

Direct handling between vessels and trucks: skipping storage of containers at seaport terminals

Direktumschläge zwischen Schiffen und Lkw: Überspringen der Lagerung von Containern auf Seehafenterminals

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Abstract: Container yards are increasingly becoming bottlenecks at the terminals. To address this, new approaches are needed. One way to redesign processes at the terminal is the direct handling of containers on the seaside. This study employs a discrete-event simulation model to analyse the effects of delayed truck arrivals on quay crane productivity during direct handling between vessels and trucks. In this context, direct handling of containers refers to the loading and unloading of containers between vessels and trucks without intermediate storage in the container yard. A simulation model using Tecnomatix Plant Simulation replicates a terminal employing both conventional and direct handling, examining various truck delay scenarios. Results indicate that minor truck delays mildly affect quay crane productivity, whereas significant delays considerably diminish productivity, especially when a larger share of containers is handled directly. Although direct handling offers efficiency potential, delayed trucks pose significant planning challenges. Future research will aim to develop strategies to mitigate these impacts, such as flexible export container loading sequences.

1 Introduction

Using containers has revolutionised international trade by handling goods in standardised units rather than loading and unloading individual items. This results in significant time and cost savings in global trade and also reduces damage and loss of cargo (Gharehgozli et al., 2016). At the same time, container handling makes it necessary to modify the layout and processes to better fit its specific needs. Historically, conventional general cargo terminals were mainly designed for direct handling, i.e., to load cargo onto a ship as soon as the cargo arrived by train or truck; similarly, cargo was picked up directly after being discharged. Containerization and vessel size growth have led to immensely larger freight volumes per port call and more time pressure, resulting in decoupling via temporary storage of containers at the

terminal (Notteboom and Rodrigue, 2009). Nowadays, direct container handling is still practiced in the hinterland at combined transport terminals between rail and road, which leads to increased process efficiency. In some cases, seaport container terminals also handle containers directly, e.g., when loading dangerous goods containers, such as explosives or radioactive material. Direct container handling is intended to minimise the risk of accidents that could occur in the port due to the volatility of the cargo (Manaadiar, 2011). At the same time, direct container handling can also help to mitigate the negative impact of larger port calls and resulting operational challenges in the yard. This might help to boost overall terminal productivity, as the yard has been repeatedly referred to as the main bottleneck of terminal operations (He et al., 2019; Wang et al., 2023; Wang, et al., 2024).

This study aims to analyse direct container handling between vessels and trucks at the terminal by using a discrete-event simulation model. Therefore, Figure 1 visualises the differences between conventional handling and direct container handling by straddle carriers (SC's).

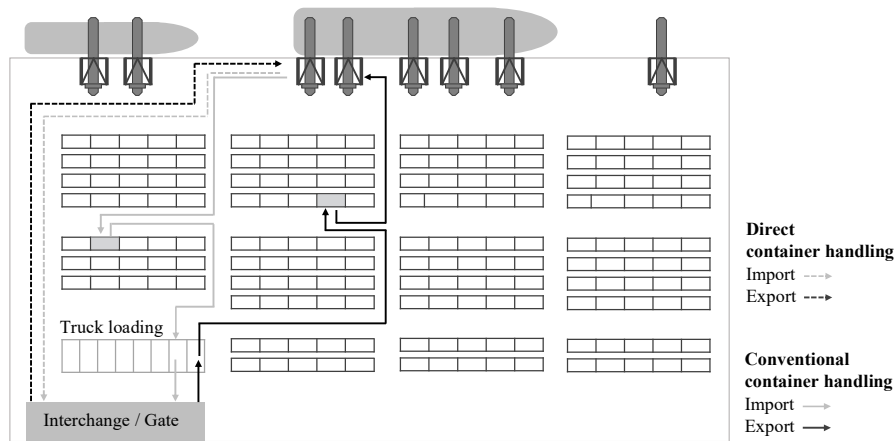


Figure 1: Layout and process illustration

The following research question is explored to satisfy this research objective: How do delayed truck arrivals in direct container handling affect the productivity of Quay Cranes (QC's)?

To answer these questions, Chapter 2 first presents current research areas on optimization approaches at container terminals. Chapter 3 provides an overview of the structure of the simulation model. Furthermore, necessary assumptions for modelling are discussed. A documentation and evaluation of the experiments carried out is provided in Chapter 4. To conclude, Chapter 5 presents a summary and outlook.

2 State of the Art

In order to maximise seaside throughput, several approaches for process optimization at container terminals exist. Grubisic et al. (2020) design an integrated model to improve seaside productivity by addressing berth and crane allocation challenges.

According to the authors, the performance of terminals can be influenced by optimising the assignment of orders to vehicles in horizontal transport. Schwientek et al. (2020) use simulation to investigate the influence of different dispatching strategies on various terminal parameters. Furthermore, yard performance is affected by the efficient use of yard cranes and storage strategies. Gunawardhana et al. (2021) investigates the impact of dynamic and static container stacking. With the help of a rule-based dynamic container stacking model, the authors can reduce handling costs caused by uncertainty. Another approach to improving terminal productivity is the integration of so-called truck appointment systems. These are designed to smooth truck arrivals at the gate while also keeping the utilisation of handling equipment at the terminal balanced. Huiyun et al. (2018) and Abdelmagid et al. (2022) provide an overview of the development of truck appointment systems in science in recent years.

In addition, there are some more specialised approaches in the literature on process design at container terminals, such as the integration of direct container handling into terminal operations. For example, Zeng et al. (2017) consider direct container handling between two ships using genetic algorithm based heuristic for nearest neighbour search. The authors' aim is to examine the influence of direct container handling on the operating costs of terminal trucks and yard cranes. They conclude that direct container handling between vessels can reduce operating costs while improving handling efficiency. Liang et al. (2012) also examine the partial direct handling between vessels. Their study focuses on berth allocation considering direct container handling between large container ships and feeders. Pourmohammad-Zia et al. (2023) present a new platooning concept for container transport between terminals and logistics hubs in the hinterland. To minimise storage and retrieval operations at the terminal, the containers are placed directly on automated guided vehicles at the seaside and then driven to a logistics hub by platooning. Finally, Nellen et al. (2021) presented a feasibility study that uses simulation to examine the direct handling of import containers at a terminal with rubber-tired gantry cranes. However, only the unloading process from one vessel was modelled. Furthermore, only containers for intra-port transport were considered. To the best of the authors' knowledge, there are no previous studies that examine the direct handling of import and export containers between vessels and trucks at a terminal with SC's.

3 Design of the simulation study

In this paper, simulation is used to examine the impact of direct handling of containers on the seaside. The experiments are carried out with the help of a discrete-event simulation model in Tecnomatix Plant Simulation (version 2201). For this purpose, a container terminal with a SC operating system is simulated, whereby both conventional and direct container handling are implemented in the model. In the following, the simulation model is presented.

On the seaside, the quay represents the system boundary of the simulation model. Arrivals of vessels are controlled by a sailing list. Overall, nine vessels are scheduled to arrive at the terminal during the planning horizon: two ultra large vessels with a capacity of 16,000–20,000 Twenty-foot Equivalent Units (TEU), three large vessels with a capacity of 8,000–12,000 TEU, and four feeder vessels with a capacity of 500 TEU each. The number of loaded and unloaded containers of each vessel is

calculated based on the vessel sizes and a typical terminal call size of the different vessel sizes according to Park and Suh (2019). Each vessel has a fixed berth, which is implemented statically in the model. The assignment of the QC's to the vessels depends on the size of the vessel: feeder vessels are served by two QC's, large vessels by four QC's, and ultra large vessels by six QC's.

When a vessel arrives, a loading and unloading list is generated, which provides information about the containers and determines the order of handling. The loading and unloading of the vessel are organised bay by bay. In conventional handling, an import container is created on the seaside, unloaded using the QC and placed at the quay. From here, the container waits until a SC is free to pick it up within a defined service time and transport it to the yard where it is stacked. The corresponding storage location is specified in the container's attributes, so that the SC has all the information to carry out the transport. Containers will always be stored in blocks close to the QC so that the travel distances of the individual SC's are balanced.

As soon as a truck arrives at the gate to pick up a container, the corresponding process is triggered. An available SC is assigned the job of retrieving the container from the yard and moving it to the transfer position. Generally, jobs are assigned on a first come, first served basis. If the container is not freely accessible because of other containers above it in the stack, restacking operations are necessary before it can be picked up. Afterwards, the container is transported to the truck's transfer position. After placing the container on the truck, it leaves the terminal and the process is complete. Export containers follow the process in reverse order.

For direct handling, an import container is created and unloaded from the vessel according to the given order. In contrast to conventional handling, the container cannot be placed at the seaside, as trucks have no option of picking up containers themselves. This results in waiting times in the handling process if the truck does not arrive at the quay on time. As soon as the truck is ready at the quay, the QC places the container on the truck and it can leave the terminal.

On landside, the system boundary is set at the gate through which trucks enter the terminal. The delivery and collection of containers by trains and barges is not considered. The number of arriving trucks is calculated based on the annual throughput, minus the transshipment incident and direct handling. It is assumed that trucks only access the terminal on weekdays, except those trucks for direct handling. The conventional truck arrivals are generated randomly based on the assumption that the terminal has a truck appointment system that minimises but does not entirely eliminate peak loads. The trucks are generated at the beginning of each full hour and forwarded to the gate within the hour using a triangular distribution function. This ensures that the terminal is not burdened with the entire number of trucks at the beginning of the hour. Instead the arrivals are spread over an hour. Especially in the morning between 10 am and noon and in the afternoon between 3 pm and 5 pm, there is an increased volume of trucks at the terminal. The generation of trucks for direct handling is triggered by the QC's and takes place according to the loading and unloading order.

Furthermore, the following assumptions are made for the model:

- The terminal has a rectangular layout. Each block has the same size.
- The blocks are aligned parallel to the quay.

- QC's can only load or unload one container at a time. Twin lifts or even tandem lifts are not included.
- QC's work in single cycles. Double cycles, i.e., the combination of loading and unloading processes in one crane cycle are not included.
- QC's can load import containers from the vessel and store them in a buffer area under the QC. There is a total of three buffer slots available per QC. If all the buffers are full, the QC is *blocked*.
- The SC's are divided into two fleets, which either serve the seaside or the landside.
- Each SC in the seaside fleet is assigned to a QC. Restrictions on driving during the weekend and at night do not exist in this case.

Table 1 shows the main input parameters of the simulation model. The required parameters are based on real terminal data and are scaled according to the model size.

Table 1: Terminal configuration data

Input parameters	Value
Maximum annual throughput	1.4 million TEU / a
TEU factor	1.6
Average dwell time of containers	4.6 days
Share of import / export / transshipment containers	40 % / 40 % / 20 %
Number of berths	3
Number of QC's	12
Service time of a QC (triangular distribution)	[120 s, 100 s, 144 s]
Yard capacity	21,888 TEU
Number of yard blocks	16
Maximum stack height	3
Number of SC's	72
Speed of SC	Loaded 15km/h; empty 20km/h
Service time of SC (triangular distribution)	[70 s, 50 s, 120 s]
Planning time horizon	7 days

4 Experiments and evaluation of the results

To investigate the impact of delayed truck arrivals on QC productivity in direct container handling, a total of 88 experiments are carried out (see Table 2). For each experiment, 50 replications are performed. In the experiments, the percentage of direct handling and the share of delayed trucks are varied. While the share of delayed trucks varies between 0 and 100 %, for direct handling only percentages between 10 and 40 % are assumed. A higher percentage of direct handling is not seen as realistic. In addition, the degree of delay can be classified as *low* or *high*. In the simulation model, trucks arriving for direct handling reach the gate 12 to 16 minutes before the actual container handling. For a low delay, the trucks arrive at the gate five minutes later

than expected in average. A triangular delay distribution of [5 min, 1 min, 15 min] is assumed. In the event of a high delay, the average delay is 15 minutes with a triangular distribution of [15 min, 5 min, 30 min].

Only preliminary evidence can be provided to demonstrate that the transfer of the real system to the simulation model is valid and that the model therefore represents the system with sufficient accuracy. No existing models are known that represent the direct handling of containers at a terminal using SC's. Therefore, a comparison with existing models is not possible. Furthermore, due to a lack of data, it is not possible to compare the model with a real system. Instead, simulation runs without direct handling are performed and evaluated to validate the simulation model. In particular, the productivity of the QC's, the productivity of the SC's, and the handling times of trucks are examined. The analyses suggest that the results can be transferred to real-world conditions.

Table 2: Design of experiments

Experiment	Direct handling [%]	Delayed trucks [%]	Degree of delay
Exp. 01	10 %	0 %	Low
⋮	10 %	⋮	Low
Exp. 11	10 %	100 %	Low
Exp. 12	20 %	0 %	Low
⋮	⋮	⋮	Low
Exp. 44	40 %	100 %	Low
Exp. 45	10 %	0 %	High
⋮	10 %	⋮	High
Exp. 55	10 %	100 %	High
Exp. 56	20 %	0 %	High
⋮	⋮	⋮	High
Exp. 88	40 %	100 %	High

Figure 2 shows the productivity of QC's (y-axis) with increasing share of truck delays (low delays) for a direct handling ratio of 10 %, 20 %, 30 %, and 40 % (x-axis) using box plots. In general, it can be seen that with increasing direct handling, QC's productivity can be increased overall from an average of 28.4 moves/h (10 % direct handling) to 28.6 moves/h (40 % direct handling) if all trucks arrive on time. This shows that in conventional handling, the availability of SC's limits the productivity of the QC's. Using more SC's between the seaside and the yard could likely achieve a similar effect. However, deploying four SC's per QC corresponds to the standard fleet size commonly described in the literature. Furthermore, it shows that, especially with a share of 10 % and 20 % direct handling, delayed trucks have a marginal impact on the productivity of the QC's. With a share of 30 % and 40 % direct handling, the average productivity of the QC's drops to shortly below 28 moves/h as soon as 90 % or more of the trucks are delayed. It can be seen that the arrival of trucks at the gate 12 to 16 minutes before the direct handling is sufficient to compensate minor delays

– averaging 5 minutes and up to a maximum of 15 minutes – without significantly reducing the productivity of the QC's.

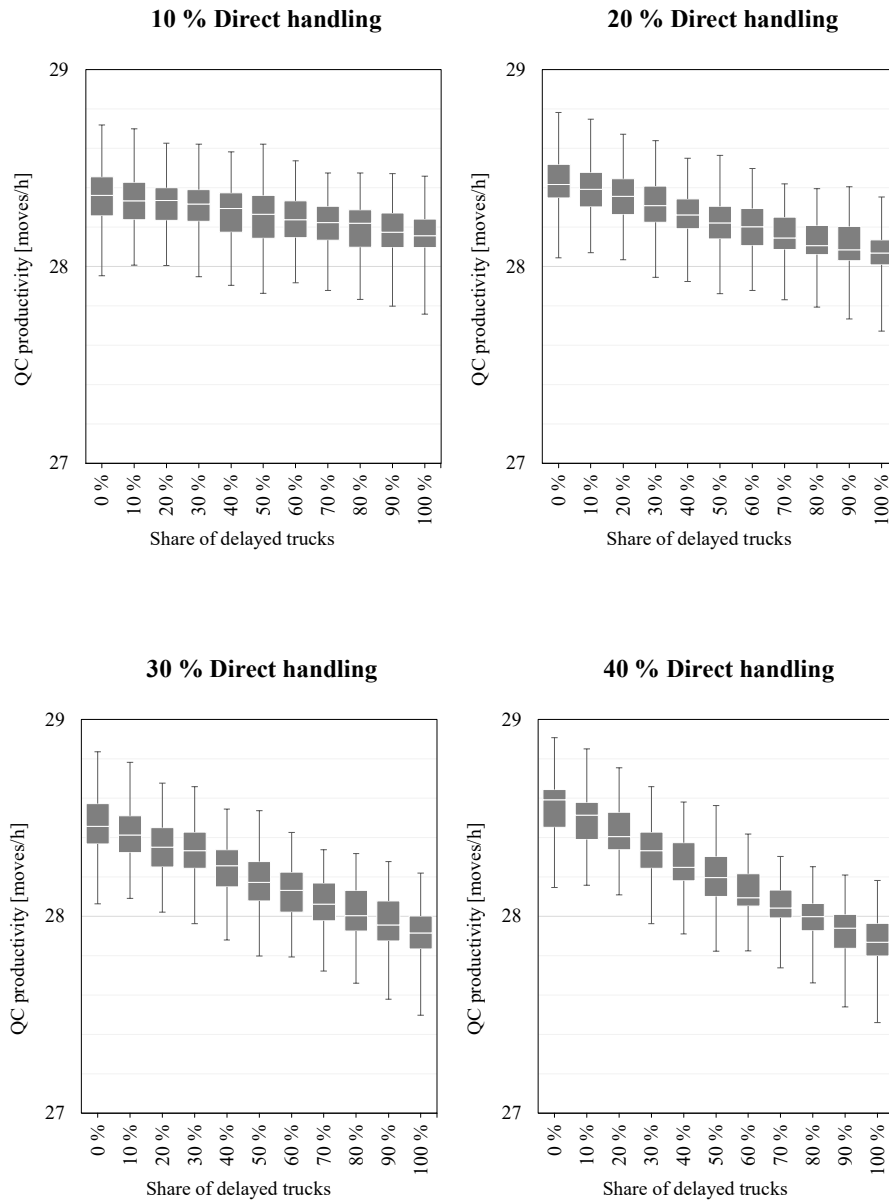


Figure 2: QC productivity for low truck delays

While QC productivity is only slightly affected by low truck delays, high delays significantly reduce QC productivity (see Figure 3). Even with 10 % direct handling

and 30 % truck delays, average productivity drops by more than 5 % to 26.7 moves/h. If all trucks arrive late, average QC productivity is reduced to just 24.2 moves/h. The higher the proportion of direct handling, the faster the QC productivity drops as truck delays increase. If half of all trucks arrive late with a 40 % direct handling ratio, productivity drops by 22 % to 22.2 moves/h, and when all trucks arrive late, productivity drops to 20.1 moves/h.

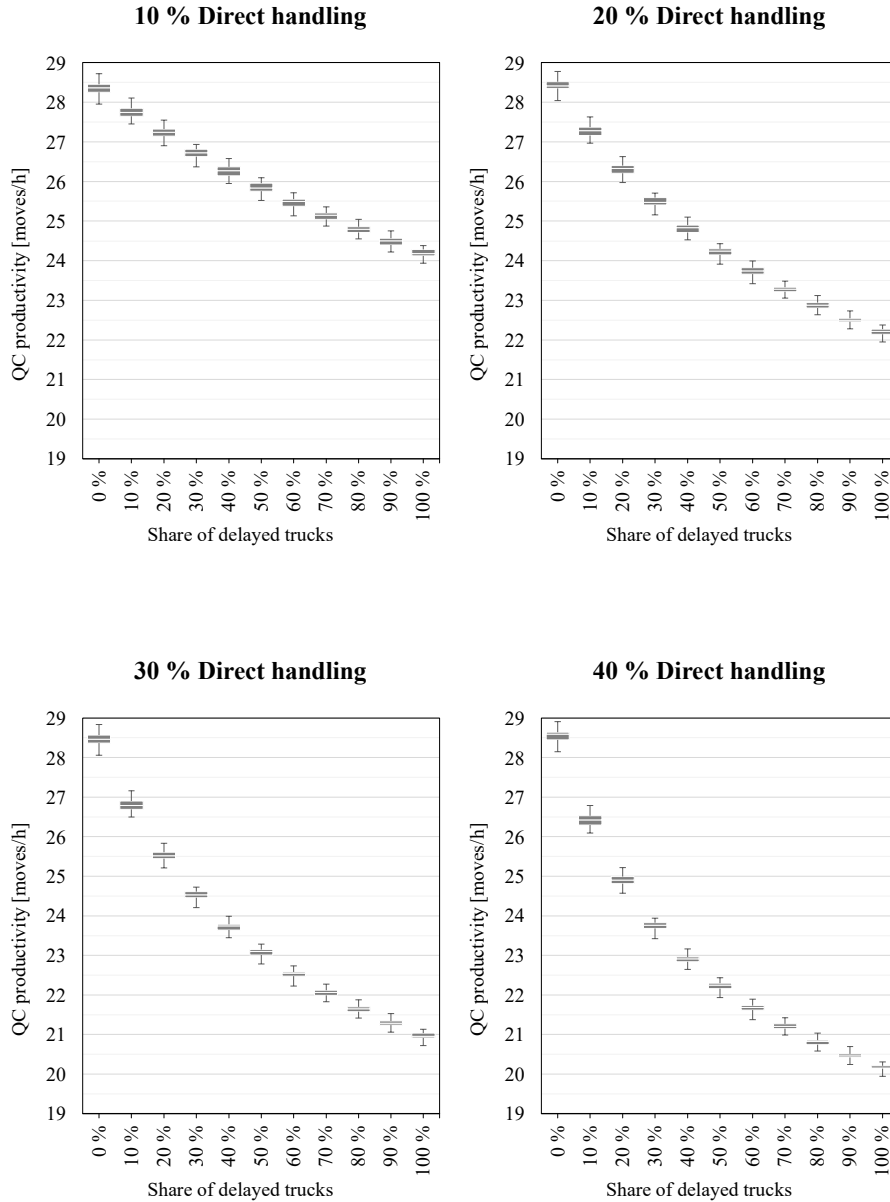


Figure 3: QC productivity for high truck delays

These simulation results come with clear business implications for terminal operators. Despite other potential advantages compared to conventional handling, QC productivity losses of more than 5 % are commonly unacceptable. Given that road congestions need to be expected, especially in ports located near urban areas, this can lead to unpredictable delays of 30 min or more. In addition, other events, such as extended waiting times at previous nodes, further impact truck schedules.

5 Conclusion and outlook

In this study, simulation is used to investigate the impact of delayed trucks in direct handling on crane productivity. It shows that crane productivity in direct handling is highly dependent on truck reliability. While minor delays could be absorbed in the model, longer delays had a significant negative impact on QC productivity. This is already the case even with a small number of delayed trucks and a small percentage of direct handling. Although the experiments reveal potential, direct handling on the seaside leads to a high degree of planning uncertainty for the terminal. Thus, the proposed adjustment of the processes appears to be particularly unsuitable for ports located near urban areas. In contrast, direct handling for closed systems, such as transport between terminals on exclusive roads within a port, could prove to be more promising.

Based on this study, future strategies should be considered to mitigate the effects of late-arriving trucks. One possible approach could be to adjust the loading sequence for late export trucks, provided that the containers match in terms of attributes such as size, weight, and destination. Additionally, the terminal could reserve a section of the yard for the temporary storage of containers that are scheduled for imminent handling. This could lead to a significant reduction in dwell times, decrease unproductive restacking operations at the terminal, and at the same time help to mitigate the impact of delayed trucks. The implementation of such strategies is planned for future simulation studies.

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