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Truck Appointment Systems – How Can They Be Improved and What Are Their Limits?

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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.

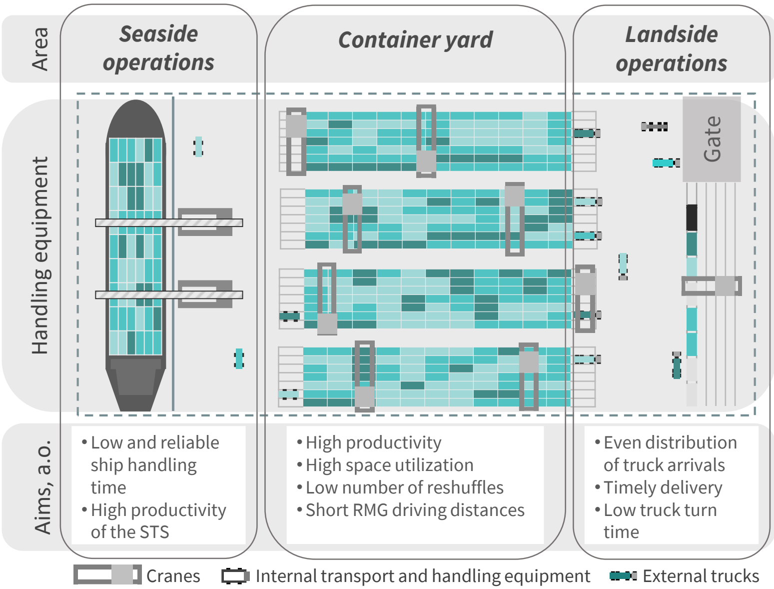

Figure 1: Schematic structure of an exemplary RMG/AGV container terminal

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.

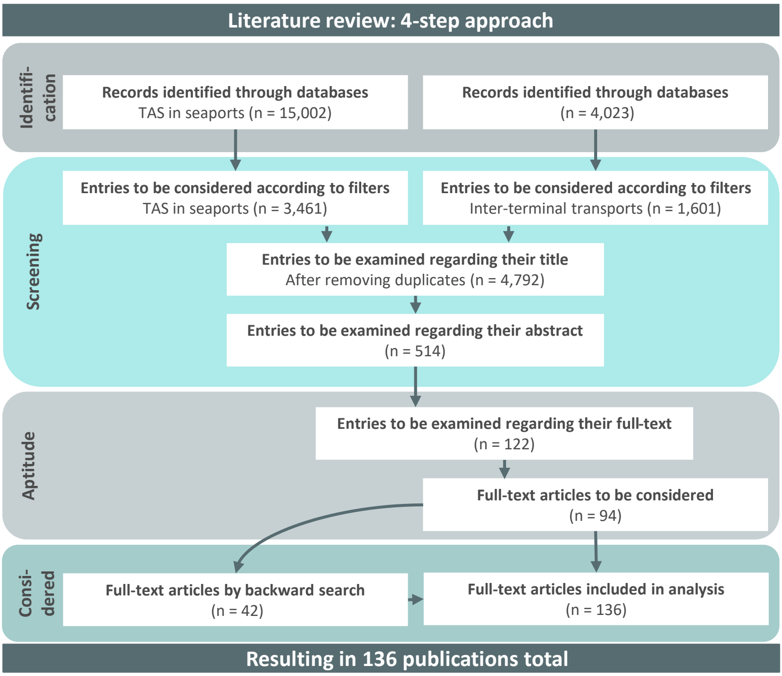

Figure 2: 4-step approach for the literature review

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.

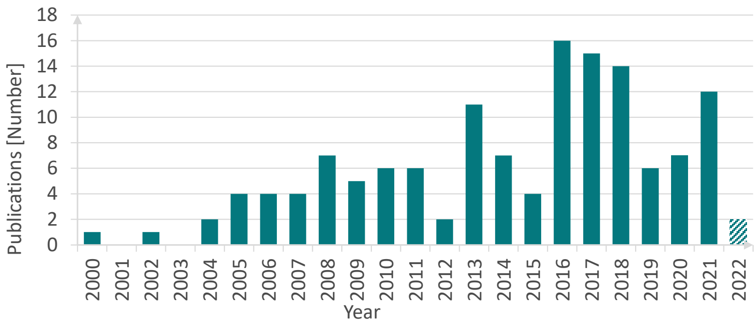

Figure 3: Number of relevant publications per year since 2000

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*.

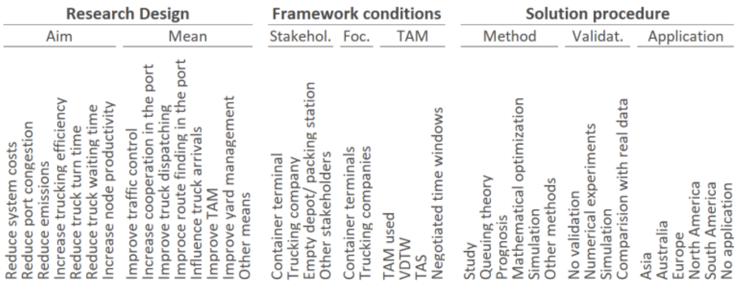

Figure 4: Categories of the classification scheme

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.

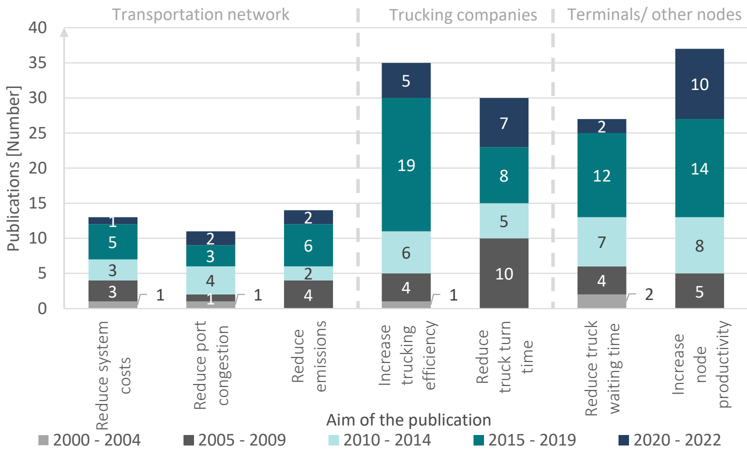

Figure 5: Frequency of aims over time

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.

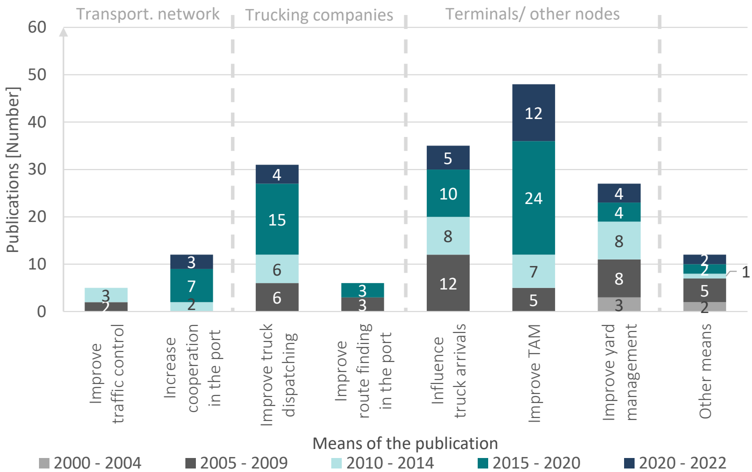

Figure 6: Frequency of means over time

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.

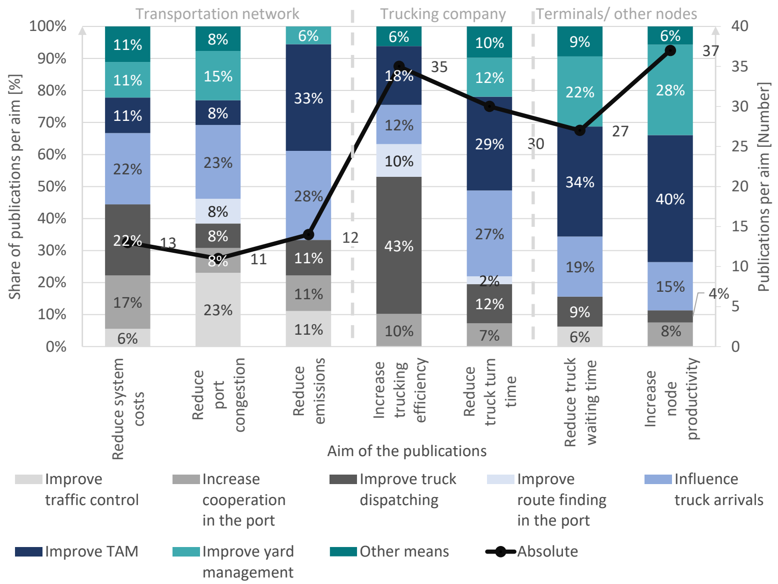

Figure 7: Mean of publications studied per aim

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).

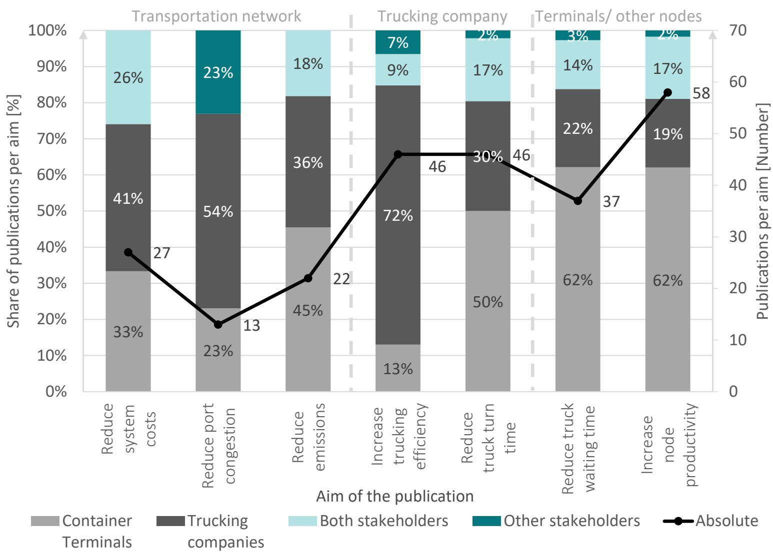

Figure 8: Stakeholders of publication per aim

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.

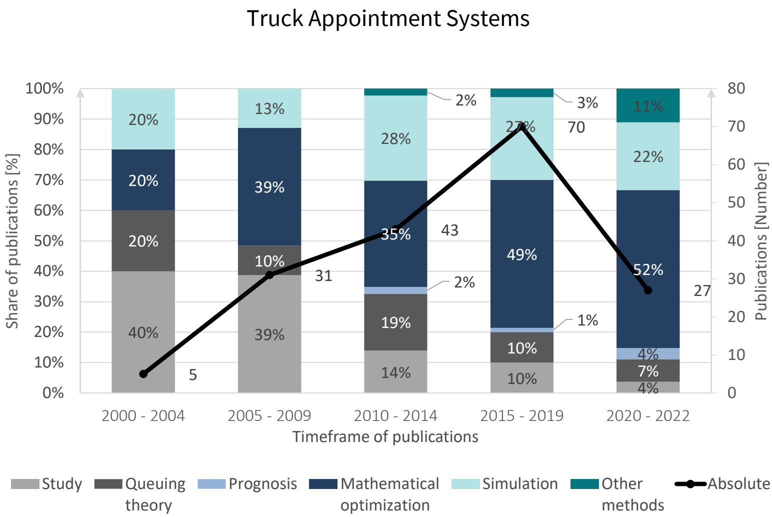

Figure 9: Relative frequency of methods over time

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.

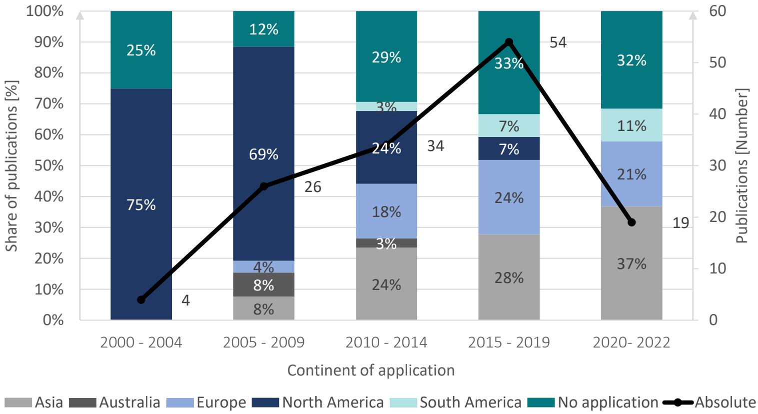

Figure 10: Relative frequency of spatial practical application over time.

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

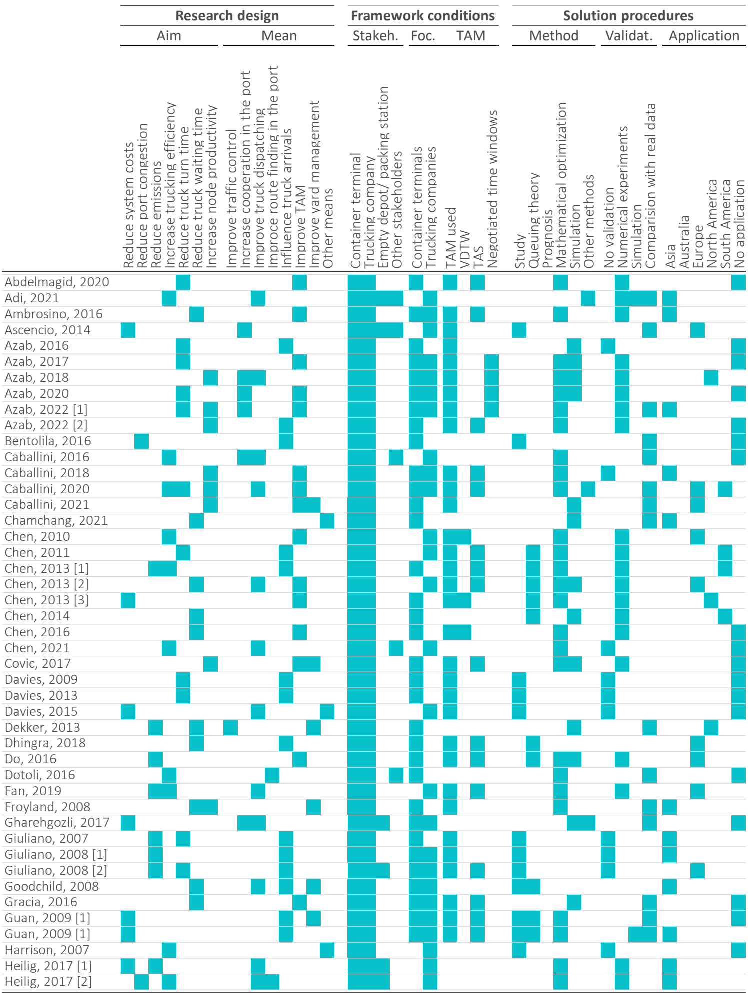

Figure 11: Classification scheme Part A

Figure 12: Classification scheme Part B

Figure 13: Classification scheme Part C

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