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Conference Paper

Potentials of direct container transshipment at container terminals

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Suggested Citation: Nellen, Nicole; Lange, Ann-Kathrin; Jahn, Carlos (2022) : Potentials of direct container transshipment at container terminals, In: Kersten, Wolfgang Jahn, Carlos Blecker, Thorsten Ringle, Christian M. (Ed.): Changing Tides: The New Role of Resilience and Sustainability in Logistics and Supply Chain Management – Innovative Approaches for the Shift to a New Era. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 33, ISBN 978-3-756541-95-9, epubli GmbH, Berlin, pp. 679-705, <https://doi.org/10.15480/882.4704>

This Version is available at:

<https://hdl.handle.net/10419/267203>

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Potentials of Direct Container Transshipment at Container Terminals



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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.*

First received: 21. Feb 2022

Revised: 22. Aug 2022

Accepted: 25. Aug 2022

Potentials of Direct Container Transshipment at Container Terminals

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)

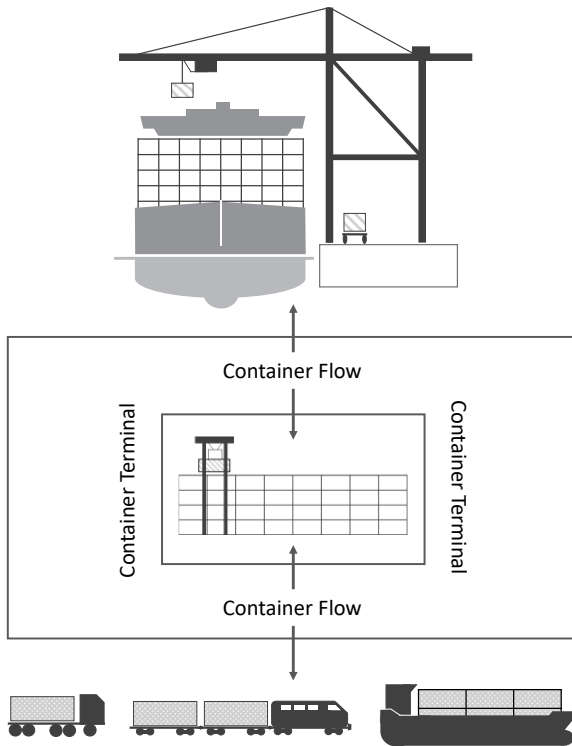


Figure 1: Schematic processes at container terminals
(based on Kemme, 2013)

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)

Potentials of Direct Container Transshipment at Container Terminals

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.

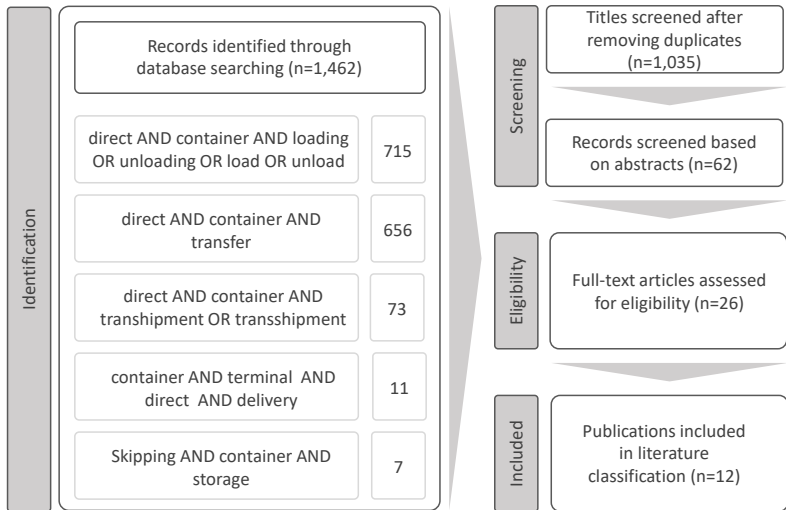


Figure 2: Approach for literature research (based on Moher, et al., 2009)

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).

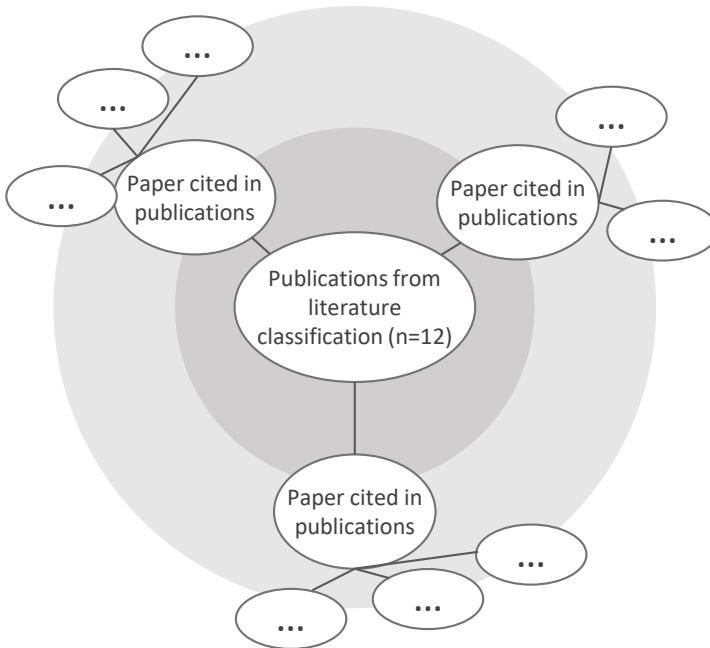


Figure 3: Snowballing approach

Potentials of Direct Container Transshipment at Container Terminals

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).

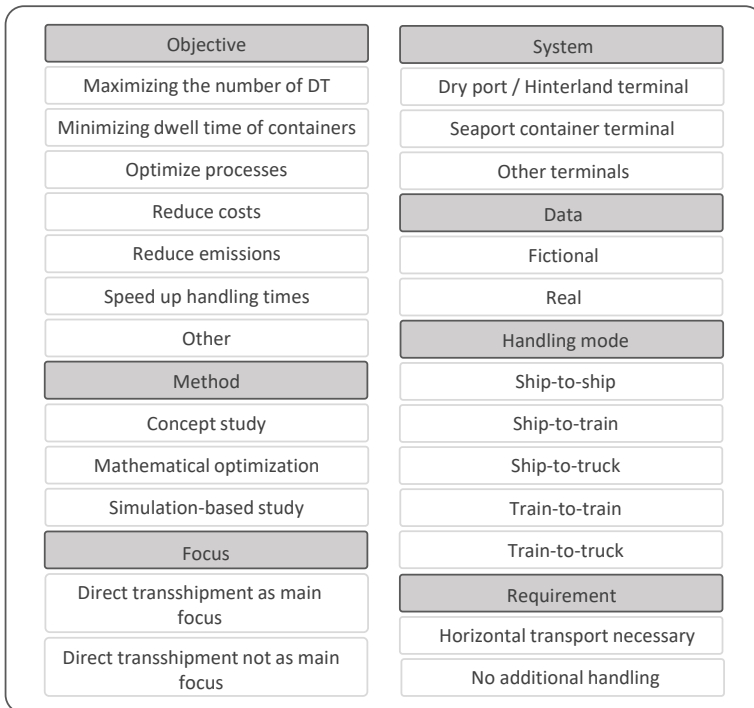


Figure 4: Classification categories and their specifications

Potentials of Direct Container Transshipment at Container Terminals

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)							
Basallo-Triana et al. (2022)							
Belošević et al. (2016)							
Blumenhagen (1981)							
Bo and Wang (2019)							
Boysen et al. (2010)							
Expósito-Izquierdo et al. (2019)							
Jurjević and Hess (2016)							
Kim and Morrison (2012)							
Lee, et al. (2006)							
Li and Wang (2019)							
Liang et al. (2012)							
Liu et al. (2002)							
Liu, et al. (2016)							
March (2020)							
Monaco and Sammarra (2018)							
Nellen et al. (2021)							
Nishimura et al. (2009)							
Wiegmans et al. (2007)							
Yan et al. (2020)							
Zeng et al. (2017)							
Zhao et al. (2020)							

Potentials of Direct Container Transshipment at Container Terminals

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.

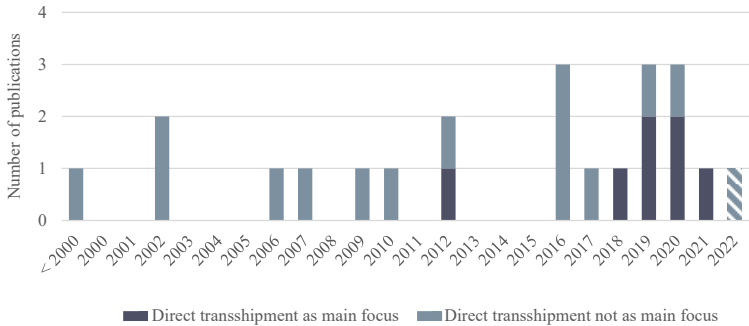


Figure 5: Relevant publications per year

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.

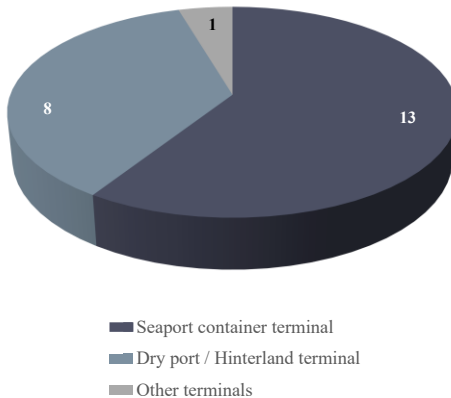


Figure 6: System focus of the publications

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).

Potentials of Direct Container Transshipment at Container Terminals

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.

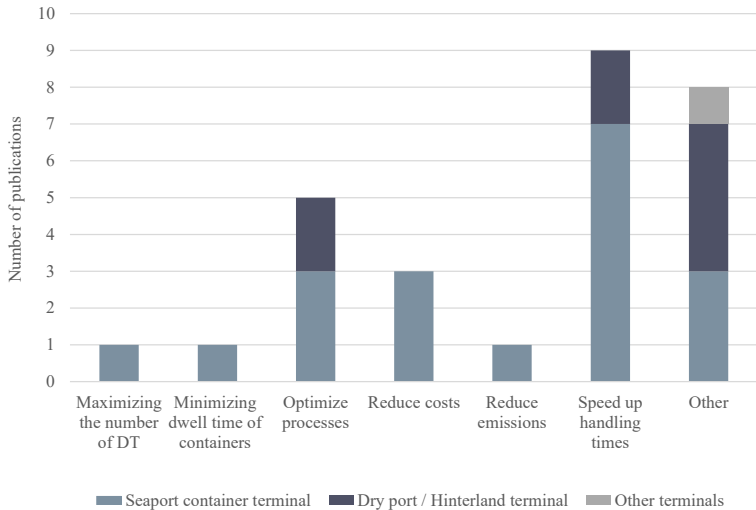


Figure 7: Objective focus of the publications depending on the system

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.

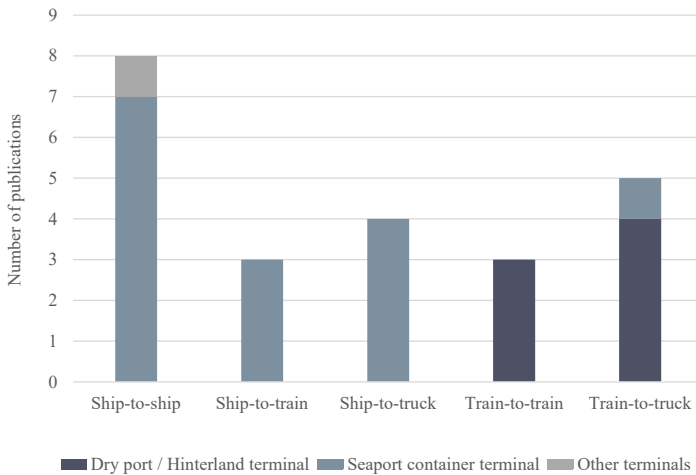


Figure 8: Handling modes of the publications depending on the system

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,

Potentials of Direct Container Transshipment at Container 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.

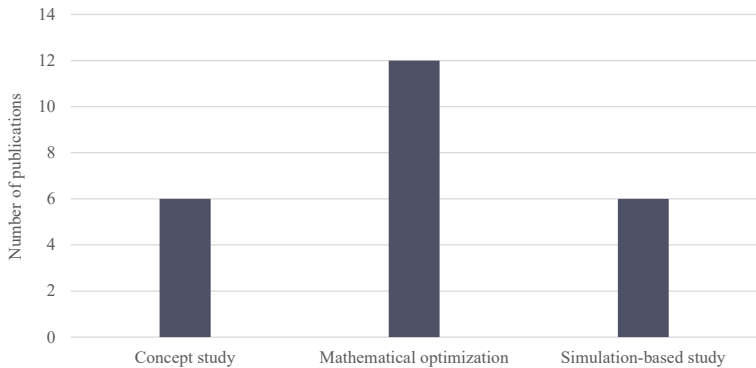


Figure 9: Publications method

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.

Potentials of Direct Container Transshipment at Container Terminals

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Potentials of Direct Container Transshipment at Container Terminals

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