen as a challenge, because, despite known ship arrivals, the forwarder cannot be given an exact time of arrival of the unaccompanied unit. Without this information, no appointment for the pick-up can be booked. However, based on the information about the respective slot on the RoRo vessel and the knowledge about the similar unloading processes by the RoRo tractors in the LIFO process, it is possible to determine both the slot on the terminal and a rough time of unloading in advance. Integrating certain information from the shipping companies into the TAS could provide greater transparency and solve this problem. On the forwarding side, an extension of the TAS can be seen in the execution of double transports, which should reduce the total number of truck arrivals. In this case, the tractors bring a trailer and subsequently carry out a pick-up. However, for extensive coordination of the double transports, TAS would have to be provided with information from the forwarding side. Specifying the direction and destination of a truck's potential empty run, it is thus possible to find a suitable available loading unit whose pick-up or drop-off point is on or near the route. Once a suitable loading unit for a double transport has been identified, it is proposed to the respective forwarder with an aligned time window. After accepting the double transport, the two transport orders are merged and the time window for truck arrival is assigned.

Implementation of reversible Gate Lanes

By using individual gate lanes with a flexible direction of travel, the entry and exit capacities can be flexibly adapted to the traffic situation. If the number of trucks entering the terminal exceeds the number leaving, a balance can be created by converting the reversible exit lanes to entrance lanes. Since the cost of a reversible gate lane is higher than a fixed gate lane, there is a risk that adding numbers of reversible gate lanes may tend to incur additional costs. Therefore, it is essential to determine the optimal number of reversible lanes in the gate system. Only if the entry and exit lanes are arranged contiguously next to each other the upstream lanes can be connected to potentially reversible gate lanes. For improved accessibility, it is recommended that the reversible gate lanes are implemented in the median between the entry and exit lanes. Once the number and location of reversible sluice lanes have been determined, the type and extent of construction measures can be specified. The necessary infrastructure must be created in the affected lane to perform both check-in and check-out processes on a reversible gate lane. Two approaches are proposed for optimal dynamic control of reversible gate lanes. The first approach involves predictive control of the gate lanes based on predetermined data (truck peak times or scheduled ship arrivals). The information collected in advance allows forecasts to be made of when gate entries and exits will be loaded and the reversible lanes to be controlled accordingly. The second approach involves short-term lane control based on information about the current queue lengths before gate entry and gate exit. However, since changing the direction of driving on a reversible lane at short notice is expected to take some time, gate efficiency may decrease in the process.

Complete automation of Gate Operation

Increasing the level of automation within the gate processes helps to increase overall capacity. Full automation of gate operations includes vehicle and freight identification and condition inspection of the loading units using OCR technology. This requires the construction of OCR gantries in front of the gate entrance and gate exit, respectively. The cameras can be used to identify the license plate numbers of the tractors and chassis and damage or hazardous material markings on the rear of the semitrailer. The second sub-measure involves the installation of self-service lanes where drivers can independently complete identification and registration tasks from within the vehicle at a gate kiosk. Equipment for a self-service kiosk can include area cameras for the front of the truck, a control module, and an intercom system. The operating system should be multilingual and straightforward in design. A vital prerequisite for carrying out automated check-in/check-out operations is freight registration by the freight forwarder in advance. This can prevent lengthy data entry at the gate and speed up the overall process.

Vessel dependent Gate Lane Assignment

Gate lane assignment based on the ship's schedule affects only the gate entrance processes. This measure targets the peak load explicitly at the gates and focuses especially unaccompanied units. For the application, trucks arriving at the terminal are first divided into different categories (urgency and type of order).

- Delivery with low urgency
- Delivery with high urgency
- Pick-up with low urgency
- Pick-up with high urgency

If a loading unit is brought to the terminal, the transport falls into a delivery category. The transport falls into the pick-up category if an empty tractor arrives at the terminal to pick up a loading unit. The urgency level represents the prioritization. If a loading unit arrives at the terminal, the onward transport of which by RoRo ship will only take place in the distant future, the transport is assigned to the category *delivery with low urgency*. If the loading unit is booked for the RoRo ship that will leave the terminal next, the transport is assigned the category *delivery with high urgency*. If a loading unit is waiting at the terminal for a more extended period to be picked up, it will be assigned to the category *pick-up with low urgency*. However, if a loading unit that originates from the last unloaded RoRo vessel is to be picked up, this is assigned the category *pick-up with high urgency*. If a vehicle with several transport orders, i.e. a delivery with simultaneous pick-up, appears at the terminal, it will be assigned the category with the higher prioritization. In practice, arriving vehicles that have been assigned a higher urgency should be provided with a larger number of gate lanes for a certain period to realize the delivery or pick-up of the loading units as quickly as possible. High urgency deliveries start three hours before the ship's arrival and end when the ship arrives. Since most of the loading units for the respective ship are received during this period anyway, it can thus be ensured that the majority are ready on time for the loading process. At the ship's arrival, the prioritization for the pick-ups with high urgency starts. A tractor can pick up loading units and transport them immediately after decoupling and parking them in an import yard. No prioritization takes place outside of these time windows. The implementation of this measure does not require any further constructional measures apart from digital display boards, which are to make clear to the drivers the allocation of the categories to the gate lanes. In addition, the prioritization time windows can be calculated even better by using external information from a TAS.

5.1.1 Evaluation of presented Measures

The measures designed are to be evaluated in terms of their benefit regarding their potential of harmonizing truck arrivals and minimization of the truck handling processes at the gate entrance and exit. Further implementation efforts concerning construction changes and Investment and operating costs are estimated. The articles where the measures were transferred are used as the basis and weighed against each other in Figure 3 concerning the criteria. For qualitative comparison, Harvey spheres are taken, where white means not applicable and black means applicable.

The TAS implementation is associated with a high effort since they strongly intervene in the processes within the transport chain. In addition, there is still the requirement that forwarders must be provided with more precise information on the time of provision of the loading units by the terminal operator to be able to book an exact pick-up date. Furthermore, there is the risk of a lack of willingness to accept such an IT infrastructure on the part of the freight forwarding companies. If TAS is successfully implemented and accepted, truck arrivals can be spread throughout the day, thus continuously utilizing gate capacity. The promotion of double transports ensures a reduction of empty runs and consequently helps to minimize truck arrivals at the terminal. Furthermore, by preventing long waiting times and minimizing empty transports on the roadside pre-and-on-carriage, the number of empty transports can be reduced. Expanding a terminal gate with reversible gate lanes can often be a simple solution since this is often impossible due to limited space.

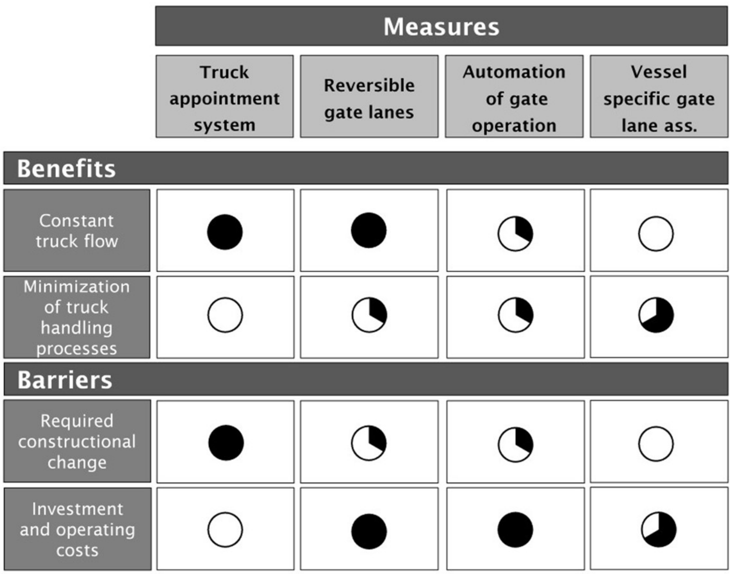

Figure 3: Evaluation of Measures

Converting fixed gate lanes to reversible gate lanes requires comparably less effort since these measures only affect individual lanes. Therefore, it is also possible to carry out conversion operations during normal gate operations. The operation of reversible lanes does not require any other areas of the terminal as well is no further involvement of the stakeholders, the control and monitoring effort can be estimated as low. Although the implementation of this measure does not directly lead to the optimization of truck handling processes in the gate system, the average gate turnaround time for trucks can be reduced by adjusting the workloads of all gate lanes, thus preventing queuing. The terminal can catch truck peaks forming immediately after a ship docks using reversible lanes.

OCR technology requires high investment costs for the installation of high-tech equipment. The investment costs are directly related to the number of gate lanes to be automated. On the other hand, if OCR systems and self-service kiosks are implemented at the gate, lower operating costs can be assumed due to the savings in personnel, which means that the investment will pay for itself after a few years. Furthermore, by increasing the level of automation, this measure can make vehicle identification and cargo control and the actual check-in and check-out processes more efficient and faster. As a result, average throughput times are reduced, and the formation of queues can also be avoided. In addition, the terminal operator can be guaranteed a high level of security against damage claims. Freight forwarders could also be provided with continuously updated data regarding the damage status of the fleet.

Since the gate lane allocation hardly requires any structural changes in the gate system and the operation is also estimated to be less complex, low investment and operating costs can be assumed here. This approach can reduce the average throughput times and queues. Gate lane allocation can also increase on-time performance by allowing loading units to reach the booked RoRo vessel even if they arrive late at the terminal. A malus rule for long idle times can be used to obtain a speedy truck pick-up after the loading unit has been unloaded at the terminal on the ship side, thus reducing intermediate storage times and relieving limited storage space.

6 Discussion

The study has revealed barriers and benefits based on the measures transferred from container to RoRo terminals. The implementation of measures from container terminals can be seen as an advantage since it is based on an area in maritime logistics that is considered the best researched. The mentioned characteristics of unaccompanied units in the inlet of RoRo terminals are similar to those of containers on chassis. From this point of view, the developed approaches can be promising. The identified connecting points are based on the approaches highlighted in the literature.

However, the precarious situation around the technical literature has a disadvantage, which has to be mentioned explicitly. Moreover, the term RoRo cannot be assigned to the rolling handling of accompanied or unaccompanied units but can also be assigned to automobile handling, which differs rudimentarily from RoRo handling and further restricts the literature. Furthermore, it is sometimes impossible to speak of a holistic approach since the existing problem of inefficiencies at terminal gates has been considered in this work exclusively from the perspective of the terminal operators. The perspective of freight forwarders and shipowners has been missing so far. In addition, there are no KPIs for evaluating gate performance from the terminal side in the literature analyzed.

The relevance of the highlighted measures has to be confirmed by discussions with practice partners. Furthermore, it must be pointed out that the approaches used to require the measurement of variables necessary for calculating KPIs.

7 Conclusions, Limitations and further Research

This study aimed to examine systemic potentials in transferring from container terminals to RoRo terminals. For this purpose, a systematic literature review was conducted to identify similar characteristics of both types of terminals. In this context, 35 papers were identified which could be used as a basis for the transfer. The gate system was identified as the main weak point of a RoRo terminal, as it proves to be a significant bottleneck and affects the overall efficiency of a terminal and was therefore chosen for further consideration. After the introduction of four measures to increase performance and evaluation of the following measures (1) Truck Appointment System, (2) reversible Gate Lanes, (3) Automation of Gate Lanes, and (4) Vessel specific Gate Lanes were conducted.

The study was constrained by limited access to current literature since the subject area of "RoRo" has so far received little attention. Therefore, the problems identified may be far less severe in practice due to technological advances. Furthermore, it cannot be excluded that after focusing on the gate processes, other well-transferable solutions do not exist in other functional areas of RoRo terminals. Due to a lack of data, we cannot test our measures. Therefore, there is an acute need for research here. Furthermore, due to the different land availability on-site at the terminals, the possibility of implementing measures can vary significantly from terminal to terminal.

The study can be used as a knowledge base for different research approaches. The work reflects the current status of the literature, but it also offers opportunities for further analysis of RoRo terminals in terms of adaptation and further development of structures and processes. Avoiding unannounced units at the terminal is considered essential and requires further research, as this is seen as a cause of congestion and capacity bottlenecks. Furthermore, the situation around track and trace of trailers is an aspect that needs to be explored to make the information situation more transparent and to reduce inefficiencies.

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Truck Appointment Systems – How Can They Be Improved and What Are Their Limits?

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Purpose: *Rising handling volumes and increasingly profound disruptions of global transport chains are placing severe stresses on container terminal processes. This affects landside handling in particular. In order to relieve this burden, more and more truck appointment systems have been introduced over the past 20 years, but they have only partially fulfilled the hopes placed in them. This study identifies the potential for improvement but also shows the limitations of this approach.*

Methodology: *In order to highlight the different approaches used both in academia and in practice to adapt truck appointment systems to the respective requirements and to arm them against disruptions, a structured literature review was conducted. A total of 136 scientific publications were classified and the results were evaluated in detail.*

Findings: *The developed solution approaches often only refer to individual sub-problems of container terminals instead of including the entire terminal or even the entire port with all its stakeholders. Furthermore, combinations of different methods are rarely used, where the weaknesses of individual methods could be compensated*.

Originality: *The massive disruption of the global transportation chain has created new challenges for truck appointment systems. A structured analysis of the possibilities and limits has not yet taken place from this point of view.*

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1 Introduction

The volumes of containerized goods transported worldwide as well as the size of container vessels have been rising steadily since the economic crisis of 2011 (UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT, 2022). As a consequence, several challenges have arisen in recent years for maritime transport chains, especially for the container terminals. A serious issue has been the heavy peak loads at the gate and on the containeryard caused by arriving means of transport. These were mainly caused by the opening hours of other actors in the supply chain or the arrivals or departures of large means of transport (Giuliano and O'Brien, 2007; Huynh, 2009). In practice, the use of truck appointment systems (TAS) to control truck arrivals and thus smooth truck arrival rates at the terminal gate has become the solution to this problem (Huynh, Smith and Harder, 2016; Shiri and Huynh, 2016; Nordsieck, Buer and Schönberger, 2017). After initial challenges in designing TAS, certain characteristics have emerged over time that have been similarly implemented by most terminal operators (Huiyun, et al., 2018; Lange, et al., 2019b). However, severe disruptions to maritime transportation chains in the wake of the Covid19 pandemic and international conflicts have shown that maritime logistics in general, and TAS in particular, have not been able to adapt quickly and reliably enough to meet new challenges. Consequences of this included accumulations of containers in the yard that could not be moved out due to delayed vessels. At the same time, containers were delivered too early because of incompletely information flows in the transport chain (for a description of the processes in seaport container terminals, see Chapter 2). This led to considerable inefficiencies resulting from the higher container yard utilization and the increased number of necessary reshuffles. In turn, this resulted in longer waiting times of trucks in front of the gate and at the terminal, and thus in poorer plannability of shipments.

Thus, contrary to previous opinions in the maritime world, TAS are not yet mature and need further improvement. In order to identify existing research gaps, the first step is to systematically elaborate (see Chapter 3) the means and methods used to scientifically study TAS (Chapter 4). From this analysis, it can be deduced how TAS can be adapted to the recent challenges (Chapter 5).

2 Landside Handling at Container Terminals

Seaport container terminals basically have a seaside and a landside interface to the environment (Gharehgozli, Zaerpour and Koster, 2019; Kastner, Lange and Jahn, 2020). On the seaside, seagoing and inland vessels are loaded and unloaded, and on the landside, mostly trains and trucks are loaded and unloaded. The requirements placed on the seaside and landside from a terminal perspective differ significantly in some cases. Figure 1 shows a schematic representation of a container terminal with rail-mounted gantry cranes and automated guided vehicles as an exemplary case and indicates important target variables of the respective terminal areas.

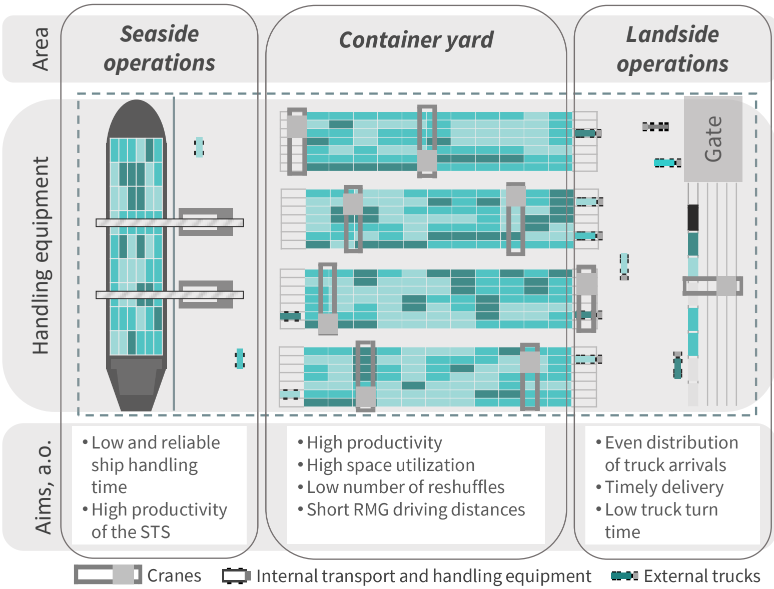

Figure 1: Schematic structure of an exemplary RMG/AGV container terminal

The players on the seaside, the shipping companies, are given a very high priority by the terminal operator as "paying customers". Thus, a high level of service and on-time delivery at the seaside are expected from the terminal. The most important goals are to keep up low and reliable handling times and to ensure a high seaside productivity, especially of the ship-to-shore cranes (STS) (Speer, 2017). The landside, on the other hand, is usually given a lower priority. This is due, among other things, to the significantly higher number of individual players and the resulting severely limited market power. On the landside, peaks in truck arrivals in particular are to be prevented, which could possibly cause a backlog on public roads and thus jeopardize on-time delivery or collection of the containers. The reduction in truck turn time of trucks on the terminal site resulting from these efforts to smooth truck arrival times is often of secondary importance (Rashidi and Tsang, 2013). The intervening container yard acts as a buffer, decoupling seaside and landside handling. There, containers are handled by large storage cranes (rail-mounted gantry cranes or rubber-tired gantry cranes) or equipment (often straddle carriers or reach stackers). The container yard must not exceed a certain fill level (approximately 80%) for the equipment to operate efficiently. (Carlo, Vis and Roodbergen, 2014a) Horizontal transport between the different terminal areas is mostly performed by manned tractors (terminal trucks) or automated-guided vehicles) and is mainly aimed to minimize the waiting time for the cranes and the driven distances of the vehicles (Carlo, Vis and Roodbergen, 2014b; Schwientek, Lange and Jahn, 2020). A more detailed overview of the structures and operations at container terminals with various handling equipment is given in Stahlbock and Voß (2007), Kastner, Pache and Jahn (2019) and Nellen, et al. (2020).

The focus of this study is on truck traffic and its handling. Investigated solutions to manage truck arrivals and increase the efficiency of their handling mostly focused on: (1) adapting and managing the infrastructure at the terminal gate and to the yard (new lanes, allocation of trucks to lanes, automation technologies) (Maguire, et al., 2012; Kulkarni, et al., 2017; Moszyk, Deja and Dobrzynski, 2021), (2) informing trucking companies/truck drivers of potential congestion through cameras, web pages, traffic light systems, information boards (Heilig and Voß, 2017; Riaventin and Kim, 2019) and (3) implementing and improving an access management by using various (digital) services (Jacobsson, Arnäs and Stefansson, 2018).

The alternative solutions under 1. and 2. have been principally displaced in science by the third category, and especially TAS, in the last 10 years. In industry, they usually occur at seaport container terminals only in addition to TAS, if at all. For an overview of the improvement approaches container terminals apply in general, please refer to the publications of Steenken, Voß and Stahlbock (2004), Stahlbock and Voß (2007), Dragović, Tzannatos and Park (2017), and Gharehgozli, Roy and Koster (2016). Good overviews of research done concerning TAS at container terminals are provided by Huynh, Smith and Harder (2016), Huiyun, et al. (2018) and Abdelmagid, Gheith and Eltawil (2022). From the perspective of the trucking companies, other priorities arise. Thus, approaches to route planning and route finding are examined in particular. Due to the specific framework conditions in the port area, only publications that focus on trucking in the port (called interterminal transport (ITT)) as a use case and specifically examine truck arrivals at container terminals in conjunction with TAS will be considered in the further course (e.g. Zhang and Zhang (2017)). This elaboration builds in particular on the results of Lange, Schwientek and Jahn (2017) but goes beyond its focus and those of the other known publications by showing the improvement possibilities of TAS and explicitly elaborating the limitations of TAS.

3 Development of the Research Methodology

In order to answer the research questions, a structured literature review was conducted first, followed by a classification of the relevant literature. The literature search is based on the approach of Vom Brocke, et al. (2009), particularly with regard to the selection of sources and databases and their coverage, the identification of key terms and the development of the search term as well as conducting an additional reverse search. The way in which the screening and analysis of the retrieved publications is based on the PRISMA statement of Liberati, et al. (2009) and was adapted as described below.

The search was conducted in April 2022 using electronic databases for scientific publications. A total of six electronic databases were searched: Springer Nature Switzerland AG's database (link.springer.com), Google's search engine for scientific publications with the German interface (scholar.google.de), Elsevier's Scopus database (scopus.com), Elsevier's ScienceDirect database (sciencedirect.com), and IEEE's Xplore database (ieeexplore.ieee.org). The search was divided into two strings. The first string includes publications on TAS in seaports and the second publications on ITT. For the search on TAS at seaports, the terms truck appointment, congestion, and container terminal were used. For ITT, the terms were port, truck, and transport. These search terms were expanded to include similar or possibly synonymously used terms to provide additional hits. Each of the above databases was searched using the search terms. In total, the search yielded 19,025 entries. In order to be able to review this large number of publications, the methodological procedure shown in Figure 2 was defined.

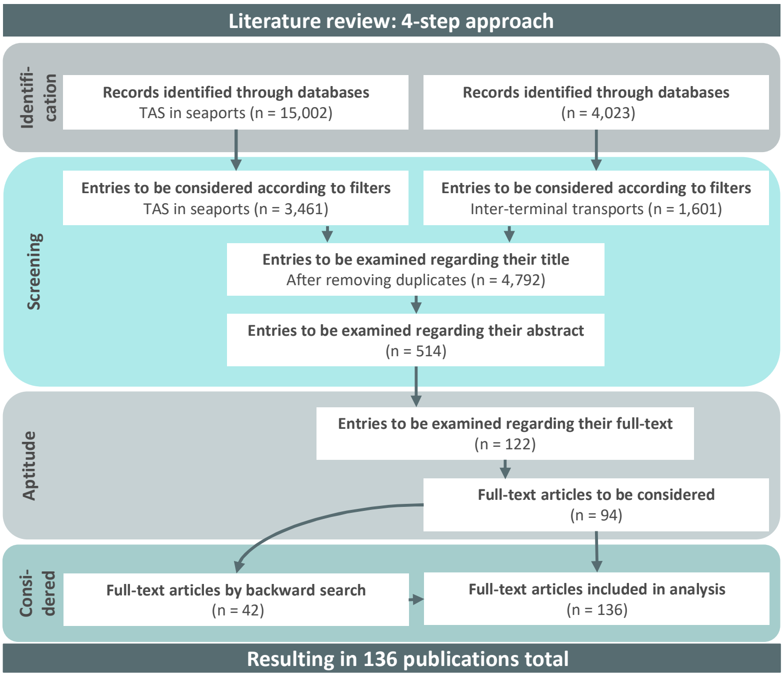

Figure 2: 4-step approach for the literature review

First, the search results were filtered. Since it was not until 2004 that a TAS was mentioned in a scientific publication for the first time (Lange, Schwientek and Jahn, 2017), it was possible to narrow down the period under consideration from 2004 to the time of the search in April 2022. Older publication, which were considered, are the result of the reverse search. With this restriction, the search still yielded 16,679 results. Subsequently, all publications were excluded that, according to the respective databases, could not be assigned to the application area of logistics. This reduced the number of publications to be considered to 5,062. Merging the two search strands resulted in some duplications, which were removed from further analysis. To further condense the selection and increase relevance, the titles of these 4,792 publications were examined. All papers that did not allow a clear reference to one of the two search strands according to their title were sorted out. In a further step, the remaining 514 publications were evaluated based on their abstracts and keywords. To reach the next level of summarization, the abstract had to deal with either landside handling at container terminals in the seaport or hinterland, the design of a time slot booking system, the scheduling of trucking companies, or traffic routing in the seaport. This was the case for 122 studies. The subsequent analysis of the full texts ultimately revealed relevance in relation to the topic for 94 publications. In order to broaden the data base, an extensive reverse search found 42 additional suitable publications (Webster and Watson, 2002; Vom Brocke, et al., 2009). In total, 136 publications were considered in the classification scheme. Figure 3 shows the distribution of the publications per year.

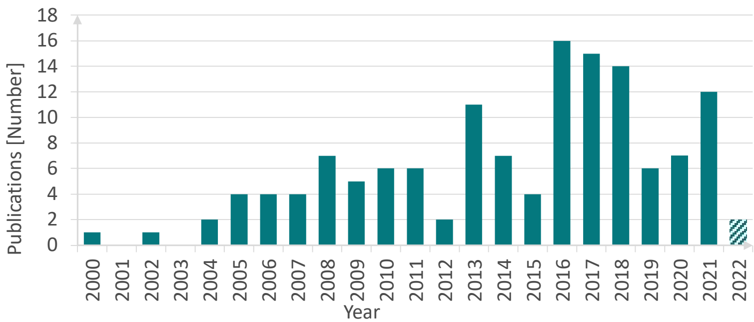

Figure 3: Number of relevant publications per year since 2000

The diagram shows that the number of relevant publications increased almost continuously from 2004 to 2016 and has remained at a high level until 2018. Most peaks are caused by special issues with several publications on TAS. The publications before 2014 deal with congestion in front of the terminal gate and possible alternative solutions without explicitly considering TAS. In the years between 2014 and 2018, most authors take a TAS at the terminals for granted and try to optimize it. Fewer publications on TAS have been published in 2019 and 2020, which may be due to the tendency of authors to view TAS as sufficiently widely researched. However, recent crises have shown that there is still a lot of potential for further development of TAS. Publication counts are expected to rise again accordingly. The slightly lower number of publications in 2022 is due to the fact that the literature search was completed at the end of April 2022.

The classification scheme is a central element for the analysis of the 136 publications. It is an extension of the literature analysis presented in Lange, Schwientek and Jahn (2017). In addition to bibliographic information (authors, year), the schema has eight content-related categories (see Figure 4). The eight categories can be characteristically assigned to the three areas *research design*, *framework conditions* and *solution procedures*.

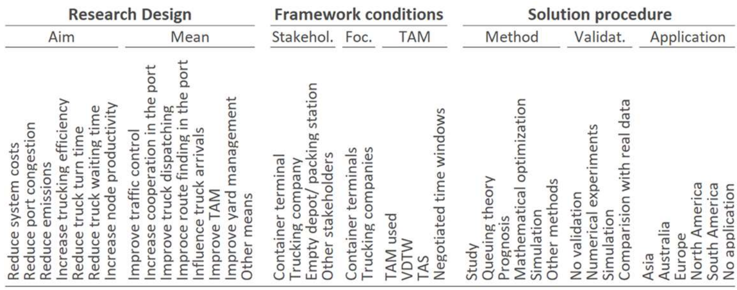

Figure 4: Categories of the classification scheme

The large number of different approaches in the analyzed publications requires them to be classified according to their aims. Seven characteristics are assigned to the *aims* category. The first three concern the entire transportation network (*reduce system costs*, *reduce port congestion*, *reduce emissions*). The next two relate to trucking companies (*increase trucking efficiency*, *reduce truck turn time*), and the last two to container terminals/ other logistics nodes (*reduce truck waiting time*, *increase node productivity*). Since these goals can be achieved in different ways, the second category in the research design section is the *means* used. It also relates to the entire transportation network (*improve traffic control*, *increase cooperation in the port*), trucking companies (*improve truck dispatching*, *improve route finding in the port*) and container terminals and logistics nodes (*influence truck arrivals*, *improve truck arrival system (TAM)*, *improve yard management*). Any means that could not be allocated were collected under *other means*.

The first of three categories in the area of *framework conditions* concerns the *stakeholders* considered. In the 136 publications, the following *stakeholders* were identified: *Container terminal*, *trucking company*, *empty depot/ packing station*. Empty container depots and packing stations are summarized, since in all publications with packing stations also empty container depots and vice versa were considered. All *stakeholders* that could not be assigned to the above-mentioned characteristics are collected under *other stakeholders*. These are mainly port authorities, customers and inland terminals. The second category highlights the stakeholder on which the publication *focuses*. In all the publications considered, the *focus* was either on the *container terminal or* the *trucking company*. The third category first identifies whether a *TAM is used* and then further distinguishes between the two most common types (*VDTW*, *TAS*). Additionally, it is indicated whether the time windows are *negotiated between the stakeholders*.

In the area of *solution procedures*, the first category is the *method* used in the publications. A total of five procedures were identified: *study*, *queuing theory*, *forecasting*, *mathematical optimization*, and *simulation*. All other procedures were grouped under *other methods*. Queuing theory could also be counted among mathematical optimization. However, due to its importance in this research area, it seemed reasonable to treat it separately. The second category is the selected *validation* with the characteristics: *No validation*, *numerical experiments*, *simulation,* and *comparison with real data*. The last category is the practical *application* and thus the continent of the port to which the approach of the publication was applied. Only those explicitly mentioned in the publications were used. Therefore, the characteristics are *Asia*, *Australia*, *Europe*, *North America* and *South America*. Since some publications do not base their approach on an existing port, *no application* was added.

4 Literature Review

The classification of the publications follows the scheme described in Chapter 3. The results of the classification scheme are shown in Figure 11, Figure 12 and Figure 13 in the appendix. A colored box indicates the mention of a corresponding expression. Since there are several characteristics in each category and more than one characteristic may be selected, the total number of mentions can significantly exceed the number of publications. The analysis of the results follows in the further course of this chapter.

Research Design

Figure 5 shows the shift in research interest since 2000. The number of publications for the respective aims is broken down by the year of publication. Here and in the further literature analysis, there is always a division of the time since 2000 four areas of five years and 2.5 years for the last range, in order to increase readability.

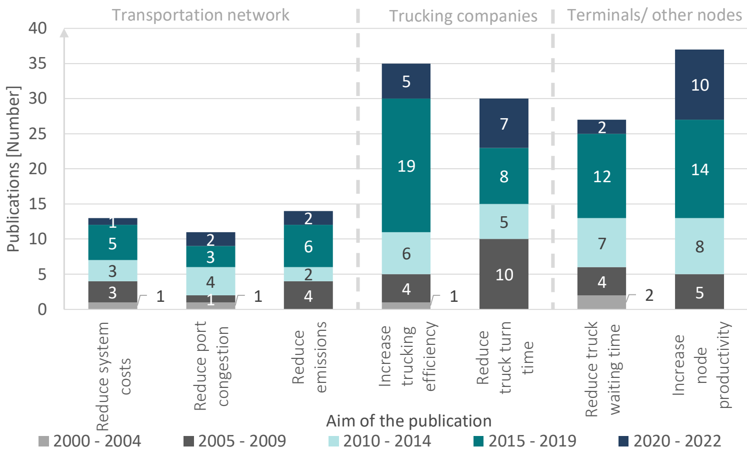

Figure 5: Frequency of aims over time

The most frequently mentioned aim is to improve node productivity (37 publications. This is followed by increasing the efficiency of trucking companies (35 publications) and reducing truck turn time (30 publications) and waiting times (27 publications). The least attention is paid to reducing congestion in the port (eleven publications). In the years up to 2009, the focus was particularly on reducing the truck turn time. Since 2010, there has been a significant interest in increasing the efficiency of trucking companies. This may be related, among other things, to the still ongoing trend of digitalization, which then also reached the transportation industry. This facilitates process simplification through increased data availability and transparency.

Figure 6 shows the number of publications per resource used. As already described, the temporal progression is color-coded in five areas.

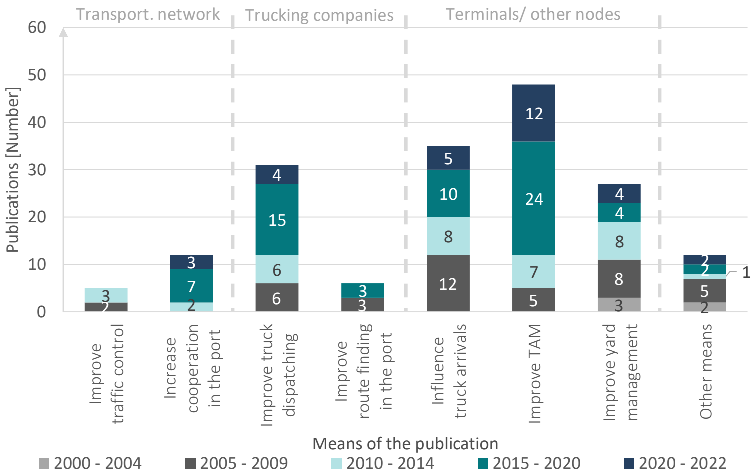

Figure 6: Frequency of means over time

Until 2004, the focus was on improving yard management and other means, which have since been pursued only marginally. Between 2005 and 2009, the focus was primarily on influencing truck arrivals and improving yard management. Many different ways to influence truck arrivals were explored and initial analyses of TAS and its design options were conducted. Dispatching at trucking companies was also looked at in more detail for the first time during this period. Between 2010 and 2014, the interest in TAM increased and remained similar for yard management, truck arrivals, and dispatching. Since 2015, there has been a particular focus on improving TAM, followed by scheduling. In particular, the cooperation between container terminals and trucking companies has been studied in more detail. Over the entire reporting period, there are the most mentions on TAM with 48 publications, followed by influencing the truck arrivals with 35 publications. The least mentioned means are improvements in traffic control and route finding, with five and six publications, respectively. This might be due in part to the fact that route finding was not specifically considered in the defined search terms.

Figure 7 shows the allocation of the means used to the respective aims. The x-axis shows the aims under consideration and the primary y-axis shows the proportions of the means used for each aim. The percentages are given to ensure better comparability. For example, 22 % of the publications that have set themselves the aim to reduce system costs want to achieve this by improving scheduling. So that the absolute number of mentions can also be considered in the interpretation, they are plotted on the secondary y-axis. In the example given, 13 publications pursue the aim to reduce costs.

The distribution of means for the various aims is naturally heterogeneous. Not all means are represented for all aims. In order to reduce system costs, the dispatching of trucks and truck arrivals in particular are improved (22 % each). More favorable route finding is not considered at all. To reduce congestion in the port, traffic control and the truck arrivals are improved in particular (23 % each). Improving the yard management is considered in 15 % of the publications. All remaining means are applied in 8 % of the cases. To reduce emissions, improving TAM is mentioned most frequently (33 %). Influencing truck arrivals is second with 28 % of the publications. This can be justified by the fact that many publications have identified trucks in general, and in particular waiting times before and on nodes, as a significant source of emissions in the port. Route finding and other means are not mentioned.

By far the most commonly cited means of increasing trucking efficiency is improving the dispatching (43 %), as this has the greatest impact on making operations as smooth as possible. Traffic control and yard management are not considered.

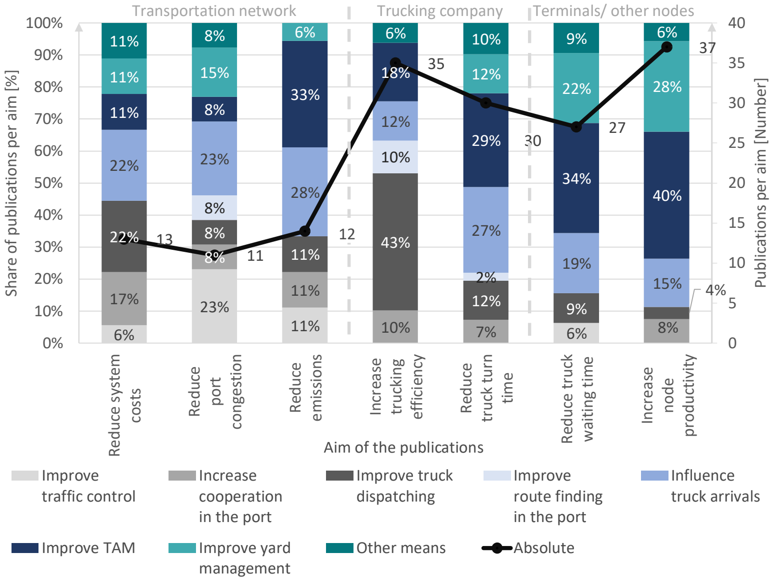

Figure 7: Mean of publications studied per aim

To reduce the truck turn time, improving TAM (29 %) is used in addition to influencing truck arrivals (27 %). This is followed by yard management improvement (12 %). The use of these three means is easy to understand, as these directly influence the terminal area and TTT mostly describes the time trucks spend on the terminal site. Accordingly, traffic management is not considered. The waiting time reduction targets especially the area in front of the gate. Therefore, the TAM in particular is improved here (34 %) and truck arrivals are influenced (19%). Furthermore, 22 % of the publications also considered the yard management, which might be a sign of an increasing integration of the different research foci. Port cooperation and route finding are not used. Node productivity depends on truck arrivals and congestion in front of the gate as well as on yard equipment management. This is also reflected in the percentages of resources used. 40 % of the mentions are related to improving TAM and 28 % are related to yard management. Traffic control and route finding are not considered here.

Framework conditions

The second group of categories are the framework conditions. Its first category are the stakeholders. Here, mainly container terminals and trucking companies are considered and less frequently empty container depots and packing stations. Other stakeholders in the port environment, such as railroad operators or customs stations, are very rarely examined. In most publications, both container terminals and trucking companies are considered, at least superficially. This is due to the fact that neither can be completely neglected in the issues under consideration. Nevertheless, there is often a clear focus on one of the two main players. It is of particular interest to determine which stakeholders are the main focus for which questions (see Figure 8).

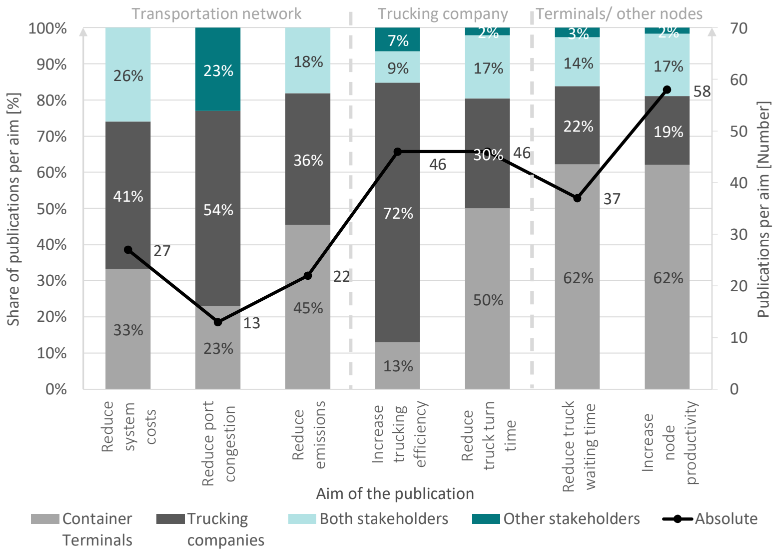

Figure 8: Stakeholders of publication per aim

In Figure 8, the aims are again plotted on the x-axis. The primary y-axis shows the shares of publications focusing on a particular stakeholder as a percentage of the total number of publications with that aim. The secondary y-axis shows the absolute number of publications with the particular aim. In an average of 15 % of the publications, both container terminals and trucking companies are considered. Furthermore, only 4 % focus on other stakeholders. Container terminals are the main focus in 110 publications and trucking companies in 92 publications. Container terminals and their processes are in the foreground especially in publications dealing with the reduction of the waiting time (62 %), truck turn time (50 %) and emissions (45 %) as well as with the increase of node productivity (62 %). Trucking companies are particularly considered in reducing system costs (41 %) and port congestion (54 %), and increasing trucking efficiency (72 %).

In 67 % of the publications, TAMs are used to achieve the set targets. In most cases, these are individually booked time slots (e.g., one hour per delivery or pickup). Four publications consider VDTW. This type of time slot is used in practice, especially in Asia. In the last decade, there has been a particular increase in the study of negotiated time windows. In these time windows, the goal is to find the best possible solution for both process partners, both the container terminals and the trucking companies. In total, twelve publications consider negotiated time windows.

Solution procedure

The first category in the area of solution procedures are the methods used. The distribution of methods in the five-year blocks is shown in Figure 9. The absolute number of publications is plotted on the secondary y-axis.

The decrease in the proportion of study-based investigations is striking. While they still accounted for 40 % between 2000 and 2004, they accounted for only 4 % between 2020 and 2022. The proportion of publications using queuing theory or simulation remained comparatively stable over the years. Simulation is used on average in 24 % and queueing theory in 12 %. The use of mathematical optimization methods increased from 20% between 2000 and 2004 to 52 % between 2020 and 2022. Furthermore, forecasting methods have also been used since 2010.

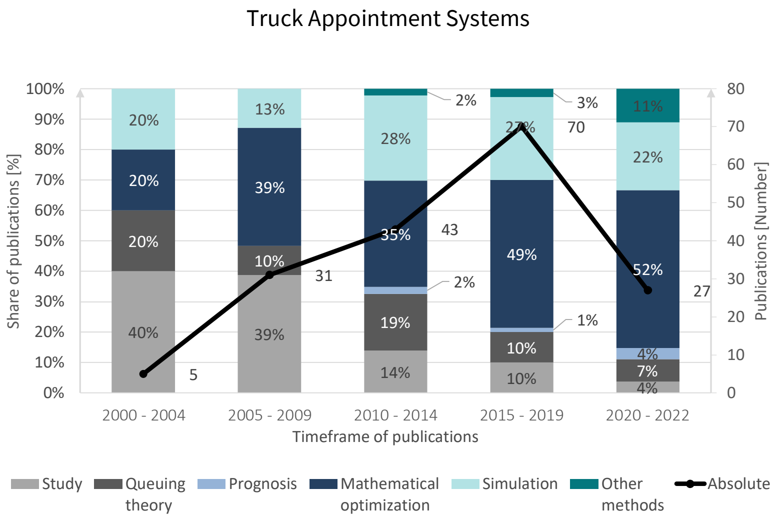

Figure 9: Relative frequency of methods over time

The methods used illustrate the development that research on port-internal container transport and related TAS has taken. Since related research questions were first raised in the early 2000s, the initial focus was on the analysis of the use case, the framework conditions, and possible solution variants. Since then, knowledge and expectations about TAS at container terminals and related processes have increased significantly in both academia and practice. For this reason, a shift to more detailed problems took place, which allowed the increased use of mathematical optimization methods. Furthermore, artificial intelligence methods have increasingly become the focus of science and practice, which is reflected here in the wider range of methods used.

The second category in the solution procedures is validation. Of the publications considered (see Figure 11: Classification scheme Part A and Figure 12: Classification scheme Part B), 90 % have at least touched on their validation procedure. Whether and how the remaining 10 % have validated their procedure cannot be seen in the corresponding publications. For validation, mainly numerical experiments with mostly quite small problem instances were performed (45 % on average). 7 % of the publications use simulation and still 37 % have compared their results with data from practice.

Figure 10 depicts the third category of solution methods, spatial practical application. The percentages of publications with practical relevance per continent are plotted. Again, the proportions are shown in five-year blocks.

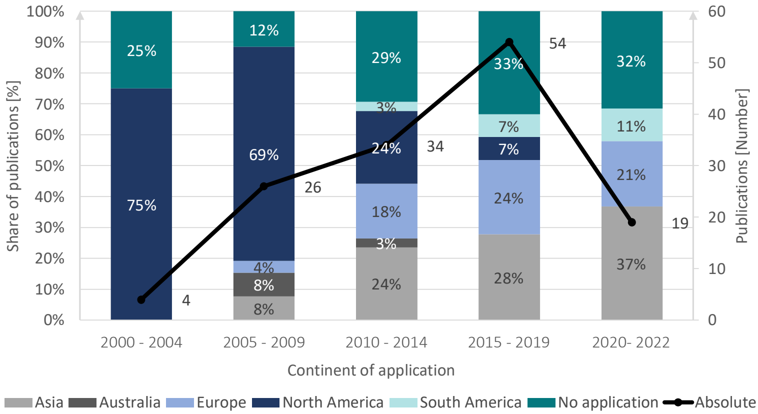

Figure 10: Relative frequency of spatial practical application over time.

Papers from the years 2000 to 2004 either had no practical relevance or referred to North America (75 %). The sharp increase in the volumes transported in international maritime freight traffic during this period posed major challenges for the ports. Stimulated by this, considerations by container terminal operators and port authorities from the USA and Canada, to reduce congestion at the terminal gate and to lower emissions, gained prominence. This particularly affected the ports of Los Angeles and Long Beach. The following five years saw the addition of isolated publications related to Asia (8 %), Australia (8 %), and Europe (4 %). However, the focus remained North America between 2005 and 2009, at 69 %. Between 2010 and 2014, the share of publications on Asia caught up with those from North America (24 % each). During this period, the first publications on South America were also added. As ports in Asia have become increasingly important and now clearly dominate the comparison of global container ports by throughput volume, the years between 2015 and 2019 have seen a particular focus on Asia (28 %) followed by Europe (24 %). The proportion of publications without direct practical relevance has risen to 33 %. In the last 2.5 years, these trends increased even more. 37 % of all the publications focused on Asia and no publication referred to North America or Australia. 21 % of the publication related to Europe and 11 % to South America.

5 Promising Improvement Possibilities of TAS

ITT with TAS have proven in the literature analysis to be a very complex research area with a multitude of sub-problems. In order to clarify the wide range of issues, different methods have been used, resources have been employed and individual actors, mostly container terminals and trucking companies, have been considered in detail. The effects of differently designed TAS on container terminals have been the subject of extensive research. Here, the effects on upstream and downstream logistics nodes for internal port transports were hardly considered. Thus, mainly either the route planning of trucking companies with fixed time windows at container terminals and at customers was investigated or studies on suitable booking processes with time window systems were carried out. The combination of these two issues leads to very complex dependencies, which have only been dealt with to a limited extent so far. Delays caused by traffic jams or obstructions on public roads and delays at upstream logistics nodes have also hardly been taken into account. For the transferability of the results into practice, it is important to consider such delays. This is especially true since even small delays can add up in the course of a tour to such an extent that previously booked time slots can no longer be adhered to and the tour can thus no longer be completed. To avoid such chains of scheduling errors, it is be desirable to use flexibility options such as rebooking, adding or swapping time slots (Lange, et al., 2019a; Beck, Lange and Jahn, 2020). Rebooking is mostly possible at short notice and only affects the slot time of the respective transport. In the case of swapping, the time slots of two transports are exchanged with each other, and in the case of adding, another container is added to an existing time slot booking. However, this is only used sporadically in practice and has been almost completely neglected in the scientific discourse.

The overall port system with its various stakeholders has been little studied due to the complexity involved. Apart from the two main actors, container terminals and trucking companies, other stakeholders, such as empty container depots, packing stations or rail terminals, have only been marginally considered. In particular, the impact of TAS on their operational processes and efficiency has hardly been studied.

The methods used have shifted more and more towards mathematical optimization in recent years due to the increasing detail of the subject under investigation. However, even with the increased use of heuristics, it is mostly not possible to model complex dependencies and solve larger problem instances. This is another reason why the focus on single subproblems has increased. The integration of several methods for the extension of the observation space has been done only very rarely so far. Especially the combination of simulation and optimization offers promising possibilities.

In terms of content, the publications often referred to North American or Asian ports. Due to regional differences in the equipment used and the associated terminal and port processes, a targeted investigation for European ports appears to be necessary.

6 Conclusion and Outlook

In the literature analysis presented here, 136 publications related to ITT and TAS in ports were thoroughly examined. Their most important characteristics were classified and the interdependencies between these characteristics were analyzed.

It has become clear that there are still significant research gaps, both in terms of content and methodology. In particular, the combination of different questions or different methods offers considerable potential, which is still far too little exploited at the present time. For example, the individual planning problems of container terminals are usually considered in isolation and their interdependencies are thus mostly ignored. Furthermore, rigid approaches are often considered, which do not provide sufficient flexibility for the actors involved in the transport chain. The use of more flexible approaches can reduce barriers for smaller companies in particular and thus achieve greater participation and thus transparency for all.

Covering these research gaps could enable a more stable transport chain in practice, even in crisis situations, and thus ensure good care for all parties involved.

Appendix

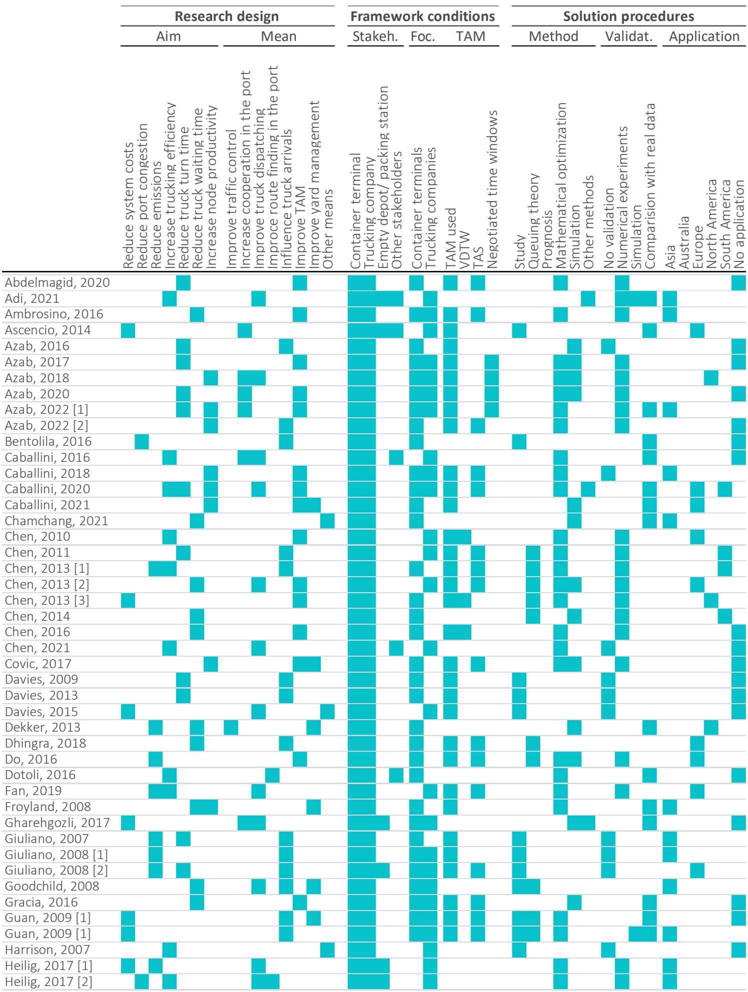

Figure 11: Classification scheme Part A

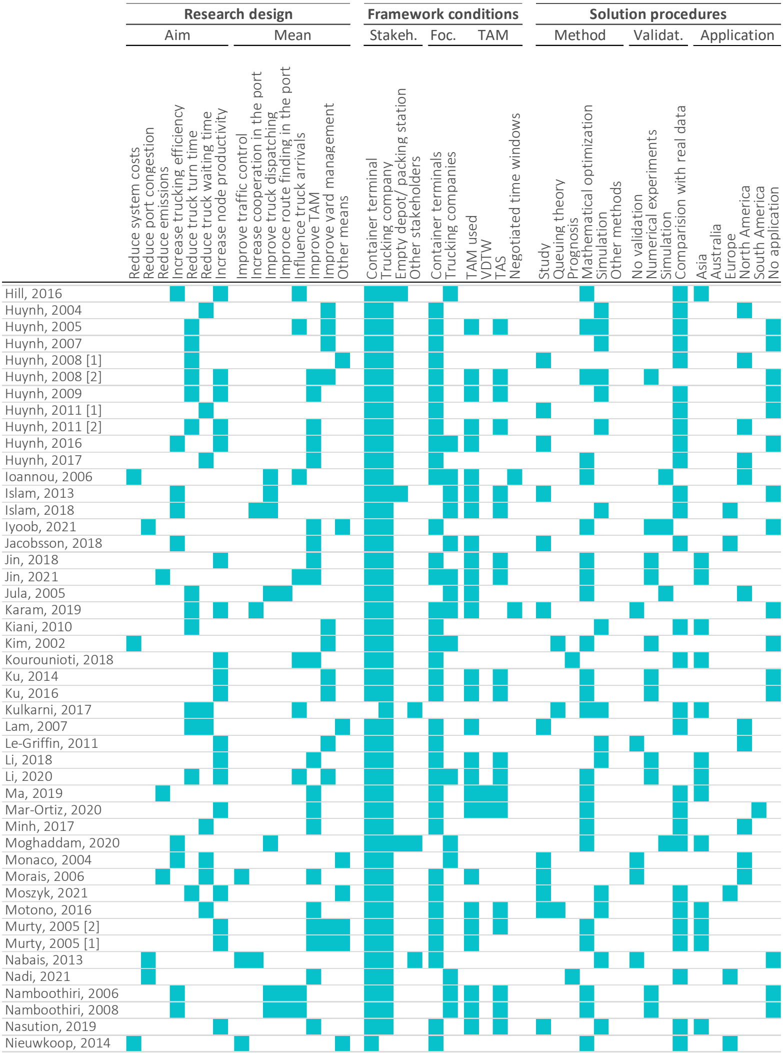

Figure 12: Classification scheme Part B

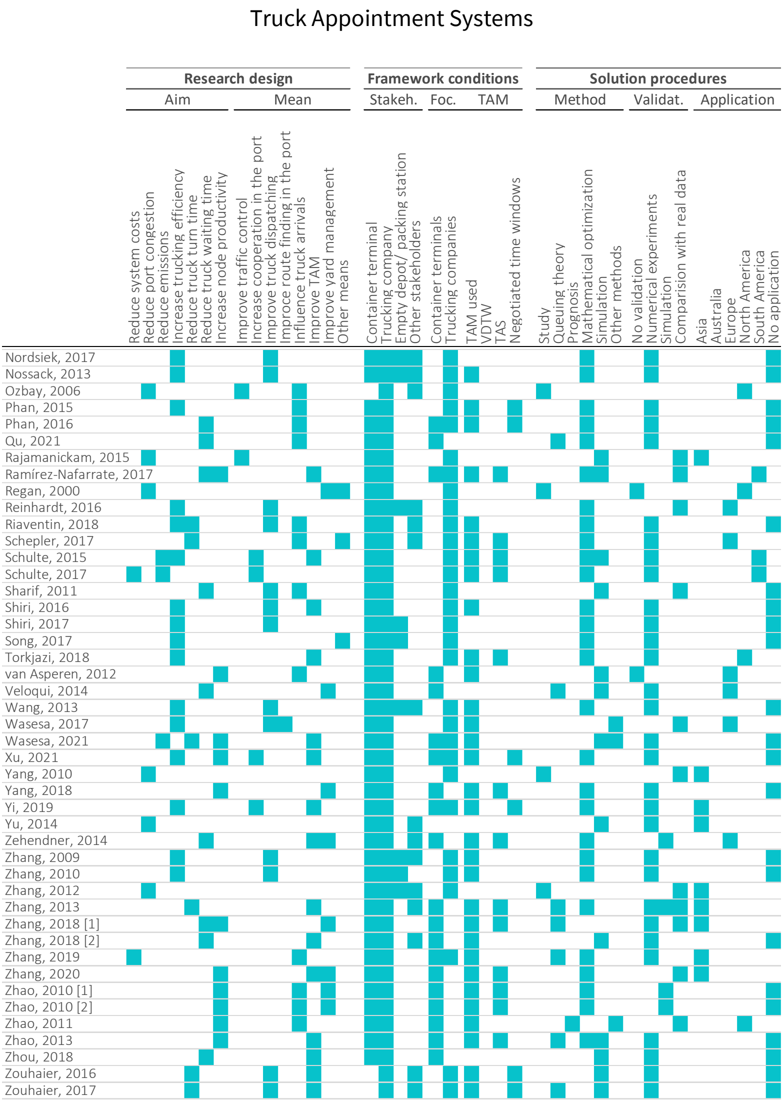

Figure 13: Classification scheme Part C

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Mining Port Operation Information from AIS Data

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Purpose: *Ports play a vital role in global trade and commerce. While there is an abundance of analytical studies related to ship operations, less work is available about port operations and infrastructure. Information about them can be complicated and expensive to acquire, especially when done manually. We use an analytical machine learning approach on Automatic Identification System (AIS) data to understand how ports operate.*

Methodology: *This paper uses the DBSCAN algorithm on AIS data gathered near the Port of Brest, France to detect clusters representing the port's mooring areas. In addition, exploratory data analyses are per formed on these clusters to gain additional insights into the port infrastructure and operations.*

Findings*: From Port of Brest, our experiment results identified seven clusters that had defining characteristics, which allowed them to be identified, for example, as dry docks. The clusters created by our approach appear to be situated in the correct places in the port area when inspected visually.*

Originality: *This paper presents a novel approach to detecting potential mooring areas and how to analyse characteristics of the mooring areas. Similar clustering methods have been used to detect anchoring spots, but this study provides a new approach to getting information on the clusters.*

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1 Introduction

Efficient maritime logistics is extremely valuable and can be improved by adequate planning of operations. This requires up-to-date and complete information on the state of the global fleet; including details on destination port and terminal of other ships on the voyage, their estimated times of arrival (ETAs), number of ships waiting to enter ports, either drifting or at anchor, port capacities (how many ships and at which pace the terminals can handle). Generally, the operator has information and knowledge of the fleet under its control; however, the past operations of the global and competing fleet are difficult to gather.

Global shipping is a game of several stakeholders. Vessels and terminal infrastructures are expensive. Ports are owned or controlled by cities or countries renting areas for companies operating terminals, with their loading and offloading equipment and berth arrangements. The different stakeholders involved have their own interests in the business, where some are collaborating and the others competing with each other (Stopford, 2009). There is no single or even one publicly open data system on past port and, more specifically, terminal calls.

Some ship types generally operate on scheduled liner traffic, such as passenger and container vessels. Whereas the most significant proportion of ship types, bulkers (both dry bulk and tankers), generally operate on the spot market, i.e., voyages are chartered individually for different cargo owners according to the market requirements. For an operating company, it is valuable to be able to know transportation patterns and situations on a global level. The AIS data reveals the location of all the vessels in the global fleet, but meaningful information on the location can be obtained only when sufficient data on port, terminal and berth locations are combined with it.

A difficulty in maritime logistics planning is knowing how the ports operate: when are they busy, what kind of services they provide, what is their capacity, etc. Some of this information can be found by contacting the port directly. However, it is not an option when we think of the planning of international supply chains where the language, continuously changing situations, and other things form barriers. Looking at the web material, e.g. the port of Brest (which has been the focus of our study), shows that it is difficult to find all the relevant information.

Although AIS data has primarily helped increase maritime safety (Silveira et al., 2015; Montewka et al., 2022), it can be used for other purposes, such as understanding port operations. For the latter, there is a need to understand fleet or even single vessel operations more accurately. It isn't even possible to know the port of departure without additional data sources. World Port Index (WPI) (National Geospatial-Intelligence Agency, 2019), and United Nations Economic Commission for Europe (UNECE) provide data sets containing global port locations. The United Nations Code for Trade and Transport Locations (UN/LOCODE) includes over 100,000 locations (UNECE Trade Division, 2021). This makes it possible to convert raw AIS data to organized and structured facts, e.g. voyages.

In this paper, we investigate the use of AIS data to understand port operations. Since 2004 all passenger ships, and all ships over the size of 300 gross tonnage on international voyages, and cargo ships over 500 gross tonnage on national and international operation are required to be equipped with an AIS transponder (International Maritime Organization, 2004) according to the SOLAS regulations (International Maritime Organization, 2014) set forth by the International Maritime Organization (IMO). Using primarily the location data of the AIS messages, which are not always very reliable (Silveira et al., 2015), we can e.g. detect the mooring areas in a harbor area, the port opening hours (via the arrival and leave times of vessels), the peak hours harbour load, and typical times different types of vessels spend at port.

Given the amount of AIS data is vast, efficient algorithms to filter, aggregate, and analyze the data are needed. This paper describes the algorithms we use to analyze the port operations and illustrates their possibilities by studying the functions of the Port of Brest in France. The port area of Brest is geometrically quite simple, all the berths are located on one shore and they are mostly oriented in a south-north axis. This makes the area quite uniform and thus easy to cluster compared to, for example, the port of Rotterdam, which is a labyrinthine collection of canals where terminals are located close to each other. In future work, we plan to implement this approach to other port areas by either tailoring the methods to the specific port area or creating a general approach that works on all port areas.

2 Related work

AIS data analysis is conducted in numerous studies to extract useful information regarding vessel movement (Zhang et al., 2020) as well as port operational patterns and performance statistics (Millefiori et al., 2016). However, to the best of our knowledge, very few studies have used AIS data to benchmark ports with various performance metrics, such as operational capacity and vessel time at anchorages (Millefiori et al., 2016). In the latter studies, AIS data is used to gain insights into specific port operations, such as bunkering (Fuentes, 2021), understand ship maneuvering (Lee et al., 2021) and congestion (Rajabi et al., 2018) in ports, and identify ports' locations and operational boundaries (Millefiori et al., 2016).

Millefiori et al., 2016 proposed a methodology that uses AIS data to define the exact seaport location and its operational boundaries. According to the authors (Millefiori et al., 2016), an accurate definition of a port's location and operational boundaries using a data-driven approach is essential when calculating the port's capacity and efficiency. The proposed method was applied to a dataset of more than 57 million AIS messages focusing on the port of Shanghai.

Lee et al., 2021 studied ship maneuvering in port based on AIS data of vessels arriving at and departing from Busan New Port in Korea collected for four months. From this data, the authors analyzed predominant ship trajectory patterns using DBSCAN algorithm. Given that accidents involving ship collisions with terminals or gantry crane collision can occur, their results were useful when developing port maneuvering guidelines.

Rajabi et al., 2018 studied how the port of Le Havre operates by analyzing AIS data recorded over a one-year interval. Specifically, they analyzed AIS data to determine the number of different types of vessels at each terminal. The authors identified the terminal that served most of the port traffic, and popular quay positions for different types of vessels. According to the authors(Rajabi et al., 2018), since the allocation of vessels at the berth is subject to the rules between the port and shipping companies, this practice results in a high concentration of vessels in some wharves compared to others. Furthermore, it was noticed that the traffic of small vessels increased continuously, which increased the waiting time of big vessels .

Compared to the prior studies, our work addresses some limitations related to the lacking description of the methodology used to study port operations (Rajabi et al., 2018). In addition, this work builds on the preceding study (Lee et al., 2021) to showcase the use of a similar approach (DBSCAN algorithm) to analyse port operations based on AIS data relevant for understanding port infrastructure.

3 Methods

Clustering algorithms have been used in data mining to extract hidden and interesting patterns from massive datasets. Specifically, density-based spatial clustering of applications with noise (DBSCAN) is useful in determining arbitrary shaped clusters in spatial databases that contain noisy data (Khan et al., 2014). DBSCAN was first proposed by Ester et al., 1996 and since then the algorithm has been used and improved extensively(Khan et al., 2014). In short, DBSCAN works by clustering points based on two parameters, minimum points and maximum distance, also called epsilon. The minimum points indicate the minimum number of points that need to be within epsilon distance of a point for it to be classified as a core point for a cluster. Points found this way are further tested if they have enough points within epsilon distance for them to be classified a core point. If not enough points are found they are classified as a border point of the cluster. This process repeats until each point is part of a cluster as a core or border point or classified as noise.

3.1 Detecting Port Mooring Areas with DBSCAN

The clustering is done on points derived from the AIS data. The clustering points are calculated by taking the median coordinates from each mooring event. A mooring event is a continuous time series of AIS messages from a single ship that has the navigational status ”moored” attached. Mooring areas are defined as either berths or quays. A berth is a place for a single ship to moor, and a quay is a structure on the shore of a harbor that can contain several berths.

In our experiment the minimum points parameter for the DBSCAN algorithm is configured to be three. This parameter is chosen since it is a minimum amount of points to form a polygon shape. Additionally setting the parameter to three decreases the probability of false positives in the data compared to having the parameter to be two.

In deciding the most optimal epsilon parameter, two things have to be taken into account. First, the epsilon parameter is expressed in coordinate degrees. This means that the epsilon corresponds to different lengths in different latitudes. A degree of change in latitude corresponds to the same distance at all latitudes. However, the distance covered by a degree of longitude changes drastically the closer to the poles the points are. To mitigating this transformation can be done by either doing a equidistant projection change for the coordinates, or configuring the DBSCAN algorithm to use the Haversine distance. The latter will increases the computational complexity, but this is negligible if relatively few points are used in the clustering process.

The second thing to take into account when selecting the epsilon is to decide whether to detect individual berths or complete quays. The detection of quays with several berths is relatively straightforward and can be easily fine-tuned by changing the parameters. However, this method produces rather large clusters that can contain multiple berths. This, in turn, can affect the analysis of the clusters if berths with differing characteristics are clustered together into a single cluster. Detecting smaller clusters would mean that the epsilon has to be defined much more robustly to detect smaller clusters. This would also most likely result in loss of certain areas, when enough points are not available in a given area. Most likely in this approach the selection of epsilon configured in a way that takes into account different positions of the transponders aboard the ships. Also, given the smaller clusters have less data points each, making meaningful analysis would be more difficult using smaller clusters.

In this study the validation of formed clusters was done manually, i.e. the clusters were overlaid on a map and checked for their location and size. The small area encompassing the dataset makes this approach feasible, but for larger datasets and automatic processes this issue would need to be streamlined. A robust validation method for the clusters would also allow for more nuanced selection of the epsilon and minimum points parameters.

4 Experiments

The experiment will be run by following the framework depicted in Figure 1. The process starts by doing preprocessing steps for the raw AIS data to both improve the quality of the data as well as improving the computational performance in the following steps. After preprocessing individual mooring events are detected and median coordinates of each mooring event are extracted to use in the clustering step. Since each mooring event is expected to be stationary (which they sometimes are not in real data), this condenses the data to easily clusterable form. These points are then clustered with the DBSCAN algorithm to produce clusters. The clusters are then combined with the processed AIS data to determine which cluster each AIS data point belongs to. Finally this combined dataset is used to analyze certain aspects of the port area.

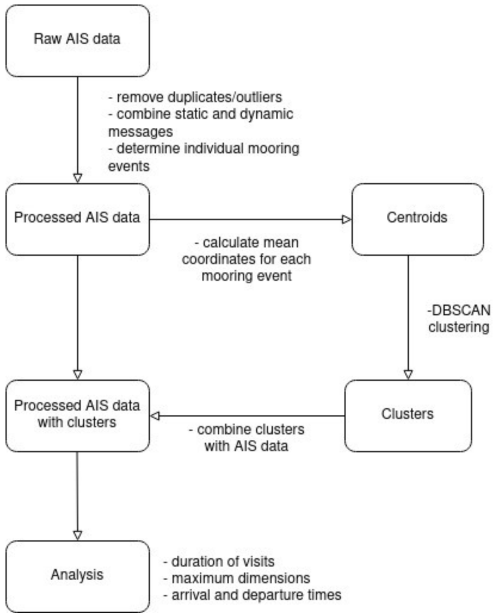

Figure 1: Framework of the experiment

5 Data description

The analysis methods were applied to the AIS dataset collected from areas near the port of Brest in France (Ray et al., 2018). The data covers a time span of six months, from October 1st, 2015 to March 31st, 2016. The data includes both the static and dynamic AIS messages. The dataset also includes the data provided by the WPI that contains geographical information, such as the coordinates of each port. This can be used to filter points from the data set to only contain coordinates near a specific port.

The dynamic messages in the dataset contain a total of 19,035,630 rows which are collected from 5055 different Maritime Mobile Service Identity (MMSI) numbers. The MMSI number is an identifier to distinguish different ships from each other. However, while at a given time an MMSI should be linked to a single ship, over time the MMSI can be reused between different ships, and a ship might change its MMSI for numerous reasons. So while the MMSI is not strictly speaking a unique identifier, in this project this is used as an indicator of individual ships. There also exists an immutable identifier called IMO number that is unique for each ship. However this identifier is missing from smaller ships and it needs to be manually inserted to the system, thus making it susceptible to data errors.

5.1 Data preparation

The AIS data is known to contain a large amount of data errors (Emmens et al., 2021). Before running the DBSCAN algorithm on the data, steps are taken to clean and filter the data. First, all the (ship-id, timestamp) duplicates are removed from the data. Second, new columns are created by parsing the time stamp to its components such as the time of day and the day of the week. Third, all the points outside a certain radius of the port to be analyzed are removed from the data. This radius is centred on the port coordinates from the WPI data set. Finally, the speed between sequential points is calculated. If a point has navigational status set as ”moored” and a speed above a certain threshold, these points are removed from the data.

The dynamic messages need to be combined with the static messages to complete some fields. This is done by using the MMSI number as a key for a joining operation. The following fields are added to the dynamic data: ship type, ship length, ship width and ship draft. Since the static messages are transmitted at six minute intervals, each MMSI number has multiple static messages. This means that some of the above mentioned fields can have multiple values for a single MMSI. Some of these changes can be attributed to ship operations, such as the ship's draft changing after loading or unloading cargo, but most of these changes can not be attributed to anything else than data errors. The static and dynamic messages are joined using an as-of merge operation, which joins the rows on closest key values, in this case timestamps.

The clustering will be done on two different data sets, one with all the ship types and a second that has only specific ship types included. The thought process is that by filtering the data beforehand, the analysis can focus on specific clusters more easily. The risk in this implementation is that some ships might have their ship type configured incorrectly and thus would not be included in the filtered data. The clusters produced by the unfiltered data can be compared with the filtered data to see if any major clusters are missed with the reduced data set.

The clustering points are generated by identifying individual mooring visits. A mooring visit is defined by a ship having the navigational status ”moored” for continuous timestamps. Since the data also contains some incorrect navigational statuses, only mooring visits of that last over an hour are included in the clustering. From each of these mooring visits, the median coordinates are taken as a clustering point.

5.2 Application of DBSCAN Algorithm

The prepared AIS data described in Section 4.2 was entered as a variable to DBSCAN algorithm employed from Scikit-learn in Python. In this study, two different epsilon parameters were used on the DBSCAN algorithm. A larger epsilon is used to detect whole quays that can contain multiple berths. For detecting individual berths, a smaller Epsilon parameter is defined. The smaller epsilon is defined to be 50 meters while the larger epsilon parameter is set to 100 meters. Further, the dataset variable is filtered to only contain the preprocessed data, or the preprocessed data with selected ship types, in our case cargo ships and tankers.

The resulting clusters with all ship types is presented in Figure 2 and Figure 3. In the figures clusters created by all of the ship types are marked as red polygons. Clusters created by data set containing only tanker ships have green outlines and clusters created by data set containing only cargo ships have blue outlines. When visual analysis is done on these clusters it would seem that all the tanker and cargo ships are contained within the clusters made by all the data. In other words filtering the data did not result in clusters in new areas. Also, we take note that when increasing the Epsilon parameter, this also does not produce clusters in new areas. In some cases the larger epsilon combined existing clusters while in some cases it produced larger clusters. A smaller Epsilon parameter is capable of producing more granular clusters and thus can bring about more precise analysis of the mooring areas. However, a larger Epsilon parameter produces clusters that have a bigger area, which can also bring new aspects to the analysis.

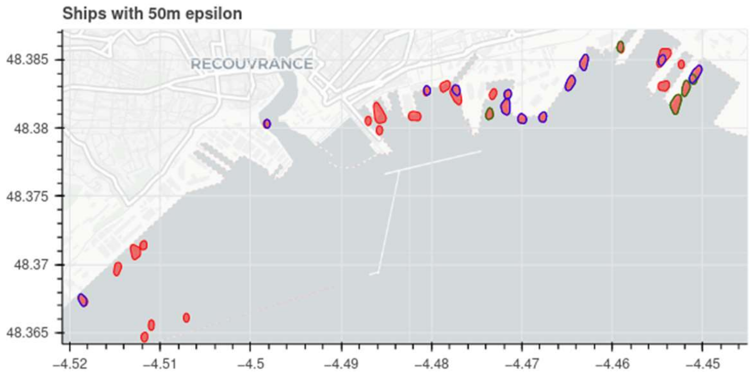

Figure 2: DBSCAN clusters created with 50 m epsilon

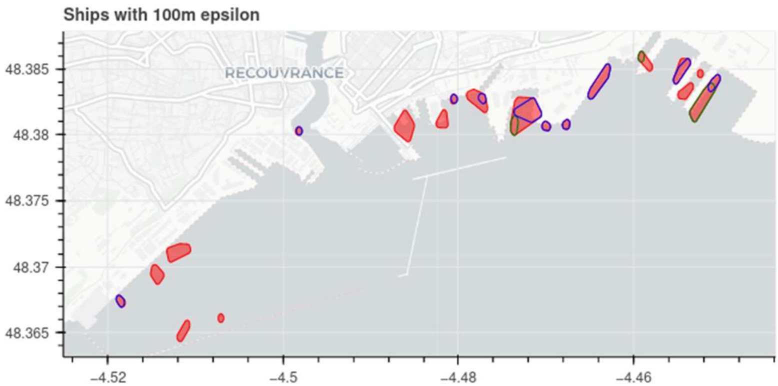

Figure 3: DBSCAN clusters created with 100 m epsilon

A too large Epsilon can produce clusters that combine multiple distinct clusters. There is also a risk that a too large Epsilon can detect clusters that go over land areas or quays. An example of an cluster where the epsilon is too big is given in Figure 4. However with a too small epsilon, bigger ships can produce two clusters when the AIS transponder is situated at a different parts of the ship or when different ships are moored with opposite directions. An example of a too small epsilon is demonstrated in Figure 3. In this picture the clusters are clearly in an area that is meant for mooring a single ship. It appears that ships moor in this place either their bow towards east or west, producing two clusters when in fact it is a single berth. Some of these issues can be counteracted by filtering the data more thoroughly. For example the cluster in Figure 5 does not go over the quay if the data is filtered to include only tanker ships as seen in Figure 6.

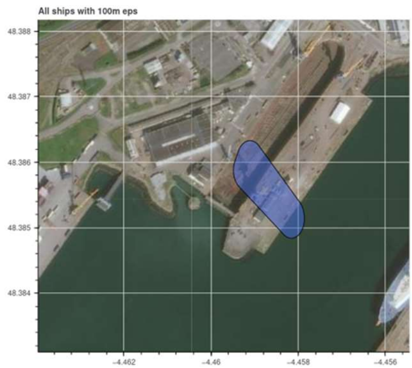

Figure 4: Cluster going over a quay when epsilon is too large

Figure 5: Dividing a single cluster in two when the epsilon is too small

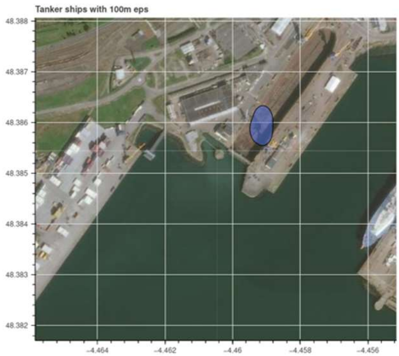

Figure 6: Cluster created after filtering to include just tanker ships

Further analysis can be done on the generated clusters to gain additional insights on the identified terminals. For example, dimensional characteristics for To achieve this, the cluster data is added to the original unfiltered AIS messages. This is done by checking each AIS message whether the coordinates are inside a given cluster. This can be done relatively fast if the messages are coded to a geospatial dataframe e.g. such as GeoPandas, thus allowing the use of spatial clustering.

5.3 Analysis of the Clusters

Further analysis was performed on selected clusters to find the following statistics for each cluster: number of visits, number of unique ships, maximum dimensions of visiting ships, mean time spend in cluster and the hours of the day that ships are entering or leaving the clusters. Additionally, a breakdown of the different types of ships that visit each cluster is calculated. The breakdown of different ship types can show whether a terminal is meant to service just one type of ship or multiple ship types such as in case of maintenance areas.

For number of visits, an individual cluster visit is defined as a continuous time series of AIS messages from a single ship that are positioning inside a cluster. The number of visits and number of unique ships can be used to determine terminals that have high traffic.

The dimensional data is collected from a separate data set that contain the static AIS messages. The dimensional data include the length and beam (width) of a ship as well as its draft. The ship dimensions tell what kind of ships each terminal can service. The amount of time spend in a cluster needs to be calculated by subtracting the arrival timestamp from the departing timestamp for each individual cluster visit.

6 Results

In this results section several clusters will be analysed to get further insight on the data. The clusters are chosen based on showing some interesting metrics that call for additional visual analysis. The visual analysis is done using aerial and satellite images provided by ESRI (ESRI, 2022). Some clusters showed interesting characteristics, but they were situated in an area that is pixelated in satellite images due to close proximity to military installations. This prevents further visual analysis of the cluster and because of this these clusters were not included into the analysis.

The analysis was done on the clusters formed by using the whole data set with a small epsilon. This was as the preferred approach since this minimizes the amount of overlapping clusters, while also at the same time gives insight on various aspects on the port infrastructure. The results of the chosen clusters are shown in Table 1 and Table 2. The AIS points are filtered to include just tankers and cargo ships (ship type numbers 70 to 89). This is done to reduce the noise in the data. Preliminary analysis indicates that some ships such as tugs have irregular and movement patterns that can affect the analysis. The AIS data is spatially joined with the clusters to include which cluster each point belongs to. Insights are analyzed from the data to study which clusters have ships staying in them for extended periods of time. In this data set the longest median visiting times are in cluster 28 (median time 14 days 21:31), cluster 27 (median time 7 days 12:00). These clusters are visualized in Figure 7. Both of these clusters appear to be situated in dry docks.

These findings would indicate that by looking for clusters that have unusually long stays in them, it could be possible to detect areas that have some sort of maintenance capacity such as dry docks.

Table 1: Analysis of Selected Clusters

Cluster ID	Berth type	Data subset	N ships	N visitits	Max Length (m)	Max draft (m)
27	Dry dock	Tanker/cargo	5	34	291.0	9.8
28	Dry dock	Tanker/cargo	5	6	291.0	8.6
5	Undefi-ned	All	20	43	176.0	8.8
10	Undefi-ned	All	17	45	136.0	7.1
1	Undefi-ned	All	18	106	136.0	6.5

Table 2: Median time in cluster

Cluster ID	Median time in cluster
27	7 days 12:00
28	14 days 21:31
5	0 days 12:10
10	3 days 10:40
1	0 days 13:19

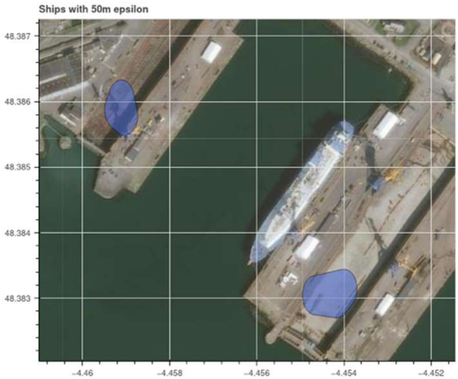

Figure 7: Cluster 27 (bottom right) and 28 (top left)

Another interesting metric to analyse is to see how many different kinds of ships visit each cluster. The ship types are expressed as integers that have two digits, where the first digit indicates the type of ship (Marine Traffic, 2022). The second integer can be used for further specification for some ship types such as the type of cargo the ship is carrying. In analysing these clusters the focus will be mainly on the ship type so for example all cargo ships are grouped into one group. For analyzing this aspect all the ship types are included to the AIS data. The data is then spatially joined with the cluster data similarly as in the previous analysis. The analysis found that clusters with significant distribution of different ship types are: cluster 1 (56% other, 37% tugs, 7% missing value), cluster 5 (75% cargo ships, 25% tanker ships), and cluster 10 (36% tugs, 25% cargo ships, 38% other, 1% missing).

Clusters 1, 5 and 10 are visualized in Figure 8. All of these clusters are situated in areas near dry docks. Additionally clusters 1 and 10 are situated adjacent to each other. This in combination with the variety of ship types visiting these clusters could potentially suggest that these areas have some connection to the dry dock areas. This area could be a waiting are to enter the dry docks or some sort of maintenance could be performed here that does not require the dock to be drained. Alternatively based on the distribution of ship types (lots of ships classified as tugs or ’other’ types) clusters 1 and 10 could be used as a waiting area for ships that help with operations related to the dry dock. Cluster 5 has only tanker and cargo ships so most likely this place is reserved for waiting to enter the dry docks. The time spend in clusters 1 and 5 would indicate that these are for short time mooring needs, such as temporary mooring for maintenance vessels. The time spend in cluster 10 is much longer, indicating that this cluster is also used for longer time mooring needs. So by analysing distribution of different ship types it might be possible to detect maintenance areas near other points of interest such as dry docks. Most notably the dry dock area above clusters 1 and 10 did not produce a cluster from the data. This could be because the AIS transponder was configured incorrectly on the visiting ships or there were no points in this dry dock in the given time frame. In any case analysing these areas that have a high distribution of different ship types might give an indication that there is potentially a dry dock area nearby. Alternatively just the presence of tugs in clusters could be enough to detect areas used for maintenance. In any case this hypothesis would need to be further tested to see if this analysis can give additional insight on the port infrastructure.

By analysing the clusters created by DBSCAN algorithm we can get some insights on the infrastructure of the port. It appears that areas that harbor some sort of dry dock capabilities are relatively easy to identify due to them having significantly longer stays within the clusters. Also by detecting areas that have high distribution of different ship types it might be possible to detect areas that are related to port maintenance.

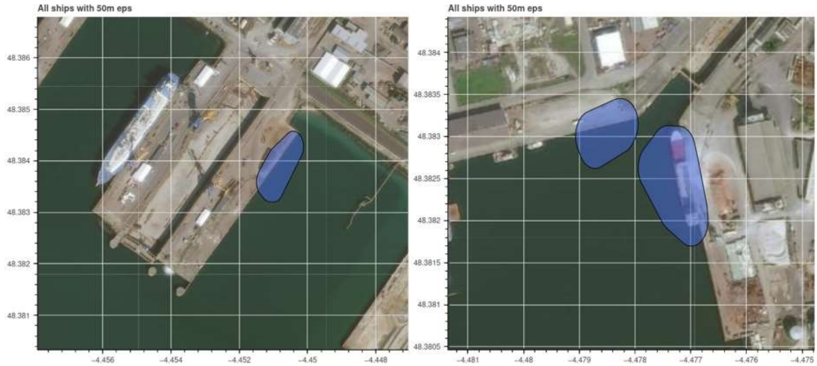

Figure 8: Cluster 5 (left image), 1 (leftmost cluster in right image) & 10 (rightmost cluster in right image)

7 Discussion

The method for mooring areas (berths/quays) identification by aggregating the AIS data were described in Section 3.1. This method solves one of the challenges - is vessel at port or not. When open data sets such as UNECE and WPI are used, the data is not up-to-date. New ports and terminals are being constantly built and old ones discontinued in use. Secondly, location accuracy is rather poor in UNECE where the two last digits refer to minutes and the two or three first digits indicate the degrees. DBSCAN makes it possible to detect and keep automatically mooring areas up-to-date, globally.

In this article we have produced a proof-of-concept approach on how to detect mooring areas based on just AIS data. The DBSCAN algorithm was able to perform quite well even given the noisiness of AIS data. While the initial approach shows promise, there are still some issues to overcome. Firstly the selection of optimal parameters is still done by a trial and error approach. While the chosen parameters uncover interesting insights from Brest harbor area, there is no guarantee that these parameters would work in other port areas. An automated approach to this would need some sort of cluster validation for evaluating the parameters. While some methods have been developed for optimal selection of DBSCAN parameters, these are still pretty much in experimental stages and would most likely not work with data as noisy as AIS messages (Starczewski, Goetzen and Er, 2020). However while it is unlikely that parameters exists that work for all port areas, we are developing methods that would allow us to select optimal DBSCAN parameters for a selected port area.

8 Conclusions

Presented method makes it possible to deduce detailed information on individual berth locations and their capacities covering all global ports and terminals. Such information enables to build up a complete picture of the ongoing operations. As different ports have different number and combination of terminals and berths attending different ship types, it is important to know these capacities, in order to define and predict potential congestion at port and to estimate time for departure after cargo operations. Manually entered fields of port of destination and estimated time of arrival, and on ship status; moored, anchored, or steaming are very useful but often unreliable or updated late due to required human input.

Estimates and predictions of waiting times for ships entering to port can be done when the capacities of the port are defined. The individual berth information together with other ship port calls enables to identify operational patterns. One port may have several terminals attending one ship type. However, these terminals with their own berths may have contracts with different operators or cargo owners, which can be revealed by analysis of operational patterns. Such analysis could be conducted with help of berth information that could be gathered globally with application of the presented method to global AIS data. The importance of detailed location information on berth level manifests especially in case of the busiest ports. These ports are often located in the areas with close passing traffic and they contain a very large number of berths as a more or less continuous line along the coast. The passing traffic often needs to slow down and sometimes the ships stop for bunkering on nearby locations. Without accurate enough berth data, which the publicly available databases do not offer, is would not be possible to define if the ship had really entered the port or not.

The analysis of the mooring area clusters gave some interesting insights, but it might be too early to tell if these methods can be generalized to be applicable to other data sets. In this case further studies are needed to see if these methods are sound. Further addition to the analysis phase could include things such as detecting whether the draft of a ship changes inside a cluster, detecting linkages between anchorage areas and mooring areas and detecting how long on average ships wait to enter a given mooring area. These could give additional benefit to the analysis and produce results that go beyond just detecting the structure of the port.

Acknowledgements

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Potentials of Direct Container Transshipment at Container Terminals

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Purpose: *On the one hand, the increasing growth in vessel size and land-based capacity constraints raise the need for optimizing the layout and process design at container terminals. On the other hand, the temporary storage of containers in the yard decouples the material flow of incoming and outgoing containers at the terminal. This study focuses on reducing the number of containers to be stored in the yard by direct container transshipment between modes of transport.*

Methodology: *Based on a systematic literature review, approaches for skipping the storage phase at container terminals are identified. For this purpose, a classification scheme was developed and applied to academic publications. The classification scheme includes various criteria, such as the methodology and the research objective of the considered publications.*

Findings: *The results show that in science, direct transshipment of containers at seaport terminals is mainly studied between ships. Furthermore, many studies do not focus exclusively on direct transshipment but consider it as a possible design alternative.*

Originality: *Only a few studies have looked at skipping the storage phase on container terminals. An overview of existing studies on direct container handling between two modes of transport and skipping the storage phase does not yet exist.*

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1 General Information

One of the most important innovations in modern maritime shipping was the development of the container at the end of the 1960s. While the volume of global containerized trade was small at the beginning, by the turn of the millennium, the annual containerized trade already amounts to 62 million Twenty-foot Equivalent Units (TEU). In 2021, the volume of global containerized trade was about 160 million TEU. This is more than a two-and-a-half-fold increase in the last 20 years. (UNCTAD, 2021) Due to the rapid growth in transport volumes and to be able to exploit economies of scale, the container vessels used are becoming ever larger. Compared with 8,000 TEU capacity in the year 2000, the largest vessel in 2021 holds nearly 24,000 TEU. (Allianz, 2021) Even if the technically possible limits of size growth have not yet been reached, the physical accessibility of ports with sufficient water depths and nautical conditions, as well as existing terminal capacities and transport connections, limits the growth of vessels. The availability of cargo volumes for larger vessels must also be given. From an operational point of view, the growth in vessel size makes it necessary to expand terminal areas and adapt handling equipment to maintain terminal productivity and handling performance. Greater space availability, especially in the yard, means that containers do not have to be stacked as high. This reduces the restacking probability of containers and minimizes unproductive handling steps. But especially at container terminals close to cities, expansion areas are often limited or not available at all. This results in a need for process optimization to speed up transshipment. As a result, it is only possible to counter developments in container shipping by designing processes efficiently. (March, 2020) In this context, the study analyzes direct container transshipment between modes of transport at container terminals. Specifically, this study addresses the following research questions:

1. How prominent is the topic of direct container transshipment at terminals in the academic field?
2. Between which modes of transport is direct transshipment primarily investigated?
3. Are direct transshipments of containers at terminals practicable?

To answer these questions, chapter 2 first introduces the basic processes at seaport container terminals and explains the concepts of direct and indirect container transshipment. This is followed by a comprehensive literature review. The methodological procedure for conducting the analysis is presented in chapter 3. The classification scheme developed is presented in chapter 4. Chapter 5 shows the results of the literature review and analyzes the relevant factors individually and about each other. To answer the research questions, Chapter 6 discusses the analysis results. In the end, chapter 7 gives a conclusion and an outlook.

2 State of Research

Terminals are generally defined as multimodal nodes in the maritime supply chain. (Kastner, et al., 2021) Equipment for loading and unloading vessels is as typical for seaport terminals as areas for storing cargo. Thereby, seaport terminals can be classified according to the type of cargo handled or the mode of transport. Thus, port facilities that are primarily used for handling containers are referred to as container terminals. (Böse, 2011)

2.1 Container Terminals

Container terminals are nodes with two external interfaces. These interfaces are given by the quay on the seaside and the gate on the landside. As shown in Figure 1, the container yard separates seaside and landside functional areas and also acts as a buffer to coordinate incoming and outgoing container flows. The dwell time of the containers in the yard differs extremely and can range from a few hours to several weeks. To minimize the dwell times of (full) containers at the terminal, many terminal operators charge dwell fees for exceeding a certain dwell time. (Carlo, Vis and Roodbergen, 2014)

All containers arriving at the terminal are moved by the equipment at least five times before they leave the terminal again. The process steps that an import container goes through at the terminal are:

- Unloading from the vessel by ship-to-shore gantry cranes
- Container transport to the yard
- Storage of the container in the yard
- Removal of the container from storage
- (Container transport to the quay/container transport to the railroad tracks in case of further transport by vessel or rail)
- Loading onto the next mode of transport (truck, rail, vessel) and vice versa. (March, 2020)

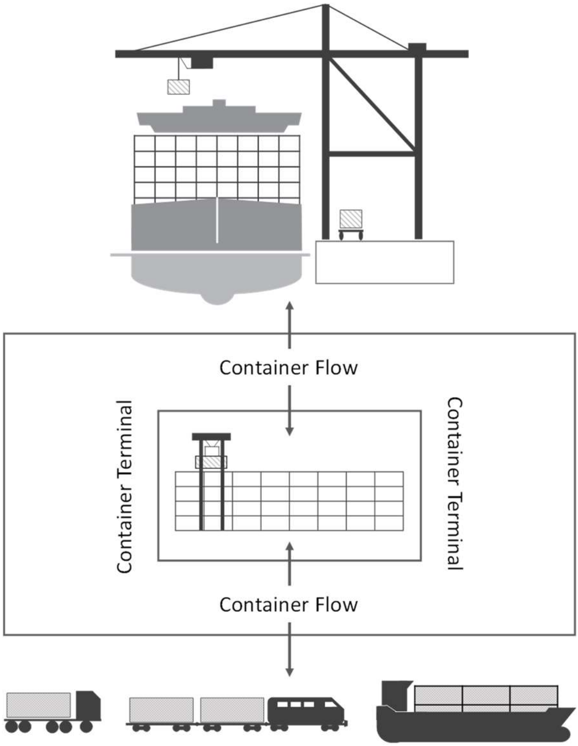

Figure 1: Schematic processes at container terminals
(based on Kemme, 2013)

Moreover, containers often have to be restacked in the yard. This results in further necessary moves. All in all, conventional container handling processes at terminals involve a lot of coordination work and require the availability of handling equipment. In addition, the containers temporarily occupy storage space in the yard. (Carlo, Vis and Roodbergen, 2014)

2.2 Direct vs. Indirect Container Transshipment

At container terminals, cargo can be transferred between two vessels or between a vessel and the intermodal transport to the hinterland. In this context, it can differ between direct and indirect transshipment. During direct transshipment, the cargo is transferred directly between two modes of transport (truck/rail/vessel to vessel and vice versa). In this case, the cargo is not temporarily stored at the terminal, as is usual for container transfer. (Manaadiar, 2011)

While direct transshipment between deep-sea vessels and land transport is a possible practice at conventional break-bulk terminals, the introduction of container vessels and the growth in cargo volume per port call made direct transshipment processes more difficult. (Notteboom and Rodrigue, 2009) Thus, the indirect transshipment of containers at terminals has become established. Indirect transshipment means that the cargo is buffered at the terminal between sea transport and landside or seaside and ongoing transport. Thus, the incoming and outgoing cargo flows can be decoupled. (Monaco and Sammarra, 2018) To ensure that the different modes of transport cannot interfere with each other, each mode of transport is given a specific area on the terminal. The physical separation of the modes of transport is the basis for indirect transshipment, in which each mode of transport follows its schedule. Within the indirect transshipment system, the terminal's yard acts as a buffer and intermediate storage between two modes of transport. (Notteboom and Rodrigue, 2009)

Nevertheless, there are still cases of containers being handled directly to the quay of the terminal. An example of this is when the containers have loaded highly hazardous dangerous goods such as explosives or radioactive material. In these cases, ports will only accept unloading or loading processes on the condition that the unloading or loading is executed as a direct transshipment. This is to minimize the risk of accidents that could occur at the port due to the volatile nature of the cargo. Another example of direct transshipment is heavy or unusual cargo that cannot be handled twice at the port due to its nature. This is also handled directly between the truck and the vessel at the quay. (Manaadiar, 2011)

Moreover, some scientific approaches exist for the direct transshipment of containers between different modes of transport. For example, Zeng, Feng and Chen (2017) look at the integrated berth allocation and the storage space assignment problem, based on direct transshipment operations between vessels and feeders by using an optimization model. To solve the model the nearest neighbors heuristic based on genetic algorithms is used. Nellen, Lange and Jahn (2021) used a discrete event simulation model to analyze the effects of direct container transshipment at the quayside on port-internal container transports. They studied the transshipment of containers between vessels and trucks.

Direct transshipment of containers has also been applied in some ports. Two of these ports are Guangzhou and Dalian in China, where some of the containers handled are loaded directly from feeder vessels onto mother vessels. (Zeng, Feng und Chen, 2017) Structured studies comparing approaches of direct container transshipment between modes of transport at container terminals have not been carried out to the authors' knowledge.

3 Research Methodology

To identify approaches for skipping the storage phase at seaport container terminals, a systematic literature review was carried out. Scopus and Web of Science were used for the search. Scopus is a database of abstracts and citations from peer-reviewed scientific content as well as a wide global and regional coverage of scientific journals, conference proceedings, and books. Web of Science has a thorough literature selection process. This is based on publication standards, expert judgment, and the quality of citation data. For the literature search, a four-step process is applied, which is shown in Figure 2 and makes the searching process transparent.

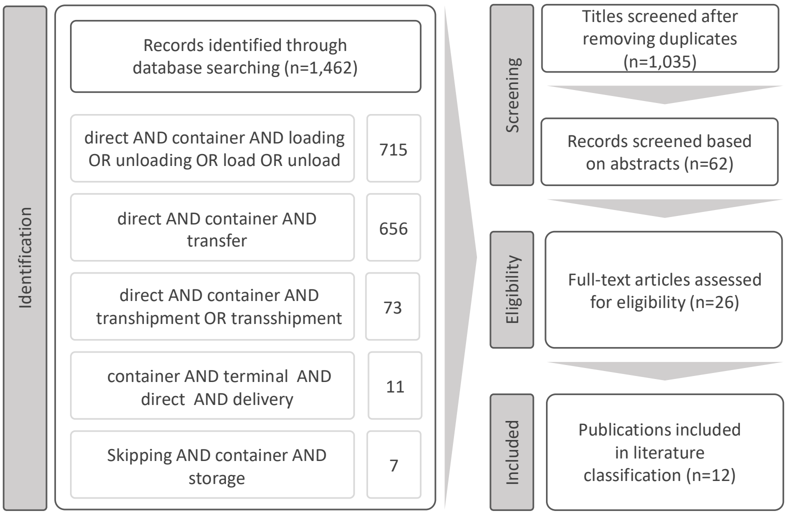

Figure 2: Approach for literature research (based on Moher, et al., 2009)

In the first step, relevant keywords are identified and combined into search strings. Thereby, the search strings are selected in such a way that as many publications as possible are found that consider the direct transshipment between different modes of transport at container terminals. In this process, 1,462 potentially relevant publications were identified (for details on the search strings and their results, see Figure 2). In the second step, duplicates are removed first. The remaining 1,035 papers are checked for suitability on basis of their title and afterward with regard to their abstract and keywords. The full text of the publications found must be available in English. Furthermore, the publications must deal with container handling at seaport container terminals. Due to the small number of hits, papers dealing with hinterland terminals are also considered. As a result, 26 publications were identified for the full-text assessment. By reading the remaining publications, 12 publications are finally identified as relevant for this study.

To identify further relevant publications that could not be found using the systematic approach described above, the snowball approach is applied (see Figure 3). A comprehensive overview of the procedure in this method is given by Wohlin (2014).

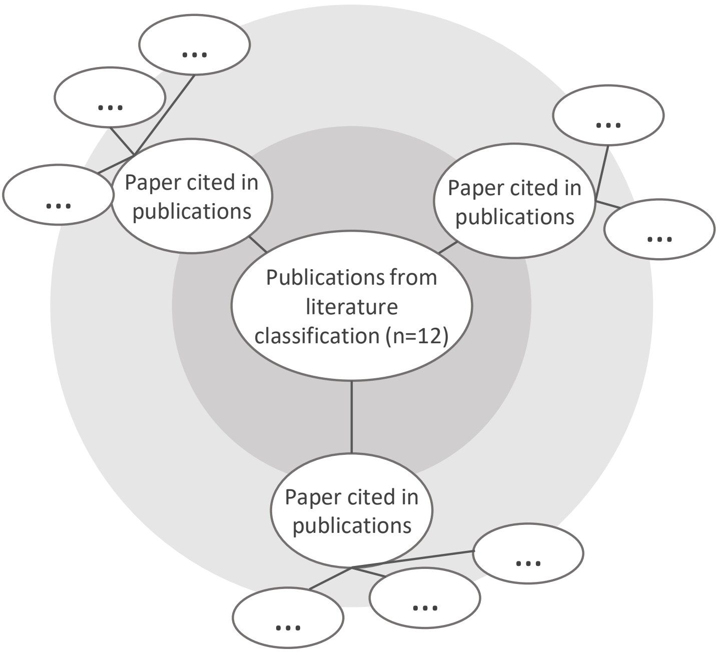

Figure 3: Snowballing approach

At the beginning of the snowball approach, the reference lists of the starting publications are scanned to identify potential publications for the literature classification. The papers need to meet the basic criteria such as language and type of publication. Publications that are already included in the starting set are removed from the list. The remaining papers are now true candidates for inclusion. The next step is to identify new publications based on the papers cited in the cited publications, as shown in Figure 3.

If no further publications are found, the snowball procedure is concluded. Using the snowball method, 10 additional relevant publications were found. As a result, 22 publications were identified to be included in the literature classification.

4 Literature Review

The literature review described in Section 3 identifies publications that addressed the direct transshipment of containers at terminals in the seaport or the hinterland. Different problems are addressed, ranging from maximizing the number of direct transshipments to reducing emissions. To design a systematic literature review of approaches that consider the direct transshipment of containers between modes of transport, a classification scheme was developed and applied to academic publications. The classification scheme is separated into seven categories: Objective, Method, Focus, System, Data, Handling mode, and Requirement (Req.) (see Figure 4).

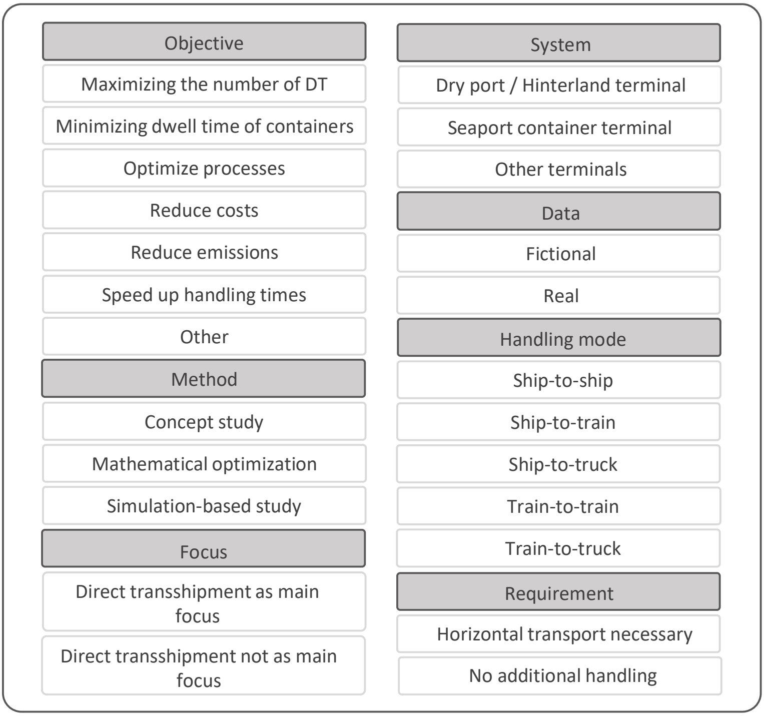

Figure 4: Classification categories and their specifications

With the help of the category "Objective", the motivation respectively the focus of the scientific publications can be compared. Therefore, seven specifications have been established ("Maximizing the number of direct transshipments (DT)", "Minimizing dwell time of containers", "Optimize processes", " Reduce costs", "Reduce emissions", "Speed up handling times" and "Other") to represent the different research objectives. "Method" describes the approach of the reviewed author to analyze the respective research question. For this, a distinction is made between the specifications "Concept Study", "Simulation" and "Mathematical Optimization". "Concept Study" includes approaches in which publications from other authors are compared, as well as publications in which new approaches to process design are presented. "Simulation" specifies publications that use simulation as their main method. The specification "Mathematical optimization" includes publications that set up an optimization model and solve it either with heuristics, metaheuristics, or exact mathematical methods. The category "Focus" was chosen to determine whether the focus of the paper is to examine direct transshipments at terminals or whether this is a secondary issue. Using "System" as a category, it can be distinguished whether the publication is looking at seaport terminals, terminals in the hinterland, or other terminals. In this context, publications can refer to a fictitious system and do general studies or explicitly refer to a real system ("Data"). In addition, various "Handling modes" are taken into account. These are "Ship-to-ship", "Ship-to-train", "Ship-to-truck", Train-to-train" and last but not least "Train-to-truck". Finally, the category "Requirement" is used to consider whether containers need to be transferred between different functional areas for the transshipment.

All in all, in some categories multiple choices are possible. These categories are "Objective", "Method" and "Handling mode".

5 Results of Literature Review

To answer the research questions, the sources are first classified using the scheme described above. In the following, additional interdependencies are shown with the help of diagrams. Table 1 represents the application of the 22 publications to the proposed classification scheme.

Table 1: Classification scheme for direct transshipment

	Objective							**Method**			**Focus**		**System**			**Data**		**Handling mode**					**Req.**	
	Maximizing the number of DT	Minimizing dwell time of containers	Optimize processes	Reduce costs	Reduce emissions	Speed up handling times	Other	Concept study	Mathematical optimization	Simulation-based study	Direct transshipment as main focus	Direct transshipment not as main focus	Dry port / Hinterland terminal	Seaport container terminal	Other terminals	Fictional	Real	Ship-to-ship	Ship-to-train	Ship-to-truck	Train-to-train	Train-to-truck	Horizontal transport necessary	No additional handling
Alicke (2002)							x		x			x	x			x					x			x
Basallo-Triana et al. (2022)						x				x		x	x			x						x		x
Belošević et al. (2016)			x					x				x	x				x					x		x
Blumenhagen (1981)							x	x				x		x		x		x						x
Bo and Wang (2019)							x	x			x		x			x						x		x
Boysen et al. (2010)							x		x	x		x	x			x					x			x
Expósito-Izquierdo et al. (2019)						x	x		x			x		x		x				x				x
Jurjević and Hess (2016)				x					x			x		x		x				x				x
Kim and Morrison (2012)							x	x				x			x	x		x						x
Lee, et al. (2006)			x							x		x		x			x					x		x
Li and Wang (2019)						x			x		x		x			x						x		x
Liang et al. (2012)						x			x		x			x		x		x						x
Liu et al. (2002)			x							x		x		x		x			x	x			x	
Liu, et al. (2016)						x	x		x			x		x		x		x						x
March (2020)					x	x		x			x			x		x		x						x
Monaco and Sammarra (2018)						x			x		x			x		x		x						x
Nellen et al. (2021)			x			x				x	x			x		x				x				x
Nishimura et al. (2009)						x			x			x		x		x		x						x
Wiegmans et al. (2007)			x				x	x				x	x			x					x			x
Yan et al. (2020)	x	x							x		x			x		x			x				x	
Zeng et al. (2017)				x					x					x		x		x						x
Zhao et al. (2020)				x					x	x		x		x			x		x				x	

The number of papers identified in the literature classification is rather small. However, looking at Figure 5, it can be seen that the scientific interest in direct transshipments between different modes of transport in the maritime context has grown.

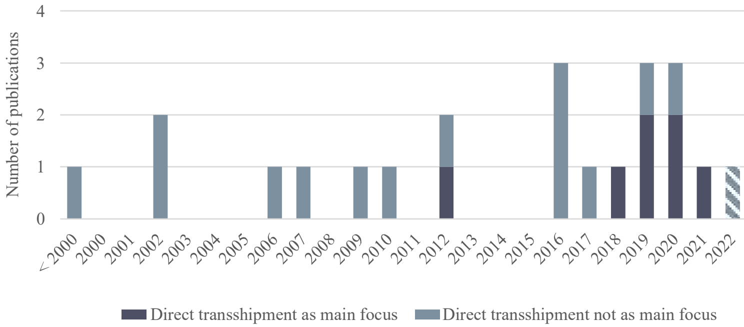

Figure 5: Relevant publications per year

While only nine relevant papers could be identified until 2016, the number of publications in this topic area has increased from 2016 onwards. Thus, in the last five and a half years, 13 publications have been published that deal with direct transshipment (see Figure 5). Furthermore, it is notable that since 2016, a minimum of one publication has steadily appeared each year. In the years before that, publications were more sporadic. In addition, the older publications dealt with the topic of direct transshipment at terminals rather marginally. This means that direct transshipment is considered one of several possibilities for process design and optimization, but it is not the main focus of the publication. Again, this has changed in recent years, and direct transshipment is the focus of nearly half of the publications since 2016. All in all, this suggests a growing research interest in this area.

Figure 6 shows that the majority of the publications found focus on direct transshipment at seaport terminals. With eight publications, terminals in the hinterland are somewhat less the focus of scientific interest. This can be explained by the fact that the optimization of processes at seaport terminals is more in the focus of science overall. Nevertheless, from a practical point of view, the direct transshipment of containers in the hinterland is easier to implement, not least because of the terminals' layout. This is also shown by the fact that direct transshipment of containers is already being practiced in the hinterland in some cases. Terminal managers of hinterland terminals have confirmed that up to 20 percent of transshipment between rail and truck is direct. One of the publications examines direct transshipment between vessels handled at offshore terminals.

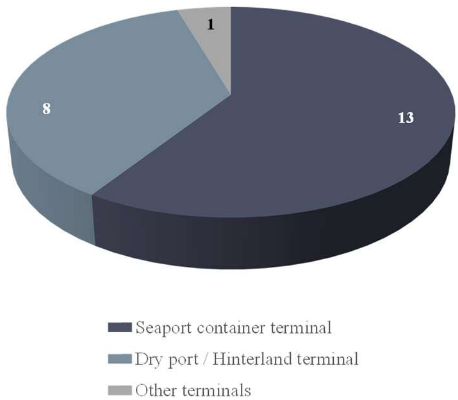

Figure 6: System focus of the publications

The fact that the productivity of terminals has to be raised due to the growth in vessel size and thus the handling times of containers have to be speeded up is shown by the objectives of the classified publications (see Figure 7). The overall most studied objective in the analyzed publications is "Speeding up handling times", which is mainly addressed in the seaports (see Figure 7). In 2009, this objective was addressed for the first time in a publication that looked at the direct transshipment of containers in seaport terminals. Since then, speeding up handling times has been mentioned eight more times, including five times between 2016 and 2020. "Optimizing processes" is a rather generally formulated objective, mentioned five times in the analyzed publications. This relates to publications focusing on the hinterland (2) as well as seaport container terminals (3).

Strikingly, this goal is also only addressed in papers that do not focus on direct container transshipment, except for one paper. "Maximizing the number of direct transshipments" as well as "Minimizing dwell time of containers" and "Reducing emissions" are each addressed once in the analyzed publications.

Looking at the hinterland terminals, Figure 7 shows that most of the objectives cannot be assigned to the specifications and are therefore grouped as "Other". For example, one publication aims to minimize the maximum workload across all cranes. One explanation could be that the layout and consequently the processes in the hinterland are much more individual and therefore the objectives of the publications differ more from each other.

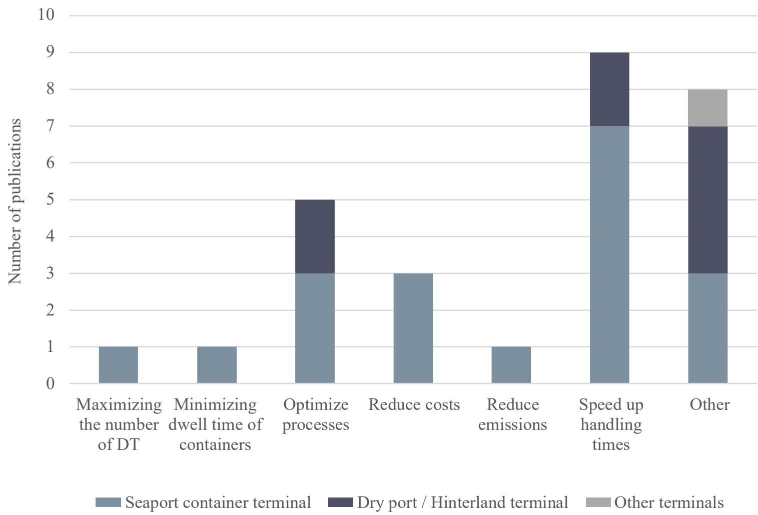

Figure 7: Objective focus of the publications depending on the system

Figure 8 shows the handling mode used in the publications. Since one publication looks at two different modes, there are more mentions than publications looked at.

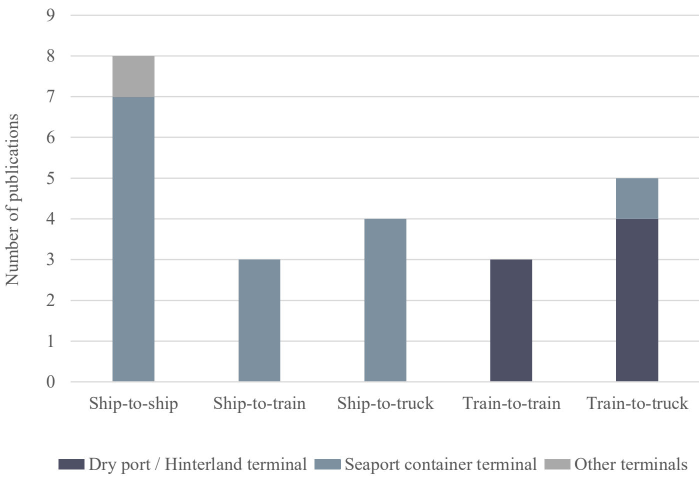

Figure 8: Handling modes of the publications depending on the system

Comparing the handling modes, it is noticeable that in the seaport mainly direct transshipment between vessels is analyzed (see Figure 8). This is surprising since direct handling between two ships not only requires overlapping time windows in handling, but also the loading lists have to be matched. Thus, direct transshipment between two vessels is a very complex planning problem, which is difficult to implement in the industry. Direct handling between vessels and trucks is the second most studied handling mode at seaport container terminals. Compared to vessels or trains, this handling mode has the advantage that trucks are not bound to a fixed schedule and can therefore follow the vessel's schedule and react much more flexibly to delays. Four publications look at transshipment between vessels and trains at a seaport. Given that in a typical layout of a seaport container terminal the quay and the rail facilities are located in separate areas, this type of handling requires additional internal transport of the containers between the two functional areas. This eliminates the need to store containers in the yard, but still requires additional container handling for horizontal transport. At hinterland terminals, the focus of research is exclusively on direct handling between two trains or between a train and a truck, whereby the former is analyzed by three publications and the latter by four (see Figure 8).

Finally, the methods used in the papers are evaluated (see Figure 9). There are also more mentions than publications examined here, due to the fact that in some publications several methods were used.

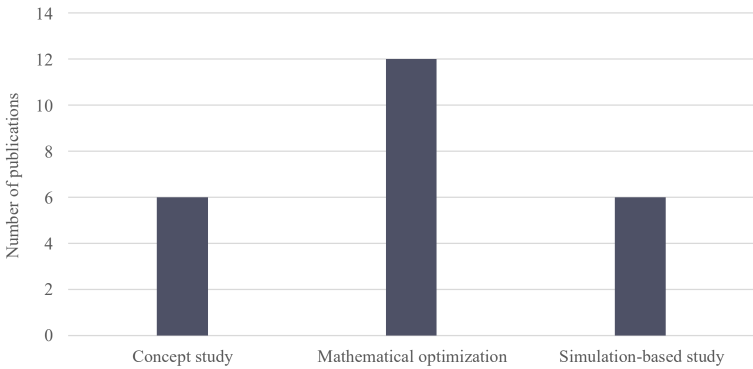

Figure 9: Publications method

In six cases, new concepts are introduced or different concepts are compared. Twelve publications use mathematical optimization to analyze the objective. Also, in six publications a simulation model is created to carry out experiments (see Figure 9). Over the past few years, mathematical optimization has become increasingly popular in science for solving problems. With the help of this method, an (approximately) optimal solution for a defined problem can be found. However, mathematical optimization reaches its limits when modeling larger problems with complex dependencies. Furthermore, the representation of stochastic influences on the system is not possible. For this purpose, the use of simulation would be more suitable. It is assumed that the success of direct container transshipment between two modes of transport is strongly influenced by unplanned and poorly predictable influences, which can rather be mapped by simulation. Therefore, it is expected that if scientific interest in direct container transshipments continues, simulation studies will be increasingly used for investigation in the future. A further possibility is the integrated application of several methods. In particular, the combination of simulation and optimization offers promising possibilities.

6 Discussion

In literature, direct container transshipment has become a small research area which has been studied from time to time over the last 20 years. Overall, it can be noted that the number of publications in this area has increased in recent years. Thereby, direct transshipment between modes of transport was considered both in seaports and in the hinterland. The focus is on ship-to-ship followed by ship-to-truck transshipments in seaports. While ship-to-ship approaches are more suitable for seaport container terminals that almost only transship containers, ship-to-truck and ship-to-train approaches are suitable for seaport terminals that handle domestic cargo (import / export containers). This is due to the fact that there must be sufficient throughput volume at the terminals for a system changeover to be profitable. However, ship-to-train handling has the disadvantage that traditional seaport terminal layouts require additional horizontal transport between the quay and the tracks.

From a theoretical point of view, the direct transshipment of containers can lead to savings in resources and to increasing terminal productivity and transshipment performance by, among other things, reducing storage capacities and transport operations. Nevertheless, it has been shown that direct transshipment often leads to longer berthing times for vessels. This can be explained by the fact that the quayside handling speed at the terminal in particular is strongly dependent on the availability of the downstream equipment. Especially with a large number of containers to be handled, the coordination effort between the equipment at the terminal increases. While delays of transport equipment in indirect container transshipment between two vessels or vessels and trucks / trains can be intercepted by temporary storage of the containers in the yard, small delays in direct transshipment lead to waiting times on the quayside. Terminals try to avoid these delays because, on the one hand, ship-to-shore gantry cranes are the most expensive equipment. On the other hand, the berthing times of the container vessels in the port are extended, which leads to an increase in costs.

While the first two research questions can be answered well with the help of the analyzed data, there is no clear answer to the third question. It has been found that the majority of the analyzed publications used mathematical optimization. Therefore, positive system behavior could be demonstrated in some cases, but the models do not exhibit stochasticity. Thus, conclusions about the behavior of the real system are theoretically possible, but cannot be applied one-to-one to reality. In addition, direct transshipment between vessels has been introduced in some ports. In the process, its feasibility has only been partially proven. Two of these ports are Guangzhou and Dalian in China. In these ports, some of the containers handled are loaded directly from barges onto mother ships.

7 Conclusion

Due to the growing annual container throughput and the accompanying increase in vessel size, there is rising pressure on terminals as central hubs to make handling processes more efficient. One way to increase terminal productivity and throughput, as well as to shorten the time vessels spend in port, is to redesign processes. Numerous traditional approaches to process optimization at container terminals can be found in the literature. This publication analyzes an innovative approach to increasing productivity at terminals. Whereas before the introduction of containers, goods were often handled directly at the quayside, intermediate storage of containers in the yard has now become established. However, there are approaches in science and industry to investigate the direct transshipment of containers between different modes of transport hoping to avoid the multiple handling and intermediate storage of containers in the yard. This approach might be able to save resources on the one hand and terminal facilities on the other.

This publication looked at approaches to direct transshipment between modes of transport at terminals. Based on a comprehensive literature search, a classification scheme was developed to analyze the publications found. Only peer-reviewed publications were considered. A total of 22 relevant publications were identified and classified. Based on this classification, concepts for the direct handling of containers at terminals could be analyzed.

It has been shown that the direct transshipment of containers is still a little researched topic in science. Although there are publications that conduct theoretical studies or use models to analyze direct transshipment, there are still considerable gaps in research in this area, both in terms of content and methodology. In particular, the use of simulation studies offers considerable potential for determining the impact of direct container transshipment between modes of transport on terminal operations. Especially a possible reduction of emissions through the direct transshipment of containers would be exciting to investigate, as sustainably designed processes are becoming more and more important. Other exciting issues arise from, for example, the investigation of pre-gate parking. Possibly, terminals could thus take advantage of direct transshipment and at the same time absorb smaller delays in transportation means.

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VII.
City Logistics

Sustainability in Urban Logistics – a Literature Review

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Purpose: *The importance of urban logistics is on the rise. On the one hand, the population in cities is growing due to urbanization processes. On the other hand, there is a significant increase in the flow of goods (e.g., a boost in online purchases). Such changes are leading cities to face social, economic, and environmental issues, which urge to be addressed. Based on these premises, this study aims to identify, classify and provide an overview of the environmentally sustainable logistics solutions for urban contexts.*

Methodology: *This study performs a systematic literature review. First, it provides a quantitative description of the results, highlighting eventual trends; second, it displays a narrative description of the papers considered to map the current solution and of the related methodology.*

Findings: *The study highlights the maturity and interest in adopting more sustainable delivery options in urban logistics. The selection of suitable transport means, the engagement of stakeholders, as well as the definition of norms and regulations, emerge as the most discussed and promising solutions.*

Originality: *This study is a first attempt to classify the existing body of knowledge related to urban logistics, analysing contributions based on different axes of classification and highlighting cutting-edge solutions to propose possible research directions.*

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1 Introduction

Urban Logistics in the last years is on the rise. The main topic under investigation concerns the process of "optimizing logistics and transport activities accounting of environment, safety and energy savings within the framework of a market economy" (Taniguchi et al., 2002). The rising trend of e-commerce, (+ 20% in 2021, concerning 2020 in Italy) is expected to endure and become a relevant sales channel, creating new challenges for logisticians in the urban context. Parcel delivery, due to order fragmentation, extensive handling operations, missing deliveries and high stop frequencies are identified as the less efficient and most expensive "leg" (around 50% of the total cost) of the logistics operations (Koning et al., 2016). The European Commission quantified, in 2015, the environmental impact of urban freight operations, which accounts for up to 25 % of GHG emissions (European Commission (EC), 2015), value that given the latest trends is expected to grow.

The increasing attention from both logistics operators and public administration led to the identification of initiatives aimed to reduce the impact of logistics in the city context. On one side, legislation (Fossheim and Andersen, 2017) promotes sustainable initiatives (e.g., delivery time windows, tolls for old diesel and petrol vehicles) on the other logistics operators that introduce changes into their delivery operations considering market economies objectives (Sanz et al., 2018). In particular, the portfolio of solutions adopted so far by logistics operators is wide and full of different alternatives

So far urban distribution problem seems to represent a widely discussed topic, with rising attention to the sustainability aspects (social, economic and environmental ones) due to the increasing interest of practicians and policymakers. Some attempts to classify the extant study exists. More in detail, previous literature reviews on city logistics (synonym of urban logistics) were conducted. For example, de Oliveira et al., (2017), identified city logistics as a highly evolving environment in terms of transport methods (e.g., drones, crowdsourcing vehicles). Consequently, a literature review was performed to assess the new configuration of operations and technologies in last–mile delivery in city logistics, that effectively addresses sustainability. Despite highlighting how freight transport is moving towards smaller size vehicle, the review focus on the implication of cargo bikes (legislations, weight limitation and health issues) and electric-powered vehicle. The authors themselves identified as too narrow their research scope, suggesting focusing future research on a broader context that considers different vehicles. Lagorio et al. (2016), reviewed from a logistics and managerial perspective identifying the main area of discussion, research methodology and instrumental papers (i.e, “core line of the development of the discipline”). The results showed how the discussion of city logistics is extremely fragmented and how research focuses mainly on technical aspects (definition/improving solutions) rather than others.

2 Objectives and Methodologies

2.1 Objectives

Coherently with the above discussion, the present paper aims to enlarge the research horizon on city logistics (CL), overcoming the limitations of the previous reviews and categorizing the existing body of literature in the context of city logistics and sustainability. This focus is driven by the rising attention of policymakers towards sustainability (European Commission (EC), 2020), the increasing commercial activities requiring logistics services in cities (e-commerce) and the variety of possible solutions in a CL context as previously highlighted by de Oliveira et al. (2017) and Lagorio et al. (2016). The objective of the research is twofold: (i) classify the extant knowledge and provides a comprehensive view of sustainable CL for academic and practitioners and (ii) identify possible research gaps.

2.2 Methodologies

A systematic literature review was conducted to reach these objectives, in line with the existing reviews (de Oliveira et al., 2017; Lagorio et al., 2016). Four stages were performed in line with Srivastava (2007) and Mangiaracina et al. (2015): literature search – papers were classified and collected; paper classification - highlights of main characteristics of papers; literature analysis – review of the selected study; identification of the potential area of investigation.

2.2.1 Literature Search

The paper classification process includes the following steps, summarized in figure 1:

- Classification context: classification context to categorize the material identified (i.e. city logistics and sustainability)
- Definition of the unit of analysis: single scientific paper, taken from black and grey literature (e.g., conference proceedings) to collect all the updated publications.
- Collection of the publications: Likewise to Mangiaracina et al. (2015) the identification of relevant publications begins using library databases (i.e., Scopus, Web of Science). Then, the research was performed using keywords, (i.e., “city logistics”, “urban freight”, “urban distribution”, “last-mile delivery”, “sustainab*”, “electric*”, “green”, “intermodal”, “innovative”) and their combination, used at least in title, abstract or keywords. The search string is available in appendix 1.
- Delimitation of the field: from all the publications collected, selection of the most relevant ones for in-depth investigation. A first discrimination was performed according to the language (only English), then a restriction on the subject area (See Figure 1) to exclude non-logistic subject areas. Finally, only publications from 2010onwards were selected, period when city logistics started to become a relevant topic. In addition, it allows capturing the most recent discussion on the subject. This first step led to the identification of 667 papers. These papers were then reduced to 341 by evaluating title and keywords and by including the ones where the scope of the paper was on city logistics and sustainability. A further screening phase was performed by reading first the abstract and then the full paper, leading to an identification of 63 eligible papers. The papers were discarded if sustainability was not a central aspect of the discussion.

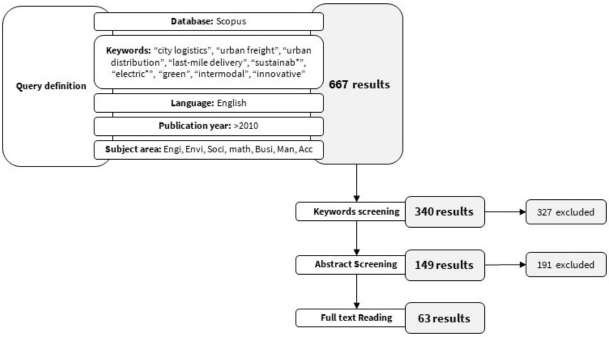

Figure 1: Literature search process (Prisma diagram)

2.2.2 Paper Classification

In phase 2, the paper selected were first classified according to their main characteristics and content (Mangiaracina et al. 2015). Then the contents were analysed and categorized to identify possible patterns that eventually could highlight interesting themes or gaps.

The papers under review were published after year 2010 with a growing interest from 2015 onward. This can be explained as follows. The increasing attention to last-mile deliveries in those years, accelerated by e-commerce growth, increased the interest also on sustainability-related aspects.

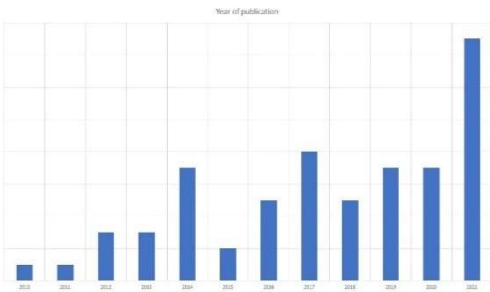

Figure 2: Publication year of the papers selected

The 63 papers under review were published in 37 different journals, addressing different publication areas, namely Logistics and Supply Chain (51 %), Business Management and Social Sciences (20 %), Sustainability (17 %), Technology (6 %) and Mathematics (4 %).

A second classification was performed based on the research methodology adopted. Following Mangiaracina et al., (2015), papers were divided into seven categories, i.e., analytical models (32%), case study (21%), simulations (16%), survey (10%), conceptual framework (7%), literature review (3%) and others (11%).

Papers were also analysed according to their nationality (see figure 3). It emerges how European countries were the most productive followed by North America and Asia, countries with high heterogeneity in city logistics solutions due to the different features of cities and policy (Negabadhi et al., 2019). This breakdown also reflects the engagements of countries in sustainability practices.

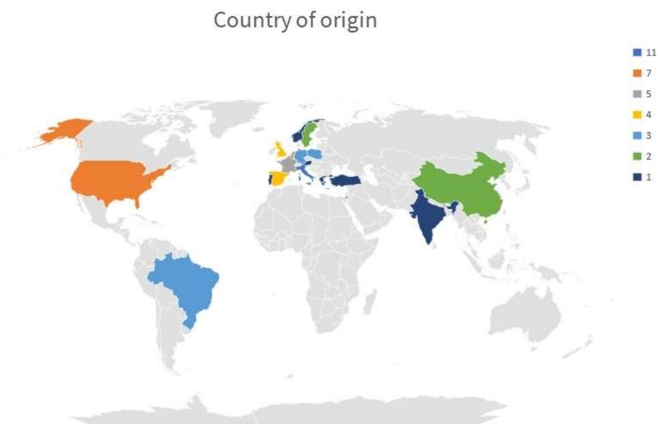

Figure 3: Country of origin of the papers considered. Colours represent the number of publications

3 Literature Analysis – Discussion of Findings

The papers were reviewed according to the contents and solutions proposed. To provide a clear reading of the results to foster a focus on the discussion, a bi-dimensional classification of the content was performed. The papers were considered according to two axes: solutions proposed to improve the sustainability of city logistics operations (i.e., "Leverages for sustainable city logistics") and methodology used to assess city logistics sustainability (i.e., "Impacts").

3.1 Leverages for Sustainable City Logistics

Based on the papers examined, three main enablers of sustainable city logistics emerged, namely transportation means, regulations and stakeholders. In this first part, a focus on the existing solution concerning the use of different vehicles is proposed, showing the characteristics and limitations of each technology. Attention is given to the sustainability aspects were possible.

Transportation means

Most of the papers evaluated, proposed the use of alternative vehicles with respect to traditional vans (i.e., internal combustion engines, ICE), going in a descending order of interest starting from Cargo-Bicycles, Alternative-Fueled Vehicles, Non-Road Transportation and finishing with Autonomous Vehicles.

Cargo bikes (human and electric powered) represent a green solution for city logistics thanks to their huge benefits and reduced investments (de Mello Bandeira et al., 2019; de Oliveira et al., 2017). Given the nature and the reduced capacity of a cargo bike with respect to a van, these vehicles require urban depots, from where parcels are sorted, loaded (Schliwa et al., 2015) and dispatched (Naumov et al., 2021). These hubs are supplied by vans, which can be traditional (Enthoven et al., 2020; Rosenberg et al., 2021) or electric/hybrid (Leonardi et al., 2021). However, while comparing cargo bikes and traditional delivery, researchers put emphasis mostly on the cargo-bikes path rather than considering the overall one (Fraselle et al., 2021; Lee et al., 2019; Navarro et al., 2016). In other cases, instead, cargo-bike activities follow non-road transportation, like railways or waterways (Divieso et al., 2021). Other authors evaluate cargo bicycles as a standalone method for last-mile delivery (Conwey et al., 2017; Melo and Baptista, 2017) while others consider a contemporary use of cargo bikes and vans, where larger parcels or the furthest are delivered from the latter (Fraselle et al., 2021; Leonardi et al., 2012; Llorca et al., 2021). Finally, vans can be used as mobile depots for the cargo-bikes on top of their traditional usage (Anderluh et al., 2017; Verlinde et al., 2014).

On the one side, the benefits identified by the adoption of cargo-bike are several (e.g., zero emissions, urban space occupation) (de Mello Bandeira et al., 2019). On the other hand, cargo bicycles are lower-performing than traditional vans in two points: maximum speed and maximum loading capacity (de Oliveira et al., 2017; Llorca et al., 2021). These two limits are partially overshadowed by the low saturation of delivery vans and city congestion (Allen et al., 2018). Other factors limiting cargo bike adoption emerged (Schliwa et al., 2015): city geography (e.g., accessibility to the city centre) and local authorities (e.g., road regulations).

Electric and hybrid vehicles become more operationally and economically attractive than before (Lebeau et al., 2015; Lin and Zhou, 2020). Alternative-fuelled vehicles show high potential for adoption as they can exploit the positive characteristics of vans while minimizing the operational and organizational effort in reconfiguration. Fully electric (EV) and hybrid vehicles (HEV) were successfully implemented due to their environmental advantages (Li et al., 2019; Lin and Zhou, 2020; Nocera and Cavallaro, 2017; Siragusa et al., 2020). To overcome some of the EVs barriers (e.g., battery capacity), they tend to be used in combination with traditional vans or depots to perform specific task of the delivery process: supply activity for urban depots (Leonardi, 2012; Fraselle et al., 2021; van Duin et al., 2013) or last-mile delivery after other vehicles supply an urban/semi-urban hub (Arvidsson and Browne, 2013; Gonzalez-Feliu, 2014; Moore, 2019). Companies' sustainability objectives, redesign of the network (e.g., recharging point, consolidation centre) and local authorities' support (i.e, financial and regulation) represent some of the barriers to the adoption of EV in a city logistics context (Quak and Nesterova, 2014).

Non-road transportation is usually coupled with road transportation to achieve a high level of synergies, enhancing features of each transport mode. High capillarity of the road network for parcel delivery to reach every destination and high efficiency (costs and emissions) of non-road transportation for freight transport (Alessandrini et al., 2012; Singh et al., 2020). In a city logistics context, the path between depots and the inner city could be performed with public transportation, by exploiting their spare capacity (Masson et al., 2017; van Duin et al., 2019) or by adding dedicated space (Pietrzak et al, 2021; Pietrzak and Pietrzak, 2021) while the remaining part by another type of transports. The main vehicles and infrastructures available are railways, with trains (Guo et al., 2021; Villa et al., 2021) and trams (Browne, 2013; Pietrzak and Pietrzak, 2021) and waterways (Bruzzone, 2021; Divieso et al., 2021; Diziain et al., 2014). Different infrastructure composes the resulted network, requiring higher coordination effort between providers and municipalities (Behrends, 2012).

Autonomous vehicles (e.g., robots and drones) were the less discussed solution. These vehicles are capable of autonomously delivering parcels to customers. Different solutions were studied and compared using an estimative model, mostly in terms of costs (Ostermeier et al., 2021) or an increase in service time (Boyesen et al., 2018; Murry and Ritwik., 2020; Simoni et al., 2020; Swanson et al., 2019). Autonomous vehicle regulation showed a lack of clear direction and many implementation barriers (e.g., acceptance, viability) limits their adoption (Bucchiarone et al., 2021).

Regulations

Policies and regulation definition represents an incentive for companies and people to foster long-term benefits for city liveability and well-being. Historically, regulators' attention was given to the definition of documents that prompt action focused on public and private mobility. However, the rising flow of goods in the city context urges integer freight planning as well, to further improve environmental and social conditions (Fossheim and Andersen, 2017). Different papers present real cases of regulations implementation (Fossheim and Andersen, 2017; Koning and Conway, 2016; Menga et al., 2013) or else present different possible regulations and their potential effects (Morfulaki et al., 2016; Patier and Browne, 2010; Sanz et al., 2018). The main policies identified are related to Limited Traffic Zones, time window operating areas, limitations on the number of vans, tolls for entering the city, benefits for electric vehicle purchase and/or usage, carbon taxes and others.

Stakeholders

Last-mile delivery operations are affected by low effectiveness and efficiency (Seghezzi and Mangiaracina, 2021), due to several factors (i.e., low saturation of vans, order fragmentation, missing deliveries). However, the collaboration between logistics providers and other stakeholders (e.g., citizens and municipalities) plays an important role in reducing the above-mentioned problems.

Thanks to the collaboration between companies more couriers can share infrastructures and/or vehicles, integrating their flows and exploiting the efficiency benefits coming from the resulting network (Bucchiarone et al, 2021; Leonardi et al., 2012; Li et al, 2019; Nocera and Cavallaro, 2012; Rosenberg et al., 2021). A vital role is performed by urban consolidation centres (UCC) and vehicles that affect cost, emission and social health. Integration needed at both operational and IT level between the systems of the different couriers represents the main barrier to the adoption.

Costumers and citizens may participate in two different ways in the delivery process. In the first case, by retrieving the parcel through the usage of parcel lockers or collection points instead of home deliveries. To optimize these “facilities”, their location plays a significant role. Results agreed that collection points have higher performances in a highly densely populated area (Cardenas and Beckers, 2018; Mommens et al., 2021). Parcel lockers may have a dual utility: in one case they can be used as a delivery point (e.g., Brown and Guiffrida, 2014; Cardenas et al., 2017; Vural and Aktepe, 2021) while in another they can be used as micro depot like in Enthoven et al. (2020), in which collection-delivery points were used in combination with cargo-bicycles.

The second option considering people involvement is crowdsourcing: a system in which mainly citizens, during a commuting or non-commuting trip in the urban area, deliver parcels to other people (Giret et al., 2018; Seghezzi and Mangiaracina, 2021; Simoni et al., 2019). Studies in this field focus on understanding the assignment of riders to parcels and customers, evaluating the effect of different transportation means used by riders and on the possibilities of bundling deliveries to decrease the number of riders needed. However, implementation complexities and variabilities (e.g transport mode used, demand and offer match, detours, delivery size) limit the systematic adoption of this solution (Seghezzi and Mangiaracina 2020, Seghezzi et al., 2021, Simoni 2019). It is worth mentioning, however, that some companies already perform this type of service (Amazon flex).

3.2 Sustainability Evaluations

The second line of classification was identified according to the objective of the research in terms of social, economic or environmental sustainability. The following classification was based on the three classical categories of sustainability.

It is first pointed out how different study methodologies to assess the same impact (i.e., quantitative vs qualitative) are used and how frequently more than one sustainability pillar is considered at the same time (e.g., Siragusa et al, 2020 assessed both economic and environmental aspects) due to their possible interaction.

The main impact under investigation is the economic one as different technology, and configurations of the system can provide not only environmental benefits but also an economic one. Several methods were adopted, mostly quantitative, where life-cycle assessments (Fraselle et al., 2021; Nocera and Cavallaro, 2017; Siragusa et al., 2020), vehicle routing problems (Enthoven et al., 2020; Lee et al., 2019; Li et al., 2019) and TPS problem (Naumov et al., 2021) emerged as the most applied. Of particular interest is the study of Gevaers et al. (2014) which attempts to simulate the total cost of last-mile deliveries according to specific last mile characteristics (e.g., transportation means, network) used as independent variables.

The model used differs according to the (i) research objectives (e.g., comparison with the existing solution, distance travelled, failure rate), and (ii) costs considered (e.g monetary or non-monetary). Monetary cost concerns investments and running cost while non-monetary evaluates the corresponding cost of the emission (€/tonCO2, congestion costs).

Complementary to the economic aspects, most of the papers discuss, employing analytical model or case study, the impact of green solutions from an environmental viewpoint. The studies vary accordingly to the micro-pollutants considered (CO2, CH4, NO2, NOx and PM10) and methodology used. Concerning the latter two main methods were the most used: (i) Well-To-Wheel (Alessandrini et al., 2012; Nocera et Cavallaro, 2017; Singh et al., 2020) that considered both the emissions produced during the usage of the vehicle and the one used for producing the energy and (ii) Life-Cycle Assessment that considers emissions related to the entire lifecycle of the product, process or activity (Fraselle et al., 2021; Siragusa et al., 2020; Melo and Baptista 2017;).

Finally, the last pillar of sustainability, social sustainability, is considered. It emerges that this is the less assessed aspect as it is difficult to assess the objectivity of the results (Navarro et al, 2019; Sanz et al., 2018), mainly performed using surveys and qualitative methodologies (i.e., case study). The main aspect considered are traffic reduction, road safety and accident, noise and quality of life improvements (Pietrzak et al., 2021; Navarro et al., 2016; Villa et al., 2021). In most cases, the social aspect is evaluated from the citizen's viewpoint, but some papers attempt to evaluate the same from a logistics worker's perspective (de Mello et al., 2019).

An explicative framework, to graphically summarize the relationship between the leverages and evaluation methods is proposed. The following relationship emerged:

- Economic evaluations were mostly assessed when transportation means and stakeholders were considered
- All the leverages identified were assessed through environmental evaluations
- Lastly, social assessments were limited and performed when regulations and stakeholders were involved.

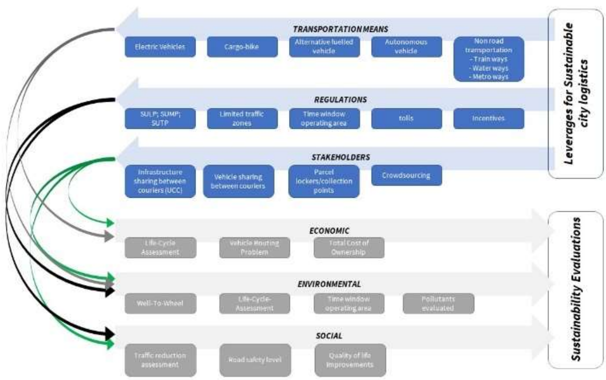

Figure 4: Graphical representation of the classification axes

4 Conclusion

Given the growing attention to sustainability in city logistics operations, a subject increasingly discussed due to the trends of e-commerce, sprawling cities and climate initiatives, this study aimed to yield an up-to-date review of the literature on these topics. The analysis focused on 63 selected papers, published between 2010 to 2021 in 37 different journals. Previous reviews were identified, however, they presented limitations in the time frame (i.e., the latest identified is from 2017), focus (i.e., attention only to operational aspects) or content (i.e., discussion on specific typologies of sustainable solutions). This review aims to overcome the previous limitations, providing a more extended knowledge of sustainable city logistics and implications.

Concerning the content, several areas of interest, all dealing with sustainability, were identified. Three main enablers for sustainable logistics were identified, namely transportation means, regulations and stakeholders. Then social, economic and environmental sustainability were identified and classified accordingly to methodologies and models to assess them. More than 70 per cent of the paper proposed combined methodologies where economic and environmental sustainability were considered together using quantitative methodologies. Limited attention is given to social sustainability due to the complexity of collecting and evaluating the results (Navarro et al., 2019).

This paper has implications for both academics and practicians. From an academic perspective, this study aims to provide knowledge and a clearer classification of the existing solutions to develop sustainable city logistics. It is expected that this paper, due to the rising attention to sustainability from both academics and governments, can provide valuable knowledge on these topics. Implications for practicians are proposed too, with a clear view of the actual solution proposed and tested, their potential benefits as well as the interaction with stakeholders and regulations.

Despite the extant literature providing relevant material on city logistics subjects, some themes are still not adequately addressed or considered. This is both a limitation for academics and practicians that can negatively affect the implementation of these solutions.

First, the extant literature focuses mainly on two specific solutions and a wide combination of them in various networks: electric vehicles and cargo bikes (de Mello Bandeira et al., 2019; Lin and Zhou, 2020; Nocera and Cavallaro, 2017). Other solution, such as shared use of public transportation, robots or drones, shows limited attention despite the great potentiality and the innovative aspects they carry (Giret et al., 2018; Singh et al., 2020; Seghezzi and Mangiaracina, 2020). However, several factors (e.g., regulations, costs, coordination, operational complexity) limit the application of these solutions. Between the options previously proposed, the use of public transport, due to the already existing infrastructure, seems to be the most promising solution for a fast green transition, thanks to a reduced effort required for the implementation.

Second, actual regulations struggle to keep pace with the evolution of city logistics, leading to a mismatch between practicians and citizen needs (Fossheim and Andersen, 2017). A more inclusive regulatory plan, considering more logistics needs would lead to a more integrated and effective mobility plan.

Third, most of the actual research focuses on the economic and environmental assessment (Gervares et al., 2014; Patier and Browne, 2010), with little attention to social assessment that would consider some external factors. With integration with traditional evaluation, a more complete picture of the sustainability objective of a specific solution would be provided.

Finally, a possible limitation of this study should be identified. Despite the research methods being as much inclusive as possible, some studies may have been unintentionally omitted. Despite that, the present review can provide a clear representation of the actual body of research on sustainability and city logistics.

Appendix

The following string was used to search for the document in library databases: TITLE-ABS-KEY(("city logistics" OR "urban freight" OR "urban distribution" OR "last-mile delivery")AND (electric* OR green OR innovative OR intermodal OR sustainab*))

Subsequently, filters on publication year, language and subject area were imposed, resulting in the identification of 668 papers.

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Operation Control Center for automated Vehicles – Conceptual Design

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Purpose: *Although automated vehicles are actively being tested in public areas, they are still limited to the operational design domain and require human assistance. The goal of this paper is to develop a concept for a module-based operation control center (OCC) that enables effective and safe deployment of different types of automated vehicles.*

Methodology: *In order to determine the modules of an OCC, the findings from the requirements engineering from the research project “AS-UrbanÖPNV” were combined with a market analysis. For a better understanding of the interaction of the OCC functions, a cross impact analysis was conducted.*

Findings: *Different use cases were collected and the functional requirements for an OCC were derived. Based on this, a modular architecture of an OCC was created. Finally, future research needs with respect to data analysis were discussed.*

Originality: *The existing OCCs are mostly specialized on the particular vehicle type or transport purpose and hardly take into account the environmental data. A scalable and adaptable OCC architecture can offer synergy effects and many advantages.*

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1 Introduction

Automated vehicles are expected to improve the traffic system in terms of higher efficiency, safety, pollution reduction, service quality and travel experience (Agora, 2020). Automated driving can be applied at different automation levels as well as for different use cases or business models. In addition to private use, collaborative mobility services in particular are becoming a much-promised business model. The greatest contribution to sustainability, better mobility and efficiency can be made by automated vehicles in a shared deployment scenario where they are integrated into public transport services (UITP, 2022). While the automation of individually used vehicles is taking place gradually, the use of automated vehicles for various service offerings in the public transport sector makes sense from automation level 4 (fully automated) (Agora Verkehrswende, 2017).

Although some vehicle manufacturers are already testing their full automated vehicles (level 4) in public area they are still very limited to the operation design domain (ODD) and dependent on human assistance in many traffic situations. In most deployments the presence of a safety person on board to intervene in an emergency or to assist beyond the ODD is required. According to forecasts the fully autonomous driving will not be achieves at least before 2030 (Lalli, 2019). The main problem areas are the human interaction and the efficiency of the journey or transport (Feiler, et al., 2020). If an automated vehicle can no longer proceed on a planned trip, it must be capable of performing a safe stop, also called a “minimal risk condition” or fallback (Waymo, 2021). The unintended standstills and waiting time reduce the efficiency and the acceptance by passengers or other traffic participants (Feiler, et al., 2020). However, in order to be able to use automated vehicles in regular operation today, industry and research are largely in consensus that a human operator should monitor the automated vehicle fleet and support it if needed remotely from an operation control center (OCC) (Leonetti, et al., 2020). Depending on the local legal regulation the remote monitoring and control from the OCC is also prescribed (to a certain extent) for deployment of automated vehicles without a safety person on board. In Germany the so-called technical supervision should monitor and intervene in emergency (emergency stop or restart function) but is not allowed, for example, to drive the vehicle remotely in public space (Bundesministerium für Digitales und Verkehr, 2022).

The goal of the traffic turnaround is to reduce the volume of traffic. Shared and combined (hybrid) transports are becoming increasingly important in this context. To enable a regular operation an OCC is needed. The existing OCCs are mostly specialized on the particular vehicle type or vehicle provider and hardly take into account data from the environment or other sources besides the vehicle sensors. The purpose of this publication is to analyze the current market situation concerning automated driving in road transportation in terms of application fields and technology offer. Based on this, the requirements for an operation control center for different kinds of on-road vehicles und use-cases are collected. Afterwards, the requirements are structured and grouped into modules of an OCC. The modular design of the OCC offers the flexibility and addresses demands of different deployment use cases for automated vehicles in public transport as well as for freight transport (Khan , et al., 2020).

2 State of the art

The SAE J3016 standard defines the level of automation of road vehicles as follows: Level 0 is non-automated driving, where all tasks are performed by the driver. Level 1 is assisted driving. Level 2 is partially automated driving. Here, the accelerator and brake as well as the steering are operated by the system over a certain period of time or in a certain situation. However, the driver must monitor the system at all times and be ready to take over all functions. In Level 3, called highly automated driving, the driver does not have to constantly monitor the system any more, but must be ready to take over the control at any time when the system requests it. Level 4 is fully automated driving. Here, steering as well as accelerator and brake are completely taken over by the system. The driver does not have to monitor the system, but must be prepared to take over all functions. If the driver does not take over the system after being asked to do so, the vehicle has to be able to perform a minimal risk condition, for example to drive to the roadside. Under certain conditions, specified in the operational design domain (ODD) it is possible to operate without a safety person on board. Level 5, autonomous driving, is defined by the system taking over all functions of the vehicle all the time, everywhere and in all conditions. In this case no safety person is needed (Shuttleoworth, 2019).

There are two design approaches for automated vehicles: the modular based and the end-to-end based. The modular design consists of separate software modules for localization, perception, mission planning, motion planning and control. The end-to-end design is based on artificial intelligence and machine learning methods to process the sensor data in order to plan and control the vehicle (Liangkai , et al., 2020). Both approaches have not yet achieved the mature technology level. The main challenges are the road detection, lane detection, vehicle detection, pedestrian detection, drowsiness detection, collision avoidance, and traffic sign detection (Khan , et al., 2020). Furthermore, technical failures or problems with human interaction are possible. Some of the challenges are briefly listed (Liangkai , et al., 2020):

- Artificial Intelligence for AVs and in particular standardization of safety issue, infeasibility of complete testing
- Multisensors Data Synchronization
- Failure Detection and Diagnostics
- Dealing with bad weather conditions and emergency maneuvers
- Interaction with smart infrastructure
- Dealing with human drivers

The fully automated vehicles (level 4) are very limited to their ODD which is specified by the manufacturer. The ODD defines for example the roadway types, infrastructure (intersections, traffic lights, roadside-units), speed range, time of the day or weather conditions under which the vehicle can safely operate. Thus, the state of the art of automated vehicles according to SAE J3016 is between "partially automated" and "fully automated" (Kostorz, et al., 2019).

To increase the safety and provide the vehicle with traffic or environmental information the v2x-technology is used. The included types of connectivity are: V2I – Vehicle-to-Infrastructure, V2V – Vehicle-to-Vehicle, V2N -Vehicle-to-Network and V2P – Vehicle-to-Pedestrian (Coppola & Morisio , 2016). The v2x-communication standard provides two types of messages. Common Awareness Messages (CAM) which are sent out periodically Decentralized Environmental Notification Messages (DENM) which are intended for alerts of hazards and other non-periodical information (Al-Dweik, et al., 2017). With the v2x-comminication (via road side units) the roadmap updating, road events detection, and making up blind spots of AVs is possible (Al-Dweik, et al., 2017). The on-board sensor set should be supplemented by the provides digital map and validated by the vehicle sensors (ERTRAC, 2022).

Furthermore, the use of remote human operators can compensate for the shortcomings and increase the safety and service level of AVs (Zhang, 2020; Kettwich & Dreßler, 2020). The leading manufacturers of automated vehicles are developing the first OCC applications to speed up the transition to regular operation. These applications enable functions such as fleet management, sensor data monitoring, passenger communication and rarely teleoperation (Zhang, 2020). In teleoperation, longitudinal and lateral acceleration can be accessed via the vehicle's so-called drive-by-wire interface, providing real-time control remotely (Phantom Auto, n.d.). The teleoperation service is mostly provided for individual cars as well as indoor and outdoor transport services, but rarely for public transport. The companies like Phantom Auto, Ottopia, Fernride (Fernride, n.d.), Einride developed first software solutions for teleoperation of cars (Ottopia Technolgies, n.d.), trucks and tractors (Phantom Auto, n.d.; Fernride, n.d.; Ottopia Technologies, n.d.; Ottopia Technolgies, n.d.). These OCC applications are quite limited to the particular vehicle type or operational scenario and consider comparatively little environmental data (v2x- or infrastructure data) or logistic data (Schaeffler Paravan Technologie GmbH & Co.KG, 2021).

Recently, the amount research in terms of required functions and implementation of OCCs for automated vehicles has increased. The permissible latency times for data transfer and teleoperation functions and the design of the optimal user interface are often addressed in the literature. However, there is comparatively little research on an OCC architecture and its components derived from the requirements of various use cases and vehicle types.

3 Methodology

In the research project “AS-UrbanÖPNV” a prototype OCC application for automated shuttle buses was developed. The requirements engineering for the control center focused on the use cases for an automated shuttle bus in public transport. Workshops and interviews were conducted with the local public transport company as a potential operator in order to define the functional requirements and its implementation design. The collected data is included in the further OCC module design.

The goal of this publication is the development a flexible and adaptive OCC architecture so that different types of vehicles can be handled. Modularization is one of the essential steps in product engineering. It contributes to more comprehensibility and combinability or recombination of the system. Modular design enables faster and easier adaptations and thus more effective development of the system (Schmidauer, 2002). In order to design the modules of an OCC for the supervision of different automated vehicles the market analysis was conducted. For this purpose, the use cases for the automated shuttle buses were expanded to include other vehicle types and services, such as freight or hybrid transport. The subject of the market analyses were on-road vehicles with automation level 4 (or 5 in the future) for passenger or freight transport and their application scenarios. Since, according to the SAE definition, up to level 3 the presence of a person in vehicle is required anyway. Furthermore, only the shared mobility use cases for public road transport were considered. The analyses exclude the vehicles for individual use and internal transport and handling of goods in logistics facilities such as city hubs and industrial plants.

The market analysis builds the basis for deriving of the main functions and requirements for the OCC and consists of use case analysis and best-practice analysis. After the requirements were collected, they were evaluated with regard to the mutual influence in order to build the functional modules. For this purpose, the cross-impact analysis according to Reibniz (Reibniz, 1992) was chosen.

3.1 Market analysis

The European Road Transport Research Advisory Council (ERTRAC) developed a roadmap for Connected, Cooperative and Automated Mobility in Europe, which defines the stepwise development of automated driving and the Vision 2050 as well as Agenda 2030. According to Agenda 2030 separate domains will emerge and offer a wide variety of use cases such as (ERTRAC, 2022):

- Highway Automation and Assisted Corridors - will enable hub2hub truck operation and cooperative assistance with strong infra support
- Confined Autonomy - will show more and more mastering complexity, main use cases are parking, separate lanes, hub-internal mobility, highway construction sites with strong infra support
- Urban Autonomy - will master complexity with growing speeds and so enable wider ODDs in unrestricted mixed traffic
- Rural Assistance with first Autonomy approaches - enable automated shuttles in sparsely populated areas on specific tracks and first automated municipal and delivery services

Especially for the urban domain vehicles such as valet parking, shuttles in restricted areas without a safety driver for last mile passenger transport or goods transport, bus transport on pre-defined routes (instead if conventional bus routes) as well as taxi-like transport on pre-defined routes are expected till 2030 (ERTRAC, 2022). The level of automation expected in predefined areas of operation by 2030 is level 4, therefore the operations control center is considered an important enabler in all use cases (Mitteregger, et al., 2022).

Since OCC already exists in different technical systems, the main functions of a conventional control center in public transport can be transferred to automated transport, but need to be supplemented with more specified requirements. In order to supplement the functions of an OCC two approaches were combined. First, the literature review and a use case analysis were conducted. Secondly, the OCC offerings of the leading manufacturers of automated vehicles and specialized providers of remote control (teleoperation) applications for road vehicles were researched.

3.2 Definition and analysis of use cases

The literature review identified 19 relevant use cases for automated vehicles for passenger and freight transportation. Of these, 12 use cases relate to passenger transport, 4 use cases to freight transport, 2 use cases to hybrid transport and 1 use case to parking services. Table 1 shows an excerpt of the use case analysis. For each use case, the following considerations (5 categories) were made: (1) purpose of the transport (goods, passenger transport, hybrid, other), (2) operational design domain, (3) target group (users), (4) provider and level of integration in public transport, (5) vehicle requirements and enablers. This enabled a more detailed consideration of each use case in order to subsequently determine the specific requirements for the OCC.

Table 1: Use cases for automated vehicles (excerpt)

Use case	Description
First/last mile feeder to public transport station	Feeder service, fixed route, operational times in parallel to high-capacity public transport, on-demand or fixed stops (e.g. during rush hour) and shared use.
Local bus service	Replacement of local public transport in small cities, on-demand shared fleet-based service, dynamic routing, 24h operation
Special service (campus, business, park, hospital)	Feeder to public transport stations and additional service on private grounds, shared use, scheduled service during morning and afternoon peak – otherwise on-demand. Possibility of hybrid vehicle use carrying correspondence and small parcels.
Bus Rapid Transport (BRT)	High frequency fixed route, fixed stops, separated lane, shared use.

Use case	Description
Robo-taxis	Point-to-point on demand premium service; for private use and sequential sharing
Car-sharing	On-demand sequentially shared private service, reserved for a period of time, dynamic routing, extended operational times.
Intercity travel	Long distance fixed route connection between urban areas on highways
Fleet Depot	Automated and optimized fleet management in the (bus) depot (parking and charging management).
Modular Platform/System	Separation of drive module and transport capsule enables a new type of modularity and thus also a new intramodality
Mobile parcel station transport	Transport of a smaller parcel station as a mobile pick-up station with cargo bikes or automated vehicles
Shuttle trips for goods transport	Shuttle between two closely located sites, e. g., to transport goods between production facilities and/or warehouses. The locations can be connected by private or public roads transports between depots and warehouses
Delivery robots	On-demand delivery tasks for smaller goods (e.g. food delivery, small parcels, tools)

For example, the following characteristics according to the 5 categories were elaborated for the use case “First/last mile feeder to public transport station”:

- Purpose of the transport: passenger transport
- ODD: urban: mixed traffic, presence of vulnerable road user, large variety and complexity of infrastructure, lower speed, day or evening time

- Target group (users): users in areas not covered by public transport core network
- Provider and level of integration in public transport: public transport company; fully integrated in public transport offer, e.g. the operating times are displayed in the passenger information system
- Vehicle requirements and enablers: shuttle buses with a ramp, space for pram/luggage/wheelchair; v2x-communication, high speed mobile network, operation control center.

3.3 Best-Practice-Analysis

As part of the best practice analysis, the typical tasks of a control center in public transport were first researched. Berger et. al. offers a structured compilation of the essential functions of a conventional control center in public transport. These include for example (Berger, et al., 2015) :

- Operations execution: Traffic and operational planning, monitoring of regular operations, vehicle dispatching in case of planned deviations from regular operation, fault management, emergency management, disaster management
- Service tasks: dynamic passenger information, passenger communication, customer service
- Vehicle / depot management: performance and quality controlling

The minimum safety requirements for the vehicle and the control center are also specified in the ordinance on autonomous driving from the German Federal Ministry of Digital Affairs and Transport. Among other things, the regulation prescribes that the control center must be able to stop (switch off) and start the vehicle remotely in an emergency (Bundesministerium für Digitales und Verkehr, 2022).

In order to gather further input for deriving the functional requirements of an OCC, the OCC applications of the leading manufacturers of automated vehicles and specialized providers of remote control (teleoperation) applications for road vehicles were researched. As table 2 shows, some of the applications include the conventional tasks of a control center and supplement them with tele-assist and/or teleoperation functions. In most cases, teleoperation is offered as a separate service by specialized companies. Teleoperation is also more likely to be used at close range, for example on a company site. Some companies offer also a platform-as-a-service to integrate customers own fleet of vehicles into their teleoperation system.

Table 2: Functions of an operation control center of selected provider of automated vehicles and remote control systems

Companies	Fleet Monitoring	Fault / Emergency Management	Dispatching / On-demand	Tele-Assist	Teleoperation	Remote Cockpit	Passenger communication	Communication authorities	Infrastructure monitoring/ control
Waymo (Google)	+	+	+	+	+	n.s.	+	+	-
Ford/Argo	+	+	+	+	-	-	+	+	-
Cruise	+	+	+	+	-	n.s	+	+	-
EasyMile	+	+	+	+	i.p.	-	+	+	-
Navya	+	+	+	+	n.s.	n.s.	+	n.s	n.s
Phantom Auto	+	n.s.	n.s.	+	+	+	n.s.	n.s.	-
Fernride	+	+	n.s.	+	+	+	-	n.s.	-
Einride	+	+	n.s	+	+	-	-	n.s.	n.s.

Legend: + - included; - - not included; n.s. – not specified; i.p. – development inprogress

Sources: (General Motors, 2018), (Jin, 2021), (Easy Mile, 2020), (Einride, n.d.), (Fernride, n.d.), (Ford, 2021), (Navya, n.d.), (Navya, n.d.), (Phantom Auto, n.d.), (THE VERGE, n.d.), (Cluff, 2021), (Argo ai, 2021), (Waymo, 2021)

However, tele-assist, when the operator assists in validating the traffic situation and decision making, is considered an essential function and is being developed by many providers. The existing OCCs have only few interfaces to the infrastructure objects in order to be able to monitor or control them.

3.4 Functional requirements for an OCC

In the first step, all essential functional requirements for a control center were collected. The requirements derived from the best-practice analysis and from the findings of the "AS-UrbanÖPNV" project were additionally supplemented with the specific requirements resulting from the use case analysis. To enable the integration of different mobility service providers, the additional information and interfaces related to logistics services were included into the requirements catalog. The requirements listed below have been identified:

Requirements for public transport

1. Monitoring of the traffic situation with the help of a digital map
2. Monitoring of vehicle sensor data (position, speed, technical status, etc.)
3. Monitoring and visualization of schedule delays
4. Monitoring of the connectivity quality (latency)
5. Classification and visualization of requests
6. Prioritization of requests
7. Vehicle dispatch and dynamic rescheduling (plannable deviations such events)
8. On-demand planning (resource overview and AI-assisted planning)
9. Fault management (technical faults, etc.)
10. Emergency management (alert concept and measures; communication with authorities and passengers)
11. Remote control or Tele-Assist e.g. by confirmation of the journey after evaluation of complex traffic situations, when intervention of an OCC was requested or maneuver-based by providing a new path for the vehicle
12. Teleoperation (with joystick or cockpit), when requested or as a regular service (e.g. parking)
13. Infrastructure monitoring (visualization and status updates traffic lights, construction sites)
14. v2x-communication monitoring (road side units, sensors, warning massages)
15. Infrastructure control (intersections, traffic lights, bollard)
16. Passenger safety (answering of the emergency calls and alerting of the authorities)

17. Passenger communication (answering requests form passengers)
18. System Diagnosis and predictive assistance / maintenance
19. Analyzing the environmental data
20. Monitoring vehicle capacity (passenger)
21. Charging and Batterie Management
22. Providing operative information and visualization of the fleet on the map
23. Demand-driven dispatching and route planning
24. Cybersecurity

Requirements for goods transport

1. Customer communication (answering requests from logistic service customer)
2. Monitoring of delivery schedules and deviations
3. Monitoring vehicle capacity (freight)
4. Providing logistics information: e.g. transport and delivery costs; delivery times; inventory; delivery quality (interface to the ERP system of the logistics service providers, if applicable)
5. Vehicle module management, if hybrid transport (automated or remote-controlled module switch, maintenance, resource overview)
6. Site and infrastructure monitoring for delivery (parking space, etc.)
7. Cold-chain monitoring

4 Building of the OCC modules

After the various functional requirements have been compiled, they are evaluated in terms of their relevance for the operations control center system. The cross-impact analysis was used for this purpose. A matrix with 31 columns and rows consisting of the requirements listed in chapter 3.4 was created. The impact of one requirement on the others was evaluated on a scale of 0 to 2, where 0 - low impact, 1 - medium impact and 2 - high impact. The row totals describe the active impact on the system and the column totals describe the passive impact. By adding the column or row totals and dividing by the number of elements, the limit score for active impact is obtained. The elements that are higher than this score have a predominantly active impact and can be described as system drivers. Our analysis resulted in 15 requirements that lie in the active area. These 15 elements build the core module of the OCC. These elements are common to mostly all application scenarios and vehicle types. Figure 1 shows the common module consisting of these 15 elements and the additional modules.

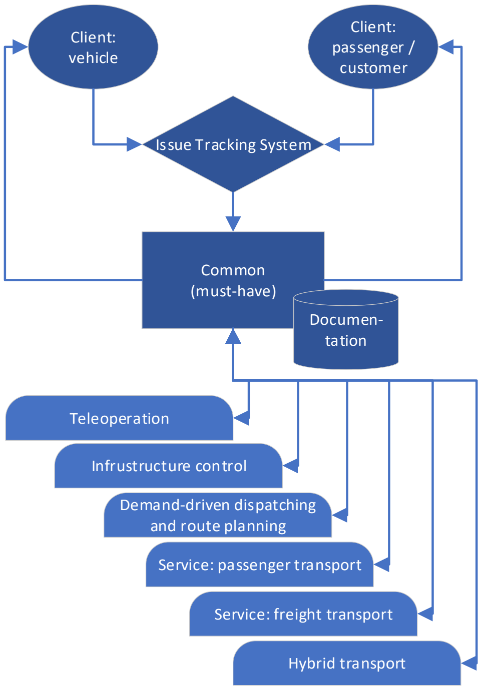

Figure 1: Conceptual modular design of an operations control center (OCC)

4.1 Standard modules

Standard modules include the functions that are essential for the OCC and for ensuring the safety of passengers, cargo and other traffic participants, as well as for the availability of the vehicle. These are also independent of the respective means of travel. Figure 1 shows a possible architecture of an OCC with a common module and further use case dependent add-on modules. These can then be added individually or in combination, for example, depending on the transport task.

The standard workflow of an OCC is to accept and process incoming requests. The requests can either come from the vehicle itself, or from a person via an interface in the vehicle or via a mobile app. For example, the vehicle may send a request at previously defined sections of the route (such as a complicated intersection or traffic circle) where additional validation of the traffic situation is required, or due to a technical error. But also a passenger may want to report an emergency or ask a question. Before the OCC can handle the request, the requests should be classified and prioritized by an intelligent algorithm, so that the most effective processing can be performed. In the prioritization, the emergency request is of course at the top of the list. For the other requests, in addition to the error message or request class itself, other environmental influences such as the current traffic situation, where the vehicle has stopped, infrastructural information, etc. should be considered.

When the requests are sorted by priority and appear in the event list, they can be processed partially automatically, e.g. by predefined automatic response messages or by outsourced intelligent assistance systems. Another part of the requests must be accepted and handled by the human operator. For this purpose, the operator can use the functions defined in the common module (see Figure 2) plus the add-on modules, depending on the specialization of the control center, to handle the issues.

The common module should enable various monitoring tasks. The vehicle fleet should be displayed on a digital real-time map. The map overview should also provide further information on current traffic reports, traffic and infrastructure information. Information on vehicle status and condition must be available on demand.

In case of deviations and error messages, appropriate measures shall be initiated. For example, a vehicle dispatching and rescheduling algorithm can solve the problems of availability of the vehicle automatically. Or the human operator uses the sensor data to assess the situation and initiate appropriate measures. For emergency situations, interfaces to the security authorities should be as automated as possible in order to initiate effective rescue measures. In order to ensure availability, safety and a high level of service, the future control centers for automated vehicles should use the possibilities of digitization and include a continuous system diagnostic. The sensor data and the environmental data can be used for predictive maintenance but also for better prioritization of the incoming requests. Controlling latency is also essential. Especially for tasks such as tele-assist and teleoperation, the operator should always be able to make sure that the delays in the video streams are within the permissible range. Tele-assist (remote control) function is a graphical user interface to interact with the vehicle and passengers. The current vehicle-related information (sensor data) should be visible on this surface and the planned control commands, such as “stop”, “start”, “open doors” or “close doors”, etc. should be implemented.

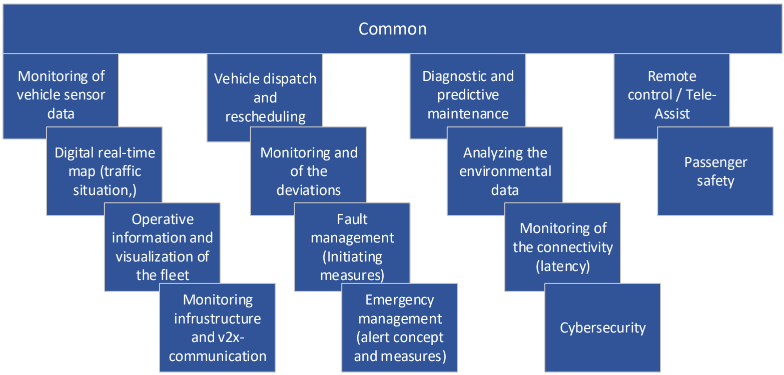

Figure 2: Components of the common module

4.2 Additional modules

The additional modules can be implemented depending on the use case. The teleoperation module is mostly useful if the vehicles are to be remotely controlled in a non-public area. This is often the case on a factory site or in a depot. Since remote control is not allowed in the public sector, at least in Europe. The installation of a remote cockpit is also suitable for teleoperation, although there are solutions with a joystick on the market.

The control of the infrastructure can make sense under certain circumstances, but requires a special permit and will therefore be difficult to implement in the majority of cases. For example, public transport companies could control the priority switching of traffic signals according to demand.

Demand-driven dispatching and route planning software can also be implemented if an on-demand service is offered. Furthermore, service modules for passenger or freight transport can be added. The passenger service module enables the operator to answer passenger requests similar to a call center. For this, the operator can rely on the public transport network information such as departure times and transfer possibilities. The freight service module enables answering of the customer requests and provides logistical information such as current vehicle capacity, delivery times and delay, delivery quality, transport and delivery costs, etc. It enables seamless monitoring of the cold chain and the infrastructure required for delivery (e.g. handling points and equipment).

5 Conclusion and further research

Since vehicle automation is an evolutionary process, it can be expected that the ODD will continue to expand in the coming years. However, as long as the technology has not yet reached the necessary maturity or automation level 5, the control center will play an essential role in the transition to regular operation and serve as a fallback. This will result in new functions for the OCC, which have only been the subject of research for a last few years. While some OCC applications already exist on the market, they are often use case specific and specialized either in fleet management and monitoring or in teleoperation. Teleoperation, however, is more commonly offered for goods transportation.

In order to meet the complexity of the requirements, the different task areas of the OCC must be more strongly networked with each other and with the environment in the sense of a digital ecosystem. Therefore, public transport companies or larger logistics companies are more likely to operate an OCC for the public domain in the future. In order to determine the essential and optional modules of the OCC, the findings from the research project “AS-UrbanÖPNV” were used on the one hand and a market analysis was carried out on the other hand. For a better understanding of the interaction of the identified functional requirements, a cross impact analysis was applied and the common (must-have) module as well as add-on modules were elaborated. The chosen methodical approach has resulted in a concept (rough system architecture) for an OCC. To create the technical and software modules, the functional requirements must be transferred into physical system components, i.e. hardware and software components, including the necessary interfaces. After this, the technical system modularization can take place by evaluating the mutual influences, e.g. with the help of a design structure matrix, and combining them with a clustering or partitioning algorithm to form technically coherent modules.

Nevertheless, by compiling the use cases for both passenger transport and freight transport, it was possible to take a comprehensive look at the functional requirements and compare them with each other. In the future, synergy effects could be achieved by combining freight transport and passenger transport, at least in densely populated urban areas, since the analysis showed that the functions of an OCC differ only slightly depending on the use case.

The common module must essentially perform the monitoring tasks, dispatching, fault management, emergency management, as well as tele-assist (remote control). The required interfaces to the environment and the bus must be ensured. In the case of tele-assist and tele-operation, interfaces in the vehicle must be exposed for communication with the OCC, which represents a possible point of attack for cybercrime. Therefore, the cybersecurity is one of the most important issues for further research. Also, the issues such as request prioritization and systems health monitoring need to be explored in relation to the very complex ecosystem consisting of a mixed traffic, the v2x infrastructure and other environmental influences.

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Guidelines for transferring sustainable urban logistics concepts

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Purpose: *Inner-city freight transports are characterized by numerous deficits, such as congested infrastructure and increasing emission and noise levels. Sustainable urban logistics is a field with many concepts to improve the efficiency and sustainability of these transports. However, guidelines how to transfer and implement successful concepts in other cities are missing.*

Methodology: *We follow a multi-method approach using a systematic literature review, a multi case study analysis and expert interviews.*

Findings: *First, we identify and characterize 16 concepts of urban logistics. Additionally, seven profiles for typical urban areas are developed based on important factors influencing urban logistics. Second, 137 projects in 70 cities are analyzed. The concepts of urban logistics are aggregated to three urban logistics systems. Their fit with typical urban areas is evaluated. Finally, the findings are assessed with expert interviews and a framework for transferring sustainable urban logistics concepts to other cities is proposed.*

Originality: *The adaptation of urban logistics concepts to specific local environments receives little attention in the literature. By proposing a framework for the transfer of sustainable urban logistics systems, this paper integrates the knowledge gained in urban logistics projects in many cities. Future projects may benefit from a faster and more efficient successful implementation.*

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1 Introduction

Increasing urbanization, along with constantly growing online retail and demographic changes, are the main drivers for the increasing demand and intensity of urban freight transport. Supply, distribution and disposal are essential to maintain the functionality of cities. The implementation of these logistics activities serves to satisfy the needs of citizens, commerce and industry in urban areas. But due to resulting negative effects, it conflicts with the ambition of creating livable cities (Straube, Reipert and Schöder, 2017).

In the past, network planning of logistics service providers was focused on supplying a small number of customers or markets with high volumes per stop. For example, freight forwarders' transshipment and consolidation centers were often located outside the city, and deliveries to customers were made by vehicles with large load volumes with an optimized vehicle capacity utilization. Dedicated logistics space in city centers was rarely considered advantageous due to high land prices and additional handling costs. More recently, the growth of online retail, among other things, has led to an increase in B2C deliveries to private households, characterized by low delivery volumes and a high number of stops per tour. This results in a reduced vehicle capacity utilization in existing freight transport concepts and at the same time an increasing number of vehicles required for supply and disposal. Therefore, a growing need for sustainable urban logistics concepts emerged and both academia and practitioners face the challenge of developing, testing and implementing scalable and transferable concepts.

So far, concept development and testing in urban logistics has focused almost exclusively on individual cities and their local characteristics. Each project is initially launched as a pilot project, developed from scratch and afterwards adapted to the specific circumstances of the focal city (Iwan, 2014). Hence, one of the biggest problems of urban logistics is not a lack of opportunities to optimize inner-city flows of goods, but a lack of concepts for successful transfer and implementation (Stoelzle and Preindl, 2019).

Initial approaches in the context of transferring urban logistics can be found in Baindur and Macário (2013). They analyze the basic requirements and transferability to other cities based on a case study of a lunch box delivery system in Mumbai. Macário (2013) considers urban zones based on three dimensions: City characteristics, stakeholder needs, and product characteristics. By analyzing the similarities and differences of the zones, a best practices approach for transferability of city logistics can be derived (Alho and Abreu e Silva, 2015). Ducret, Lemarié and Roset (2016) develop a spatial clustering of urban zones based on local geographic characteristics with the aim to support logistics service providers and public administration in location planning and development. Based on the clustering, transferability of logistics systems can be tested to a limited extent (Ducret, Lemarié and Roset, 2016). Still, it is limited by only considering geographic influencing factors and by missing adaptation strategies across unequal clusters.

The adaptation of urban logistics concepts to specific circumstances receives little attention in literature. Tadić, Zečević and Krstić (2014) develop a general procedure for the structured selection of the most suitable components of urban logistics concepts based on local characteristics. Specific influencing factors must be determined individually for each city by expert groups. However, possibilities for the design of the components are not considered in detail.

There is a lack of practice-relevant models for transferability strategies of successful urban logistics concepts (Stoelzle and Preindl, 2019). Future projects can be implemented faster and more successfully by systematically considering factors that influence the optimal design of urban logistics concepts (Bienzeisler, et al., 2018). Considering the large number of projects currently ongoing and in planning, this can lead to significant time savings, efficiency gains and a higher success rate of implementation.

Addressing this research gap, the subject of this article is the transfer of sustainable city logistics concepts to representative city profiles. Decision makers and logistics companies shall be supported in the development of a specific city logistics system and practice-relevant guidelines for a successful transfer of already established logistics concepts.

2 Theoretical background

The literature on urban logistics is highly fragmented and no universal definition of urban logistics exists in academic literature. An overview of different definitions of urban logistics can be found in Rose, et al. (2017) and Wolpert (2013), among others. Following Gonzalez-Feliu, Semet and Routhier (2014), the authors of this article view urban logistics as a multidisciplinary field that aims to understand, analyze and link the different stakeholders, logistics concepts and planning actions related to the improvement of supply chains, logistics systems and freight transport in urban areas, emphasizing their synergies and decreasing related negative externalities.

One of the main characteristics of urban logistics is that it operates in a complex and highly condensed environment with a large number of different stakeholders (Nesterova and Quak, 2016). As some of these stakeholders pursue very different objectives it becomes important to consider the individual interests and interactions with each other when planning and designing urban freight transport. Taniguchi (2014) identifies shippers, transportation companies, public administrations, and residents as relevant stakeholders of urban logistics. Similar approaches can be found in Nathanail, Gogas and Adamos (2016), Wolpert (2013), Bozzo, Conca and Marangon (2014), and Russo and Comi (2010). The objectives of these stakeholders overlap only in parts and are highly divergent in several aspects, something which should be considered in urban logistics design.

Individual measures that support achieving the sustainability goals of urban logistics are called urban logistics concepts. Each of these different concepts affects only a part of the overall urban logistics objectives. One example of this is the substitution of vehicles with conventional drives by battery-electric vehicles or cargo bikes on the first and last mile (Sinn, 2020). Among other things, this substitution enables a reduction in local emissions, but may not be economically advantageous for the transport companies (Taniguchi, 2014). In order to compensate for the disadvantages of individual concepts and/ or to realize synergy effects, several concepts can be combined, such as the subsidization of electric vehicles by local and national governments. The resulting construct is described as an urban logistics system. A successful urban logistics system addresses the interests of all stakeholders involved, i.e., economic, environmental, and social goals (cf. Figure 1). To achieve this, individual urban logistics concepts must be tailored to the local conditions of the city (concept-level) as well as to each other (system-level).

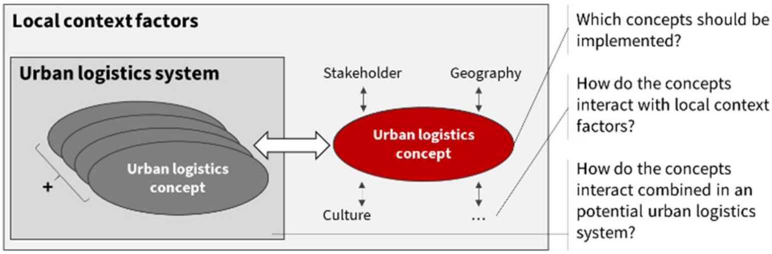

Figure 1: Context factors of urban concepts and systems

So far, interactions between urban logistics concepts and urban spaces on the one hand and between the different concepts themselves on the other hand have only been examined to a limited extent. Therefore, it is necessary to identify successful concepts and their local influencing factors. To enable the transfer of sustainable urban logistics concepts to other cities, it is also necessary to identify possibilities to adapt each concept to the specific circumstances of the focal city.

3 Research design

The topic is addressed using a multi-method approach. First, a systematic literature review is conducted to gain insight into urban logistics concepts as well as factors influencing urban logistics and possibilities to customize the identified concepts. Second, a case study analysis is performed and data on urban logistics projects in European cities is collected. Profiles for typical urban areas are derived and best practices for each profile are identified. Third, semi-structured interviews with urban logistics experts are used to validate and complement the results and to form a framework for transferring sustainable urban logistics concepts to other urban areas. In the following, the different methods are described in more detail.

3.1 Systematic literature review

The systematic literature review is employed using the approach by Durach, Kembro and Wieland (2017). It is chosen because it is a framework specifically designed for the research area of logistics and supply chain management. In addition, the Subject Pearl Growing method is used. This method describes the process of successively deriving keywords from a small number of relevant works and defining exclusion criteria. The terms and criteria identified from these are used in subsequent searches to achieve a higher quality of search results. (Zwakman, et al., 2018)

Three search iterations are performed. At first, relevant publications are found by means of an internet search on common search portals (Google, Bing, Ecosia) and the involvement of experts. Resulting keywords are used in a second iteration to identify additional works via the Web of Science and Ebsco portals. The following search strings are used:

(i) urban logistics AND concept

(ii) urban logistics AND sustainable

(ii) (urban OR city OR last mile) AND (Logistics OR freight transport OR freight distribution) AND (concept OR system OR approach OR characteristics OR measures OR models OR typology).

In addition, in a third iteration, the bibliographies of particularly promising works were examined for further publications and included in the pool of literature. A total of 260 search results were identified. The results were consolidated, and duplicates were removed which led to the exclusion of 29 works. This was followed by the elimination of publications based on the developed exclusion criteria given in Table 1 by screening abstracts and conclusions. On this basis another 92 search results were excluded. Finally, after examining the full text, another 47 works were excluded. The final literature sample comprised 92 works.

Table 1: Exclusion criteria for literature review

Exclusion criterion	Reason for exclusion
Language not English or German	Limited by language skills of the authors
Not last mile logistics	Research focus on urban logistics

Exclusion criterion	Reason for exclusion
General descriptions, no focus on urban logistics concepts	Low probability of identifying concrete influencing factors and design options
No freight transport	Pure passenger transport is outside the scope of work
No focus on sustainability	Traditional urban logistics only relevant for basic understanding
Pure mathematical optimization and/or software integration	Low probability of identifying concrete influencing factors and design options

3.2 Case study analysis

The objects of analysis are existing and past urban logistics projects in Europe. The focus on Europe was chosen to allow a higher comparability of the projects. Europe was identified in the systematic literature review as the epicenter of research on urban logistics. In addition, due to the major changes that have occurred in urban logistics as a result of digitalization, only projects completed in the year 2000 or onwards are considered.

The cases were identified via online search based on projects already identified through the systematic literature review and an additional selection of European cities. A diverse selection of cities emerged in terms of population size and the related country.

Table 2: Project-specific success factors

Area of success	Success factors
Economic	Duration of the project; continuance of the project; extensions of the project; successful collaborations; sales increases; cost reductions; image improvements
Ecologic	Reduction of emissions (CO2, NOX, particulate matter, etc.); reduction of fuel consumption; reduction of driven (ton) kilometers; higher utilization rates of vehicles
Social	Reduction of noise; reduction of congestion; reduction of driven (ton) kilometers; access to new services; creation of jobs

On the one hand, data specific to the project was gathered to be able to evaluate the success of the project. Namely information on economic, ecologic, and social factors were collected (cf. Table 2). The lack of public access to information about the projects makes a clear assessment difficult for some factors. In this case, an estimation had to be made.

On the other hand, project-independent information on the city was gathered to analyze the context in which the projects operate successfully (cf. Table 3). The success factors are based on the results of the literature analysis. The lack of (public) availability of information on some factors poses a major challenge.

Table 3: Project-independent, city-specific context factors

Area of context	Context factors
Shipment structure	Population; population density; GDP; GDP (growth); GDP per person; GDP per person (growth); e-commerce share (based on De Marco, Mangano, and Zenezini, 2018; Rose, et al., 2017)
City prosperity	GDP; GDP per person

Area of context	Context factors
Land availability	Number of inhabitants; area; population density; prices of inner-city areas
Urban infrastructure	Infrastructure quality according to European Regional Competitiveness Index; congestion levels; smart city ranking;
City clustering	Number of epicenters of daily life in the city (Senate Department for Urban Development and Housing (2017))

3.3 Expert interviews

To validate the findings and to fill the gaps that could not yet be answered via the systematic literature review or the case study analysis, semi-structured interviews are conducted. The interview guideline consists of three sections: section 1 gives statements on assumptions and customizing of urban logistics concepts; section 2 focuses on urban logistics on a system level; and section 3 is dedicated to the implementation and applicability. Three experts from (academic) research in logistics and supply chain management from German and Swiss universities were interviewed. The experts were given statements, such as “Do you agree with the most important influencing factors in the category "infrastructure approaches"? Which factor do you rate as particularly relevant?”. They were asked to rate the statements on a five-level Likert scale and to comment. The interviews were subsequently transcribed and send to the experts. They validated the transcripts. If they gave any comments, those were incorporated accordingly.

4 Review results

The literature review is conducted with the aim to (i) identify concepts of urban logistics, (ii) identify local context factors influencing the urban logistics concepts and (iii) identify possibilities for adapting the concepts in different environments.

The formal analysis of literature characterizes the authors, year of publication, country of publication, methodology (theoretical/ empirical), point of view (descriptive/ normative), and research area. Classification based on these criteria is a common procedure for literature analysis in logistics and supply chain management (Croom, Romano and Giannakis, 2000; Olsen and Ellram, 1997).

The final literature selection consists of 92 unique works , which are listed in detail with a brief summary in the appendix. Urban logistics has seen a clear increase in scientific publications over the last decade. There is a global interest in urban logistics, with Europe identified as the epicenter of urban logistics research. Descriptive and normative research is about equally present in the literature on urban logistics.

Regarding the content of the identified literature, four research areas within urban logistics are identified: (i) theoretical foundations, (ii) enablers/ basic technologies, (iii) urban logistics concepts and systems, and (iv) evaluation and assessment.

A total of 16 urban logistics concepts are found and assigned to five categories. Table 4 lists the concepts to each category and gives a brief description. In addition, local context factors for each category of concepts are compiled and shown in Table 5.

Table 4: Concepts of urban logistics

Concept	**Description**
Category 1: Approaches to land use	
Loading bays	Dedicated handling areas in public spaces that act as pick-up/ drop-off stations for fine distribution in the city (Wolpert, 2013).
Multiple use lanes	Road lanes that, on the basis of certain characteristics, may only be used by a subset of all vehicles (Russo and Comi, 2010).
Category 2: Infrastructure approaches	

Concept	Description
Urban Consolidation Center (UCC)	Urban Consolidation Centers are decentralized logistics sites in the periphery of urban areas where freight flows are consolidated and distributed with fewer and/ or smaller delivery vehicles (Morfoulaki, et al., 2016; Souza, et al., 2014).
Micro Consolidation Center (MCC)	Micro Consolidation Centers are decentralized logistics sites in urban areas where freight flows are consolidated and delivered with fewer and/ or smaller delivery vehicles to their point of destination (Crainic, et al., 2009).
Pick-up/ drop-off stations	Similar in function to UCC/MCC but connecting carriers and shippers/ recipients. The carrier delivers the goods to the station, which later are picked up by the recipient. Returns can be handed over to the carriers (Quak, Balm and Posthumus, 2014).
Modal split concepts	Shifting freight traffic from road to other modes of transport, e.g., rail/ public transport, water, air (Liu, et al., 2008; Mazzarino and Rubini, 2019).
Category 3: Technological approaches, traffic management	
Environmentally friendly drives	Use of emission-free/ low-emission means of transport for freight transport on the road (Taefi, et al., 2016).
Cargo bikes	(Electric) bikes with transport capacities between 50-500 kg, that are often used for last mile deliveries in urban areas (Nürnberg, 2019).
Intelligent transportation system (ITS)	Collecting, transmitting and processing of traffic-related data with information and communication technologies with the aim to optimize and shape inner-city traffic (Moerke, 2007).

Concept	Description
Category 4: Access restrictions	
Access restriction	Access restriction based on physical attributes (e.g., weight, length/ width, load factor, emission levels) or time limits (e.g., delivery window) (Russo and Comi, 2010).
Toll/ road pricing	Fee for the use of transport infrastructure, e.g., roads (Marco, et al., 2018).
Category 5: Other approaches	
Overnight logistics	Shifting transports for delivery or pick-up to the nighttime (Kirsch, et al., 2017).
Crowd logistics	Transferring the concept of the sharing economy to logistics, specifically outsourcing of transport contracts to private operators (Buldeo Rai, et al., 2017).
Logistics pooling	Transferring the concept of the sharing economy to logistics, specifically sharing logistical resources between companies (Gonzalez-Feliu, and Salanova Grau, 2012).
Use of future technologies	Significant support for urban logistics by maturing technologies, e.g., 3D printing, robotics technology, autonomous driving (Savolainen and Collan, 2020; Graham, Mehmood and Coles, 2015).
Logistics outsourcing	(Mandatory) outsourcing of logistics activities to external companies

Table 5: Local context factors

Category	Urban logistics concepts	Local context factors
Approaches to land use	Loading bays; multiple use lanes	Land availability, freight traffic volume, enforceability
Infrastructure approaches	UCC; MCC; Pick-up/ drop-off stations; modal split concepts	City prosperity, land prices, land availability, shipment structure
Technological approaches, traffic management	Environmentally friendly drives; cargo bikes; ITS	City prosperity, technology availability, infrastructure quality, consignment structure
Access restrictions	Time limits; restrictions based on physical attributes; toll/ road pricing	Structure of the local economy, congestion, acceptance of the measures
Other approaches	Overnight logistics; crowd logistics/ logistics pooling; use of future technologies; logistics outsourcing	n/a (concepts are too different)

Based on the case study analysis, seven types of city profiles are identified. The decisive criteria for subdividing the profiles are the number of inhabitants and the average GDP per person, which is intended to reflect the prosperity of the city (cf. Table 6). The respective city profiles contain internally homogeneous characteristics of relevant factors for urban logistics, such as land availability, land prices, congestion levels, infrastructure qualities and e-commerce levels.

Table 6: Classification of typical city profiles and examples

Type	Description	Population	Average GDP per person	Example
1	Large metropolis with high GDP per capita	> 500.000	> 65.000 € p.a.	Paris, Munich
2	Large metropolis with medium GDP per capita	> 500.000	> 35.000 € p.a. < 65.000 € p.a.	London, Berlin
3	Large metropolis with low GDP per capita	> 500.000	< 35.000 € p.a.	Barcelona, Lisbon
4	Small metropolis with high/ medium GDP per capita	< 500.000 > 100.000	> 35.000 € p.a.	Zurich, Bologna
5	Small metropolis with low GDP per capita	< 500.000 > 100.000	< 35.000 € p.a.	Porto, Bergen
6	Medium-sized city with medium/ high GDP per capita	< 100.000 > 10.000	> 35.000 € p.a.	St. Gallen
7	Medium-sized city with low GDP per capita	< 100.000 > 10.000	< 35.000 € p.a.	Lucca

The location of the analyzed 137 urban logistics projects is shown in Figure 2. The highest number of projects was identified for city type 2, large metropolis with medium GDP per capita (39%), followed bay city type 4, small metropolis with high/ medium GDP per capita (16%) and city type 1, large metropolis with high GDP per capita (13%).

Only 30% of the reviewed projects focus on one single logistics concept was implemented whereas 70% of projects are combining multiple logistics concepts. This highlights the relevance of researching urban logistics systems in practical implementation. The most common urban logistics concepts identified in the analyzed projects were the usage of environmentally friendly drive technologies (39%) and access restrictions, including tolls (26%). 20% of the projects distribute via micro consolidation centers and another 20% follow a modal split concept by handling at least part of their inner-city transports by rail or passenger transport. The usage of cargo bikes for urban distribution was seen in 19% of the projects. Approaches to land use are only considered in 7% (loading bays) resp. 4% (multiple lane use) of the projects.

Figure 2: Locations of analyzed urban logistics projects in Europe

Also based on the case study analysis, three types of successful urban logistics systems could be identified. Each of these types is to be understood as a "basic framework" that can be adapted to local contextual factors and expanded on a case-by-case basis with other urban logistics concepts. In addition to these "basic types" of urban logistics systems, there are also intermediate stages with parallel use of two types of urban logistics systems, particularly in problematic areas.

Type A: Single-stage UCC-based urban logistics systems

Type A urban logistics systems are primarily used in medium sized cities (city types 6 and 7), as well as in isolated cases in city type 5. They consist of a provider independent UCC on the outskirts of the city from which the supply to the city center is ensured by a neutral last mile service provider (cf. Figure 3). In most cases, the focus lies on a problem area (esp. downtown) or a problem customer (e.g., trade fairs, construction projects). A major hurdle in implementation and operation is the low freight traffic volumes in cities of this type. The adoption of UCC services is therefore usually supported by the implementation of accompanying regulatory instruments, e.g., access restrictions in the inner-city area. In this case, the vehicles of the UCC can access the inner-city area either exclusively or with discounted access. The access-restricted zone contains loading bays for carrying out necessary handling processes. In addition, access to the zone is protected with conventional ITS, e.g., by means of a barrier and access control based on an electronic identification procedure. As an additional regulatory instrument, the use of the UCC can also be made obligatory for deliveries into the city center.

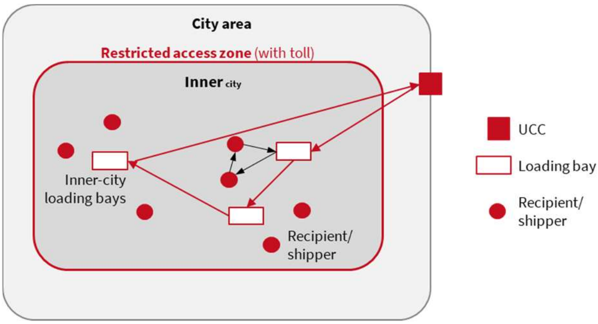

Figure 3: Urban logistics system – Type A

Type B: Single-stage complex UCC-based urban logistics systems

Urban logistics systems of type B show a high prevalence in cities of types 3 and 4, and in somewhat lower proportions in types 2 and 5. Cities of these types are characterized by intensive freight movements for supply and disposal. The volumes are high enough to allow UCCs to operate profitably even without regulatory instruments apart from environmental taxes. For this reason, concepts such as private dedicated UCCs of a single logistics service provider are enabled. This simplifies the transition to UCC-based systems and reduces administrative expenses, but is accompanied by lower bundling effects. The urban logistics system here usually focuses on entire urban areas or large areas within the city.

Compared to Type A, Type B systems are characterized by a higher degree of complexity, i.e., in addition to the pure bundling of goods flows, further urban logistics concepts are implemented. These include pick-up/ drop-off stations, access restrictions based on vehicle emission levels, ITS (automatic toll controls, traffic telematics) loading bays, multiple use lanes, and multimodal approaches (water, rail).

Type C: Multi-stage complex UCC-based urban logistics systems

Type C urban logistics systems are predominantly used in type 1 cities and partially in Type 2 cities. The high level of e-commerce shipments in these cities requires the use of a two-tier urban logistics transport system with a UCC on the outskirts of the city and a multitude of micro hubs within the city. Environmentally friendly drive technologies and modal split concepts are applied in the transportation relation from UCC to micro hubs. Furthermore, between micro hubs and the end customer and/ or pick-up/ drop-off stations, cargo bikes and hand trucks are used. The city's supply and disposal can be parallel single-stage or also use the micro depot network. Stakeholders of the UCC are connected via a digital platform and advanced ITS (e.g. dynamic toll systems, intelligent traffic control, parking sensors) are implemented.

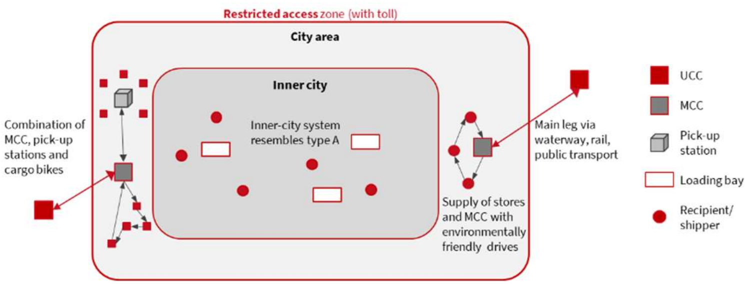

Figure 4: Urban logistics system – Type C

Due to the large number of urban logistics concepts, some of which are implemented in parallel, type C systems are the most complex of the three successful types of urban logistics systems.

Based on the previous findings, the identified urban logistics concepts can be classified into four categories based on their advantageousness in different city types (cf. Figure 5). The most beneficial combination, shown in black, represents the "basic" type of urban logistics system. Red indicates urban logistics concepts that are not absolutely necessary for the implementation of the core system but are still advantageous. The third level - shown in grey - marks urban logistics concepts that can eliminate or reduce deficiencies of the urban logistics system in certain situations in a particular city type. In addition, white entries mark urban logistics concepts that have little/ no advantage or even disadvantage in the respective city type.

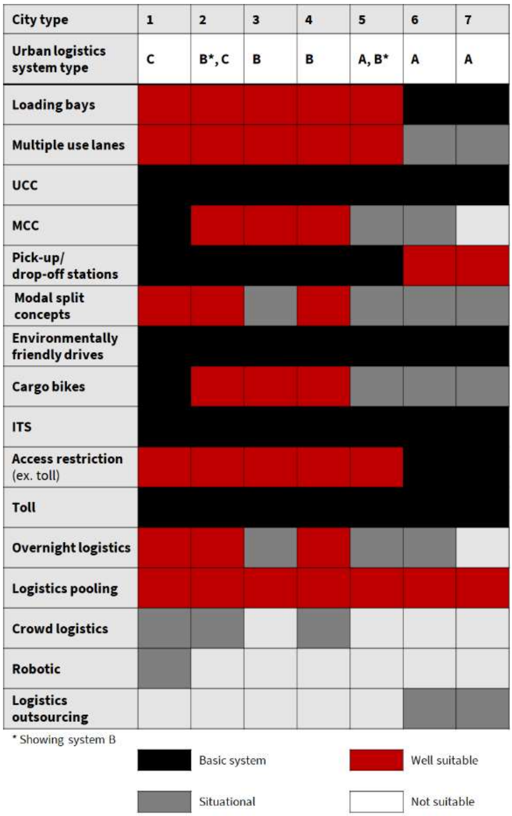

Figure 5: Suitability of city logistics concepts per city type

Three types of urban logistics systems (A, B and C) emerge, each of which can be assigned to specific city profiles. In addition to the "basic framework" of these types, urban logistics concepts can be found, which are well suited or at least situationally well suited for implementation in this system. In a next step, the possibility of adapting the urban logistics concepts within the system will be explained.

5 Framework and guideline

To develop a framework, the process of implementing urban logistics systems is divided into three phases: (i) design and assessment phase, (ii) implementation phase and (iii) evaluation phase (Taniguchi, 2014). This paper focuses primarily on the design phase. However, downstream factors of the implementation phase must also be considered in the design of an urban logistics system, as it reduces the susceptibility to error during implementation.

Three approaches can be distinguished in the design phase: (i) Complete redesign, (ii) transfer and adaptation of best practices and (iii) direct copying of best practices (Iwan, 2014). A complete redesign has the greatest degree of freedom and thus the greatest adaptability of the system to local contextual factors but is associated with the greatest expenditure. Direct copying of best practices, on the other hand, is the easiest option and gives the advantage of relying on proven solutions. Without an adaptation of the transferred best practices, this again has the disadvantage of not integrating local factors into the design.

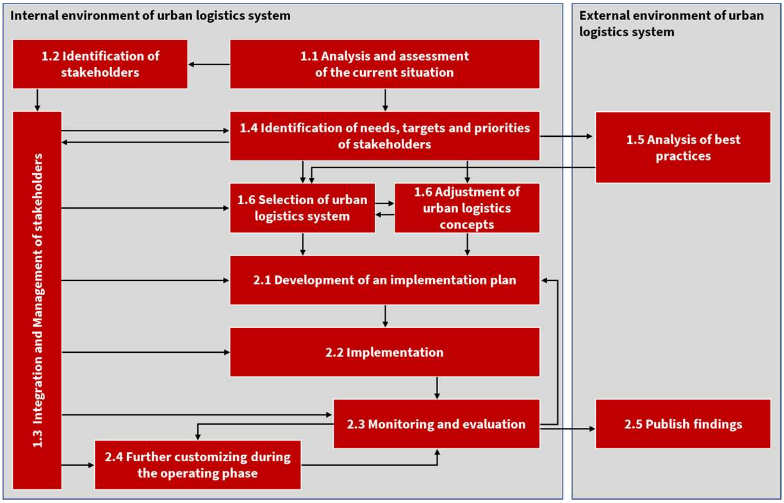

Figure 6: Framework for transferring urban logistics systems

The advantages of both approaches are combined by approach (ii), the transfer and adaptation of best practices, thus mitigating the mentioned disadvantages. The methodological guide by Iwan (2014) serves as an underlying framework for transferring and customizing best practices and is further developed. Figure 6 gives an overview of the resulting framework.

1. Design and assessment

The urban logistics project starts with the design of the urban logistics system. For this, the existing situation must be analyzed, and a suitable system must be identified. Important factors in the design of urban logistics systems are the integration of all stakeholders, an accurate and realistic analysis of the potential of the urban logistics system and the integration of the individual measures into a system.

1.1 Analysis and evaluation of the current situation

The first block involves recording the current inner-city flows of goods and analyzing them with regard to possible weaknesses/ efficiency losses in the existing freight transport system. Primary and secondary data (concrete flows of goods, general customs statistics, etc.) can serve as a data basis, but it should be noted that little information on intra-urban flows of goods is (publicly) available (Ibeas, et al., 2012). A realistic estimation regarding the volume of goods traffic has a high relevance, because incorrect estimation was one of the main reasons for the failure of urban logistics systems in the past (Faure, et al., 2013). This step can be initiated by a private sector company or group of companies, or by a public sector actor (Stoelzle, et al., 2020). In both cases, it is recommended that a neutral public last mile coordinator is identified early on to take the lead on the project (Ninnemann, et al., 2017).

1.2 Identification of Stakeholders

Parallel to the analysis of the current situation, the identification of the (most important) stakeholders should be carried out. This forms the basis for the subsequent integration of the stakeholders into the process and enables the direction of the urban logistics project to be set at an early stage.

1.3 Stakeholder integration and management

Involving stakeholders as early as possible and proactively managing them is one of the factors for the success of urban logistics. The neutral public last mile coordinator has the task of bringing all stakeholders together and to ensure their commitment throughout the entire process (Iwan, 2014). It is also important to communicate (interim) results to stakeholders who are not actively involved (e.g., a large part of the population) and to address their concerns. This will increase the acceptance rate of urban logistics systems (Morfoulaki, et al., 2016).

1.4 Identification of stakeholder needs, goals and problems

Successful integration of stakeholders into the process requires that the individual needs, goals and problems of the stakeholders are taken into consideration. These can be presented by the stakeholders themselves, (e.g., at citizens' meetings) or generalized listing of objectives of individual stakeholder groups can be used, as given in Taniguchi (2014), Nathanail, Gogas and Adamos (2016) or Russo and Comi (2010).

1.5 Analysis of best practices

The next step is to develop a catalog of urban logistics concepts. This should contain the most important information on the modes of action, sustainability, influencing factors and adaptation possibilities of the concept components.

1.6 Choice und Customizing

Based on the collected data and interviews, the urban logistics system is selected and designed. This includes the selection of the urban logistics concepts that will be integrated in the urban logistics system, their specific design and the underlying business plan. The business plan must be based on realistic estimates of freight traffic volumes (Faure, et al., 2013) and to rely on fair, economically sustainable profit distribution, possibly with recourse to compensation payments (Stoelzle, et al., 2020). Furthermore, the extent to which the project is publicly funded should be decided, as urban logistics systems without public funding and/ or legislative support are characterized by low success rates (Gonzalez-Feliu; Salanova Grau, 2012).

The selection of urban logistics concepts should also consider the extent to which the concepts are adaptable to local factors that are not covered by city profiles, e.g., topography or the "shape" of the city (e.g., long/ stretched or circular). Furthermore, concepts should not only adapt to local context factors, but also to other concepts used in the system.

2. Implementation and evaluation

The design and assessment phase is followed by the implementation and evaluation of the previously designed urban logistics system. The measures with the highest priority should be implemented first and successes should be communicated. Implementation of the urban logistics system should be fast and iterative, and detailed adjustments to the concepts should be made during operation. The publication of findings serves as a global exchange of experience and best practices.

2.1 Developing an implementation plan

As a first step, an implementation plan should be developed. This includes, among others, the distribution of tasks, the required resources and time schedules and is the basis for the subsequent implementation step. A well-planned implementation process is an important factor in the success of urban logistics (Quak, et al., 2016). At this point, the focus should already be on embedding the individual urban logistics concepts in the overall context of the urban logistics system.

2.2 Implementation

In the context of this research, various success factors for the implementation of urban logistics systems were identified: One of the key components of successful implementation is proactive stakeholder management. In addition, policy participation and enforcement of urban logistics measures by law enforcement agencies are also relevant. Implementation should be incremental and prioritize the most important or effective measures. Successes achieved in the process should be clearly communicated to the population. Parallel advertising of the urban logistics system in the delivery area can help to attract customers and thus increase its overall efficiency even further.

2.3 Monitoring and evaluation

Urban logistics is a complex and dynamic subject area. No implemented urban logistics system will be able to unfold its full potential initially or remain static over time. For this reason, constant monitoring of the system and an evaluation of the (interim) results is necessary. Methodologies from the Lean Startup/ Kaizen approach can be used to make systems robust and flexible in the face of internal and external changes (Taniguchi, 2014).

2.4 Further customizing during operation

The findings from the previous phase of monitoring and evaluation can be used to adjust the system during operation. This may be the case, for example, if shipment structures change, new technologies bring efficiency benefits, or the legal framework is adapted.

2.5 Publish findings

Urban logistics is a globally important issue. Individual, isolated, and scattered projects are a first step toward reducing transportation-related emissions, but in the long term, the goal should be a wide-spread improvement of overall urban logistics. The active exchange of knowledge gains through publications, partnerships or similar measures can contribute to a higher success rate of urban logistics projects worldwide.

To summarize, the developed guideline addresses the need to adapt urban logistics systems to local contextual factors. The active involvement of policy makers, in particular through the appointment of a neutral last mile coordinator as project manager who will ensure stakeholder integration and management, is highly relevant for the success of urban logistics initiatives.

In addition, attention should be paid to a system design that is suitable for implementation. Although adjustments must also be made during operation, the earlier they are implemented, the less effort is required to make the adjustments.

6 Conclusion

In this paper, we propose a framework to develop strategies for transferring successful urban logistics concepts from one city to others. Urban logistics systems can draw from a set of 16 different concepts, which are categorized into five groups, namely (1) approaches to land use, (2) infrastructure approaches, (3) access restrictions, (4) technological approaches and traffic management, as well as (5) other approaches, such as overnight and crowd logistics. After analyzing 137 urban logistics projects in 70 cities and extracting context factors from the literature, seven typical city profiles are identified based on number of inhabitants and average GDP per person.

Further the following findings are established:

- Three basic urban logistics systems (A, B, C) are identified and assigned to the typical city profiles.
- Four urban logistics concepts are identified, that can be applied in any type of city and result in positive benefits for the economic, ecologic, and social sustainability. Those are UCC, environmental tolls, environmentally friendly drive technologies and ITS.
- Some urban logistics concepts can be applied situationally to generate sustainable benefits. This includes, for example, delivery to the city center by water when inland routes are not available.

The final framework provides a guideline for decision makers. It comprises the three phases of design and assessment, implementation, and evaluation and addresses the need to adapt urban logistics systems to local contextual factors.

7 Limitations

One of the primary goals of this paper is to give impulses for future in-depth research on strategy development for transferring successful city logistics concepts. It is not the ambition of this work to develop a complete guide for the exact design of urban logistics systems. Accordingly, the findings obtained should be critically reflected before applied.

The systematic literature review is undertaken in a way that aims to mitigate the subjectivity of the research, it is characterized by inherent limitations (Durach, Kembro and Wieland, 2017). For example, the sample of literature found may not adequately reflect the total literature available (sampling bias) or the selection of literature may not include relevant works (selection bias). During the formal analysis of the literature, misentries may occur that influence the evaluation (with-in-study bias). In addition, the results expected by the authors may have an effect on the objectivity of the results (expectancy bias). Also, due to the independent execution of the method by several authors, a subjective influence cannot be completely excluded.

The case study analysis is subject to a number of limitations. As with the majority of qualitative studies, the scope of the investigation is restricted. For example, the selection of projects analyzed may not be representative of urban logistics. The limitation to urban logistics projects in Europe may make it difficult to generalize the findings beyond the European region. Also, the conclusions drawn from the case study analysis could be influenced by the authors' expectations or the limited number of case studies.

The expert interviews served to validate the collected findings. Due to the small number of experts interviewed and the concentration of experts in German and Swiss academia, the plurality of opinions may not be sufficiently given. Interviewing additional experts from other regions and industries could result in divergent findings. Expert interviews also have other intrinsic limitations with regard to sample composition, the capture of frames and norms, recall, and the authenticity of response behavior (Sowka, 2016).

Additionally, in the expert interviews, the lack of political context factors was pointed out. Thus, there is a need for further research, in the dimension of political context factors. In addition, the findings may change over time. The use of new technologies or other changing framework conditions can change the advantages of the urban logistics concepts. The emergence of new urban logistics concepts is also likely.

Acknowledgements

The authors would like to acknowledge the support of the two academic institutions involved in this project, namely the Chair of Logistics at Technische Universität Berlin and the Institute of Supply Chain Management at the University of St. Gallen. The authors would furthermore like to acknowledge the work of Klose, et al. (2021), in which some of the results are published with a narrower scope and a greater focus on practical implications.

Appendix

Table 7: Final literature selection of systematic literature review

ID	Reference	Summary
1	Akyol, D. E.; De Koster, R. B. M. (2018): Determining time windows in urban freight transport: A city cooperative approach	**Interactions between delivery windows of neighboring cities.**
2	Alho, A. R.; de Abreu e Silva, J. (2015): Utilizing urban form characteristics in urban logistics analysis: a case study in Lisbon, Portugal	**Empirical verification of the logistics profiles from Macário (2013) using a case study in Lisbon, Portugal.**
3	Alho, A.; Bhavathrathan, B. K.; Stinson, M.; Gopalakrishnan, R.; Le, D.-T.; Ben-Akiva, M. (2017): A multi-scale agent-based modelling framework for urban freight distribution	**A model for urban logistics system planning, considering various concepts and interacting stakeholders.**
4	Alho, A.; Silva, J. D. E.; Pinho de Sousa, J. (2014): A state-of-the-art modeling framework to improve congestion by changing the configuration/enforcement of urban logistics loading/unloading bays	**A model for location and size planning of transshipment areas in parking lots.**
5	Allen, J.; Browne, M.; Cherret, T. (2012): Investigating relationships between road freight transport, facility location, logistics management and urban form	**Analyzing the relationships between the shape of a city and intra-urban freight transport.**

ID	Reference	Summary
6	Awasthi, A.; Chauhan, S. S. (2012): A hybrid approach integrating Affinity Diagram, AHP and fuzzy TOPSIS for sustainable city logistics planning	**A framework for choosing the most appropriate urban logistics concept for a specific city.**
7	Baindur, D.; Macario, R. (2013): Mumbai lunch box delivery system: A transferable benchmark in urban logistics?	**Description and evaluation of a lunch box delivery service in Mumbai using urban logistics systems.**
8	Bienzeisler, B.; Bauer, M.; Mauch, L. (2018): Screening City-Logistik	**Aggregation and analysis of different urban logistics projects.**
9	Boudoin, D.; Morel, C.; Gardat, M. (2013): Supply Chains and Urban Logistics Platforms	**Identification of stakeholders and concepts of urban logistics and providing recommendations for future urban logistics systems.**
10	Bozzo, R.; Conca, A.; Marangon, F. (2014): Decision support system for city logistics: literature review, and guidelines for an ex-ante model	**Development of an ex-ante model for the evaluation of urban logistics efforts.**
11	Buldeo Rai, H.; Verlinde, S.; Merckx, J.; Macharis, C. (2017): Crowd logistics: an opportunity for more sustainable urban freight transport?	**Analyzing the concept of crowd logistics and its relevant characteristics.**
12	Cao, C. (2018): Measuring Sustainable Development Efficiency of Urban Logistics Industry	**Ex-ante evaluation of the urban logistics efficiency of cities.**

ID	Reference	Summary
13	Cirovic, G.; Pamucar, D.; Bozanic, D. (2014): Green logistic vehicle routing problem: Routing light delivery vehicles in urban areas using a neuro-fuzzy model	**Route planning of green vehicles assuming limited resources of vehicles.**
14	Crainic, T. G.; Ricciardi, N.; Storchi, G. (2009): Models for Evaluating and Planning Logistics Systems	**A model for operational planning of routes and resources in urban logistics systems.**
15	Crainic, T. G.; Sgalambro, A. (2014): Service network design models for two-tier city logistics	**A model for route planning in two-tier intra-urban distribution networks.**
16	Dablanc, L.; Patier, E.; Gonzalez-Feliu, J.; Augereau, V.; Leonardi, J.; Simmeone, T.; Cerda, L. (2011): SUGAR. Sustainable Urban Goods Logistics Achieved by Regional and Local Policies. City Logistics Best Practices: a Handbook for Authorities	**Description and evaluation of different urban logistics initiatives in Europe.**
17	De Marco, A.; Cagliano, A. C.; Mangano, G.; Perfetti, F. (2014): Factor influencing Logistics Service Providers Efficiency' in Urban Distribution Systems	**Analyzing the influence of operational variables in urban delivery on the resulting number of stops and overall efficiency of last-mile deliveries.**
18	De Marco, A.; Mangano, G.; Zenezini, G. (2018): Classification and benchmark of City Logistics measures: an empirical analysis	**Evaluating the dissemination of urban logistics measures in cities in correlation with different local characteristics.**

ID	Reference	Summary
19	de Souza, R.; Goh, M.; Lau, H.-C.; Ng, W.-S.; Tan, P.-S. (2014): Collaborative Urban Logistics – Synchronizing the Last Mile a Singapore Research Perspective	**Description of collaborative urban logistics concepts.**
20	Dell'Amico, M.; Hadjidimitriou, S. (2012): Innovative logistics model and containers solution for efficient last mile delivery	**Analyzing the combined use of standardized load carrier and BentoBox on delivery vans.**
21	Dong, J. J.; Xu, Y. X.; Hwang, B. G.; Ren, R.; Chen, Z. L. (2019): The Impact of Underground Logistics System on Urban Sustainable Development: A System Dynamics Approach	**Analysis of strengths, weaknesses, opportunities and threats of urban logistics systems in China. Derivation of Recommendations for policy makers.**
22	Donnelly, R.; Thompson, R. G.; Wigan, M. (2012): Process validation of urban freight and logistics models	**Analyzing ways to improve traffic flow data quality.**
23	Duarte, G.; Rolim, C.; Baptista, P. (2016): How battery electric vehicles can contribute to sustainable urban logistics: A real-world application in Lisbon, Portugal	**Evaluation of the sustainability of an electric vehicle deployment in Lisbon.**
24	Ducret, R.; Lemarie, B.; Roset, A. (2016): Cluster analysis and spatial modeling for urban freight. Identifying homogeneous urban zones based on urban form and logistics characteristics	**Analyzing the influence of local characteristics on the selection and design of urban logistics systems.**

ID	Reference	Summary
25	Eitzen, H. (2017): A Multi-Objective Two-Echelon Vehicle Routing Problem. An Urban Goods Movement Approach for Smart City Logistics	**Development of a routing and scheduling system in two-tier urban distribution networks.**
26	Faure, L., Battaia, G.; Marques, G.; Guillaume, R.; Vega-Mejia, C. A.; Montova-Torres, J. R.; Munoz-Villamizar, A.; Quintero-Araujo, C. L. (2013): How to anticipate the level of activity of a sustainable collaborative network: The case of urban freight delivery through logistics platforms	**Ex-ante evaluation of profitability of UCC depending on the number of stakeholder and location of the UCC.**
27	Ferreira, J. C.; Martins, A. L.; Pereira, R. (2017): GoodsPooling: An Intelligent Approach for Urban Logistics	**Developing a concept for transferring the "Uber" concept on urban logistics.**
28	Ferreira, J. C.; Monteiro, V.; Afonso, J. L.; Martins, A. L.; Afonso, J. A. (2017): Mobile Device Sensing System for Urban Goods Distribution Logistics	**Analyzing mobile devices for improved connectivity and effectiveness of urban logistics systems.**
29	Fossheim, K.; Andersen, J. (2017): Plan for sustainable urban logistics – comparing between Scandinavian and UK practices	**Comparison of the prevalence of urban logistics measures in the United Kingdom and the Scandinavian countries.**
30	Fraile, A.; Larrode, E.; Magrenan, A.; Sicilia, J. A. (2016): Decision model for siting transport and logistic facilities in urban environments: A methodological approach	**A tool for locating UCC sites.**

ID	Reference	Summary
31	Gonzalez-Feliu, J. (2018): Sustainable Urban Logistics: Planning and Evaluation	**Development of planning and evaluation tools for urban logistics systems.**
32	Gonzalez-Feliu, J.; Pronello, C.; Salanova Grau, J. M. (2018): Multi-stakeholder Collaboration in Urban Transport: State-of-the-Art and Research Opportunities	**Analyzing sharing models in the urban logistics.**
33	Gonzalez-Feliu, J.; Salanova, J.-M. (2011): Defining and Evaluating Collaborative Urban Freight Transportation Systems	**Comparison of different levels of collaboration and their effect on relevant KPIs.**
34	Gonzalez-Feliu, J.; Salanova, J.-M. (2012): Is urban logistics pooling viable? A multistakeholder multicriteria analysis	**Multi-actor multi-criteria analysis for the design of UCCs.**
35	Graham, G.; Mehmood, R.; Coles, E. (2015): Exploring future cityscapes through urban logistics prototyping: a technical viewpoint	**Description of possible future developments in urban logistics.**
36	Gupta, A.; Heng, C. K.; Ong, Y. S.; Tan, P. S.; Zhang, A. N. (2017): A generic framework for multi-criteria decision support in eco-friendly urban logistics systems	**Development of a routing and scheduling system while incorporating sustainability dimensions.**
37	Guyon, O.; Absi, N.; Feillet, D.; Garaix, T. (2012): A modeling approach for locating logistics platforms for fast parcels delivery in urban areas	**A model for site planning od UCC (i.g. location, number, size).**

ID	Reference	Summary
38	Ibeas, A.; Moura, J. L.; Nuzzolo, A.; Comi, A. (2012): Urban freight transport demand: transferability of survey results analysis and models	**Estimation of the flow of goods in Rome and Santander and considerations on transferability to other cities.**
39	Iwan, S. (2014): Adaptative approach to implementing good practices to support environmentally friendly urban freight transport management	**A framework for implementing urban logistics solutions.**
40	Iwan, S.; Kijewska, K. (2014): The Integrated Approach to Adaptation of Good Practices in Urban Logistics Based on the Szczecin Example	**A framework for representing interactions between urban logistics concepts in the implementation of urban logistics systems.**
41	Janjevic, M.; Winkenbach, M. (2020): Characterizing urban last-mile distribution strategies in mature and emerging e-commerce markets	**Local influencing factors and differences in the design of last mile distribution networks for eCommerce in developed and developing countries.**
42	Kauf, S. (2016): City logistics – A Strategic Element of Sustainable Urban Development	**Categorizing urban logistics concepts into joint delivery systems and innovative technologies.**
43	Kelly, J.; Marinov, M. (2017): Innovative Interior Designs for Urban Freight Distribution Using Light Rail Systems	**Re-design of streetcars for integrating public transport and urban freight transportation.**

ID	Reference	Summary
44	Kijewska, K.; Johansen, B. G. (2014): Comparative analysis of activities for more environmental friendly urban freight transport systems in Norway and Poland	**Comparison of the prevalence of urban logistics measures in Norway and Poland.**
45	Kikuta, J.; Tomiyama, I.; Yamamoto, S.; Yamada, T. (2012): New Subway-Integrated City Logistics System	**Pilot testing of urban logistics systems in Sapporo (JAP) and evaluation of resulting effects.**
46	Kin, B.; Verlinde, S.; Mommens, K.; Macharis, C. (2017): A stakeholder-based methodology to enhance the success of urban freight transport measures in a multi-level governance context	**Multi-actor multi-criteria analysis for the selection of urban logistics concepts for a specific city.**
47	Kirsch, D.; Bernsmann, A.; Moll, C.; Stockmann, M. (2017): Potenziale einer geräuscharmen Nachtlogistik	**Analysis of technical and local potentials to implement silent overnight logistics in German cities.**
48	Kordnejad, B. (2014): Intermodal Transport Cost Model and Intermodal Distribution in Urban Freight	**Analyzing the advantageousness of intermodal urban logistics concepts depending on local characteristics.**
49	Kunze, O. (2016): Replicators, Ground Drones and Crowd Logistics A Vision of Urban Logistics in the Year 2030	**Opportunities to deploy future technologies in urban logistics.**
50	Lagorio, A.; Pinto, R.; Golini, R. (2017): Urban Logistics Ecosystem: a system of system framework for stakeholders in urban freight transport projects	**Transferring the biological concept of ecosystems to urban logistics.**

ID	Reference	Summary
51	Le Pira, M.; Marcucci, E.; Gatta, V.; Inturri, G.; Ignaccolo, M.; Pluchino, A. (2017): Integrating discrete choice models and agent-based models for ex-ante evaluation of stakeholder policy acceptability in urban freight transport	**Stakeholder decision model for ex-ante selection of urban logistics regulations.**
52	Liu, Y.; He, K.; Liu, J.; Xu, Y. (2008): Analysis of the Concept of Urban Rail Transit Based City Logistics System	**Description of a system for designing urban logistics based on combined public transport use of the subway.**
53	Maes, J. (2017): The potential of cargo bicycle transport as a sustainable solution for urban logistics	**Evaluation of the cargo bike usage in Belgium and derivation of recommendations for policy makers and logistics service providers.**
54	Malecki, K.; Iwan, S.; Kijweska, K. (2014): Influence of Intelligent Transportation Systems on Reduction of the Environmental Negative Impact of Urban Freight Trnasport based on Szczecin Example	**Evaluation of the use of ITS in urban logistics in Szczecin.**
55	Masson, R.; Trentini, A.; Lehuede, F.; Malhene, N.; Peton, O.; Tlahig, H. (2017): Optimization of a city logistics transportation system with mixed passengers and goods	**Solving the two-echelon routing problem with a combined use of buses for urban logistics.**

ID	Reference	Summary
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57	Mazzarino, M.; Rubini, L. (2019): Smart Urban Planning: Evaluating Urban Logistics Performance of Innovative Solutions and Sustainable Policies in the Venice Lagoon—the Results of a Case Study	**Analyzing the use of small boats in the Venice area for freight transportation.**
58	Montwill, A. (2014): The Role of Seaports as Logistics Centers in the Modelling of the Sustainable System for Distribution of Goods in Urban Areas	**Possibilities and existing projects for using seaports as logistics centers.**
59	Morfoulaki, M.; Kotoula, K.; Stathacopoulous, A.; Mikiki, F.; Aifadopoulou, G. (2016): Evaluation of Specific Policy Measures to Promote Sustainable Urban Logistics in Small-medium Sized Cities: The Case of Serres, Greece	**Analysis of the advantageousness of different urban logistics concepts.**
60	Murat, Y. S. ; Uludag, N. (2008): Route choice modelling in urban transportation networks using fuzzy logic and logistic regression methods	**A model for route planning considering uncertainties on the operational level (e.g., congestion, driver willingness to follow the route).**

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61	Nathanail, E.; Adamos, G.; Gogas, M. (2017): A Novel Approach for Assessing Sustainable City Logistics	**Evaluation of urban logistics measures from the perspective of the city and logistics service providers.**
62	Nathanail, E.; Gogas, M.; Adomos, G. (2016): Smart Interconnections of Interurban and Urban Freight Transport towards Achieving Sustainable City Logistics	**A framework for evaluating urban logistics measures based on a multi-actor multi-criteria approach.**
63	Nesterova, N.; Quak, H. (2016): A city logistics living lab: a methodological approach	**Description and evaluation initial "City Logistics Living Labs" based on a public-private partnership.**
64	Pamucar, D.; Gigovic, L.; Cirovic, G.; Regodic, M. (2016): Transport spatial model for the definition of green routes for city logistics centers	**Routing and scheduling for sustainable urban logistics based on a Dijkstra algorithm.**
65	Papoutsis, K.; Nathanail, E. (2016): Facilitating the selection of city logistics measures through a concrete measures package: A generic approach	**Evaluation of different urban logistics measures and their effect on sustainability goals.**
66	Perboli, G.; Rosano, M. (2018): A Decision Support System for Optimizing the Last-Mile by Mixing Traditional and Green Logistics	**Development of a routing and scheduling system for a combination of traditional and cargo bike delivery.**

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67	Quak, H.; Balm, S.; Posthumus, B. (2014): Evaluation of City Logistics Solutions with business Model Analysis	**Analyzing the "BentoBox" business model in Berlin, Turin and Lyon.**
68	Quak, H.; Lindholm, M.; Tavasszy, L.; Browne, M. (2016): From freight partnerships to city logistics living labs - Giving meaning to the elusive concept of living labs	**Deduction of success factors of urban logistics projects and description of an urban logistics living lab.**
69	Quak, H.; Nesterova, N. (2014): Towards zero emission urban logistics: Challenges and issues for implementation of electric freight vehicles in city logistics	**Summary of opportunities to promote the adoption of electric vehicles in urban logistics.**
70	Roca-Riu, M.; Estrada, M. (2012): An evaluation of urban consolidation centers through logistics systems analysis in circumstances where companies have equal market shares	**Analysis of the advantageousness of UCC assuming equal market shares of logistics service providers.**
71	Rodseth, K. L. (2017): Productivity growth in urban freight transport: An index number approach	**Calculation of efficiency gains from urban logistics systems.**
72	Rose, W.; Bell, J.; Autry, C.; Cherry, C. (2017): Urban Logistics: Establishing Key Concepts and Building a Conceptual Framework for Future Research	**Description of theoretical foundations of urban logistics and providing directions for future research.**
73	Russo, F.; Comi, A. (2010): A classification of city logistics measures and connected impacts	**Categorization and description of various urban logistics concepts.**

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74	Russo, F.; Comi, A. (2013): A model for simulating urban goods transport and logistics: the integrated choice of ho.re.ca. activity decision-making and final business consumers	**Simulation of the level of activity in urban logistics networks in the hotel, restaurant, and catering sector.**
75	Santos, R.; Silva, J. (2012): Technical and economic feasibility of the use of airships within two Portuguese market niches: the tourism and the urban logistic case studies	**Evaluation of shifting the mode of transport to airships for the main run.**
76	Schroder, S.; Liedtke, G. T. (2017): Towards an integrated multi-agent urban transport model of passenger and freight	**Analyzing the impact of urban logistics systems and its interactions with existing passenger transportation networks.**
77	Semanjski, I.; Gautama, S. (2019): A collaborative stakeholder decision-making approach for sustainable urban logistics	**Development of a routing and scheduling system incorporating sustainability dimensions.**
78	Serna, M. D. A.; Uran, C. A. S.; Uribe, K. C. A. (2012): Collaborative Autonomous Systems in Models of Urban Logistics	**Analyzing the current state of research and advantages of collaborative logistics concepts.**
79	Sheu, J. B. (2006): A novel dynamic resource allocation model for demand-responsive city logistics distribution operations	**A model for resource allocation in urban logistics systems based on clustering customer groups.**

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81	Tadic, S.; Zecevic, S.; Krstic, M. (2014): A novel hybrid MCDM model based on fuzzy DEMATEL, fuzzy ANP and fuzzy VIKOR for city logistics concept selection	**Framework for choosing the most appropriate urban logistics concept for a specific city.**
82	Taefi, T. T.; Kreutzfeld, J.; Held, T.; Fink, A. (2016): Supporting the adoption of electric vehicles in urban road freight transport - A multi-criteria analysis of policy measures in Germany	**Evaluation of policy tools to promote electric mobility in urban logistics.**
83	Taniguchi, E. (2014): Concepts of city logistics for sustainable and liveable cities	**Description and evaluation of joint delivery systems including examples from Japan.**
84	Taniguchi, E.; Thompson, R. G.; Yamada, T. (2014): Recent Trends and Innovations in Modelling City Logistics	**Systematic literature review on modeling and evaluating urban logistics measures.**
85	Teoh, T.; Kunze, O.; Teo, C. C. (2016): Methodology to evaluate the operational suitability of electromobility systems for urban logistics operations	**A model for determining the deployment feasibility of electric vehicles.**
86	Visser, J.; van Binsbergen, A.; Nemoto, T. (1999): Urban freight transport policy and planning	**Describing theoretical foundations of urban logistics and providing directions for future research.**

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88	Wesolowska, J. (2016): Urban Infrastructure Facilities as an Essential Public Investment for Sustainable Cities – Indispensable but Unwelcome Objects of Social Conflicts. Case Study of Warsaw, Poland	**Problem analysis in the siting of inner-city infrastructure buildings.**
89	Wolpert, S. (2013): City-Logistik	**Quantitative and qualitative Analysis of selected urban logistics projects in Central Europe.**
90	Wolpert, S.; Reuter, C. (2012): Status Quo of City Logistics in Scientific Literature	**Systematic literature review on actors, challenges and concepts of urban logistics.**
91	Yang, K. D.; Roca-Riu, M.; Menendez, M. (2019): An auction-based approach for prebooked urban logistics facilities	**Analyzing auction-based booking of loading/unloading bays.**
92	Zhao, L.; Li, H.; Li, M.; Sun, Y.; Hu, Q.; Mao, S.; Li, J.; Xue, J. (2018): Location selection of intra-city distribution hubs in the metro-integrated logistics system	**Development of a model for locating UCCs in urban logistics systems that use public transport networks (subway).**

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Sustainable urban logistics concepts – a collaborative design approach considering stakeholder perspectives

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Purpose: *Goods flows in cities increase due to urbanization and growing e-commerce. Deliveries become more fragmented and more difficult to consolidate and control. This leads to an ever-increasing strain on urban infrastructure and logistics systems. With our work, we aim to design a stakeholder-oriented urban logistics concept to improve sustainability and relieve urban infrastructure.*

Methodology: *We chose a design thinking approach augmented by proven scientific methods. First, we analyzed the requirements of urban logistics stakeholders by conducting both a literature review and twenty-one qualitative interviews. Second, we carried out ideation workshops with different stakeholder groups to elaborate new solutions for urban goods flows.*

Findings: *The findings offer deep insights into urban logistics stakeholders' challenges, requirements and wishes and outline a clear point of reference for the development of sustainable urban logistics concepts. The results show stakeholders' strong focus on consolidation, on intermodal transport and on a better connectivity between relevant IT applications as well as a strong interest in autonomous transportation systems.*

Originality: *The work evaluates innovative urban logistics concepts empirically that have not yet been developed, designed or further investigated in this combination before. Thus, numerous opportunities for further work using modelling, simulation or field-testing are offered.*

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1 Introduction

Urban logistics can be described "as the means over which freight distribution can take place in urban areas as well as the strategies that can improve its overall efficiency while mitigating congestion and environmental externalities" (Rodrigue, 2020). For the scope of this paper, the authors' similar but simplified definition "the optimized flow of goods into, within and out of urban agglomerations" will be used.

The Covid-19 pandemic beginning in 2019 shed light on the importance of urban logistics systems (BIEK e.V., 2021). Besides Covid-19, the relevance of urban logistics has been driven by various factors in recent years. In general, goods flows in cities increase (BIEK e.V., 2019) due to urbanization and growing e-commerce (Stölzle and Schreiner, 2019). Deliveries become more fragmented and more difficult to consolidate and control. This leads to an ever-increasing strain on urban infrastructure and logistics systems (Seeck and Engelhardt, 2021).

Current urban logistics systems, optimized in economic terms only, also come with a high price tag in other than infrastructural aspects, generating traffic jams, vehicle noise, environmental pollution and evoking perceived and/or factual reductions in quality of living for urban inhabitants (Van Audenhove, De Jongh and Durance, 2015). This resulted in a demand for urban logistics systems to be compatible with a sustainable development approach, i.e. being evaluated in terms of economic, social and environmental dimensions (United Nations, 1992). Achieving such environmental and social goals in addition to preserve economic viability actually means to satisfy more stakeholders' interests and their respective requirements. Those additional stakeholders include municipal, regional and federal government agencies.

The state-funded project "Warenströme in Städten – Paket und Stückgut" (flow of goods in cities – parcel and general cargo; WAS-PAST) was launched in 2021. First, it aims to design a stakeholder-oriented urban logistics concept that improves sustainability as well as urban infrastructure utilization while being economically viable. The second objective is to test this concept during a 6-month field test in Berlin. The stakeholder analysis, that is part of the project, will be elaborated upon in this paper.

2 Foundations

The challenge of planning and implementing goods flows in urban agglomerations has been a scientific subject even before the turn of the century. Various projects and pilot tests were conducted, but without significant success. These projects however were mostly limited to the supply of major points of sales and/or small- and medium-sized brick-and-mortar stores. As such, they lacked a holistic approach to urban logistics and/or a viable business case. More recent projects also tend to concentrate on individual aspects of urban logistics.

A focus on technical prerequisites/individual means of transportation such as developing delivery trucks for urban applications can be found e.g. in EU-sponsored projects FIDEUS (Schönewolf, 2007) and FURBOT (European Commission, 2015a) and some industry-driven research, e.g. DHL trying to replace fossil-fueled delivery trucks (Schuh, 2020) using small e-cars to reduce carbon footprint. Other projects focused on underground transportation as in Cargo Sous Terrain Project (Cargo Sous Terrain AG, 2020), cargo bikes as in KoMoDo in Berlin (LNC LogisticNetwork Consultants GmbH, 2020) or robots/drones as in DHL-Paketkopter (Deutsche Post AG, 2018), Starship (Hermes Germany GmbH, 2016) and BUGA:log (Hochschule Heilbronn, 2019). Using trams for urban goods flows was addressed for Brussels (Strale, 2014), Poland (Pietrzak and Pietrzak, 2021) and Istanbul (Gorcun, 2014).

Projects CITYLOG (Fraunhofer-Gesellschaft e.V., 2011) and STRAIGHTSOL (European Commission, 2014) looked at case-specific solutions for goods flows in cities. The SMARTFUSION project (2012-2015) focused on reducing emissions on the last mile in general (European Commission, 2015b).

Autonomous transportation was evaluated in the VanAssist project (ZENTEC, 2020). Ecological sustainability was addressed in LaMiLo (PTV Planung Transport Verkehr GmbH, 2015) and NKI: Klimafreundlicher Lieferverkehr (BUND e.V., 2020). LoMaCro+ (TU Wien, 2018) dealt with using crowd delivery concepts, whereas ”Verkehrsfreie Friedrichstraße“ tested road access limitations in Berlin (Changing Cities e.V., 2020) and a UPS pilot test in Hamburg (United Parcel Service Deutschland S.à r. l. & Co. OHG, 2020) used micro hubs. Recent last mile projects KoMoDo (LNC LogisticNetwork Consultants

GmbH, 2020) and FONA – Stadtquartier 4.0 (LNC LogisticNetwork Consultants GmbH, 2020a) also provide relevant input for our project.

Jacyna and Szczepanski (2013), Kin et al. (2018), Amaya, Arellana and Delgado-Lindeman (2020) as well as Pronello, Camusso and Rappazzo (2017) followed a more holistic approach; the last two papers also include a stakeholder analysis.

It can be derived that the challenge of how to manage urban logistics in a sustainable, socially acceptable and still economically viable way remains unresolved for the time being. Recent conferences deal explicitly with this challenge, e.g. “Tag der Verkehrswirtschaft – Vernetzte Citylogistik”, “Digital und Intermodal“ (2018 and 2019) and “International VDI Conference – Smart Last Mile Delivery“ (2018) and “Wissenschaftsforum Mobilität“ (2020).

All efforts to improve efficiency and service quality in urban logistics systems are of present relevance. Thus, project WAS-PAST intends to design an urban logistics system that incorporates relevant technological, legal and organizational requirements as well as especially stakeholder-related aspects in a holistic approach.

3 Methodology

3.1 Methodological Framework: Design Thinking

We selected a design thinking approach as overarching method to collect and display stakeholders’ requirements to develop afterwards collaboratively with industry experts new urban logistics solutions. The design thinking approach can be divided into four phases: empathize, define, iterate and prototype (Gerstbach and Gerstbach, 2020):

- Empathize: Develop an understanding of stakeholders’ issues and challenges.
- Define: Define an accurate user-oriented problem definition.
- Iterate: Generate as many ideas as possible, evaluate, prioritize, and select suited ideas.
- Prototype: Create a prototype based on ideas, get feedback.

The design process is not straightforward but rather an iterating process. You can always go back to the previous phase or skip a phase (Gerstbach and Gerstbach, 2020).

Figure 1 assigns the design thinking phases to the research methods applied and refers to the respective chapter. Based on project review (3.2.1), qualitative interviews (3.2.2) and ideation workshops (3.2.3), a field trial is planned to validate the results. An outlook on the field trial can be found in chapter 4.2.2.

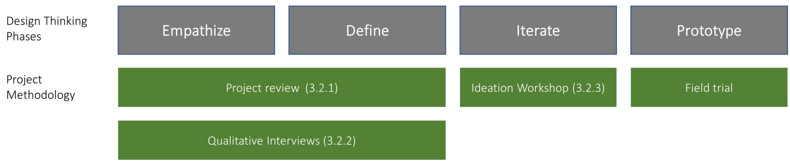

Figure 1: Allocation of design thinking phases to project methodology

3.2 Data Collection and Analysis

To start the design thinking process, a solid data groundwork is necessary. We selected the following methods:

- Review the latest scientific and practical projects and scientific papers as it helps to identify and prioritize requirements, measures and systems along the research process (3.2.1).
- Conduct qualitative expert interviews with a heterogeneous group of relevant stakeholders to explore new urban logistics concepts and their related challenges as well as to identify new aspects not yet mentioned in the literature (3.2.2).
- Conduct ideation workshops, considering the latest developments in industry and science, with the aim of developing new concepts for urban logistics to increase sustainability (3.2.3).

3.2.1 Project Review

The project review was conducted as part of the design thinking phases “Empathize” and “Define”. The strategy to identify practice-oriented projects and field trials related to urban logistics was to search in Google, Google Scholar and ResearchGate after keywords like “urban logistics projects”, “urban cargo”, “urban cargo projects”, “urban cargo transport", "cargo tram", "cargo boat", "alternative city logistics projects", "city tram", "city train", "city boat", "urban logistics systems". The identified projects were assessed based on 17 criteria, e.g. logistics system characteristics, reason for failure or success and project metadata.

By using this approach, we could identify and better understand the relevant outcomes of these projects and field trials as well as extract stakeholder requirements on sustainable urban logistics concepts, reasons for failure, used logistics systems and modes of transport. Based on the project results, we were able to exclude or include different means of transport for our field trial.

3.2.2 Qualitative Interviews

To conduct semi-structured qualitative interviews, a questionnaire was developed for all stakeholder to be interviewed based on the literature review. The questionnaire consists of five sections:

1. General information about the interviewee
2. Questions about the status quo in logistics
3. Experiences with alternative means of transport (compared to "classic" diesel van/truck)
4. Ideas of what an alternative logistics system could look like
5. Ways and means to support the use of alternative means of transportation

Each interviewee received the questionnaire 1-2 days before the interview took place. Depending on the type of stakeholder, the questionnaire was slightly adjusted, e.g. for politicians questions like "How do you deliver today?" were unsuitable. The interviews took place between June and August 2021 and lasted 60 minutes on average.

Figure 2 presents the number of interviews per stakeholder group. Logistics service providers include courier, express and parcel (CEP) companies, cycle logistics and general cargo companies. Mobility includes local public transport companies and "Other" includes companies like manufacturers of cargo bikes or last mile software companies.

Each interview was conducted by two interviewers and was recorded as well as transcribed afterwards. To analyze the interviews a qualitative content analysis according to Mayring (Mayring and Fenzl, 2019) was applied. Thereby, the interviews were coded deductively based on the interview questions. They were then analyzed to identify overall statements and patterns within and across stakeholder groups.

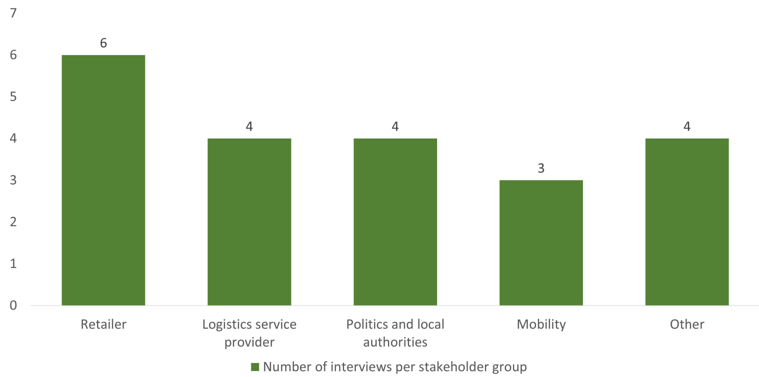

Figure 2: Number of interviews per stakeholder group

3.2.3 Ideation Workshops

Within the design thinking phase "Iterate", different ideation workshops were held to avoid thinking bias and to work collaboratively with industry experts to gain their perceptions and ideas related to new urban logistics concepts. Therefore, these workshops also play an essential role when it comes to discuss feasibility of theoretical urban logistics concepts.

The ideation workshops took place every two months in a ninety-minute workshop between September 2021 and March 2022. Due to the Covid-19 pandemic, they were mostly held online. The workshops were moderated and consisted of the main question: "How can we design an innovative, sustainable and economic viable urban logistics system that benefits all stakeholders in urban areas?" In the first two workshops, ideas were generated and afterwards further elaborated. The concepts were proposed and discussed in the following workshops. In the course of the workshops, one concept was selected from which all urban logistics stakeholders could benefit from.

Each ideation workshop was documented and evaluated. The results were shared with all participants after each workshop so they could add further thoughts.

4 Findings and Discussion

Based on the research findings of the project review and the qualitative interviews (4.1) a proposal for a new urban logistics solution will be presented (4.2).

4.1 Requirements for Urban Logistics Solutions

Firstly, the findings of the project review are outlined (4.1.1) and afterwards the findings of the qualitative interviews are displayed (4.1.2) and lastly summarized in ten central findings (4.1.3).

4.1.1 Results of the project review

Table 1 presents past and ongoing urban logistics projects with the following information: transported goods, project goals and key insights.

Table 1: Review of past and ongoing sustainable urban logistics projects

Project	Goods	Goals	Key insights
Car Go Tram, Dresden 2001-2020	Automotive Parts	Efficient and ecological supply of glass manufacturer close to the city	Change of logistics concept for Dresden plant which no longer needs the tram
Cargo Tram, Zurich 2003	Waste disposal for city habitants	Ecological disposal of e-waste and recyclable waste	Ecological savings, good citizen acceptance, no additional burden for citizens

Project	Goods	Goals	Key insights
Güter Bim, Vienna 2004-2005	Supplies such as batteries, wheel tires, driver's side	Use of public transport network for freight transport	Missing customers, unloading in parallel to passenger service at stops, unloading times too long, as forklifts have been used
City Cargo, Amsterdam 2007-2008	Supplies for pubs, restaurants, hotels	Reduction of truck traffic and of emissions, delivery to the city center, also after 11 a.m. (existing delivery restriction in Amsterdam, 7 -11 a.m.)	Project company had to finance itself without public funds, was not supported politically, had to build new tracks and pay for them itself, did not receive any funds due to the financial crisis, but high ecological savings possible, could make sense economically
Cargo Hopper, Utrecht 2011	Supplies for pubs Restaurants, Hotels	Utrecht wanted to remove commercial traffic from narrow streets, reduce environmental pollution	Created a separate company for operations, politics strongly supports this project, but is not as efficient as it could be because some companies don't share transport space with competitors, even if it is cheaper
Tramfret, Saint Etienne 2017-2018	Supplies for grocery stores	Use of discarded streetcars for freight transport on existing public transport infrastructure	Lack of financial resources of the project company, in particular for the operation of the distribution center, despite positive results, but according to the food retail casino, the transport led to efficiency gains and profitability

Project	Goods	Goals	Key insights
Last Mile Tram, Frankfurt am Main 2020	CEP parcels	Efficient and ecological supply of an urban neighborhood with high stop density using trams and existing city infrastructure	Transport of parcels via tram in combination with vans and bikes is possible under certain preconditions e.g. separate tracks and trams
Hôtel logistique, Paris 2021	All kind of goods and supplies	Enhance ecological delivery options	No results available yet

Finding 1: Based on the project review, the key requirement for the success of an urban logistics project is the commitment of different stakeholders. The key difference between successful and the non-successful projects is the strong commitment of all relevant parties. In Zurich, the project could generate benefits for all stakeholders and therefore all parties (politics, citizens and operator) are committed to success (Johnsten, 2021). In Utrecht there is also a big commitment by the local authorities and politics as well as from local pubs and restaurants (de Jong, 2013). However, there are also bigger shipping companies who are not willing to use a collaborative system, which makes it harder to operate a collaborative system economically (Eltis, 2015). The inclusion of these parties is a critical success factor for the prospects of this system. When politics, public authorities and relevant shippers are not willing to cooperate, a project will fail, as it occurred in Amsterdam (Arvidsson and Browne, 2013). Even though the calculated savings, economically and ecologically, were promising, the whole project failed in the end due to the lack of commitment of relevant stakeholders.

4.1.2 Results of the qualitative interviews

As mentioned in chapter 3.2.2, 21 interview partners answered the same basic questionnaire adjusted to their industry. In contrast to our expectations, we could not observe patterns along stakeholder groups, e. g. “all logistics service providers demand wider streets and less bike lanes", but we were able to find similar answers that were given across all stakeholder groups. In general, we observed that each stakeholder group was well aware of the challenges in urban logistics and are keen to find solutions.

Finding 2: In general, all interviewed experts agreed that all urban logistics stakeholder groups need to intensify the dialogue in order to find suitable solutions. The dialogue between e.g. logistics service providers (LSP) and local authorities is regarded as too slow and too little. In particular, the LSP, but also the retailers and mobility companies demand clear and long-term regulations for traffic organization in urban areas. They point out that they can work with less space e.g. through extended bike lanes. However, they need the commitment of the authorities that rules will apply for the next years. All stakeholders favor loading zones and most of them would replace car parking lots with loading zones. Furthermore, they also expressed their concern of the feasibility to control the usage of loading zones.

Finding 3: Each interview partner made demands which could accelerate zero-emission urban logistics flows. The following demands were made by nearly every interview partner: More space for hubs, more knowledge about urban logistics in local governments, more financial commitment, more charging points for electric vehicles / cargo bikes and substantially more incentives for companies and consumers to use ecological means of transport and therefore urban logistics systems.

Finding 4: However, when it comes to white label transports and depots, the opinions of the interviewees differ a lot. Some interview partners demand more cooperation and collaboration between the different market actors; others reject these demands by referring to local optimization and pointing out that their trucks are already filled-to-capacity. In general, conditions for collaboration between market actors need to be created by local governments, associations and joint ventures.

Finding 5: Data transmission, standardization and interfaces to enable collaboration along the urban supply chain. Every interview partner formulated the requirement to define and use open-source standards in data transmission between supply chain partners. This would enhance the idea of collaboration and would give small market actors a fair chance to establish alternative urban logistics systems.

Finding 6: Some interview partners mention night delivery as a big chance to relieve city traffic and demand from politics and local authorities to approve those, e.g. for supermarkets. Others see night deliveries critical as long as noise problems are not solved.

Finding 7: The critics of night deliveries suggest testing a concept of retiming deliveries. The key aspect of this concept is to deliver to e.g. supermarkets in smaller batches with smaller vehicles and more often per day. The store's inventory will be moved to e.g. an urban/macro hub. The macro hub functions as the central goods-in point for the city and can store goods for a certain period. Smaller vehicles can start their tours at the macro hub and deliver the stores with the required goods.

Finding 8: A requirement all interview partners agreed on is a change in consumer expectation. Consumers need to accept higher delivery charges for sustainable deliveries. They shall accept three-day deliveries to enhance bundling effects as well as the end of door deliveries and the use of parcel lockers instead. However, the consumer perception is a completely different one. They prefer fair working conditions for delivery drivers (Engelhardt, Seeck and Malzahn, 2021; Spectos GmbH, 2022), they want bundled deliveries and not one delivery per service provider (Seeck and Göhr, 2018; Seeck and Engelhardt, 2021), and they prefer to differentiate delivery options by price and performance (Quiter et al., 2021). Especially in this respect, there is a huge gap between companies and consumers expectations for an alternative urban logistics solution.

Finding 9: The use of the right mode of transport is important for all stakeholder groups. Many interviewees mentioned they already tried electric trucks, cargo bikes and hydrogen trucks as well as liquid natural gas (LNG) trucks. Depending on their use cases, they had mixed results and experiences with alternative modes of transport. For smaller cargo, most interviewees had good experiences with the use of cargo bikes. For heavier cargo, most interviewees said there is no sustainable alternative to the diesel truck yet.

Finding 10: One mode of transport currently broadly discussed is the use of railway transportation in urban areas, e.g. the use of trams. Based on our research it can be deduced that cargo trams are only a useful alternative if operated on an own network with dedicated trams (Strale, 2014; Pietrzak and Pietrzak, 2021). For this purpose, strong political willingness, investment readiness and long-term planning is necessary

(Arvidsson and Browne, 2013; Strale, 2014). The requirements for the usage of railway transportation are strong and durable trains as well as network availability (Strale, 2014; Pietrzak and Pietrzak, 2021). Therefore, cargo transportation needs its own network which requires a lot of investment in city infrastructure (Arvidsson and Browne, 2013; Strale, 2014).

4.1.3 Summary of requirements for new urban logistics concepts

In the following, the findings will be summarized:

1. Key requirement for the success of an urban logistics project is the commitment of the involved stakeholders
2. Intensify dialogue between all relevant stakeholders
3. More infrastructure support from local governments and more incentives for sustainable transport solutions
4. Conditions for more collaboration between willing market actors need to be created by local governments or associations
5. Define and use standards in data transmission and interfaces
6. Define conditions for night deliveries
7. Test retiming of deliveries with the use of macro hubs
8. Consider gap between consumer expectations and practical system performance
9. Companies already made experiences with alternative modes of transport with mixed results
10. Use of railway transportation depends on strong political willingness, local investment readiness and long-term planning

4.2 Proposal of new urban logistics solutions

This chapter presents a proposal for a new urban logistics solution and explains how it can be tested in a field trial. The proposal is based on the findings presented above and was elaborated within the ideation workshops.

4.2.1 Solution structure

The intention was to consider as many findings as possible when creating the network. Based on that, seven key targets for the new systems were derived:

1. B2C as well as B2B consignments
2. As many different modes of transport as possible
3. Central delivery point which can receive goods via road, rail and riverine waters as well storing items for a certain period, so night deliveries or retiming concepts can be tested
4. Network of micro hubs across the city to be able to supply a large area within the city
5. Include as many stakeholders as possible, e. g. public local companies, local authorities, big shippers and technology manufacturers
6. Use existing infrastructure
7. Use standards in data transmission

The heart of the new distribution system is a so-called macro hub. All shippers participating in the field trial are requested to deliver their items to the macro hub. There, the items will be handled, picked, sorted and distributed to their destination tours. If the destination is reachable directly from the macro hub, the last mile tour starts from the macro hub. Else, there is an intermediate transport from macro to micro hub. For the field trial, it is planned to operate two micro hubs across the city. The micro hubs will be used as handling points. Intermediate transport is carried out using medium sized vehicles like an E-Van or a cargo bike train.

At the micro hub, the items will be transferred to smaller vehicles like cargo bikes. The micro hub will be used as short-term storage site, but typically, no item will be stored longer than six hours. Finally, cargo bikes will deliver the items to their individual destinations. Each hub has its dedicated delivery area, differentiated by postcodes. The final sorting of items to tours will be done at the macro hub. In addition, it is planned to try the usage of small, unmanned cargo boats to carry goods via rivers and canals across the city, which will be carried out in collaboration with another scientific project. This research project already tested the general feasibility of these boats. This model can only be applied to cities that have suitable rivers and canals. Figure 3 shows the structure of the derived solution.

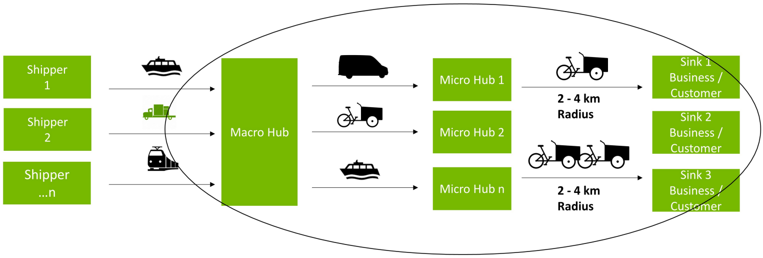

Figure 3: Structure of an alternative urban logistics system

The scope of this project only considers deliveries and not disposal transport. A fully comprehensive urban logistics concept should also include disposal logistics.

4.2.2 Design of the field trial

The last step of the design thinking process is prototyping, which is implemented as a field trial of the derived concept. The design of the field trial, which is currently in the planning status, is explained below.

For the macro hub, two prerequisites should be met: The possibility to store, pick, sort and distribute goods within a relatively small space, and a good traffic connection via more than one transportation way. Therefore, Berlin Westhafen was chosen as macro hub.

Two micro hubs were selected: One at Berlin Alexanderplatz, and the other at Berlin Tempelhofer Damm. In combination with the macro hub, around 60 postcode areas in Berlin can be serviced by cargo bikes or E-Van. The overlap in delivering areas between the three hubs is low.

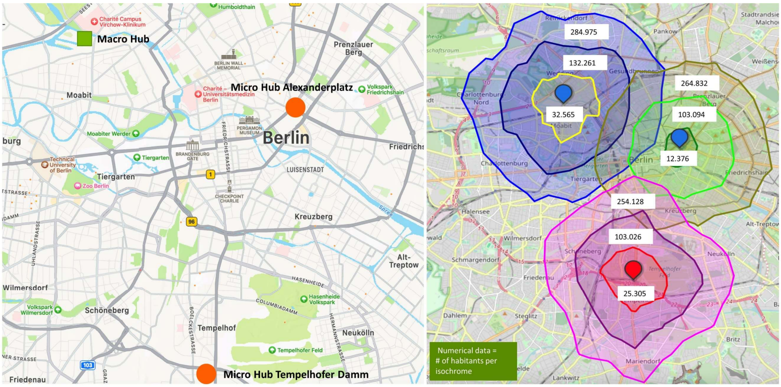

Figure 4: Location of micro hubs in Berlin and presentation of the isochrones from each hub

Figure 4 shows the exact locations of the micro hubs in berlin (left picture) as well as the isochrones per location. The values within the isochrones indicate the number of habitants which can be reached within five minutes (inner isochron), ten minutes (middle isochron) and fifteen minutes (outer isochron) by bike. A ride longer than fifteen minutes (one way) causes low tour productivity and is therefore not considered. Ca. 800.000 habitants respectively nearly the entire inner subway circle of Berlin can be reached by these three locations.

4.2.3 Expected results from the field trial

The basic requirements for the field trial are the same as for every logistics network: To deliver the right goods at the right time at the right place with the right quality and in the right quantity.

Additionally, the field trial needs to prove that a two-stage urban logistics solution can cope with the logistics requirements, is far more ecological than todays' solutions and can meet economic efficiency criteria. The most crucial aspect in terms of delivering the items in time is the delivery time of incoming goods at the macro hub. In terms of economic efficiency, there are three important aspects. First, a high level of collaboration between the shippers to ensure an optimum capacity usage of the hubs and transportation vehicles is necessary. Second, the labor costs for personnel at the macro and micro hubs are to be considered. The key driver for minimizing the costs is the capacity limit of the different transportation modes. This field trial tests a variety of different transportation modes, all capable of loading at least one euro pallet, sometimes even more. Third, the field trial needs to prove a significant drop in emissions per delivered item as well as a reduction in heavy duty trucks.

However, this field trial does not cover first mile operations like “how will the goods be delivered to the macro hub?”. This question is object of further research projects.

5 Conclusion

It can be concluded from the design thinking process that although there are many approaches to the problem of the last mile, a final solution has not been found yet, or is not even on the horizon. However, the results of the process reveal requirements and conditions for such a solution.

On the one hand, it can be stated that purely theoretical concepts have little chance of success without practical testing in the context of field trials or case studies. Practice-oriented projects, on the other hand, often focus on individual aspects of the problem and do not represent an overall solution. This is especially true for practical projects on the use of alternative means of transport (trams, e-mobiles, cargo bikes, drones, robots). In these projects, valid statements are made on the usability, such as a good practicability of cargo bikes in urban areas or the lack of practicability by using trams or similar passenger transport by rail for transporting goods. However, the integration of such results into an overall concept for urban logistics, which has a special focus on sustainability, urban compatibility and resilience while at the same time being easily realizable and economically feasible, is still pending.

Such a solution concept must therefore include the use of different means of transport, but use them depending on their meaningfulness in the respective context. Another result of the design thinking process is the absolute necessity of cooperation between the various stakeholders in the last mile process. Only through overarching cooperation, the success of urban logistics solution concepts can be achieved. This is not only clear from the examination of past projects, but also from the evaluation of the expert interviews. The success of holistic urban logistics solutions is often based on the implementation of bundling, which can only be sensibly realized through cooperation between the logistics service providers involved. However, other stakeholders, such as the municipal and political bodies of a city, are also imperative for the success of such projects.

Based on these results, a field trial is conceptualized for the implementation of a possible holistic urban logistics concept. This concept is based on the use of different means of transport for the different parts of the urban supply chain as well as the bundling in macro hubs and micro hubs. The concept presented will be implemented in Berlin in the second half of 2022. The results of the field test will be published after completion of the project.

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Appendix

Questionnaire

Question category 1:

Questions about the person and the company

1. In which company do you work?
2. What is your position in your company?
3. How long have you been employed by the company?
4. In which industry does your company operate?
5. In which industry do your customers operate?

Question category 2:

Information on the status quo in logistics

1. How is your logistics system structured?
2. In which loading equipment will your goods dispatched? / How do you receive?
3. How will be shipped in general? / How do you receive in general?
4. What are your key figures for delivery / supply?
5. Are there any special requirements for shipping and receiving goods?
6. Do you have time restrictions for receiving and/or issuing goods?
7. What quantities in QU (quantity units) do you ship per day? What is the delivery cycle?
8. How do you organize and control your logistics system?
9. What software do you use to control your logistics system?

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Question category 3:

Field reports of alternative modes of transport (compared to the "classic" diesel van/truck)

1. What do you see as the biggest challenges in supplying cities?
2. How could these problems be solved?
3. Do you have experience with the use of alternative modes of transportation?
4. Do you know any projects using alternative logistics systems?
5. If yes, can you briefly describe your experience? What were the advantages and disadvantages?

Question category 4:

What could an alternative logistics system look like?

1. What could an alternative logistics system look like for you?
2. Are you already working on a new system? If yes, why?
3. What are components of an alternative logistics system?
4. What are your requirements for alternative modes of transportation?
5. What are the requirements for you to consider using the alternative modes?
6. What are barriers / requirements for a CO2 free delivery?
7. What requirements do you see for a software for planning, control and optimization in urban logistics?
8. To what extent do you see the possibility to cooperate with other market participants to realize an alternative logistics system (e.g. by sharing data, sharing freight space, realizing intermodal transport chains)?

Question category 5:

Ways and means to support the use of alternative modes as a means of transportation

1. What needs to happen to organize commercial transport in a sustainable, environmentally and urban friendly way?

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VIII.
Sustainability

Possible Impacts of the European Green Deal on Turkey's Logistics Industry

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Purpose: *The concept of the Green Deal is one of the important roadmaps adopted to build a more livable world against the climate crisis and make the current system cleaner and more sustainable. Businesses in the EU are subject to sustainability rules required by the Green Deal. Since Turkey is a signatory power to the agreement, the Turkish companies are also hinged on to the Green Deal. The logistics sector emerges as one of the priority areas on this matter. In this sense, Turkey has also prepared a 'Green Deal Action Plan' to adapt to the new situation. In this study, Turkey's competencies in international logistics will be evaluated, and the compatibility of the planned actions with the green deal process will be discussed.*

Methodology: *This research is conducted to review literature from recent journals, governments reports, and the World Bank's logistics performance index (LPI) to draw out secondary data that helped analyze the drivers of the EU's green deal practices and the challenges faced by Turkey's logistics industry in implementing them.*

Findings: *Turkey's competencies in international logistics and action plans to comply with the Green Deal are examined.*

Originality: *This study is novel in examining Turkey's logistics compatibility with EU's Green Deal rules.*

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1 Introduction

Logistics is defined as “an important part of the supply chain process that plans, implements and controls the efficient, effective forward and reverse flow and storage of goods, services, and information flowing between the point of origin and the point of consumption in order to meet the needs of customers” (David, 2007).

The concept of logistics, which is very important in every period of history, appears as a military term that provides food/ammunition supply and transportation for armies. Logistics management also aims to provide resources and manage physics flows in this process. What is meant by physical flow is defined as the technical and managerial control flow between the production and consumption point of raw materials and products (Tudor, 2012).

Significant developments in the global economy and increasing trade competition have improved the importance of the logistics industry. Accordingly, thanks to the developments in this sector, logistics has become a driving force in the economic development of countries. Since trade and transportation are so important economically, it can be said that the development of a country largely depends on logistics activities (Martínez, 2011).

An effective logistics system necessitates the common use of more than one transportation type and strengthens the technical infrastructure. Providing such an infrastructure reduces the economic cost of transportation and logistics activities and contributes to economic and social sustainability by eliminating externalities that negatively affect the population (Leal, 2011).

According to Globaltranz (2015), the benefits to be achieved through sustainable practices in logistics are listed as follows.

Emission reduction: The transportation sector causes a serious carbon emission by transporting products from one place to the targeted places. Emission rates can be reduced by reducing the total distance traveled and using clean technology and energy-based vehicles instead of fossil fuels. Solutions such as electric vehicles, multi-modal transportation, and route optimization can be offered. In general, multi-modal transportation, which brings together the best of every mode of transportation in terms of reliability and flexibility, has many advantages in terms of economic, environmental, and social aspects (Abiral et al., 2020).

Reducing the amount of waste products: The service life of existing vehicles and equipment is increased by reducing distances in transportation and increasing efficiency. Thus, all parts in these vehicles remain in use for a longer period of time. In addition, road damage will be reduced, and savings will be achieved in road construction.

Reducing energy consumption: The fastest option is not always the most efficient option. In line with sustainability goals, new generation technologies that consume less energy are used, and renewable and clean energy sources are preferred. Both energy savings are made, and environmental benefits are provided thanks to the conversion to clean energies.

Compliance with official regulations: Sustainable logistics activities facilitate compliance with the states' regulations as penal and incentives within the scope of sustainability. In this way, both sustainable activities are rewarded, and illegal activities are prevented due to penal sanctions.

Increasing awareness among consumers: thanks to the increase in sustainable activities, there is an increase in consumers' awareness of the products they buy and how the relevant vendors work. This ensures that, besides economy and quality, sustainable activities are also determinants in determining the image of companies.

2 Theoretical Background

Logistics and transportation activities are responsible for approximately 25% of greenhouse gas emissions, one of the biggest environmental problems today (Çetin and Sain, 2018). In addition, in line with the countries' development plans, logistics is very important both in ensuring economic growth and environmental improvement and in line with the employment areas it includes. While protecting and developing its natural capital by reconsidering its economic growth strategies, the EU aims to protect the health and well-being of its citizens from environmental risks (Abiral et al., 2020).

According to the Sustainable and Intelligent Transport Strategy announced by the EU within the scope of the European Green Deal, increasing the share of sustainable and green transport modes by developing combined transport; increasing rail and inland waterway transport in freight transport; launching zero-emission vehicles in the road, air and maritime transport; development of electric vehicle infrastructure; increasing the production/use of sustainable and alternative fuels in all modes of transport; Green pricing in transportation and the development of smart transportation systems are gaining importance. In addition, by creating an environmentally friendly, smart, competitive, safe, accessible, and affordable transportation system, it aims to reduce transportation emissions by 90% until 2050. In line with this target, it has been decided to reduce emissions by at least 55% by 2030. The Green Deal is the economic transformation model to be used as a roadmap to achieve this goal (European Commission).

A significant portion of 75% of inland freight transport carried by road is planned to be shifted to railways and inland waterways. Airlines emissions will be greatly reduced by re-starting the Single European Sky in Aviation. Thanks to digitalization, smart traffic management systems will be created, and thus traffic congestion and air pollution will be reduced, especially in crowded cities. In addition, transportation pricing will be calculated by considering the impact of traffic density on the environment and health. In other words, taxation encourages people to prefer clean transportation vehicles. In addition, measures will be taken to increase the production of sustainable alternative automobile fuels. It is expected that 13 million zero or low emission vehicles will be on European roads by 2025. It means that one million public charging and filling stations will be needed for these vehicles (Mısır and Arıkan, 2022).

In July 2021, the Ministry of Trade of Turkey published the Green Deal Action Plan. The action plan includes steps to be taken in a wide range of areas, such as combating climate change, green finance, EU border carbon regulation, a green and circular economy, clean, economical, and safe energy supply, sustainable agriculture, sustainable smart transportation, and diplomacy.

The plan aims to inform companies, especially Small and Medium-Sized Enterprises (SMEs), on environmental labeling and waste management issues, to raise awareness for recycling food scraps and waste, and to raise awareness of consumers.

2.1 Turkey's Logistics Industry

According to Erkan (2014), logistics is among the most popular sectors after tourism, and Turkey sees logistics as a tool to achieve its foreign trade and sustainability goals on the international platform. It is seen that the importance of logistics in the changing world trade is gradually increasing. Located between two continents with the largest share of world trade in terms of its geopolitical position, Turkey has important airline and seaway infrastructures on its logistics routes. Turkey is beginning to stand out in logistics by strengthening its technical infrastructure in transportation and logistics with increasing infrastructure investments.

Logistics Performance Index data is accepted by local governments, regional groups, and international organizations such as the OECD and the United Nations (Arvis, 2018). According to the World Bank data, the Logistics Performance Index (LPE) is a benchmarking tool created to reveal the difficulties and opportunities encountered in countries' trade logistics and improve them. The LPE is based on a worldwide survey of global shipping companies and carriers that provides information on the logistics performance of the countries in which they operate and trade. Feedback from operators in the field provides quantitative data on the performance of key logistics components in that country. LPE consists of six different components, including customs performance of countries, quality of infrastructure, and timeliness of shipments. Measured data for Turkey are presented in Table 1 (World Bank, 2022).

Table 1: LPE evaluations (Turkey)

Year	LPE Score	LPE Rank	Customs	Infrastructure	International shipments	Logistics quality and competence	Tracking and tracing	Timelines
2007	3,15	34	3,00	2,94	3,07	3,29	3,27	3,38
2010	3,22	39	2,82	3,08	3,15	3,23	3,09	3,94
2012	3,51	27	3,16	3,62	3,38	3,52	3,54	3,87
2014	3,50	30	3,23	3,53	3,18	3,64	3,77	3,68
2016	3,42	34	3,18	3,49	3,41	3,31	3,39	3,75
2018	3,15	47	2,71	3,21	3,06	3,05	3,23	3,63

Source: World Bank (2022)

Turkey ranked 34^{th} in the world with 3.15 points in 2007. In 2018, it dropped to 47^{th} place with 3.15 points. Here, it is seen that the biggest decrease is due to customs. Turkey showed its best period in terms of logistics performance in 2012-2014 and ranked 27^{th} in the world in 2012. Timing is the part where Turkey gets the highest score from the logistics components, and certain stability is maintained. Although it is quite efficient in terms of logistics timing in Turkey, it is clear that there is a problem in the customs with the lowest score and a need for improvement.

Industry professionals in Turkey make recommendations to the decision-makers for the Turkish logistics sector to adapt to the Green Deal. The best ways for adaptation include; investing in environmentally friendly technologies, encouraging the sector's environmentally friendly technology investments, promoting sustainable alternative fuel and electric vehicle use, increasing investment support during the transition to green technologies, and increasing the use of environmentally sensitive vehicles in road transport, strengthening the railway infrastructure, enabling uninterrupted transportation, promoting intermodal transport, the establishment of railway connections of ports, and facilitation and development of transit transportation (Eldener, 2020).

Transit passes provide great gains, especially when they are by rail. The Middle Corridor, in which Turkey is located, is the most important railway corridor of the new silk road, starting from Western China and reaching the borders of Western Europe through Kazakhstan, Azerbaijan (with the Caspian Sea passage), Georgia, and Turkey. With the completion of the Baku-Tbilisi-Kars railway, the Turkish connection to this line has also been strengthened. In this context, Turkey has geographical importance will improve trade relations between China and Europe (Tümenbatur, 2021).

3 Research method

Pianta and Lucchese (2020) state that the European Green Deal (EGD) is a major climate change policy that the European Commission launched in December 2019. It is a long-term strategy for the transition to a low-carbon economy in alignment with the 2015 Paris Agreement. It aims to make Europe the first carbon-neutral continent by 2050 (Pianta and Lucchese, 2020).

In their study Maris and Flouros explain the EU’s target to meet the aims set for 2030 as follows:

1) reduce greenhouse gas (GHG) emissions by a minimum of 40 percent,
2) increase the renewable energy sources (RES) quota to a minimum of 32 percent EU energy use,

3) increase energy efficiency by a minimum of 32.5%,

4) guarantee a minimum of 15% electricity inter-connection levels among neighboring the member states, and

5) support Research and Innovation (R&I) initiatives through the available financing tools. (Maris and Flouros, 2021)

This research used content analysis to review literature from recent journals, magazines, and newspapers to draw out secondary data that helped analyze the drivers of the EU's green deal practices and the challenges Turkey's logistics industry faced in implementing them. The main objective of this paper is to investigate Turkey's competencies in international logistics and evaluate the compatibility of the planned actions with the green deal process. The following research questions address the purpose of this paper:

RQ 1: Is Turkey's logistics performance ready for the green deal?

RQ 2: Will the action to be taken for the green agreement increase the logistics performance of Turkey?

RQ 3: Will Turkey be able to implement its action plan?

We illustrated our extended research framework in figure 1.

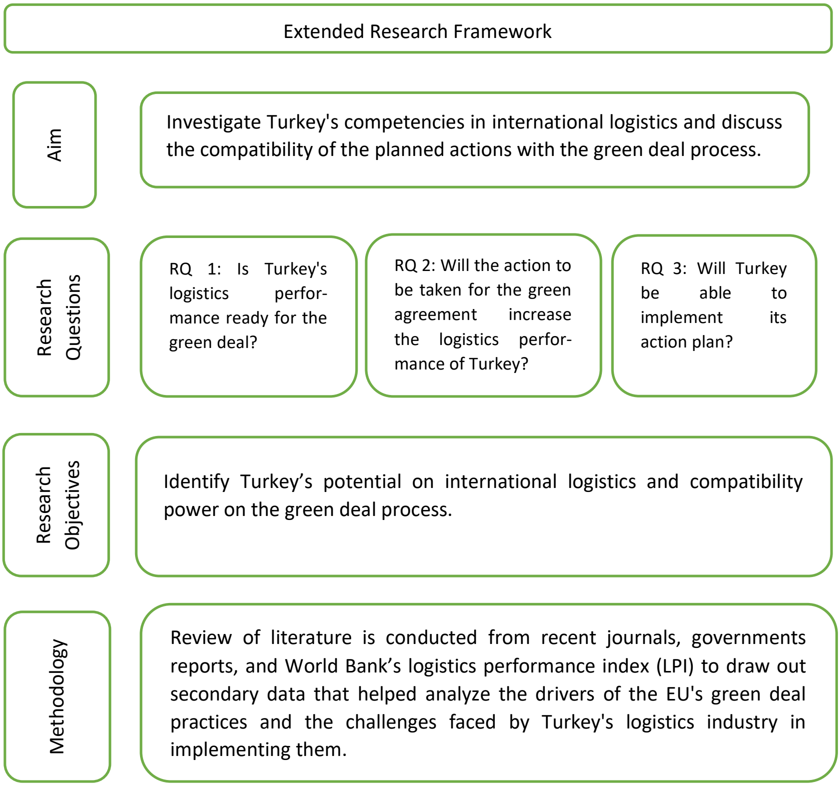

Figure 1: Extended Research Framework (adopted from Mohr & Khan, 2015)

4 Results

The European Green Deal is a growth strategy of the European Union aiming at net zero emissions of greenhouse gases by 2050 in the fight against climate change and global warming. Since the EU's weight in Turkey's total exports is just over 40 percent, Turkey has also prepared a 'Green Deal Action Plan' to adapt to the new situation. According to the Ministry of Trade of Turkey (2021), “Action Plan has been announced in order to contribute to the transition to a sustainable and resource-efficient economy and to adapt Turkey to the comprehensive changes envisaged by the European Green Deal, in a way that will preserve and further the integration achieved under the Turkey-EU Customs Union. Therefore, information and awareness activities classified as; border carbon regulations, green and circular economy, green finance, clean, affordable and secure energy supply, sustainable agriculture, sustainable smart transportation, combating climate change, diplomacy and European Green Deal implementation”.

Road transport is mainly used in trade with the EU. Road transport accounts for about 40% of the increase in global oil demand. This shows that emissions from road transport are in a rapid increase trend. For this reason, the road transport sector, which is one of the sectors that have the most impact on greenhouse gas emissions worldwide, and businesses that want to exist in the sector, should prioritize environmental awareness, implement strategies that will minimize their negative economic effects and increase their service quality, and turn to environmentally sensitive transportation methods (Eldener, 2020).

In line with the goal of sustainable smart transportation, a road map that the Turkish officials announce includes:

- The Combined Transport Regulation will be put into effect.
- Logistics Centers Regulation will be put into effect to support the balanced development of transportation types and methods.
- Developing railway infrastructure between the EU and Turkey will be continued.
- It is aimed at preparing the national legislation regarding the Green Port Certificate Program.
- Preparatory work will be carried out to declare the Mediterranean Sea as a SECA (Sulfur Emission Control Area).
- Research will be conducted to reduce harmful emissions from the maritime sector and to support green shipping.
- Strategy development and planning will be made to develop electric vehicle and charging infrastructure.

- Effective implementation of the use of electric vehicles in public transport fleets and encouragement of public transport action will be planned.
- In order to reduce exhaust emissions and to provide alternative fuel, low emission individual transportation opportunities, necessary legislative studies will be completed to increase the use of micro-mobility vehicles.
- Bicycle/e-scooter roads, parking, and charging stations will be built. (Ministry of Trade of the Republic of Türkiye, 2021)

Hundreds of standardization, certification and accreditation studies are carried out to increase the quality of logistics in Turkey and Europe. In Turkey, there is a need for a budget to be allocated for logistics companies to have these standards and a workforce that will bring these standards to institutions and operate according to the standards in practice. International standards give prestige in the global market. It gives strength in the competition. It ensures that innovation takes place in the routine work of the institution and works in coordination with strategic partners. In the process of Turkey's accession to the European Union, these standards should be known in all rings of the supply chain and the necessary quality certificates should be obtained, and the legislation should be updated to include these standards (Adıgüzel, 2020).

According to the subject matter experts, although it may seem difficult for Turkey to adapt to the green deal, it is predicted that the transformation can take place rapidly with the right regulations and incentives. As a result of the interviews, we came up with the following results:

- In the transformation process, public, private sector, and non-governmental organizations and universities should act together.
- It is of great importance that the processes of data collection and carbon footprint calculation regarding the transformation are carried out transparently.
- In order to reduce the total greenhouse gas emissions originating from the logistics sector in Turkey, more importance should be given to railway investments by both the public and private sectors.
- It is necessary to shift the freight transported mainly by road to environmentally friendly transportation types such as rail and combined transportation.

- Logistics centers, where freight transfers between transportation modes are facilitated, should be designed correctly, and legislation and implementation changes should be updated based on the sustainability principle.

In addition, Turkish companies that are the logistics industry stakeholders make investments by developing some practices to minimize the damage they cause to the environment during their activities. In particular, efforts to reduce carbon emissions in transportation activities are of great importance in the green transformation process. Practices of companies related to Sustainable and Green Logistics:

- Using alternative environmentally friendly fuel vehicles such as LPG and CNG in production and shipment,
- Using vehicles with environmentally friendly engines such as EURO 5,
- Installing noise and sound suppressors on vehicles,
- Using environmentally friendly, efficient transportation and distribution systems,
- Reducing general packaging processes and materials used,
- Using recycled materials instead of plastic materials in packaging,
- Using pure (unmixed) products in a sustainable way,
- Environmentally friendly recycling,
- Training of personnel in cognitive and affective fields,
- Efforts to raise awareness of customers.

5 Conclusion

Globalizing trade and rapid change in technology are changing the needs of countries day by day, revealing the importance and necessity of foreign trade in terms of growth and development goals of countries. One of the elements whose influence is felt strongly in this process of change is logistics network services. The performance of countries in logistics and administrative processes is of great importance in terms of both foreign trade and the effectiveness of inter-country competitiveness. This paper presents the EU’s Green Deal implementations and their possible effects on Turkey’s logistics industry. Turkey’s responsive and adaptive action plans are also mentioned regarding the issue.

In Turkey's adaptation process to the Green Deal, establishing an incentive mechanism for Turkish companies as in Europe will make the transformation faster and more successful with the support of the state. For Turkey to continue its cooperation with the EU, it will need to understand the regulations in the logistics sector better, follow the developments and develop the ability to take quick steps to comply with the standards established within the Green Deal scope.

Turkish companies that foresee green transformation and implement it in their structures and make it a part of their strategies; will be more agile and more competitive in both national and international markets; be able to access and benefit from global financial resources easily; they will make their product portfolio greener and more sustainable. In addition, it will be easier for these companies to reach international standards, and their opportunities to open up to international markets and do business will increase.

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Sustainable Last Mile Delivery Network using Social Media Data Analytics

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Purpose: *The purpose of this research was to identify effective strategies to engage consumers to participate in the creation of a sustainable last-mile delivery network using social media and data analytics.*

Methodology: *The research uses the data gathered through surveys to evaluate the customer motivation to contribute to the sustainability paradigm. Also, interaction models have been designed to elaborate the conceptual model and stakeholder interactions.*

Findings: *Using social media as a tool, there would be a considerable potential to motivate the customers for contributing and enabling allowances for the last mile delivery problems. Customer engagement and communication will increase their role to achieve sustainable last-mile delivery. The application of autonomous methods of delivery should be considered to increase the awareness and trust of customers.*

Originality: *This research is unique in terms of engaging the customers for sustainable last-mile delivery planning. Most of the sustainable last-mile delivery research focuses on business responsibility while also they are required for fulfilling the best service level for customers. Increasing awareness among customers can increase their participation for a trade-off in delivery service level while fulfilling sustainability.*

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1 Introduction

1.1 Research motivation

Logistics and supply chain activities saturate almost every aspect of our daily lives. Thus, their capability to affect the natural environment is essential. Last-mile logistics is judged as the most polluting section of the supply chain. With the rapid growth of the e-commerce industry, it is now considered one of the giant emitters of Carbon dioxide (Co2) (Awwad, Shekhar and Iyer, 2018a), which has led to climate change. Climate change has become increasingly apparent to everyone, either heard about its effect or experienced it. It is no longer just a concern; instead, it is an enormous threat to our environment. It is generally understood and confirmed by science that human-induced climate change. Here is a lucid cycle that explains better the process of climate change and its effects. Human activities are the leading cause, primarily through forestation and burning of fossil fuels, for example, industry, electricity generation, driving cars, flying planes, and space heating, which led to the release of carbon dioxide (Co2) and other heat-trapping “greenhouse gases.” The increase of greenhouse gases led to increased radiative forcing (Global warming), further leading to surface heating, increasing the temperature, precipitation rates, latent heating, and storm intensity. As a result, increased Runoff and increased flooding (Trenberth, 2018).

1.2 Co2 and last mile delivery

The question might arise, why focus on reduction of Co2 in last-mile delivery? In the European Union commission report, they raised their concern about the greenhouse emissions released in the transport sector. They demonstrate how a quarter of all Europe’s greenhouse emissions are made by transport and are the primary reason for air pollution in cities. While road transport (last-mile delivery) itself makes 70% of all greenhouse gas emissions from the transport sector, insofar as the first emitter in that sector. The vulnerability is that compared to the other sectors, the transport sector was left behind in terms of a progressive decline in emissions (EU commission, 2021). Moreover, carbon dioxide (Co2) gets more attention than other greenhouse gases, even if it is considered the second worst greenhouse gas after “water vapor.” Proven by more than 100 scientists in the Intergovernmental Panel on Climate (IPCC), reviewed quantity wise carbon dioxide (Co2) as the first greenhouse gas emitted by human activities and takes the first place as a contributor to climate change than any driver of climate change (Sabine, 2014).

To find a solution to detrimental health, economic and social impacts caused by greenhouse gases, particularly Co2. From InterContinental's level to the nation, to companies up to the individual consumer, every party should engage in making it possible. On the national level, for example, Germany is pledged to an EU action to enhance corporate social responsibility in global supply chains (Burkhardt, 2020). The aim of 2020 to reduce 40% of the greenhouse was met through likely extraordinary factors. However, with a target to reduce 55% by 2030 and complete the greenhouse gas neutrality target by 2050, it will take more than enough effort to achieve it (umweltbundesamt, 2021). In that regard, A decision of March 24, 2021, by the Federal Constitutional Court in Karlsruhe is, therefore, a novelty in the history of environmental policy in the Federal Republic of Germany. It forces politicians to make changes in their climate protection planning. The court criticized the lack of sufficient requirements for further emission reductions from 2031 onwards. However, Germany takes it more seriously than ever; recent events such as the flood disaster that shook the Federal Republic in July 2021 with more than 180 deaths (Jacobsen, 2021).

1.3 The logistics firms and consumers' roles

Logistics Companies are the dominant generator of Co2 emissions. However, Logistics is more than just transporting goods and people; it includes storage and material handling. In other words, it is the fore and aft from the origin point, up to the consumer, and in between dealing with the movement of goods, related information, and services to archive customer's need. Of the five major phases in the supply chain, last mile logistics is the last and the most challenging as it is specified as the final leg of the journey as it has to convey the product to the customer's hands. It focuses on customer satisfaction, cost, and time. There is always a conflict between those three points, making the last mile delivery a considerable challenge. Not only in terms of cost but harm to the environment

(Co2 emissions, noise, safety, congestion, and the list goes on), which will get worse (Awwad, Shekhar and Iyer, 2018a).

The government's environmental policy's strength requires logistics companies to shift to sustainable logistics. Sustainable logistics is structured to evaluate, analyze, and reduce the negative impact of logistics operations. Therefore, it is a beneficial key to using the digital calculation of Co2 emissions due to the high volume of transactions made by logistics companies. Although there are standards and regulations, companies fail and still struggle to adhere to them (waves, 2021). Although Logistics companies frequently use market research to access consumers, it primarily improves their sales by introducing new products. However, not about working with consumers to reduce CO2 (Jaworska, 2018).

1.4 Social media and data analytics

Social media have offered a novel possibility to consumers to engage in social interaction on the internet. Consumers utilize social media, for instance, an online community, to create content or campaigns to connect with others. With the rise of digitization, social media is defined as a great advantage for business gain (Hajli, 2014). It is the primary weapon used in sharing information. It has become a marketing key tool between consumers and brands. In parallel, it is a safe place for consumers to express themselves and advocate the change they need about any company or product.

The rise of social networks has highly promoted users' consumption experience, which affects the trends in one way or another despite the location. It has also enhanced better communication between two parties, allowing consumers to have a closer connection with the brands in terms of endorsement or even a solid and balanced association. Daily internet usage statistics from Euromonitor international demonstrate how almost 99% of mobile devices in 2022 will be connected to the internet. Moreover, that increases sharing of information about consumers' experiences through social media. Consequently, it plays a crucial role in product, brand, or service trends (Post DHL, 2018). Reviews made on social media influence the buying behavior of millions of customers. Social Media information extensively predicts, attracts, and influences consumers' decisions. The wide use of social media platforms has generated massive user-generated content (UGCs). To leverage user-generated content UGCs, organizations need to develop the capability of collecting, storing, and analyzing social media data for harvesting information and actionable knowledge for decision making and forecasting (He et al., 2019).

In this paper, research is conducted on how logistics firms can execute mitigation of green gas emissions in last-mile delivery, using social media to enable consumer engagement concerning their perspective. Together, creating a sustainable (reduction of Co2), the last-mile delivery network could be provided involving both sides. A survey was conducted in the Federal Republic of Germany through a local company's social media platform and reached 6000 consumers. Only 360 subjects volunteered to participate in the whole study.

The Research questions are answered using an internet panel survey of participants between the age range of 17-25 up to 66+ years old, inquiring about their preferences for last-mile delivery options, which all act in reducing CO2. A German residence only simple as the company used in this research had only access to those subjects. The novelty of this research is how consumers assess different last-mile delivery services. Not only in terms of cost and time but values insofar as the emission of local air pollutants and greenhouse gas emissions (CO2); furthermore, logistic companies should invest in market research to gain consumer knowledge to fight climate change together.

The rest of the paper is organized as follows: Section 2 provides a literature review and research gap analysis. Section 3 introduces a proposed conceptual model. Section 4 briefly discusses the preferable sustainable model and elaborates all the options given to consumers. Section 5 concludes the paper results and future insights.

2 Literature review

This study focuses on the engagement of consumers. It contributes to creating a sustainable last mile delivery using social media to communicate with logistic companies. It discussed different attitudes which support this study. In this chapter, the researcher defined the term Last mile delivery, sustainability in this matter, Consumers related to last-mile delivery, and explained the use of social media technology and data analytics to improve the relationship between consumers and Logistics companies and evaluate it. The Literature review also discussed the previous studies on those four perspectives (which include Last-mile delivery, sustainability, consumers, social media, and data analytics) and the relationship between them. In the end, Research Gap Analysis will provide a foundation to create a conceptual model and propose a solution.

2.1 Last mile delivery

Last mile logistics is the last step of the supply chain from the final distribution center to the receiver's favorite destination point (Gevaers, Van De Voorde, and Vanelslander, 2009). It operates in the business-to-customer (B2C) market and footed on home deliveries (Iwan, Kijewska, and Lemke, 2016). Subject to several factors, Last mile delivery is the most expensive, polluting, and inefficient. Assessment from many studies confirms that 13%-75% of the whole supply chain is for the last mile alone (Gevaers, Van de Voorde, and Vanelslander, 2014). The Causes for that inefficiency depend on different factors such as concentration of consumers, timeframe, fragmentation of deliveries, congestion, and shipment size. Last mile logistics are an external factor for mainly Greenhouse gas emissions, air pollution, noise, and congestion (Olsson, Hellström, and Pålsson, 2019). For these reasons, last mile logistics has attracted much attention and has become an alarming topic worldwide. However, the following triggers are the provoker of the concern seen in last-mile delivery (Boysen, Fedtke and Schwerdfeger, 2020; Sodachi and Valilai, 2021).

- A tremendous increase in demand, rapid population growth and the majority of consumers are urbanized. E-commerce is blooming unexpectedly, where internet retail quintupled from $290.4 billion to 1.6 trillion (Post DHL, 2018).
- Sustainability, the rise of urban parcel demands stimulates many city-delivery vans (Hu et al., 2019).
- Costs, the traditional way to handle the parcel to a recipient using a regular delivery van is expensive. A study based on real-world data in Finland demonstrated that a standard (traditional) van-based delivery costs 2 to 6 euros (Punakivi, Yrjölä, and Holmström, 2001).
- Time pressure: Last mile delivery encounters a very tight deadline and significant time pressure. Additional online orders fluctuated weekly, making

Monday's peak workloads (Prodhon and Prins, 2014). The situation worsened during the seasonal sales (Boysen, de Koster, and Weidinger, 2019). It requires the last mile concept to be expandable even on short notice to resist a steady varying workload (Boysen, Fedtke, and Schwerdfeger, 2020).

- The aging workforce is still a concern in industrialized countries regarding staffing requirements (Otto et al., 2017). Primarily in physically demanding conditions, such as delivering the parcel to the customer's home (Peterson, 2018).

2.2 Sustainability in last mile delivery

Several works of literature addressed the function of sustainability in logistics and supply chain management (SCM). One of the highlighted terms is "green SCM." As the term implies, the focus is on the environmental facet of supply chains (Brockhaus, Kersten, and Knemeyer, 2013). Sustainable evolution has encouraged numerous green and sustainable logistics operations to reduce the negative impact of transportation (Abbasi and Nilsson, 2016). Sustainable logistics is structured to evaluate, analyze and reduce the negative impact of logistics operations (Awwad, Shekhar, and Iyer, 2018b). Green and sustainable logistics are specified to plan, control, manage and implement logistics systems within advanced logistics technologies and environmental management to decrease contaminants and promote logistics performance (Bask and Rajahonka, 2017).

The aim of sustainable logistics does not only cease supplying green goods or services to customers (Pourhejazy, Sarkis, and Zhu, 2019). However, it also includes the green and sustainability of the whole lifecycle of the logistics routine. It enhances good environmental and social feedback (Zhang et al., 2015; Sodachi, Sahraei, and Valilai, 2020). Because it will increase resource utilization, decrease resource consumption waste, mitigate environmental contamination when performing logistics activities during rational planning, and maximize resource allotment and environmental technology (Hasan Qaiser et al., 2017). More literature emphasizes the importance of innovation in sustainable logistics. Björklund and Forslund (2018) Stated innovation as the primary driver of sustainability. Innovation through sustainability can considerably impact companies' performance due to their reputation and beneficial market effects. Research has shown that Innovation thinking is a must in solving the environmental and social problems in building sustainable logistics (Andersson and Forslund, 2017).

Björklund Maria, Forslund (2015) continued to show that a better way to achieve social and environmentally sustainable progression, implementation of innovation will significantly make progress. However, there is still a lack of research on the measurement of innovation in Sustainable logistics (Andersson and Forslund, 2017)

Few research papers have focused on consumer preferences for last-mile deliveries in the sharing economy. Nevertheless, few, like Caspersen and Navrud (2021) conducted a study on females between the age of 18-70 regarding their preference for environmentally sustainable last mile deliveries. Results showed that females have a disutility from delivery time and a positive utility from information services. Female consumers will likely agree to the increased delivery time if it implies reduced emissions.

2.3 Consumers and sustainability

Other literature has discussed the role of consumers in a corporation and its sustainability. Collins, Steg, and Koning (2007) stated that Consumers are the predominant stakeholders. Thus, corporations must consider consumers in determining corporate policies and priorities. Collins, Steg, and Koning continued to stress that customers' power can impact their buying behavior when exercised as a stakeholder group. By purchasing or not purchasing a product from a particular company, customers have a crucial power to influence that company. Agle, Mitchell and Sonnenfeld (1999) In their journal publication "Who matters to CEO? An investigation of stakeholder attributes and salience, corporate performance, and CEO values", managers' reports revealed that customers are the most salient stakeholder group; they are the priority before the manager's team. Thus, customers are "principally" stakeholders. Therefore, if customers' demands demand social and environmental performance, corporations should respond or gamble the corporation's downfall (Hillman and Keim, 2001). Nevertheless, customers' opinions have been chiefly expressed through market research to ascertain a product and services they order. Seldom studies are done from the stakeholders' perspective (Consumers) (Collins, Steg, and Koning, 2007).

2.4 Social media and data analytics in sustainability

A variety of literature argues about the role of social media in promoting sustainability. Zeng et al. (2010) stated that the main force behind the surge of social media is the internet and mobile, offering technological platforms for information distribution, content generation, and synergistic communications. In the for-profit domain, social media has been a gold mine of information and a Business-performance platform for innovation and product design, consumer and stakeholder relationship supervision, and marketing (Olad and Valilai, 2020). Young (2014) stated how social media has rapidly escalated and turned out to be a sustainable essential in daily life; he continues to demonstrate the benefits firms will get in the presence of social media. Howells and Ertugan (2017) discussed how social media can assist firms in supporting the promotion and marketing of their brands to their customers. Which will improve the external communication, awareness, and reflection leadership. Tseng (2017) stated that social media is a public channel company could use to broadcast information. However, little work has considered combining qualitative and quantitative information or discussed social media's role in decision-making. Social media endorses customers' requirements and enhances the firm's performance (Effing and Spil, 2016), even if social media is a challenge for firms due to its inherent pitfalls. For instance, end consumers' amorphous, qualitative, and subjective perceptions of subjects placed on social media platforms (Chan et al., 2016). Social media can immensely impact consumers' decision-making (Tseng, 2017).

On the side of Logistics companies, social media is an innovation to reach social supply sustainability by improving efficient information flow from both in and outsources (Orji, 2019). Social media encourages social sustainability in operations and supply chain management (Wang et al., 2019). promoting social media and other innovations in supply chain social sustainability, especially in the logistics industry, has made Critical success factors in managing the entirety of decisions and processes in the firms as well its supply chain. However, literature is still insufficient regarding the critical success factor for using social media in the logistics industry (Ahmadi, Nilashi, and Ibrahim, 2015).

2.5 Research gap analysis

Previous research has approached several aspects of sustainability in last-mile delivery (Hu et al., 2019; Boysen, Fedtke and Schwerdfeger, 2020; Hasan Qaiser et al., 2017). The role of consumers in sustainability (Hillman and Keim, 2001; Stöckigt et al., 2019) (Brockhaus, Kersten, and Knemeyer, 2013) and how social media is a tool to facilitate a sustainable last mile delivery (Ahmadi, Nilashi and Ibrahim, 2015; Wang et al., 2019; Orji, 2019).

However, in addition, research on the combination of sustainability in the last mile delivery and sustainability in consumption using social media encompasses several new dimensions that lately have attracted research attention in other disciplines (Young, 2014; Hu et al., 2019; Olsson, Hellström and Pålsson, 2019). Some of these new combinations appear essential and worthy of investigation in achieving a sustainable last-mile delivery. Investigating these issues is essential because consumers' contribution is crucial in this matter. Furthermore, previous empirical research has focused primarily on customers' opinions expressed through a market research perspective; very little research has been done on consumers' genuine opinions (Collins, Steg, and Koning, 2007; Stöckigt et al., 2019).

In this study, the seek was to extend the research by addressing the gap in the engagement of consumers (their opinion on their perspective) in diminishing Co2 emissions in last-mile delivery (Björklund Maria, Forslund, 2015; Collins, Steg and Koning, 2007). Even though corporates have put effort into market research to get consumers' opinions. But it was most of the case solely to promote their products, not in the matter to work together with consumers to resolve climate change issues (Jaworska, 2018) and using social media data analytics as a tool (Ahmadi, Nilashi, and Ibrahim, 2015).

The study investigates the impact of four perspectives, Last mile delivery, sustainability, consumers, and social media & data analytics. In addition, interrelationships among them are examined.

3 The proposed framework and workflow solution

The paper proposes a framework model to enable the sustainable last mile delivery by benefiting the data analytics in social media platforms. The conceptual model is shown in Figure 1. The interaction among the model elements can be described as:

1. Last Mile Delivery Firms in their digital campaign, send triggers to social media audiences in order to figure out which Consumers are interested. E.g., The firm will post #environment .... or send a request to consumers.
2. Data analytics will be used to analyze data, using information fed by social media.
3. Willing consumers and None-Willing Consumers ones will be recognized with the help of data analytics.
4. Using the data from workflow 4. And the assessment model, the decisions for delivery will be model and result are shared with consumers individually to gather their opinions.
5. The feedback from willing consumers would be Analyzed and the required modifications will be considered in order to select the most likely propositions.
6. The firms will finally create the final sustainable last mile delivery models with a participation of consumers.

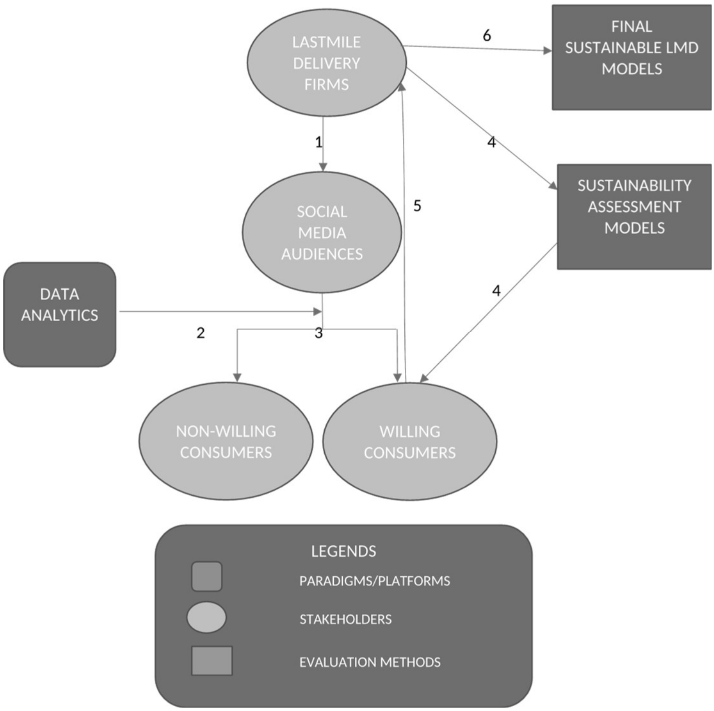

Figure 1: Proposed Conceptual Model

The details of interactions among model stakeholders are elaborated in Figure 2.

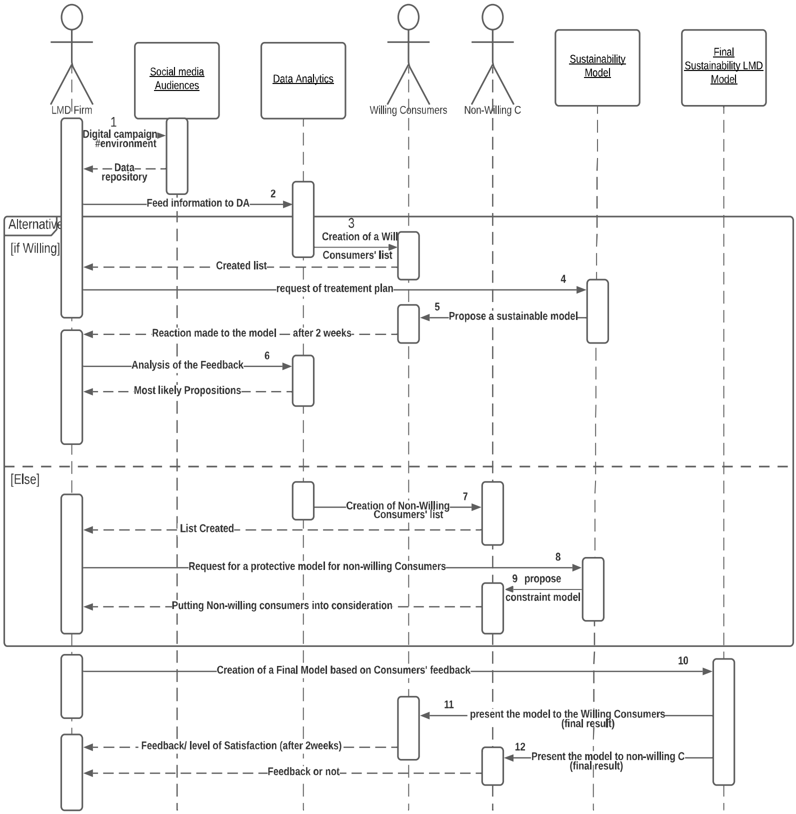

Figure 2: The interaction of model stakeholders

The recommended interactions can be explained as:

1. Last mile delivery (LMD) firm runs a digital campaign to social media platform e.g., sending request and LMD will gather data from social media as a return message.
2. The data will be feed to the data analytics to be analyzed.

3. Data analytics analyze data from social media audiences searching for consumers who responded to the request and classify them as willing consumers. Alternative frame is created to symbolize the choice between willing consumers and non-willing consumers and a willing consumers list is created.
4. Actor LMD requested a sustainable plan for the object "sustainability model".
5. Then the "sustainability model" sends a sustainable proposal to willing consumers. Willing consumers will respond to the proposal and give their feedback within a period 2weeks.
6. LMD sends the feedback to a data analytics object to be analyzed, as a response data analytics object will provide a segmentation of feedback according to similarity or preference.
7. If not willing option, data analytics will provide a list of non-willing consumers to LMD.
8. LMD will request a protective model to object "sustainability model" to recognize and protect non-willing consumers.
9. The object "sustainability model" will propose a constraint-based model to non-willing consumers.
10. LMD will create a final model made of willing consumers' feedback.
11. The object "Final sustainability LMD model" will send it to actor "willing consumers" as a response, willing consumer will send their level of satisfaction to LMD.
12. The object "Final sustainability LMD model" will send it to actor "non-willing consumers", as a response, willing consumers will send their level of satisfaction or not to LMD.

The primary purpose is to make the output sustainable, by enabling consumer's engagement using social media data analytics as a tool for the purpose to reduce Co2 emission in last mile delivery. To achieve that goal, the proposal is displayed in a manner where firstly, Logistic firms runs a digital campaign with a purpose to create a sustainable last mile delivery network in cooperation with customers, sending environmental messages, posting e.g., # go green, #carbon footprint etc., and customers who are all part of the analysis are considered. Using a dataset from "Feld forum Ruhr" company, a specific set of customers are segregated based on the type of activities they are involved in on social media or the responses to the digital campaign they provide. A data analytics method is used to extract the data to achieve the objective to obtain two types of customers: the willing customers type who volunteer to participate in the digital campaign and the non-willing customer group.

Then, possible scenarios are analyzed and will be proposed to customers. The proposed scenarios are decided with respect to the logistic site considering what and which type of scenarios are realistic. Upon choosing from the logistic site a sustainable matrix theory will be developed and delivered to both groups. different sustainable options will be presented to the willing customer group, and they will have the power to rate the options given, even be able to create their own sustainable options according to their perspectives. The same action will be applied to the non-willing customer group, instead a constraint-based model will be proposed to them, so that this group will be protected and put in consideration their values. A period of 2 weeks will be given to the customers to give their feedback (comment, rating, observation, opinion, reaction, creation etc.). The feedback will be analyzed by data analytics tools from there a final model will be developed and delivered again to both specific sets of consumers. This time they will be given 2 weeks to evaluate the final sustainable models and express their satisfaction.

4 Evaluation and analysis

4.1 Implementation phase Methodology

In the implementation phase, the strategy involves using qualitative and quantitative methodology. The first-round qualitative methodology will be used because the focus is on collecting and analyzing customers' feedback as the objectives are exploratory. Plus, to segment the customers into different groups and address individual customers based on natural behaviors to avoid including pre-conceived notions and assumptions by only focusing on aggregated data. Qualitative online surveys will be conducted. Questions will be presented to participants in written format via market research platforms, alongside quantitative survey questions on the same topic. Participants are required to respond to questions in text (in detail) to clarify their perspective or experience, which prompts a diversity of responses. Additionally, Online surveys will collect a significant number of responses compared to face-to-face and phone survey approaches. The second round will be a full quantitative methodology as the objectives are confirmatory; the target is to measure how satisfied the participants are. In that matter, Python will be used for the data analysis part. A few steps will be implied to analyze survey data. First, data preparation will be done. Using Code to analyze the survey data, it is needed to get it in the form of a .csv file. Spider anaconda tool will be used for coding as it is quick to set up and very convenient. Panda was used to import csv file into spider anaconda environment.

4.2 Experiment design

The paper has adopted an Online survey to reach many participants regardless of geographical location in a shorter time. Moreover, it is convenient in economic, environmental, and safety terms, as there is no need to print countless papers or postages, plus no additional transportation costs or face-to-face interviews with covid-19 pandemic restrictions. For efficiency, it will enable testing each choice set equally and randomly across the sample. The online platform google forms online survey was utilized to create the necessary survey due to its considerably customizable capabilities.

As part of a survey, more than 6,000 participants were contacted, through market research (Feldforum Ruhr), usually answering questions in return for payment. Three hundred sixty subjects were prepared to complete the questionnaire and give their opinions for free. Participants are professionals in different domains; some work in logistic companies such as DHL and Helmes. Participants came from all over Germany (within 16 federal states). For that reason, the surveys were conducted in the German language.

Here is an overview of the overall homogeneous socio-demographic data: According to gender, 56,5% of participants were female, and 43,5% were male. According to the work situation,71,5%work full-time and 28,5% part-time. Age ranges from 17-25 was 4.5%, 26-35 was 18.8%, 36-45 was 22.7%, 46-55 was 23.5%, 56-65 was 21.3%, 66+ was only 9.2%. In household situations, only 2,8% have more than 4 people in their household, while 65,3% have 1-2 persons and 31,9% has 3 to 4 persons. According to the Living situation: 82,7% are Urban residents while only 17,3 are rural residents. About their interest in the environment, only 0,6% are not interested while 66,9% are extremely interested. Active on social media: 50% prefer to use Facebook, 43,8% use Instagram, 12,6% Linkedin, Twitter 11%, and 26% use as well other social media platforms not listed above. Subjects were asked to complete a questionnaire via Feldforum Ruhr's platforms.

The survey's questions were structured into multiple choice questions, checkbox questions, and answer text. Five sustainable options were presented with their description, advantages and disadvantages, and their respective questions. Participants should answer the questions and write their opinions about their preferred sustainable option. Participants could give their opinion on more than one sustainable option. Also, with the following questions in each case, a detail of a selected option could be determined. Towards the end of the questionnaire, participants were asked to specify a preference for each option presented. Adherence to a ranking order was not mandatory. For example, rank one could be given to all options. Note that the five sustainable options were the result of various previous research. The sustainable options and their questions were presented as follows:

4.2.1 Option1: "The use of only one delivery person" (Incharge, 2021)

Description: Here, one company collects all packages from different logistics companies and delivers them to customers.

The advantages:

- The customer receives all the parcels once a day at a certain time and does not have to open to the messenger several times a day.
- The company uses electric vehicles, which reduce noise, emissions and dirt.
- Traffic and its congestion in the city center are reduced.
- Diesel driving bans are alleviated.
- Traffic safety will increase.

Disadvantage:

The additional fee incurred (currently, businesspeople in downtown Düsseldorf pay an additional 1.- Euro per package). The participants were asked how much per package they will be able to pay, between no further fee up to more than 2€. At the end of this question, participants were asked if they have any additions or suggestions regarding the option above.

4.2.2 Option 2: “The use of autonomous robots”

Description: Electrically powered ground vehicles enable parcel delivery, without a delivery person. This could save a lot of cost as a statement made by Hermes Supervisory Board Chairman Schibur "70 percent of Hermes costs are due to personnel" and "The delivery from the distribution center to the front door alone, i.e. the last mile, accounts for 50 percent of expenses." (handelsblattt, 2018).

- The autonomous delivery robots (SADRs). These are pedestrian-sized robots that only use sidewalks or pedestrian paths.
- The street robots (RADRs). Here, autonomous delivery is done with driverless vehicles that share the road with conventional vehicles.

The Advantages:

- Carbon dioxide emissions are significantly reduced because of the electric motors. Cost savings because no or fewer technologies are needed for drivers, can lead to lower prices. (No additional cost of labor which lead to lower price)

Disadvantages:

- Not complete pedestrian safety.
- Additional sidewalk congestion at the beginning of the still new technology.
- Downtown traffic is not that relieved.

Participants were asked, what would the cost savings be used for? Between 1.to lower the prices for parcel delivery, 2.to co-finance environmental projects at home and abroad, 3.to support educational offers for precarious workers.

At the end of this question, participants were asked if they have any additions or suggestions regarding the option above.

4.2.3 Option 3: “The use of drones”

Description: The drones will deliver the packages.

The advantages:

- Cost savings through driverless technologies.
- Less traffic and congestion in the city.
- Reduction of Co2.

The disadvantages:

- Drones can only transport packages up to about two kilos.
- Human labor is replaced by robots.

Participants were asked, what would the cost savings be used for? Between 1.to lower the prices for parcel delivery, 2.to co-finance environmental projects at home and abroad, 3.to support educational offers for precarious workers. Additional question was “does the maximum package weight of 2kg plays a role for you?” participants should choose between 1.no, because my packages never weigh that much. 2.no, I take the weight into account when ordering. 3.yes, but this type of delivery is still in its infancy. 4. Yes that’s why heavy parcels must be able to be transported. At the end of this question, participants were asked if they have any additions or suggestions regarding the option above.

4.2.4 Option 4: “The use of pack stations”

Description: Packages are delivered on foot or by bicycle from post office boxes, lockers in shopping centers, Train stations, or from a local store itself.

The advantages:

- Carbon dioxide emissions are significantly reduced.
- Traffic and its congestion in downtown areas are reduced.

Disadvantage:

- If one uses vehicles with combustion engines, the advantages are reversed.

Participants were asked: “there are exceptions that cause you to pick up the parcels by car (combustion engine)”. And participants should choose between 1. Yes, in bad weather. 2. Yes, if the package is too heavy. 3. Yes, when I am pressed by time. 4. No, I will go without the car when I pick it up. At the end of this question, participants were asked if they have any additions or suggestions regarding the option above.

4.2.5 Option 5: “accept longer waiting times”

Description: The service provider first collects parcels for your residential area and delivers them one or a few days later. The customer may receive a price or other benefit for the additional wait time.

The advantages:

- Carbon dioxide emissions are reduced.
- Traffic and its congestion downtown are reduced.

Disadvantage:

- Delivery is often delayed.

Participants were asked, what compensation do you expect from the service provider? Between 1. I do not expect anything, I only do it for the environment, 2. I am expecting a discount for the late deliveries, 3.i expect a price reduction in favor of environmental projects. Additional question was “if you are ready to wait, how long would you wait?” participants should choose between 1. max. one day, 2. Up to two days, 3. Up to three days, 4. Up to one week, 5. More than a week. At the end of this question, participants were asked if they have any additions or suggestions regarding the option above. After reviewing all the five sustainable options, participants had an opportunity to rate the options according to their preference from 1 as the best sustainable option and 5 as the worst. And participants were asked the reason behind their rating.

4.3 Result and discussions

4.3.1 The final ranking

- 1st place with 180 votes in 1st place received option 1, the use of only one delivery person
- 2nd place with 92 votes in 1st place went to option 4, the use of parcel stations
- 3rd place with 76 votes in 1st place received option 5, accepting longer waiting times
- 4th place with 27 votes in 1st place received option 3, use of drones
- 5th place with 21 votes in 1st place received option 2, use of autonomous (driverless) robots

The results show that the selection does have a very individual character. All options received votes for the first rank. So, there is no option that has no supporters. But there are favorites. And one that outshines all the others is Option 1 of course. But the differences diminish, when the 1st ranks, and the second ones are added and weigh them equally. The previous ranking remains, but the gaps become smaller.

- 259 (180 + 79) for 1st place the use of only one carrier
- 216 (92 + 124) for 2nd place use of packing stations
- 156 (80 + 76) for place accepting longer waiting times

Drones and autonomous robots remain behind in 4th place (69) and 5th place (67). The survey reveals that, even though, the majority of participants were skeptical about innovation using drones and autonomous robots. A group of participants who declare themselves as extremely interested in environment, interestingly they chose option 2 and 3 which use drones and autonomous.

After the analysis of these facts and participants' opinions, the paper proposes 3 models.

- Model 1: this model was a result of a combination of option1 (The use of only one delivery agent) + option 4 (The use of parcel station (parcel locker))

With this model 3 variants are conceivable. The deliverer always tries to meet the customer. If the recipient is not present, she/he puts the parcel in the parcel stations, from which the customer picks up his parcel later. The delivery person only delivers to the parcel station and there is no option to meet with the customer (contactless option). The delivery agent only delivers to the pick-up stations. However, if requested or if there are special circumstances (for example, the parcel exceeds a certain value or weight), he or she will call the customer directly. As a precondition: The parcel stations would have to be accessible quickly and in an environmentally friendly manner. Optimally within walking distance of the place of residence.

- Model 2: Combination of option1 "only one delivery person" + option5 "longer waiting times".

In this model, the assumption is that the parcel carrier first delivers parcels that the customer has marked as urgent in advance. In addition, or on other trips, he carries parcels that have been waiting for delivery for a longer time. There would be a need for separation into "urgent" and "can wait" actually exists because the messenger normally has his vehicles filled with urgent packages. Additional trips ensure that not-so-urgent deliveries also reach the customer.

- Model 3: A combination of option4 "Parcel station" + option5 "longer waiting times”

Deliveries are made only to the Parcel station. First with urgent parcels, later with packages that can wait. As precondition, Packingstations of all suppliers would have to be quickly and environmentally accessible. Optimally within walking distance of the place of residence. The need for a separation into "urgent" and "can wait" exists because the messenger normally has his vehicles filled with urgent packages. Additional trips ensure that not-so-urgent deliveries also reach the customer.

The three final sustainable models were presented to participants, through the same channel (official website of Feldforum Ruhr) first was to assure that their opinions to mitigate Co2 emission in last-mile delivery were taken into account, and secondly, how satisfied they are with the results provided. The participants had to give scores to models on a scale of 1 to 10. 1 as not satisfied and 10 very satisfied with the model. To rate them properly the accumulation of the last 3 digitals was done to get a tangible comparison. Model 1 was the most favorite with 63,8%, model 2 was the second favorite with 21,7%, and lastly model 3 with 19,2%. It is abundantly clear the huge gap between model 1 and the rest. a gap of 42% has been proven. It is interesting that participants who were in favor of model 1 have their opinion on models 2 and 3. Even if the majority has chosen the model1, the participants who were in favor of model 2 were not at all interested in model 1, surprisingly were more attracted to model 3. Nevertheless, All the 3 Models had votes, and all of them should be considered and further research is needed. Below all five options are presented in detail.

4.3.2 Option1. “The use of only one delivery person”

With 180 votes in first place and only 19 in last place, the majority of respondents are in favour of this as a solution to reduce Co2 emissions. The majority of the participants had not yet heard of this model. When choosing this option, the question was also whether a fee should be charged for this additional service and, if so, how high it should be.

As shown in Figure 3, 18,9% are not willing to pay an additional fee. By delivering the parcels from DHL and Co only to the last mile delivery service, costs are saved. This financial advantage can be passed on to the last mile service provider. Thus, no additional costs added. Additional fees could be waived. But other proposals to avoid additional charges also seem worthy of closer consideration. Thus, one should be able to select this last supplier immediately when ordering goods. Or that delivery could remain free of charge if returns were generally subject to a charge. 247 people stated that they would be willing to pay a fee, 93 of them (22%) were even prepared to pay more than one euro per parcel. However, the willingness to pay more is not only due to environmental considerations. With or without an additional delivery fee, objections to electric vehicles were generally raised. In many cases, it was doubted that these actually avoid Co2, since the production and disposal of batteries pollute the environment too much. In addition, it was often not possible to ensure whether the electricity consumed by the electric vehicle is actually so-called "green" electricity. These critical voices were also heard for the following options 2 and Option 3.

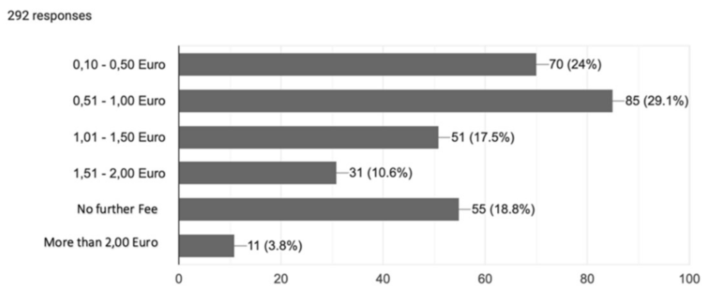

Figure 3: Ratings for extra cost per package

4.3.3 Option 2. “The use of autonomous robots”

With only 21 votes in first place and 120 in last place, the majority of respondents are against this solution. The choice of this option was also about the question of what the savings gained by eliminating high personnel costs would be used for. The assumption that personnel costs account for a significant share of parcel delivery is supported, among other things, by a statement made by Hermes Supervisory Board Chairman Schibur "70 percent of Hermes costs are due to personnel" and "The delivery from the distribution center to the front door alone, i.e. the last mile, accounts for 50 percent of expenses." (handelsblattt, 2018). Figure 4 presents (1.to lower the prices for parcel delivery, 2.to co-finance environmental projects at home and abroad, 3.to support educational offers for precarious workers). While almost a third of the votes cast (48 people) see a direct cost benefit for themselves in the savings, more than half (57.6%) would prefer to spend the cost savings on environmental projects. As many as 40.5% of the votes were cast for the option of providing education for precarious workers. In many cases, an improved education first provides the opportunity to take up "better" employment and, associated with this, better pay. People who now make up the largest proportion of personnel in the "last mile business" could also benefit from this. From a social point of view, a vote for people and the environment. But surprisingly, not one person has commented in this direction. Instead, there are numerous messages against the use of robots. In many cases, a cost saving was also doubted, as the production and operation of the robotic elements also caused high costs.

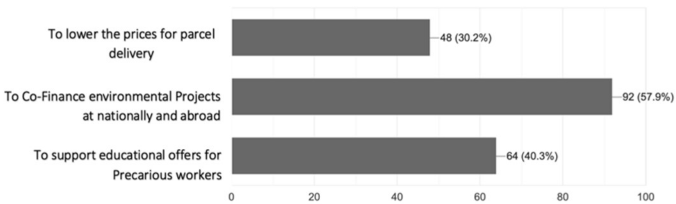

Figure 4: Ratings for the use of money saved for option 3"the use of autonomous robot"

4.3.4 Option 3: “The use of drones”

With only 27 votes in 1st place and 106 in last place, this solution option only reaches the penultimate 4th place. In choosing this option, the question was, just as in option 2, what the savings gained by eliminating high personnel costs would be used for (1.to lower the prices for parcel delivery, 2.to co-finance environmental projects at home and abroad, 3.to support educational offers for precarious workers.). Of course, drones are also robots. They differ from driverless robots only essentially in the type of traffic route. This led to the assumption that there would be little difference in the assessment compared to Option 2. In fact, the results were fairly identical on the question of the use of saved personnel costs. Almost exactly one-third of the votes cast (33.9%) saw the savings as a cost benefit to themselves. The vast majority, however, would prefer to spend financial resources on environmental projects and educational opportunities for precarious workers. A comparability of the comments made also emerged. With the exception of one ("a considerable relief for parcel deliveries"), all additional comments on the subject are negative. As shown in Figure 5, since drones can currently only carry weights of around 2 kg, there is also the question of whether that concern play any role for participant. Many doubts uncomplicated delivery in city centers, especially in large housing estates, apartment blocks and high-rise buildings. Others also think that the risk of accidents, which can also harm people, is a risk that should not be taken. The technical limitations also play a not insignificant role in the largely negative assessment of this option. The development of logistics drones is still in its infancy. The technology is not yet mature enough to allow quadcopters to carry heavy loads. The weight restriction also has an impact on the acceptance of drones.

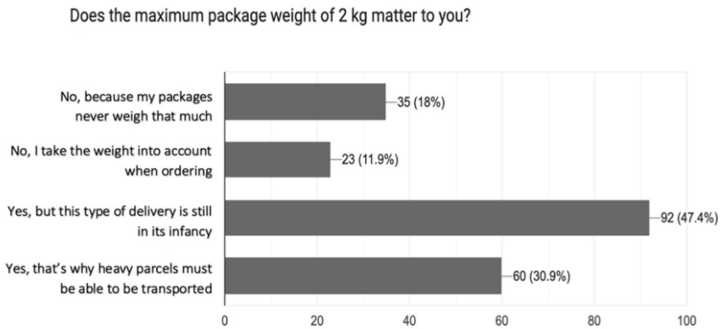

Figure 5: Ratings for the role of weight for option 4, "the use of drones "

4.3.5 Option 4: "The use of parcel station (parcel locker)"

With only 92 votes on rank 1 and only 30 on the last rank the Parcel station reaches rank 2 of the presented options. When choosing this option, the decisive factor is how you pick up your parcels from the Parcel station. In order to save CO2, one would have to forego the use of a vehicle with an internal combustion engine. As shown in Figure 6, Only 13.6% of all votes cast would consistently forego CO2. Weather conditions and time pressure are reasons why just under half of the vote-getters would use CO2 to get their parcel. ¾ of all votes, see no possibility of CO2 savings with heavy packages. The comments made on this are complex. But no additional environmental problem to pick up the parcel with the combustion engine see many under the following condition. Many complain that there are too few of these stations. Particularly in rural areas, people sometimes have to drive considerable distances to pick up their parcels.

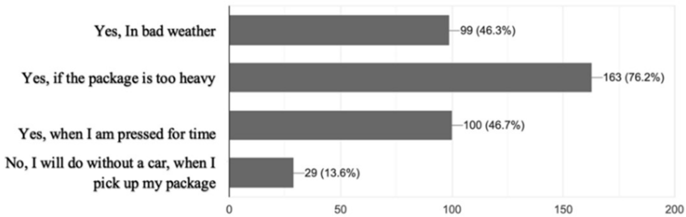

Figure 6: Rating for reasons to pick up the parcels by car (combustion engine)

4.3.6 Option 5: "accept longer waiting time"

With only 76 votes on rank 1 and 50 on the last rank the longer waiting times reach rank 2 of the presented options. When choosing this option, the decisive factor is how long you are willing to wait for your package to be delivered. Details of the answers can be found in Figure 7: (1. max. one day, 2. Up to two days, 3. Up to three days, 4. Up to one week, 5. More than a week). A maximum of 14% would wait a day, 33.6% would wait 2 days and just under 30% would even wait up to three days for their own package. Up to a week and beyond even more than 23 %.

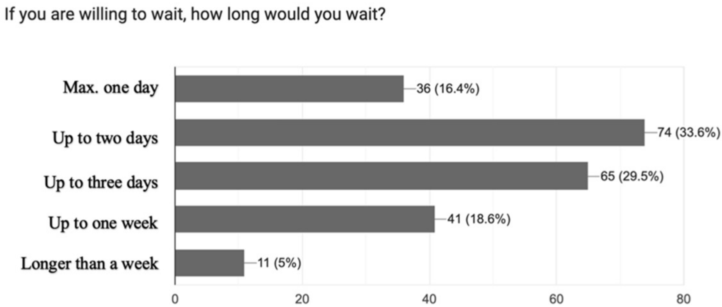

Figure 7: Rating for the waiting time

5 Conclusion

The purpose of this research was to identify effective strategies to engage consumers to participate in the creation of a sustainable last mile delivery network using social media and data analytics. Based on the analysis, it can be concluded that social media is a convenient way for a firm to carry out a sustainable campaign. Moreover, customers' opinions have been expressed through their perspectives. However, it is imperative to strengthen the cooperation of consumers and logistic firms in finding sustainable logistics innovation. Consumers' willingness is at their disposal. Unfortunately, they are not mostly updated with sustainable logistics innovation, which weakens consumers' opinions. The survey conducted in this research reveals that of the sustainable options presented to the participant, only a minor part is open-minded to using technologies such as drones and robots for the sake of the environment. While for others, it still sounds like science fiction. Even the models created from consumers' opinions show skepticism toward innovation. Seeing the immense challenges connected to last-mile delivery in the urban area shows a deep complexity that just one model cannot support a CO2-neutral solution for all stakeholders. Place of residence, living situation, age, mobility, social networking, shopping habits, and willingness to support sustainability are just a few examples that need to be considered in last-mile delivery. Moreover, due to consumers' safety concerns, direct contact with drones and autonomous delivery vehicles may remain problematic. Thus, acquiring the right decision assist innovative last-mile delivery concepts based on autonomous driving and consulting consumer engagement offers many interesting future research tasks. The results obtained from this research can be used to establish social media influences on customers to participate with the last mile delivery service providers through sustainability paradigms. As different strategies for engagement of customers are analyzed and investigated the important aspects for implementation and fulfilment of strategies can be used for more robust and successful marketing trends.

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