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Influence of Drayage Patterns on Truck Appointment Systems

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Truck appointment systems (TAS) are a well-recognized method to smooth the peaks in truck arrivals at seaport container terminals and thereby reduce operation costs for the terminals and waiting times for trucking companies. This study analyzes the influence of different drayage patterns on the success of a TAS at seaport container terminals by means of a discrete event simulation model. These drayage patterns vary in the percentages of transports between container terminals and container terminals and other logistics nodes. Past studies mainly focus on the general impact of TAS on container terminals or on trucking companies. Rarely different TAS' characteristics are analyzed regarding their impact on the performance. To the authors' knowledge, the influence of varying shares of different drayage origins and destinations have not been studied so far. The results show that the pattern of drayage transports has a considerable influence on the success of TAS. As the transport from terminals to logistics nodes and vice versa is bound to the opening hours of the logistics nodes, trucking companies often need to execute inter terminal transports at night.

Keywords: Truck Appointment System; Port Drayage; Container Terminal; Simulation

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1 Introduction

Maritime transport has a high worldwide importance due to the large amount of global trade transported by ships and handled in ports, by volume 80 % and by value 70 %. In 2016, world seaborne trade grew 2.8 % in contrast to 2015 and reached a volume of 10.3 billion tons. The global containerized trade grew even faster at a rate of 3.1 % in 2016, with a volume of estimated 140 million 20-foot equivalent units (TEU). (UNCTAD, 2017) To deal with the rising amount of containerized goods, stricter ecological regulations and lower margins, shipping companies respond with rising ship dimensions. This leads to severe challenges for all stakeholders in the maritime supply chain, especially for the seaports. Seaports are essential interfaces in the overall maritime supply chain, connecting the main carriage via ocean carrier and the hinterland transportation via barge, train or truck. Container terminals, as the most important part of the maritime supply chain in seaports, aim to uphold the guaranteed handling times for their clients, even if these are not rising proportionally to the vessel sizes. Generally, container terminals consist of four functional areas: waterside, horizontal transport, container yard and landside (i.a. Brinkmann, 2011; Steenken et al., 2004). The strategies and processes in all of these functional areas need to be optimized to meet the challenges imposed by the growing vessel sizes.

Especially, container terminals struggle with the strain caused by peaks at land-side operations due to the arrival of large vessels and the related arrivals of many external trucks at the terminal gates. Due to the peaks, the right amount of personnel is hard to estimate and often the capacity of the terminal gate and the handling equipment on the container yard doesn't fit the demand imposed by the arriving trucks. This either leads to high waiting times at the terminal gate and on the terminal yard or to inefficient high labor costs for the terminals due to over capacities. Drayage transportation is accountable for a large share of container terminals' truck arrivals as well as for a high percentage of the overall transportation costs (Harrison et al., 2007; Shiri and Huynh, 2016). A well-established definition of port drayage is: "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). Drayage transports are mainly used for transports from one container terminal to others. In addition, they are used for transports between terminals and freight stations, empty container depots, customs stations located in the port and vice versa. The transports are executed by specialized trucking companies. They mostly employ truck drivers as owner operators, which get paid for every completed trip. These drivers rely on a minimal number of daily trips to cover the expenses.

Therefore, waiting times at terminals or other logistics nodes as well as congestion on public streets lead to less successful trips per day and, thereby, reduce the income per truck driver. Furthermore, waiting times and congestion also affect the accessibility of public streets and related port companies, e.g. forwarders, empty container depots or freight stations. In addition, the waiting times cause higher emissions due to running truck engines.

One popular solution to smooth truck arrival peaks in ports is to implement a truck appointment system (TAS). This is a vehicle booking system used by trucking companies to book time windows within the operating times of container terminals. The truck drivers have to arrive in these time windows for being handled. For late arrivals or missed time windows, penalties can be defined by the TAS operator. Furthermore, there can be penalties for the TAS operator for too long waiting times for trucks arriving at their time window. Due to the existence of (mainly mandatory) TAS at terminals, trucking companies lose part of their flexibility to dispatch their orders to trucks and risk executing less orders per day. Other logistics nodes might have to deal with changes in truck arrival times, affecting their opening hours and capacities.

This paper focuses on drayage transports and on the handling at all relevant stakeholders. Seaside and train operations are excluded in this analysis. For an extensive overview on general container terminal operations and optimization potential, please be referred to e.g. Vis and De Koster (2003), Stahlbock and Voß (2007) and Carlo, Vis and Roodbergen (2014a; 2014b). This paper aims to analyze the effects of different drayage patterns on the efficiency of TAS. A drayage pattern is defined as the share of transport relations between different kinds of sources and drains. Sources and drains of drayage transports can generally be divided in two main groups: container terminals with TAS and other logistics nodes without TAS. The drayage pattern can vary in the amount of sources and drains belonging to either of these groups. In section 2, the current state of research concerning port drayage transports and TAS is presented. The simulation study is described in section 3. Finally, the simulation results and the conclusion and outlook will be given in sections 4 and 5.

2 State of Research

Drayage transports often result from transshipment containers being unloaded from a vessel at one container terminal and needing to be loaded on a vessel at

another terminal. The transport between the two container terminals is mainly done by truck or to a minor degree by barge or train. Other causes for drayage transports are the transport of empty containers to specialized depots for long time storage, repairs or cleaning and the delivery of empty container to freight stations to be loaded with goods from one or several clients and afterwards the transport to a container terminal for shipping, vice versa. A special case is the transport of full containers to customs stations for checking. In this case, there are always two transports necessary, one for the way to the station and one back.

Depending on the size and the structure of the port, a truck driver manages three to twelve drayage transports per day. Container terminals are often either source or drain. Therefore, a lot of the truck arrivals at container terminals are drayage transports. Due to this, long waiting times at terminals (or other logistics nodes) have a high impact on drayage transports and, thereby, on the drayage trucking companies. Still, the main motivation for the implementation of improvement methods or systems is to reduce the congestion in front of the gates and thereby to enhance the productivity of the terminal. In the past, several different approaches have been studied. Analyzed approaches are inter alia: specialized gate lanes (Gracia, González-Ramírez and Mar-Ortiz, 2016), promoting the use of off-peak shifts (Bentolila et al., 2016), informing about congestion by the use of webcams at the gate (Huynh et al., 2011) and implementing and improving a truck arrival management (i.a. Huynh and Walton, 2011; Guan and Liu, 2009).

The first TAS was implemented in 2002 in the ports of Los Angeles and Long Beach with the aim to decrease CO₂-emissions in the port area. Due to the fact that different TAS were implemented at the different logistics nodes in the port area and that most of the systems were voluntary, there were high barriers for trucking companies and as a consequence a low participation in the different systems. (Giuliano and O'Brien, 2007) Since then, other ports, e.g. Vancouver, Sydney and Southampton, implemented a TAS successfully with the lessons learned from their predecessors. Furthermore, studies aiming at improving these systems have been conducted (i.a. Huynh, Smith and Harder, 2016; Davies and Kieran, 2015).

Another research focus is the reduction of congestion in the port by optimizing drayage operations. In addition, the productivity of drayage companies can be enhanced. Diverse research methods are used: for example, the operations of drayage companies are studied and different dispatching and routing algorithms are developed (Namboothiri and Erera, 2008; Julia et al., 2005). In addition, possible benefits of cooperation between trucking companies and companies in

the port are studied (Caballini, Sacone and Saeednia, 2016). Other, broader approaches include using supply chain management instruments (Ascencio et al., 2014), implementing a new traffic control system (Rajamanickam and Ramadurai, 2015) or dry docks with concepts like a chassis exchange system (Dekker et al., 2013). An extensive literature classification about TAS and drayage transports can be found in Lange et al. (2017).

The focus of many papers lies on container terminals and their productivity. Drayage trucking companies are studied as well, but less extensively. Other stakeholders, as empty container depots or freight stations, are nearly never analyzed (Lange et al., 2017). Furthermore, the proportion of transports between the different stakeholders, here called the drayage pattern, is mostly kept static. Therefore, its impact has not been analyzed so far. It can be expected to have a high effect on the productivity of drayage trucking companies as well as on the arrival times of trucks at the logistics nodes and therefore, also on their benefits and costs.

3 Simulation Study

In the following sections, the simulation study will be described. In the first subsection, the relevant constraints are highlighted and the necessary assumptions are presented. Afterwards, the structure of the simulation model is illustrated in detail. In the last subsection, the experimental design is explained.

3.1 Constraints and Assumptions

A discrete event simulation model is used to analyze the mentioned effects of drayage patterns on the success of TAS. The model is built using the simulation software Tecnomatix Plant Simulation version 13. The success of a TAS is influenced by the traffic in the ports and by the productivity of the logistics nodes. As only port drayage transports are analyzed, the model is limited to the port area. The traffic in the port area was determined with a distance matrix application programming interface provided by Google Maps. With this API, the average transport durations at different times of the day between all considered stakeholders were calculated and implemented in the simulation model. Therefore, it was not necessary to model all single streets as the transport duration combined with

stochastic elements can be taken out of a distance matrix. This led to much lower run times for the simulation experiments.

Furthermore, five types of stakeholders are considered: trucking companies, container terminals, empty container depots, freight stations and other relevant logistics nodes. For trucking companies, a depot is implemented, where the dispatching of the trucks is located and where the trucks start and end their shifts. Between tours, the trucks are not required to return to the depot, except when they can't be assigned to another order or during shift breaks. To simplify the model, a truck can load only one container and therefore has only one loading and one unloading address. The distance between the unloading address of one tour and the loading address of the next tour is called empty transport and should be minimized. All logistics nodes have specified opening and closing hours. The container terminals are open 24/7. Furthermore, the queuing times at the gate and the handling times vary stochastically depending on the time of the day and the related demand.

The analysis is based on data of the port of Hamburg, obtained by different stakeholders in the port area. Transport data was generated by analyzing the orders and their execution of a medium sized trucking company in the port of Hamburg. Additional information was given by container terminals and other logistics nodes. This information includes data about truck arrival rates at different times of the day and also about handling times. The port of Hamburg is the third largest container port in Europe and handled 8.82 million TEU in 2017. 36 % are transshipment containers, which enter and leave the port of Hamburg via ocean carrier. All other containers either arrive or leave via train, barge or truck. For this simulation model, the four big container terminals in the port of Hamburg, six empty container depots, six freight stations and five other logistics nodes have been considered.

3.2 Structure of the Simulation Model

The analysis is based on previous work displayed in Lange et al. (2018), which was refined to answer the stated research question. The simulation model is divided into two main parts: (1) booking time windows at container terminals for specific transport orders and (2) dispatching transport orders to the different trucks (see Figure 1).

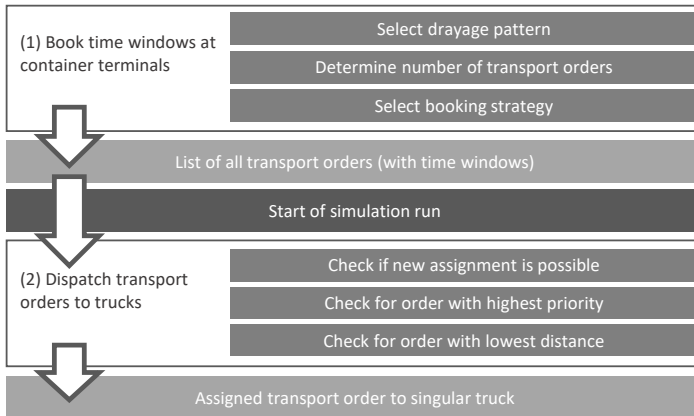


Figure 1: Structure of the simulation model

Before the start of a simulation run, the drayage pattern has to be selected to generate the order list. To do so, the user can decide about the share of transports between the different stakeholders. As there are different companies for every type of stakeholder, the defined shares are divided randomly on the corresponding companies. In the next step, the user has to decide about the amount of orders, which shall be generated in total for one day. Furthermore, the number of trucks, which is later imported by the simulation model, needs to be determined. The third important parameter is the booking strategy, defining for which orders a time window is booked with high priority. After selecting all these parameters, an order list, containing source and drain for every order, is generated. The specific time windows are added to this list in the next step.

Time windows are only required for loading or unloading of containers at container terminals. As a time window has the duration of one hour, there are 24 different time windows types per day. Container terminals are often operated 24/7. As a consequence, the time windows are assigned to three shifts (11 p.m. until 7 a.m., 7 a.m. until 3 p.m., 3 p.m. until 11 p.m.). There is the same capacity for all hours in one shift and therefore the same amount of potential time windows. It is assumed that the competitors of the considered trucking company book

their time windows in advance. Therefore, not all potential time windows are available to be booked. Furthermore, in the times with a higher demand, less time windows are available. The demand is calculated based on data of one container terminal in the port of Hamburg. For every booked time window, the free capacity is reduced. If no capacity is left, other times have to be selected. For the booking process, opening and/or closing hours of source and drain as well as already booked time windows for the source have to be considered. Furthermore, for every transport distance a triangular distribution based on Google Maps API data is considered. Only viable time windows are selected.

In part (2), the list with all transport orders and the required time windows is imported in the simulation model. In the simulation model, the dispatching of transport orders to trucks is done. If a truck has no order assigned, the order list is checked for the orders with the highest priority. Reasons for a high priority of orders are a soon expiring time window for this order or a soon closing source or drain. Furthermore, for orders with the same priority, the order with the lowest driving distance between the current location of the truck and the source of the order is selected. When the truck reaches the drain of the current transport and the container is unloaded, the next order is assigned to the truck. Exceptions are if a break is due for the driver or if no further order is viable at the moment. In these cases, the truck heads to the depot and stays there until the break is over or a new order is available.

3.3 Experimental Design

In the simulation model, the focus is on one trucking company. The size of this trucking company, especially the amount of transport orders and the number of trucks, is set to a medium level of 375 orders per day and 25 trucks. It is possible for a truck to manage up to 15 transport orders per day. In reality, trucking companies always aim at reducing the costs due to very low margins. Therefore, the minimal possible amount of trucks is often used. The same is done in this simulation model. With the 25 trucks used, every delay has a direct impact on the amount of successfully executed transport orders. The simulation horizon is one day. All orders that are not successfully executed at the end of the day are marked as failed and registered in the related statistics. All time windows are booked before the start of the simulation model. It is not possible to change a time window during the simulation run.

Six simulation experiments are considered. They vary in two criteria: the booking strategy and the drayage pattern. The booking strategy refers to the order in which time windows are booked for different transports. When the strategy is "Low Priority ITT", transports between container terminals with TAS, called inter terminal transports (ITT), have a lower priority than transports between a container terminal and the three other types of logistics nodes. Vice versa, if the booking strategy is "High Priority ITT", the transports between container terminals have a higher priority than all other transports. Furthermore, three different drayage patterns are examined. In the first drayage pattern, all transports are executed between container terminals. In the second, 50 % of all transports are ITT and all other transports are evenly distributed between all other relations. Lastly, in the third drayage pattern, no transports are executed between container terminals. All other transport relations have the same percentage. The overview of all experiments and their parameters is shown in Table 1.

Table 1: Plan of experiments (CT: Container terminal, ED: Empty container depot, FS: Container freight station, OL: other logistics nodes)

Exp.	Booking Strategy	CT-CT	CT-ED	CT-FS	CT-OL	ED-CT	FS-CT	OL-CT
1	Low Prio. ITT	100%	0%	0%	0%	0%	0%	0%
2	Low Prio. ITT	50%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
3	Low Prio. ITT	0%	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%
4	High Prio. ITT	100%	0%	0%	0%	0%	0%	0%
5	High Prio. ITT	50%	8.3%	8.3%	8.3%	8.3%	8.3%	8.3%
6	High Prio. ITT	0%	16.7%	16.7%	16.7%	16.7%	16.7%	16.7%

4 Simulation Results

One of the main differences between the six experiments are the shares of the successfully executed transport orders (see Figure 2). A transport order is successfully executed if the source as well as the drain have been reached in the correct timeframe and the order has been handled correspondingly. Possible reasons and times of cancelations are shown in Figure 3.

Experiment 1 and 4 have the highest rate of successfully executed orders with nearly 100 %. Experiment 2 and 5 have a medium share of successful orders (70 to 90 %). The lowest success rate is visible for experiments 3 and 6 (less than 70 %). It is noticeable that experiments with the same drayage pattern result in similar success rates. In experiments 1 and 4, only transports between container terminals are considered while in experiments 3 and 6 only transports with one stop at a container terminal are relevant. Thereby, it can be concluded, that a higher share between container terminals leads to a lower rate of unsuccessful orders. This is most likely due to the limited opening hours of all other logistics nodes. Furthermore, it can be assumed that the booking strategy with a high priority on ITT has a slightly negative impact in comparison to the other booking strategy. This may be caused by the fact, that it favors transports with less restrictions and, therefore, leads to missing time windows for the non-ITT transports. This fact is analyzed in detail in Figure 3. There, the share of times when a transport order is canceled are shown. It is evident that experiment 3 and 6 have very high cancelation rates.

If an order is canceled before the start of the simulation run, it was not possible to book a time window for either source or drain fitting the requirements, especially the opening hours and the booked time window, of the other destination. Therefore, it is not possible to execute this specific order on the given day. A cancelation of an order before the start of the execution is due to an estimated late arrival of the truck at the source. Because it was assumed that the source will be either closed or the time window will be expired, the order was canceled before the beginning of its execution. A similar case is the cancelation of an order during the transport execution. Here, the truck arrived too late at the source or drain of its transport and, thereby, wasn't able to load or unload the container due to limited opening hours or a missed time window. If one order is not chosen by a truck for execution, it is canceled at the end of the simulation run. In this case the capacities of the trucking company are too low to execute all orders.

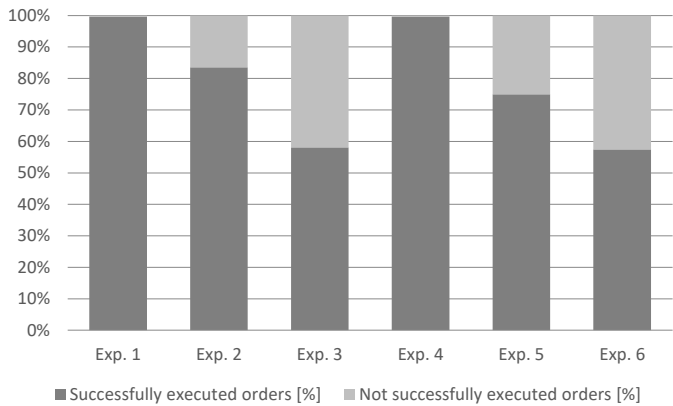


Figure 2: Successfully executed orders

The reasons for order cancelations in experiment 1 and 4 and in experiment 3 and 6 are quite similar. In experiment 1 and 4, some orders are canceled during the execution of the transport, because they arrived too late at the source or drain of the transport. No orders are canceled in the other two phases. As explained before, this is caused by the fact that all transports happen between container terminals, which are open 24 hours per day. Therefore, the transports can be evenly distributed over the day. The cancelations during a transport are similar for all other experiments. These cancelations are probably caused by transports happening at peak times. These transports face a lot of congestion in the port area and the variance of the transport duration is higher, causing truck delays and missed time windows. The source or drain of the transport has no or only a small impact on the delay. The high cancelation rates in experiment 2 and 5 and even higher rates in experiment 3 and 6 are also caused by a lower number of viable time windows fitting to the opening and closing hours of the logistics nodes. As some of the potential time slots are located in the off-peak hours at the morning and in the evening, it is harder for trucking companies to find a match if many of the transports need to happen in peak times. The difference in cancelation rates and times between experiment 2 and experiment 5 result from

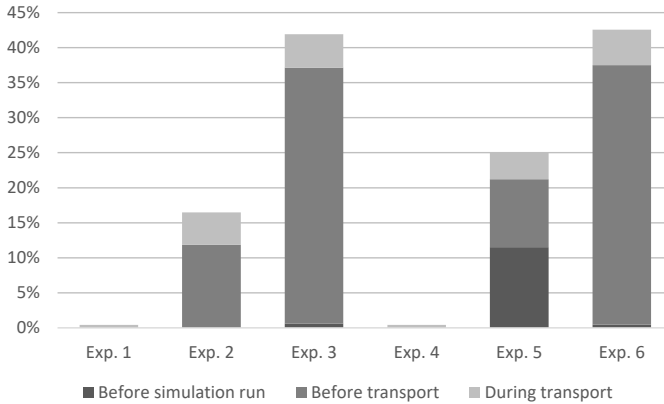


Figure 3: Times of transport order cancellations

the different booking strategies. In experiment 2, the non-ITT transports have a higher priority. Therefore, they are booked on the limited time windows at peak times. In experiment 5, these time windows with a high demand are given to the ITT orders. Thereby, less time windows in peak times are available for the non-ITT orders, which mostly cannot be executed in off-peak times. This leads to a higher number of cancellations before the start of the simulation run in experiment 5. To gain further insight, the times of booked time windows in experiment 1, 2 and 3 are shown in Figure 4 and the ones of experiment 4, 5 and 6 in Figure 5.

Figure 4 and Figure 5 show the amount of time windows booked during different phases of the day. One phase has a length of 4 hours. The amount of time windows is differentiated by the type of transport (ITT and non-ITT) and if the time window is booked for the source or the drain of the transport.

It is noticeable, that the booked time windows for experiment 1 and 4 are, as expected, distributed among all phases of the day. Furthermore, many transports happen during off-peak times due to the higher amount of bookable time windows. For experiment 3 and 6, nearly all booked time windows are located in the daytime hours. Again, this is consistent with the results shown in the figures

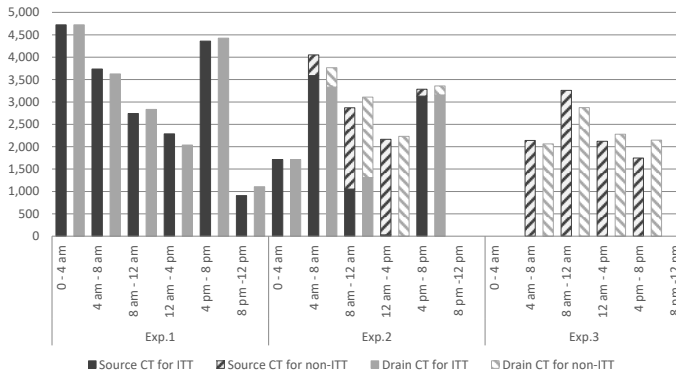


Figure 4: Booked time windows for experiments 1 to 3

above. As all transports in these experiments are non-ITT, the opening hours of the other logistics nodes limit the viable time windows at the container terminals. On the one hand, the delivery time of containers at container terminals depends on the opening time of the source. On the other hand, the pick-up of a container at a container terminal needs to happen before the closing hour of the drain. Furthermore, long waiting times for the trucks between picking up and delivering a container are discouraged in the model as well as in reality. In experiment 2, most ITT time windows are situated in the off-peak hours. The non-ITT orders have booked time windows in the peak times. This is vice versa for experiment 5.

In conclusion, the booking strategy of possible time windows has a high impact on trucking companies if they execute ITT orders as well as non-ITT orders. In this case, it is recommended to prioritize transports with higher constraints, in this case the transports to logistics nodes with limited opening hours.

The effect of the different strategies and drayage patterns can be seen as well in the working times and driven distances of the trucks. In Figure 6 the different states per truck per day are shown. The states are differentiated between driving, handling at logistics nodes, idle due to break and idle due to no available order. Due to the limited amount of trucks, the time spent idle due to missing executable orders is low especially for experiment 1 and 4. As more orders are canceled

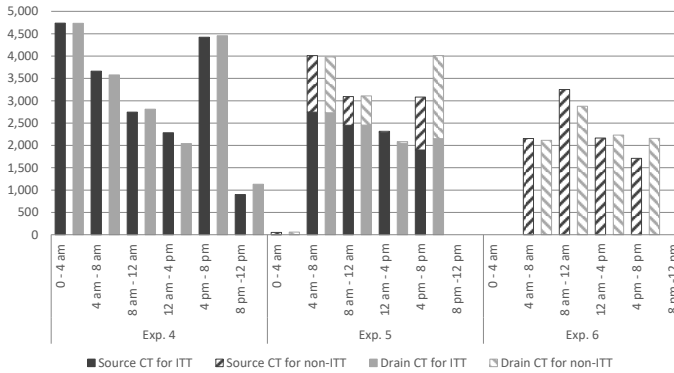


Figure 5: Booked time windows for experiments 4 to 6

early on, there is a higher share of idle time in experiments 2 and 5 and an even higher share of idle time in experiments 3 and 6. The driving time fits in inverse proportion.

In Figure 7, the driven distances per truck and day for every experiment are shown. The more transport orders a truck driver has to handle, the longer are the driven distances. As a truck driver executes more transports in experiment 1 and 4 than in the other experiments, the results also show higher driven distances. Nevertheless, the differences between the experiments are not as high as the differences shown before. This is caused by the fact that for experiment 1 and 4 there are more possible transport orders for the trucks. Therefore, a better fit, with less waiting time and/or empty travel distance can be selected. Furthermore, the container terminals in the port of Hamburg are situated in close proximity, whereas some other logistics nodes are located further away. This leads to longer driven distances especially in experiment 3 and 6.

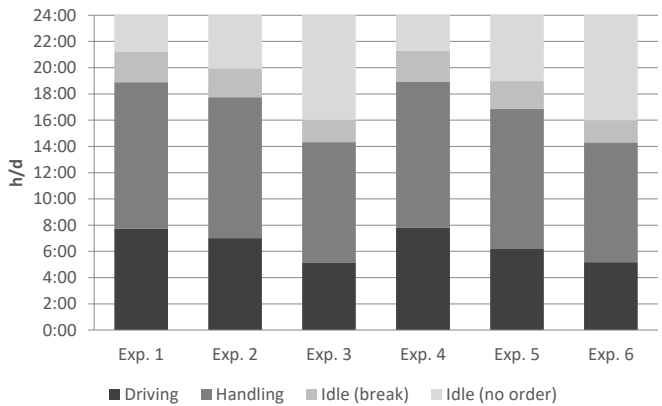


Figure 6: Truck states per day

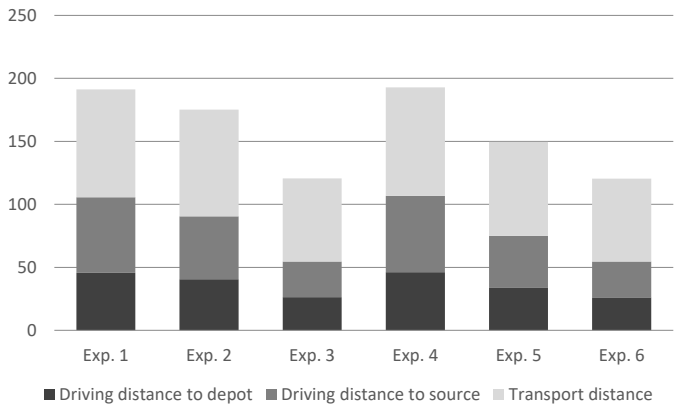


Figure 7: Driven distances per truck and day

5 Conclusion and Outlook

The focus of this study was to evaluate the impact of different drayage patterns and booking strategies of time windows on the productivity of a TAS at container terminals and on related stakeholders in the port. The analysis was conducted using a discrete event simulation model and data provided by different stakeholders in the port of Hamburg. The stakeholders were divided into container terminals and other logistics nodes. Transports between container terminals are called ITT. The results showed that the impact of the booking strategy of time windows is higher, when the drayage pattern is mixed between ITT and non-ITT orders. In the case of limited time windows during the opening hours of the logistics nodes in the port, the booking strategy should favor non-ITT transports to mitigate bottlenecks in the peak hours. Furthermore, the limited opening hours of some logistics nodes pose the biggest challenge for a successful implementation and use of a TAS. A possible strategy is to transfer many of the ITT orders in the off-peak hours to ensure enough capacity for the non-ITT orders during daytime.

This analysis is limited to a fixed number of free time windows per day, not flexibly considering the size of the trucking company or the amount of competitors. Furthermore, the time windows are booked before the dispatching process. In reality, these two parts are interwoven. In addition, trucking companies might be allowed to switch or cancel time windows. Due to these reasons, some flexibility is lost in the model, which might cause in a lower productivity.

In future research, the impact of the TAS on other logistics nodes, e.g. on the arrival rates of trucks or the required personnel, should be analyzed. Furthermore, different drayage company sizes could be studied in detail. It can be expected that larger trucking companies have advantages in the dispatching process due to a higher amount of possible orders and time windows and, therefore, due to a higher optimization potential. Furthermore, the booking and dispatching should be done simultaneously.

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