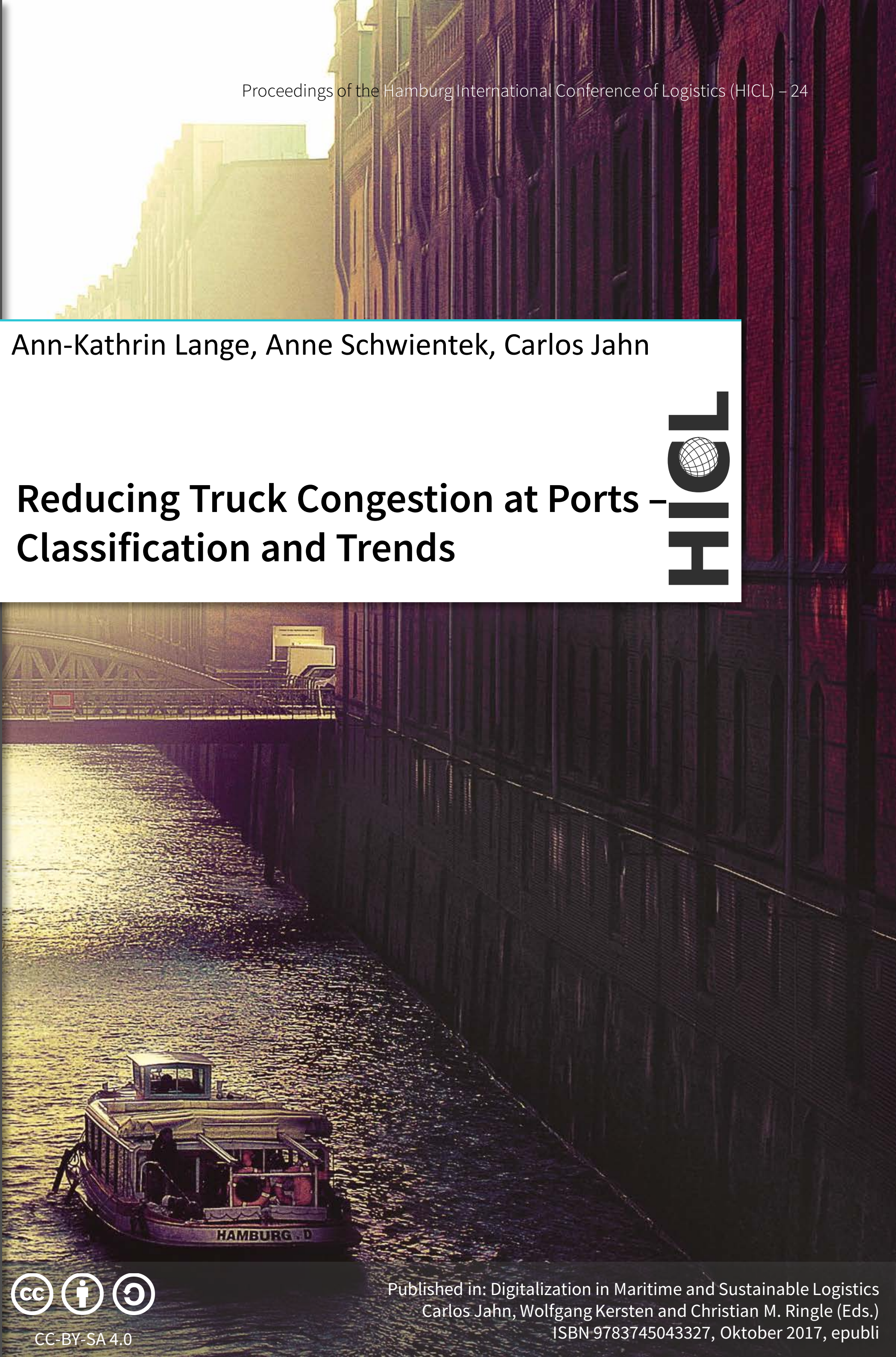

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Reducing Truck Congestion at Ports – Classification and Trends

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Truck drayage in container ports faces several challenges. Due to the ongoing growth of container ship sizes, there are increasingly high peak situations in land-side container handling at logistic nodes in the port, e.g. container terminals, empty depots, freight stations. In combination with rising demands to improve the port's ecological footprint this requires the port and its companies to adapt to the situation in order to reduce congestion. To identify important methods, key parameters, past developments and future trends a classification scheme based on an extensive literature survey on waiting times at terminals and drayage operations is conducted and applied to 71 publications. The analyzed methods to reduce congestion in the port range from optimizing the infrastructure to controlling truck arrival times. While this problem is mainly analyzed from a container terminal perspective, its impacts also affect other stakeholders in the port as trucking companies, empty depots or freight stations. Past literature surveys mainly focus on either one method or one stakeholder. This led to limited assessments for the whole drayage networks in ports. Therefore, the developed classification scheme is a basis to identify promising further research areas while enabling a more holistic approach.

Keywords: drayage; port logistics; congestion; classification scheme

1 Introduction

Seaports are the main interface connecting main carriage and hinterland transportation in maritime supply chains. The amount of world seaborne trade increased more than 2% in millions of tons loaded in 2015 compared to 2014 (UNCTAD, 2016). Combined with rising ship dimensions, especially for container ships, seaports face severe challenges to achieve the productivities demanded by their clients. Furthermore, other stakeholders as the government, environmental organizations and local residents impose demands on port companies regarding environmental and social aspects. The ongoing growth of container ship sizes leads to high peak situations in landside container handling and thereby to a high traffic load on the port street network. In combination with rising demands to improve the port's ecological footprint, this leads to the necessity to reduce truck congestion at container terminals and in the port. Furthermore, port drayage is an important part of maritime supply chains, which often accounts for a high percentage of the overall transportation cost and for a large proportion of truck arrivals at container terminals (Harrison et al., 2007; Shiri and Huynh, 2016). Therefore, main focus of this paper will be on terminal gate, related yard operations and drayage transportation. Seaside (berth, quay, related yard areas and horizontal transportation) and train operations are not considered in this paper. For an extensive overview on operations of container terminals and possible improvement strategies, please consider e.g. Vis and De Koster (2003), Stahlbock and Voß (2007) and Carlo, Vis and Roodbergen (2014a; 2014b).

The first aim of this paper is to present a classification scheme for approaches to reduce truck congestion at logistics nodes in the port, especially at container terminals. It bases on an extensive review of literature during the last 20 years on waiting times in the port and drayage operations. The second aim is to apply the developed classification scheme to 71 publications to identify important methods, key parameters, past developments and future trends. The methods applied in studies to reduce truck waiting times at container terminals range from optimizing the infrastructure to controlling truck arrival times. While this challenge is mainly analyzed from a container terminal perspective, it also affects other stakeholders in the port as empty depots or freight stations. The paper is organized as follows: Section 2 provides information about truck transportation and handling, especially of drayage trucks, in a port, current industry trends and main research done concerning this topic. In section 3 the approach for developing the classification scheme and necessary definitions are given. The classification scheme for approaches to reduce truck congestion at logistic nodes

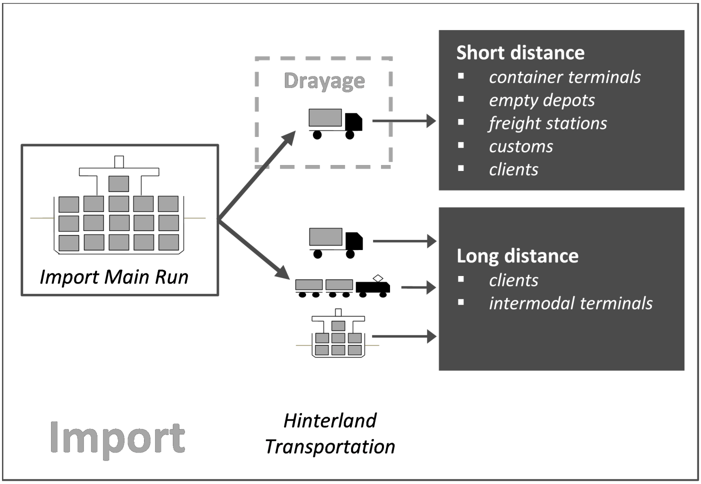

Figure 1: Drayage as a part of the import transport chain

in the port is presented in section 4 and an in depth overview of the reviewed publications based on the classification scheme is given. Finally, in section 5 future trends and promising research areas are presented.

2 Developments and Challenges in Port Related Truck Transportation and Handling

Port drayage is defined as “truck pickup from or delivery to a seaport, with the trip origin and destination in the same urban area” (Hartmann, 2004; Huynh et al., 2011). Figure 1 illustrates exemplarily the different possibilities for transporting an import container from a seaport. Furthermore, the scope of the term drayage in contrast to long distance transportation is shown.

Import containers, either full or empty, are brought to a port on the main carriage mainly by ocean carriers. Depending on their destination and the required specifics of transport, there are several possible options for further transportation. If the container is a transhipment container, it will either be loaded on another ship at the terminal of arrival or be transported to another terminal in the port to be loaded there. Another option is the transport of the container to the hinterland either via short sea vessel, train or truck. Some trucking containers are only transported a short distance, because the recipient, e.g. client, empty depot, is located in the port area.

Export containers can be brought to the port by different means of transport. These mirror the transport options of the import supply chain. The means of transportation can either be ocean carriers with a transhipment container for another vessel or short sea vessels, trains or trucks. Following the given definition, all short distance truck transports of containers to or from the port - no matter if import, export or transhipment container - are considered port drayage.

2.1 Description of Current Situation

The increase in vessel sizes and the relating strain imposed on the landside operation of container terminals due to peaks in truck arrivals for delivering or picking up a container lead to a rising interest in improvement strategies in both industry and research. Based on the high fluctuation in truck traffic load the capacity at the terminal gates and in the yard are mainly either too high or too low, leading to high labor costs for the terminal or to long waiting times for the trucks and as a consequence to congestion at the gates. This phenomenon also affects public streets and the performance of other companies in the port, e.g. freight stations, empty container depots or customs. As the truck engines are running most of the time while queuing or waiting in a traffic jam, the situation leads to higher emissions in the port area. The port drayage sector is highly impacted by these developments due to its focus on transport in the port area and the dependency on the container terminals as main sources and drains of drayage transports. Furthermore, the drayage truck drivers, which are mainly owner operators and get paid per successful trip, are dependent on a certain amount of trips per day to pay their expenses. Extensive waiting times lead to a low number of trips per day for the drivers and therefore to financial challenges.

2.2 Current Industry Trends and Main Research Areas

Several different approaches to reduce waiting times at logistics nodes in the port and in drayage are developed, analyzed and in some cases implemented. Many of the studies focus on container terminals and aim at smoothing the peaks in truck arrivals. Analyzed approaches are among others: controlling the gate lanes (Gracia, González-Ramírez, Mar-Ortiz, 2016), offering incentives for using night or off-peak shifts (Bentolila et al., 2016), installing webcams at the gate to inform truckers about the queues (Huynh et al., 2011) and introducing and optimizing a truck arrival management (inter alia Guan and Liu, 2009; Huynh and Walton, 2011).

Another starting point is to improve drayage operations to reduce congestion and increase the profit for the drayage companies. Therefore, studies with drayage truck drivers are conducted and different scheduling and routing algorithms are developed (Jula, Dessouky, Ioannou and Chassiakos, 2005; Namboothiri and Erera, 2008). Cooperations between truck drivers and other companies are explored (Caballini, Sacone and Saeednia, 2016). Furthermore, more general approaches as implementing a new traffic control system (Rajamanickam and Ramadurai, 2015), introducing supply chain management instruments (Ascencio, González-Ramírez, Bearzotti, Smith and Camacho-Vallejo, 2014) or introducing dry docks while using new concepts like an chassis exchange system (Dekker et al., 2013) are analyzed.

In industry, the introduction of the first what is now called Truck Appointment System (TAS) in the ports of Los Angeles and Long Beach in 2002 in response to California Assembly Bill (AB) 2650 posed a starting point for a development which is still ongoing. The idea was to use a vehicle booking system to control the number of trucks arriving at the terminal at different times of the day. The success of the program has been controversial due to its voluntary nature and the fact that all terminals in the port implemented a different system. This led to high barriers for the truck drivers and therefore to a low participation (Giuliano and O'Brien, 2007). This happened at a time with rising challenges at the terminal gates due to high numbers of arriving trucks with increasing fluctuations. Therefore, the TAS as well as other approaches have been studied increasingly. Today, several successful TAS are running in different parts of the world, e.g. Vancouver, Sydney and Southampton, but the development goes on to improve these systems or to find better alternatives (inter alia Davies and Kieran, 2015; Huynh, Smith and Harder, 2016).

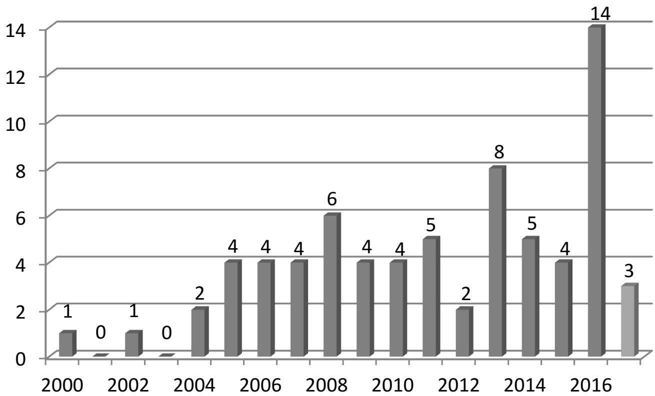

Figure 2: Publications per year 2000 – 2017 (preliminary)

3 Approach and Definition of Research Focus

In an extensive research in scientific databases, e.g. Google Scholar, ResearchGate, ScienceDirect, a broad basis for the literature review was extracted. The keywords used for the search were truck appointment system, gate congestion and drayage. The search was completed by checking the cited work for each paper and adding them to the list, if they met the mentioned focus of this study. 71 papers are considered relevant, published between 2000 and 2017. Because the necessity to reduce gate congestion occurred around 2000 for the first time, no prior papers are considered. Figure 2 shows the number of publications per year considered in this review. It demonstrates that the interest in this topic has increased constantly since 2000. The year with the most publication so far has been 2016. Since the challenge is still growing, an increasing number of publications can be expected.

Figure 3 shows how many publications apply their findings to existing ports on each continent. To illustrate the changes of focus over the time, two diagrams with different time spans, 2000 to 2008 and 2009 to 2017, are given.

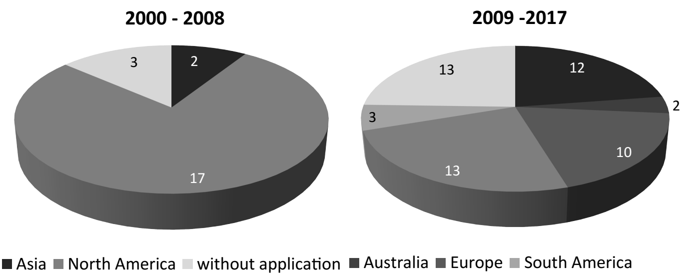

Figure 3: Publications' application focus per continent

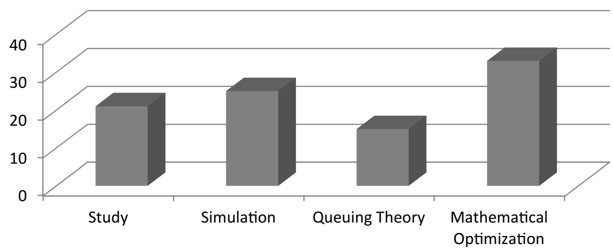

Figure 4: Used methods in relevant publications

It can be seen that the research started at first in North America. After around 8 years more publications focused on ports on other continents. The level of publications about Asian and European ports is similar. Still a very small number considers ports in developing or emerging countries. A growing number of publications is purely theoretical and doesn't include any applications on real live terminals. Figure 4 presents an overview of the applied methods in the publications. Studies and simulation models focus mainly on analyzing or improving existing terminals with or without TAS. Queueing theory models and mathematical optimization models either concentrate on working with existing terminals or develop a solution for a theoretical problem in this research field.

4 Classification Scheme for Approaches to Reduce Congestion of Drayage Trucks

The proposed classification scheme is illustrated in table 1. It consists of five main criteria which can be divided in total into 29 specifications. The specifications can either take the value 0 or 1, meaning no or yes. For every specification either a short description or some examples are given in table 1 to facilitate the understanding. The application of the 71 publications to the proposed classification scheme is presented in figure 5 at the end of this section.

As there are many different approaches how to reduce congestion for drayage trucks at logistic nodes and in the port street network, it is reasonable to first classify the publications by their aim. The aims of the examined publications can roughly be grouped by their focus: the whole transportation network (reduce system costs, reduce congestion in the port, reduce emissions in the port), the trucking companies (increase drayage productivity, reduce truck turn time) and the container terminals/logistic nodes (reduce queue/queueing time, increase node productivity). As these aims can be reached by many different ways, the second criterion in the classification scheme is the used mean to handle the challenge. The rough division applied for the aims is also applicable here: the whole transportation network (improve traffic control, improve cooperation in the port), the trucking companies (improve truck scheduling, improve route finding) and the logistics nodes (influence truck arrival, improve TAS, improve yard management). Some other means have been studied occasionally. These are collected in the specification other.

The third criterion is the recipient of the improvement. The recipient is the stakeholder, which benefits most of the proposed improvement. This can differ from the focus described above, because even if the aim or mean focus on one party, e.g. the whole transport network, another party can have a bigger benefit, e.g. the container terminal. Based on the observed 71 publications, the following specifications have been developed: trucking company, container terminal, both (trucking company and container terminal) and other. The fourth criterion is the method used in the publications. As mentioned above, four main methods have been identified: study, simulation, queueing theory and mathematical optimization. Queueing theory could also be counted in the area of mathematical optimization, but due to its importance in this research field it seemed reasonable to treat it separately.

The last criterion is the continent of the port, to which the approach of the publication was applied. Only the continents mentioned in the relevant publications have been considered further. Therefore, the specifications are Asia, Australia, Europe, North America and South America. As some publications don't apply their approach to an existing port, the specification no application was added.

In the following subsections a detailed overview of literature focusing on the different aims is given, along with the classification of the 71 analyzed publications between 2000 and 2017. If a publication focuses on more than one aim, it is presented in the subsection of the first aim mentioned.

4.1 Reduce System Costs

In this subsection six papers are presented, which focus on reducing the system costs. System costs are mainly understood as the combined costs of trucking companies and container terminals for one transport. Therefore, the recipients of the benefits in most papers are trucking companies as well as container terminals. Furthermore, most publications use several methods, mainly a study part, queueing theory and mathematical optimization combined. Only one of the studies uses simulation. The approaches developed in the papers are applied to North America in three cases, to Asia and South America each in one case and one paper has no application to an existing port.

Ascencio et al. (2014) develop a collaborative logistics framework for the transport chain in the port. With this framework the different stakeholders in the port and the port processes are integrated to improve their performance. Several papers analyze the impact of influencing truck arrivals on gate congestion. Guan and Liu (2009a,b) apply queueing theory to model the congestion of inbound trucks at container terminal gates to quantify waiting costs and to find possible ways to optimize the gate processes. Ioannou et al. (2006) present an algorithm to generate cooperative time windows and study their effects by using a container terminal simulation model. Chen, Govindan and Yang (2013) implement vessel dependent time windows for arriving trucks to flatten the peaks and thereby reducing truck congestion at the terminal gates. Kim and Kim (2002) present a cost model which is used to identify the optimal amount of storage space and transfer cranes for import containers considering the costs for space costs and costs for cranes and trucks.

Table 1: Proposed classification scheme for reducing port congestion

	Specification	Description/Example
Aim		
1	reduce system costs	overall cost of all stakeholders
2	reduce congestion in the port	on public streets
3	reduce emissions in the port	by trucks or handling equipment
4	increase drayage productivity	of trucking companies
5	reduce truck turn time	on the terminal or in the port
6	reduce queue/queuing time	at/on logistics nodes
7	increase node productivity	e.g. of container terminals
Means		
1	improve traffic control	port authority point of view
2	improve cooperation in the port	between different stakeholders
3	improve truck scheduling	e.g. job sequence, organization
4	improve route finding	use of algorithms
5	influence truck arrivals	e.g. opening hours, incentives
6	improve TAS	e.g. slot length, booking, rules
7	improve yard management	e.g. space allocation, equipment
8	other	e.g. decision support systems
Recipient		
1	trucking company	focus on trucking company
2	container terminal	focus on terminal operator
3	both	trucking company and terminal
4	other	e.g. freight stations, empty depots
Method		
1	study	e.g. interviews, regression analysis
2	simulation	e.g. agent based, discrete-event
3	queuing theory	e.g. non-stationary queuing models
4	mathematical optimization	e.g. genetic algorithm, tabu search
Application		
1	Asia	e.g. Hong Kong, Shenzhen, Tianjin
2	Australia	e.g. Sydney
3	Europe	e.g. Genoa, Marseille, Rotterdam
4	North America	e.g. Long Beach/LA, NY, Vancouver
5	South America	e.g. San Antonia, Santiago de Chile
6	no application	no reference to existing port

4.2 Reduce Congestion in the Port

The eight papers presented in this subsection concentrate exclusively on reducing the congestion in the port. Only half of the papers specifically consider congestion at terminal gates and none considers TAS. As a consequence, the main recipients of the benefits in these papers are the trucking companies. Two papers focus on other stakeholders and one on container terminals. Both trucking companies as well as container terminals are not considered. The methods used in the papers are studies or simulation. Five of the papers apply their work to Asian ports, two to North American and one has no application to an existing port.

Bentolila et al. (2016), Ozbay, Yanmaz-Tuzel and Holguin-Veras (2006), Regan and Golob (2000), Yang, Chen and Moodie (2010) and Zhang et al. (2012) study the effect of existing programs to reduce congestion in ports in different parts of the world. The ”Good Night” program in Israel, the Time-of-day Pricing Initiative in New York/New Jersey, the trucking industry in California and the situation in China are evaluated. Nabais et al. (2013), Rajamanickam and Ramadurai (2015) and Yu et al. (2014) use simulation to evaluate ways to reduce congestion in the port. Rajamanickam and Ramadurai (2015) aim to find the causes for congestion in a port city. Yu et al. (2014) present the interactive factors which have an impact on the land transportation in a port city. Nabais et al. (2013) analyze the effects of a multi-agent system to guarantee cooperation among terminals within a seaport.

4.3 Reduce Emissions

Four of the eight papers presented in this subsection focus on another aim besides reducing the emissions in ports. Influencing the truck arrivals and optimizing existing TAS are the most employed means. All but one paper focus at least partially on container terminals. One focusses only on trucking companies and two on both trucking companies as well as container terminals. The methods used are nearly evenly distributed. More than 50% of the papers apply their work to North American ports.

Morais and Lord (2006), Giuliano and O’Brien (2007; 2008) and Giuliano et al. (2008) focus on the congestion in the ports of Los Angeles and Long Beach. They analyze the first implemented TAS and its effects on congestion and emissions in the port. They point out that the right setting and implementation of a TAS is important for it to work properly. Chen, Govindan and Golias (2013) examine the relationship between influencing truck arrivals and reducing emissions at container terminals. The impact of an off-dock terminal with chassis exchange system to reduce loading and unloading times at marine container terminals is investigated by Dekker et al. (2013). Do et al. (2016) present a system with individual time slots per truck, which don't have to be booked in advance. Schulte, González and Voß (2015) analyze ways to reduce empty truck trips by implementing collaboration among truckers working in a port with a TAS.

4.4 Increase Drayage Productivity

Two thirds of the papers presented in this subsection concentrate exclusively on increasing the drayage productivity. The means used to reach this goal vary over nearly all possibilities. All of the papers focus on trucking companies. Only one paper also considers container terminals and another one other stakeholders. Mathematical optimization clearly dominates the used methods in these papers. In one third of the papers the results are not applied to existing terminals.

Harrison et al. (2007) and Monaco and Grobar (2004) study the characteristics of drayage operations in Houston and in Los Angeles/Long Beach and give recommendations for further improvement. Hill and Böse (2016) present a decision support system for improved resource planning and truck routing at logistic nodes. Huynh, Smith and Harder (2016), Chen and Yang (2010), Phan and Kim (2015) and Shiri and Huynh (2016) present solutions to influence the truck arrival times to avoid congestions and to improve existing TAS inter alia by introducing a negotiation system between terminal operator and trucking companies. Namboothiri (2006), Namboothiri and Erera (2008) and Wasesa, Stam and van Heck (2017) develop scheduling and routing solutions for drayage companies to improve their productivity. Caballini, Sacone and Saeednia (2016) examine a possible cooperation between trucking companies in a port and its impact.

4.5 Reduce Truck Turn Time

The focus of twelve of the eighteen papers in this subsection is exclusively on reducing the truck turn time. This is mainly done by controlling the arrival time of the trucks or by optimizing the TAS. Either trucking companies or container terminals benefit in these papers, but only once both of them and no other stakeholders are considered. The methods used are evenly distributed over all papers. A high percentage of the papers apply their results to North American ports.

Lam Park and Pruitt (2007) collect detailed data on truck arrival and waiting times at the port of Los Angeles/Long Beach and analyze their impact for the terminal. Azab and Eltawil (2016), Chen, Zhou and List (2011), Davies (2009; 2013), Huynh (2005) and Schepler et al. (2017) aim to reduce the truck turn time by influencing the truck arrivals patterns. Huynh (2009), Huynh and Walton (2008; 2011), Zhang, Zeng and Chen (2013) and Zouhaier and Ben Said (2016; 2017) improve existing TAS to help to reduce the truck turn time. Amongst other different booking strategies, slot capacities and penalties for late deliveries or know shows are analyzed. Jula et al. (2005) examine algorithms for improved scheduling and routing in the port. Huynh and Walton (2007) present a simulation model to analyze the required amount of yard cranes to reduce the waiting to an acceptable level. In Huynh and Hutson (2008) sources of delay for drayage transport are investigated and recommendations for future mitigation are given.

4.6 Reduce Queue / Queuing Time

Twelve of the sixteen papers presented in this subsection aim exclusively at reducing the queueing time of trucks. Many different means are used in these papers, but influencing the truck arrival times and improving existing TAS dominate this group. Improving the yard management and optimizing dispatching and routing of trucking companies are often studied as well. Many of the papers apply their results to North American and European ports or use no real live data. None of the papers consider other stakeholders besides trucking companies and container terminals and only four focus on both.

Davies and Kieran (2015) analyze congestion and drayage with a study and an additional simulation model. Goodchild and Mohan (2008), Phan and Kim (2016) and Sharif, Huynh and Vidal (2011) present solutions to influence truck arrival times. Ambrosino and Peirano (2016), Chen et al. (2013), Chen and Jiang (2016) and Gracia, González-Ramírez and Mar-Ortiz (2016) improve existing TAS to reduce the queue at the terminals gate or on the yard. Zehendner and Feillet (2014) also aim to improve the service quality of trains, barges and larger vessels. Chen and Yang (2014) and Huynh et al. (2011) develop methods to estimate the queue length in front of the gate and the caused delays either by a queuing theory model or by implementing camera technology at the gate. Huynh, Walton and Davis (2004) and Veloqui (2014) present ways to reduce the queuing time by improving the yard management at container terminals. This is mainly done by reducing the service time in the yard, e.g. by adding more handling equipment.

4.7 Increase Node Productivity

In this subsection fourteen papers are presented. Five of them focus on one other goal as well. The means analyzed in these papers are to either optimize the TAS or the yard management. All but one paper focus on container terminals and the main method used is mathematical optimization. Most papers are either applied to North American ports or have no application to an existing port at all.

Van Asperen, Borgman and Dekker (2013) and Zhao and Goodchild (2010a; 2010b) present solutions to increase the node productivity by influencing truck arrivals. On the one hand the truck arrival information are used to shorten the handling times and on the other hand the amount of reshuffles in the container block are minimized by intelligent stacking orders. Furthermore, possibilities to coordinate terminal and truck drayage operations through sharing information, e.g. TAS or GPS on trucks, are investigated. Li, Chen, Govindan and Jin (2016) and Zhao and Goodchild (2013) improve the terminal performance by analyzing the impact of different TAS characteristics and evaluating disturbances in truck arrivals. Ku and Arthanari (2016) and Le-Griffin, Mai and Griffin (2011) analyze the impact of an improved yard management on the node productivity. They evaluate the impact of improved stacking algorithms and optimized route finding of terminal trucks based on known truck arrival times. Murty et al. (2005a) and Murty et al. (2005b) develop a decision support system for improving the terminal productivity. A part of this decision support system is the yard management as well as the truck arrival control.

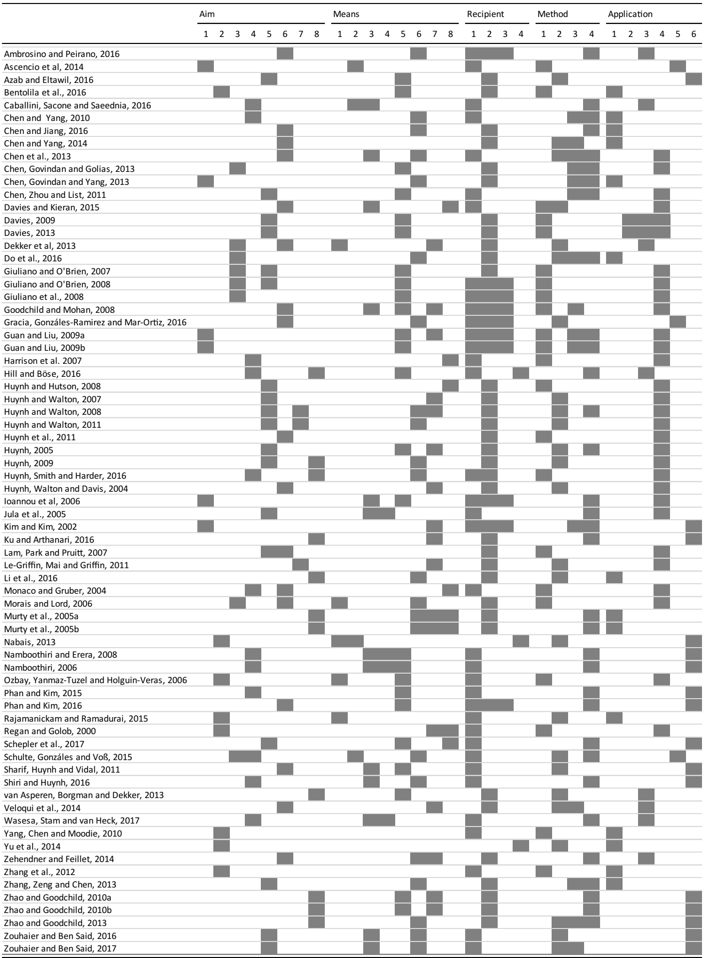

Figure 5: Classification of relevant publications

5 Present and future research areas and conclusions

Based on the information gathered in the previous sections, the characteristics of the present research are derived. Furthermore, gaps in this state of research are identified and promising future research areas are pointed out.

Reducing congestion in ports is a very diverse research field. Various approaches are analyzed with several different aims, which have only been combined in some few later papers. In future it is important to strengthen the interfaces between these approaches and to use the results from existing research.

Main focus points of relevant papers are container terminals. Less frequent, but still extensively studied are trucking companies. Other stakeholders are examined rarely. Furthermore, most of the time just one stakeholder is considered. Exceptions are some papers where trucking companies are studied as well as container terminals. This is not sufficient to completely analyze the impacts of methods to reduce congestion, especially TAS, on the port network and on drayage. This is pointed out in the conclusions of many papers but never executed. In future research it is important to close this gap to get realistic results.

Furthermore, most of the time an author focusses on the same port in all papers, probably because of existing data. Due to that only some ports have been analyzed so far. Some of the world's biggest ports haven't been considered and ports in developing or emerging countries have nearly not been studied at all. These ports might present challenges to existing research solutions due to different organizational structures, technology levels and objectives. Therefore it is important to expand the research focus on these ports.

Many authors point out that it is hard to get sufficient data for their explorations. Existing data is mainly generated by cooperation with terminal operators or interviews with trucking companies. Complete data about all operations in a port is challenging to get. Still, in future a more extensive data basis is recommended to produce more conclusive results. Due to the ongoing digitalization in the logistics sectors in general and especially in ports, it seems reasonable to assume, that more complete data sets will soon be available.

In the beginning, there were many different designs of TAS. But over time and due to many assessments, all proposed TAS share some criteria, e.g. their obligatory nature, the length of time windows and the use of penalties for trucking companies as well as for container terminals. It is necessary to use these findings in future research but also to not to be limited to this design. Some promising papers show promising out of the box thinking, e.g. the implementation of dry docks or a more extensive supply chain collaboration, which will help this research area to develop further.

In this paper methods for reducing the congestion in ports and at container terminals, especially for drayage trucks, are discussed and the current research and future trends are presented.

The current situation of truck transportation in the ports and the specifics of drayage are described. Due to the fact that severe challenges are arising for this sector, the implementation of new operational practices is important. These are presented combined with an overview about recent research solution in this area. To have a basis to analyze promising future research fields a classification scheme for approaches to reduce truck congestion is developed. Its criteria are the aim of the paper, the mean to achieve this aim, the recipient of the improvement, the used method and the continent of port, to which the results are applied to. This classification scheme is applied to 71 relevant publications and their characteristics are presented in detail.

In conclusion, the research done in this field, even though it is extensive, only covers some parts of the overall topic. Interfaces between different aims, means or focus points are limited. Furthermore, the research is only applied to some specific use cases. In future it is important to strengthen these interfaces and connect the separate research foci.

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