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Potential of container terminal operations for RoRo terminals

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Potential of Container Terminal Operations for RoRo Terminals

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Purpose: *With the increasing environmental pollution due to the growing freight transportation, the roll-on roll-off (RoRo) transport is considered one of the most promising alternatives in short sea shipping to the dominant pure road transport. The interruption of the transport chain by freight handling represents a potential for improvement. Therefore, the handling processes at the RoRo terminals, in particular, must be optimized to increase competitiveness.*

Methodology: *A systematic literature review is applied to identify innovative approaches for container terminals to increase terminal efficiency. Gained insights will be examined concerning their transferability to RoRo terminal processes.*

Findings: *The research identified various novel optimization approaches for the functional areas of truck operations, gate-system, storage, transportation, and quay operations. The gate system is the most critical functional area with tremendous potential for improvement; measures based on the optimization approaches are developed.*

Originality: *Based on highly efficient container terminals, optimization potentials for RoRo terminals are identified. This approach has not been pursued before and offers many research opportunities.*

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1 Introduction

Short sea shipping plays a vital role in achieving the EU transport target of reducing 55 % of transport-related greenhouse gas emissions by 2030 (European Commission, 2020) and shifting 30% of road freight transport over 300 km to other modes by 2030 (European Commission, 2016).

A shift of freight transport from road to short sea shipping requires frequent and reliable maritime transport, combined with a fast and straightforward transshipment system. Short sea shipping competes directly with road transport on many routes, and the obstacles to shifting back to pure road transport are small, shipping companies and terminal operators, in particular, must strive to meet customer requirements and offer a high-quality transport service (Notteboom, 2020; Christodoulou, Raza and Woxenius, 2019). Intermodal transport chains, such as RoRo, suffer from inevitable interruptions during transshipment between the port's land and seashores. The terminals are the weak link in the entire RoRo transport process in terms of lack of resilience and vulnerability to problems (Balaban and Mastaglio, 2013). Delays in vessel handling can lead to delays in vessel schedules, terminal operations, and, ultimately, the entire transportation chain (Maksimavičius, 2004; Saurí, et al., 2012).

For this reason, efficient and well-connected RoRo terminals are an essential prerequisite for shifting freight traffic from road to sea (Sambracos and Maniati, 2012). Due to the increase in traffic volumes and larger ships, RoRo terminals face major challenges that require increasing terminal capacity through possible terminal expansions or performance improvements (Eckert, Fliege and Steinhauer, 2008; Morales-Fusco, Saurí and Spuch, 2010). The transport of general cargo by container has developed into one of the most efficient transport systems, so container terminals are a suitable subject of investigation. Therefore, the focus of the present work is to examine container terminals concerning their transferability to the structures and processes of RoRo terminals. The research questions are, therefore, as follows:

1. Which characteristics of container terminals offer the potential for transfer to the processes of RoRo terminals?

2. Which identified measures offer the most excellent opportunities for optimization to increase overall terminal efficiency?

A systematic literature review methodology is used to answer the first research question. The second research question investigates the highlighted results on question one about their transferability in RoRo terminals. The paper is organized as follows. The following section presents the theoretical background of RoRo terminals. The subsequent section shows the methodology of the systematic literature review and describes the results of this paper, including possible approaches to optimize RoRo terminals based on approaches from container terminals. Many of the identified publications focus on handling automotive vehicles, which likewise functions under the wording RoRo. This framing of the literature is not part of the underlying publication. The results are then analyzed in a benchmark study for selected approaches. Finally, the benefits of the presented solutions for implementation in RoRo Terminals are evaluated, and our conclusion and outlook are presented.

2 Theoretical Background

The following chapter provides an insight into the state of research regarding RoRo terminals showing the structure and processes.

2.1 RoRo Traffic

Horizontal transshipment in RoRo Terminals places lower infrastructural demands on the storage and transshipment areas, requiring a smaller investment outlay than container transshipment (Schieck 2009). These characteristics give the RoRo system certain flexibility, allowing lines to be established at short notice, and discontinued when demand stagnates (Brinkmann 2005). Pure road transport and container transport in terms of short sea shipping are among the main competitors of RoRo transport (Jia et al. 2019). However, RoRo transport offers more competitive total costs than pure road freight transport. Furthermore, external costs can be significantly lowered by reducing congestion and increasing road safety (Deutsch, 2013; Fancello, Serra and Mancini, 2019).

Potential of Container Terminal Operations for RoRo Terminals

Efficient, fast, and well-connected ports are necessary for shifting freight transport from road to sea (Casaca and Marlow, 2007; Medda and Trujillo, 2010). In RoRo traffic, the ratio of sea time to port laytime is much lower, and thus ships and port facilities are more closely interrelated, special attention must be paid to the design and operation of RoRo terminals (Lüsich, 2005; Balaban and Mastaglio, 2013). Terminals must allow for rapid cargo handling so that the total transit time of the supply chain is not longer than for a purely road-based alternative (Santos and Soares, 2020). Both RoRo and roll-on/roll-off passenger (RoPax) ferry terminals handle rolling cargo, with unaccompanied transports dominating at RoRo terminals, while accompanied transports were more common at ferry terminals. In accompanied transport, self-propelled loading units, such as trucks, are loaded onto RoRo vessels. If the drivers do not remain with the cargo during the main run, it is called unaccompanied transport, which includes trailers or semitrailers next to roll trailers, cassettes, and containers. (Santos and Soares, 2020) In these cases, the loading units are parked at the terminal after the initial run. New drivers take over the loading units at the destination port and take over the loading units to transport them on the onward leg (Schieck, 2009; Daduna, 2007; Deutsch, 2013). Due to the increasing number of large RoPax vessels, which in addition to classic passenger transport, carry out accompanied and unaccompanied transports, the former boundaries between the two terminal types are becoming blurred (Lüsich, 2005). Since this scientific paper focuses exclusively on handling unaccompanied transports, the structure and processes of classic RoRo terminals are explained below. However, most of these explanations can also be transferred to (RoPax) ferry terminals, whereby structural facilities that would be necessary for passenger transfer and the handling of accompanied transports are omitted. In addition, only facilities that cover the transfer between road and ship will be considered.

2.1.1 Layout and structure of RoRo terminals

While the operations at RoRo terminals are relatively uniform worldwide, there are often significant discrepancies in layout or equipment used (Muravev, et al., 2016).

A RoRo terminal can be viewed as a continuous system (Mhand, Boulmakoul and Badir, 2019). This system consists of several subsystems and functional units, which are further explained below.

Gate system

The terminal gate system includes check-in and check-out counters, gate entry and gate exit buffers, scanning facilities, and border control and customs clearance, where applicable. The gate system, therefore, acts as an interface between the terminal site and the hinterland and is one of the most important facilities of a RoRo terminal (Moszyk, Deja and Dobrzynski, 2021). The number of gates and the optimal scheduling of the gate system are composed of the critical indicators for managing traffic flow during peak hours at the RoRo terminal.

Storage area

In the storage area of the RoRo terminal, loading units are temporarily parked. The parameters of the storage area include the total area, the number, the area of parking spaces, and the type of parking system. The number of parking spaces is closely related to the traffic volume and the dwell times of the loading units. The higher the traffic volume and average dwell times, the more storage space is needed for the loading units (Santos and Soares, 2020). The parking spaces at RoRo terminals are often arranged at an angle, which allows for better space utilization. In general, storage areas can be subdivided into import and export areas. Berth-related slots are used for intermediate storage of cargo units, which are usually assigned to a direct ship berth.

Cargo handling area

Non-rolling cargo units, such as containers and swap bodies delivered to the RoRo terminal without semitrailers, must first be lifted onto cassettes or terminal trailers for transport on the premises and onto the ship (Muravev, et al., 2016).

Ship berths

RoRo terminals have one or more ship berths. Since most RoRo vessels are equipped with a bow or stern ramps, the vessel must moor in a corner of the quay for loading and unloading (Ventura et al. 2020, p. 49).

Potential of Container Terminal Operations for RoRo Terminals

The ship's ramp connects to the shore ramp to provide vehicle access.

Stevedoring

Seaward cargo handling is carried out by stevedores, who are usually employed by the terminal operator. They are organized in groups and tow the unaccompanied cargo units to or from the RoRo vessel in a predetermined sequence using terminal tractors (Santos and Soares, 2020).

2.1.2 Processing in RoRo Operations

This subchapter will describe the handling processes at RoRo terminals in more detail.

Export case

A driver from the shipping company brings the loading unit to the RoRo terminal. If the forwarder has yet made no pre-booking, this process must occur before entry. The gate personnel then check the booking documents and announce the slot number for the loading unit. For temporary storage, self-rolling loading units are usually parked on the terminal premises. If the unit is already booked for a specific ship, it is assigned to a corresponding berth-related export slot. In case of multiple bookings or inaccurate data, loading units are taken to an export consolidation yard until the situation is clarified. In all cases, the driver drives to the designated berth and uncouples the trailer or chassis (Muravev, et al., 2016). To ensure that the actual transshipment runs as smoothly as possible, precautions are taken by the terminal operator. Firstly, loading units that have previously been parked at the export staging area are brought to the berth-related bays by the tractor units after successful booking (Muravev, et al., 2016). Second, semitrailers and chassis can be jacked up for the subsequent loading process (Saurí, et al., 2012; Paternina-Arboleda, 2019).

Import case

The processes for picking up an unaccompanied loading unit are similar to those for delivery. The tractor unit appears at the terminal for the pick-up of a loading unit. All required documents are checked by gate personnel at the check-in counter, and the data is matched. A preliminary check of the security code entered by the carrier on the check-in slip is already carried out to avoid disruptions during check-in. If all the data is correct,

the driver receives the number of the parking space where the loading unit to be picked up is located. The driver then picks up the loading unit (Muravev, et al., 2016).

3 Systematic Literature Analysis

To investigate possible shift opportunities from container terminals to RoRo terminals, a systematic literature review is conducted according to Fink (2014). For this purpose, the literature databases Scopus and Web of Sciences are used, which contain the research output from the fields of natural sciences, technology, medicine, social sciences, and the humanities. To have a sufficient database synonyms and extensions of the term 'container terminal' are used. Therefore, the search query in both Scopus and Web of Science databases is as follows:

```
("container terminal*" OR "container terminal*" OR "container port*" OR "container-port*") NOT ("crane")
```

3.1 General Results

The source search in the two databases resulted in a hit count of 6,251 (Figure 1). Due to many hits, the search result was further specified according to various criteria. The period of publication was set from the years 2017 to 2021. Furthermore, the literature selection was limited exclusively to journal articles. Studies are examined that relate to specific functional areas, processes, or subject areas (summarized below as functional areas) of a container terminal and contain innovations or approaches that can generate optimization potential. The focus should be on landside processes. Studies that do not meet these criteria will be excluded from further investigation. These include economic studies, analyses, comparisons, evaluations of different container terminals, and various financing approaches. In addition, topics related to vessel-based applications, such as

Potential of Container Terminal Operations for RoRo Terminals

congestion planning, berth allocation, or liner planning, are treated as further exclusion criteria.

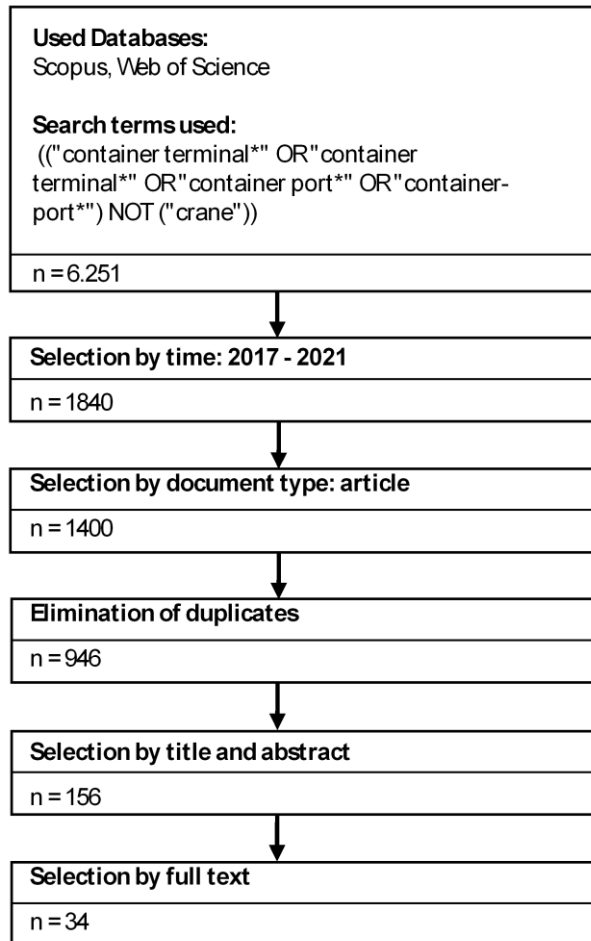


Figure 1: Documentation of conducted systematic literature research

156 sources can be identified, after initial consideration, as potentially relevant for answering the research question. These are subjected to an analysis of approaches with transfer potential. On the one hand, the transferability of each approach applied at container terminals to the processes of RoRo terminals and, on the other hand, the similarity of the problem definition of both terminal types are examined. The latter is whether the problem to be addressed and the set objective of the respective approach match those of a functional area or process in the RoRo terminal. If these properties are not fulfilled, the source is excluded.

The performed literature analysis has identified 34 sources, which show in their problem definitions extensive overlapping amounts with structure and processes in functional areas of general RoRo terminals.

3.2 Identified relevant function areas

This subsection shows the most promising relevant functional areas to optimize different aspects of RoRo terminal processes. Table 1 shows a literature classification of the relevant functional areas where transfer potential from container terminals to RoRo terminals exists.

Table 1: Literature Classification for relevant functional areas of container terminals

Author	Gate	Truck Operation s	Quay	Storage	Transport
Azab et al. (2020)		x			
Caballini et al. (2020)		x			
Chamchang and	x				
Chao and Lin (2017)	x				
Deng et al. (2021)					x
Díaz-Ruiz-Navamuel			x		
Fan et al. (2019)		x			

Potential of Container Terminal Operations for RoRo Terminals

Author	Gate	Truck Operation s	Quay	Storage	Transport
Fu and Sun (2020)	x				
Gharehgozli et al.				x	
Hill and Böse (2017)		x			
Jacobsson et al. (2018)		x			
Jin et al. (2021)	x				
Kadir (2017)	x				
Karam and Attia (2019)					x
Kim et al. (2021)				x	
Li et al. (2020)		x			
López-Plata et al.					x
López-Plata et al.					x
Man et al. (2021)				x	
Minh and Huvnh (2017)	x				
Moszyk et al. (2021)	x				
Nadi et al. (2021)		x			
Peng (2021)			x		
Peng et al. (2019)			x		
Radwan (2019)			x		
Torkiazi and Huvnh		x			
Torkiazi et al. (2018)		x			
Wang et al. (2018)	x				
Wu and Wang (2020)			x		
Xu et al. (2021)		x			
Yang et al. (2019)			x		
Yi et al. (2019)		x			
Zaerpour et al. (2019)				x	

In summary, discrepancies between terminal types exist and prevent the transferability of the identified innovation and optimization approaches. The differing handling characteristics of the loading unit can be seen as a significant factor influencing the

terminal handling processes. Whereas container terminals use standardized containers as the central loading unit, which are stackable and easy to handle, unrollable and rollable goods, which are not stackable, are handled at RoRo terminals. Their properties require different handling processes, limiting the transfer potential of functional areas of storage and intra-terminal transport. Since containers and semitrailers are moved similarly by a tractor unit in the hinterland, more transferable optimization approaches can be identified. Another reason for the inhibition of knowledge transfer is the varying complexity of terminal processes. Many problem areas within a container terminal, such as the stacking problem in the yard, the complex stowage planning, or simply the higher handling volume, require solutions that do not offer a transfer requirement for RoRo processes. The distribution of sources for the various functional areas is shown in Figure 2 below.

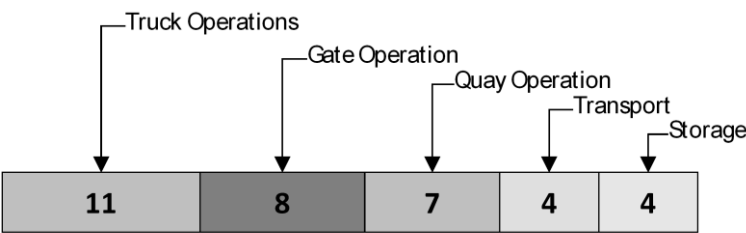


Figure 2: Number of publications according to the different functional areas

In the following, the focus will be on functional area and discussed in terms of transfer to RoRo terminals.

4 Findings

Our study has contributed that the gate processes of RoRo and container terminals, based on the conducted analysis, are characterized by a strong similarity regarding the handling processes in im- and export of loading units at container terminals and RoRo terminals. Therefore, the focus of this chapter will be exclusively on the gate system

Potential of Container Terminal Operations for RoRo Terminals

based on identified characteristics at container terminals. A detailed exposition of the gate systems as the transfer object is carried out.

According to the analysis of the literature, for both terminal types, the gate turns out to be a critical point in terms of terminal performance. As a challenge, the high vulnerability of gate processes at peak times can be mentioned, which manifests itself in congested gate lanes and long queues. In the context of performance evaluation, no exact comparisons based on KPIs due to the lack of data, but estimations based on relevant sources are done. In the simulation model developed by Keceli, Aksoy and Aydogdu (2013), which was tested using data from a RoRo terminal in Turkey, the average utilization of the terminal gate was found to be less than 25%. RoRo terminals are used particularly frequently during peak hours, but hardly at all outside these hours. Due to the high volume of trucks during peak hours, the risk of truck queues increases given the insufficient entry capacities. The forwarders carry out the deliveries in advance and the collections in the aftermath transporting unaccompanied loading units at their discretion, irrespective of the traffic situation. Peak times in the export process, i.e. for accompanied loading units arriving on land at the terminal entrance, can be defined as the period of two to three hours before the arrival of the respective ship. At this time, about 80% of loading units arrive at the gate of a RoRo terminal (Maksimavičius, 2004). In the case of imports, the immediate time after a vessel's arrival can be defined as the peak time for gate exit (Keceli, Aksoy and Aydogdu, 2013). Accompanied units leave the terminal area immediately after the vessel docks. In addition, the aim is to collect unaccompanied loading units as soon as possible after they have been staged at the terminal area. The loading principle by which stowage occurs on a RoRo vessel, which must necessarily follow the last-in-first-out (LIFO) procedure, can further exacerbate the formation of these peak periods (Saurí, et al., 2012). Loading units arriving late at the terminal are often the last to be loaded, allowing them to be the first to leave the ship at the destination port. In addition to the high gate loads during peak hours each truck's extended gate handling time, especially for export, leads to queues. One reason can be seen in the overbooking by the shipping company and the unannounced arrival of unaccompanied or accompanied units, which increases the handling time at the gate due to the manually booking of slots (Saurí, et al., 2012; Keceli, Aksoy and Aydogdu, 2013).

In addition, deficiencies in terminal layout and gate management can also lead to congestion in the entry and exit lanes. Insufficient handling space and undersized entry and exit lanes and poor performance of check-in and check-out counters, lead to problems and can thus exacerbate congestion situations (Saurí, et al., 2012).

5 Development of Measures

In the following section, four measures are introduced in terms of transfers from gates of Container terminals to gates of RoRo terminals. The measures proposed are then compared and evaluated. Then the overall efficiency of the terminal gate is evaluated.

5.1 Presentation of Measures

The inefficiencies highlighted cannot be addressed by one measure alone. Nevertheless, solving one problem has positive implications for other performance gaps. The most appropriate measures adapted from the analyzed papers dedicated to gate function area for RoRo terminals are presented below.

Introduction of a Truck Appointment System

Using a Truck Appointment System (TAS), which acts as a communicative interface between shipping companies, terminals, and freight forwarding companies, a reduction of the landside transport volume and the equalization of truck arrivals at the terminal can be achieved. The TAS allocates a defined number of handling slots per time window. This procedure allows the capacity of the gate to be regulated. The notification of the pick-up of an unaccompanied unit by the terminal operator can be seen as a challenge, because, despite known ship arrivals, the forwarder cannot be given an exact time of arrival of the unaccompanied unit. Without this information, no appointment for the pick-up can be booked. However, based on the information about the respective slot on the RoRo vessel and the knowledge about the similar unloading processes by the RoRo tractors in the LIFO process, it is possible to determine both the slot on the terminal and a rough time of unloading in advance. Integrating certain information from the shipping companies into the TAS could provide greater transparency and solve this problem. On

Potential of Container Terminal Operations for RoRo Terminals

the forwarding side, an extension of the TAS can be seen in the execution of double transports, which should reduce the total number of truck arrivals. In this case, the tractors bring a trailer and subsequently carry out a pick-up. However, for extensive coordination of the double transports, TAS would have to be provided with information from the forwarding side. Specifying the direction and destination of a truck's potential empty run, it is thus possible to find a suitable available loading unit whose pick-up or drop-off point is on or near the route. Once a suitable loading unit for a double transport has been identified, it is proposed to the respective forwarder with an aligned time window. After accepting the double transport, the two transport orders are merged and the time window for truck arrival is assigned.

Implementation of reversible Gate Lanes

By using individual gate lanes with a flexible direction of travel, the entry and exit capacities can be flexibly adapted to the traffic situation. If the number of trucks entering the terminal exceeds the number leaving, a balance can be created by converting the reversible exit lanes to entrance lanes. Since the cost of a reversible gate lane is higher than a fixed gate lane, there is a risk that adding numbers of reversible gate lanes may tend to incur additional costs. Therefore, it is essential to determine the optimal number of reversible lanes in the gate system. Only if the entry and exit lanes are arranged contiguously next to each other the upstream lanes can be connected to potentially reversible gate lanes. For improved accessibility, it is recommended that the reversible gate lanes are implemented in the median between the entry and exit lanes. Once the number and location of reversible sluice lanes have been determined, the type and extent of construction measures can be specified. The necessary infrastructure must be created in the affected lane to perform both check-in and check-out processes on a reversible gate lane. Two approaches are proposed for optimal dynamic control of reversible gate lanes. The first approach involves predictive control of the gate lanes based on predetermined data (truck peak times or scheduled ship arrivals). The information collected in advance allows forecasts to be made of when gate entries and exits will be loaded and the reversible lanes to be controlled accordingly. The second approach involves short-term lane control based on information about the current queue lengths before gate entry and gate exit. However, since changing the direction of driving

on a reversible lane at short notice is expected to take some time, gate efficiency may decrease in the process.

Complete automation of Gate Operation

Increasing the level of automation within the gate processes helps to increase overall capacity. Full automation of gate operations includes vehicle and freight identification and condition inspection of the loading units using OCR technology. This requires the construction of OCR gantries in front of the gate entrance and gate exit, respectively. The cameras can be used to identify the license plate numbers of the tractors and chassis and damage or hazardous material markings on the rear of the semitrailer. The second sub-measure involves the installation of self-service lanes where drivers can independently complete identification and registration tasks from within the vehicle at a gate kiosk. Equipment for a self-service kiosk can include area cameras for the front of the truck, a control module, and an intercom system. The operating system should be multilingual and straightforward in design. A vital prerequisite for carrying out automated check-in/check-out operations is freight registration by the freight forwarder in advance. This can prevent lengthy data entry at the gate and speed up the overall process.

Vessel dependent Gate Lane Assignment

Gate lane assignment based on the ship's schedule affects only the gate entrance processes. This measure targets the peak load explicitly at the gates and focuses especially unaccompanied units. For the application, trucks arriving at the terminal are first divided into different categories (urgency and type of order).

- Delivery with low urgency
- Delivery with high urgency
- Pick-up with low urgency
- Pick-up with high urgency

If a loading unit is brought to the terminal, the transport falls into a delivery category. The transport falls into the pick-up category if an empty tractor arrives at the terminal to pick up a loading unit. The urgency level represents the prioritization. If a loading unit arrives at the terminal, the onward transport of which by RoRo ship will only take place in the distant future, the transport is assigned to the category *delivery with low urgency*. If the

Potential of Container Terminal Operations for RoRo Terminals

loading unit is booked for the RoRo ship that will leave the terminal next, the transport is assigned the category *delivery with high urgency*. If a loading unit is waiting at the terminal for a more extended period to be picked up, it will be assigned to the category *pick-up with low urgency*. However, if a loading unit that originates from the last unloaded RoRo vessel is to be picked up, this is assigned the category *pick-up with high urgency*. If a vehicle with several transport orders, i.e. a delivery with simultaneous pick-up, appears at the terminal, it will be assigned the category with the higher prioritization. In practice, arriving vehicles that have been assigned a higher urgency should be provided with a larger number of gate lanes for a certain period to realize the delivery or pick-up of the loading units as quickly as possible. High urgency deliveries start three hours before the ship's arrival and end when the ship arrives. Since most of the loading units for the respective ship are received during this period anyway, it can thus be ensured that the majority are ready on time for the loading process. At the ship's arrival, the prioritization for the pick-ups with high urgency starts. A tractor can pick up loading units and transport them immediately after decoupling and parking them in an import yard. No prioritization takes place outside of these time windows. The implementation of this measure does not require any further constructional measures apart from digital display boards, which are to make clear to the drivers the allocation of the categories to the gate lanes. In addition, the prioritization time windows can be calculated even better by using external information from a TAS.

5.1.1 Evaluation of presented Measures

The measures designed are to be evaluated in terms of their benefit regarding their potential of harmonizing truck arrivals and minimization of the truck handling processes at the gate entrance and exit. Further implementation efforts concerning construction changes and Investment and operating costs are estimated. The articles where the measures were transferred are used as the basis and weighed against each other in Figure 3 concerning the criteria. For qualitative comparison, Harvey spheres are taken, where white means not applicable and black means applicable.

The TAS implementation is associated with a high effort since they strongly intervene in the processes within the transport chain. In addition, there is still the requirement that

forwarders must be provided with more precise information on the time of provision of the loading units by the terminal operator to be able to book an exact pick-up date. Furthermore, there is the risk of a lack of willingness to accept such an IT infrastructure on the part of the freight forwarding companies. If TAS is successfully implemented and accepted, truck arrivals can be spread throughout the day, thus continuously utilizing gate capacity. The promotion of double transports ensures a reduction of empty runs and consequently helps to minimize truck arrivals at the terminal. Furthermore, by preventing long waiting times and minimizing empty transports on the roadside pre-and-on-carriage, the number of empty transports can be reduced. Expanding a terminal gate with reversible gate lanes can often be a simple solution since this is often impossible due to limited space.

















Measures				
	Truck appointment system	Reversible gate lanes	Automation of gate operation	Vessel specific gate lane ass.
Benefits				
Constant truck flow				
Minimization of truck handling processes				
Barriers				
Required constructional change				
Investment and operating costs				

Figure 3: Evaluation of Measures

Potential of Container Terminal Operations for RoRo Terminals

Converting fixed gate lanes to reversible gate lanes requires comparably less effort since these measures only affect individual lanes. Therefore, it is also possible to carry out conversion operations during normal gate operations. The operation of reversible lanes does not require any other areas of the terminal as well is no further involvement of the stakeholders, the control and monitoring effort can be estimated as low. Although the implementation of this measure does not directly lead to the optimization of truck handling processes in the gate system, the average gate turnaround time for trucks can be reduced by adjusting the workloads of all gate lanes, thus preventing queuing. The terminal can catch truck peaks forming immediately after a ship docks using reversible lanes.

OCR technology requires high investment costs for the installation of high-tech equipment. The investment costs are directly related to the number of gate lanes to be automated. On the other hand, if OCR systems and self-service kiosks are implemented at the gate, lower operating costs can be assumed due to the savings in personnel, which means that the investment will pay for itself after a few years. Furthermore, by increasing the level of automation, this measure can make vehicle identification and cargo control and the actual check-in and check-out processes more efficient and faster. As a result, average throughput times are reduced, and the formation of queues can also be avoided. In addition, the terminal operator can be guaranteed a high level of security against damage claims. Freight forwarders could also be provided with continuously updated data regarding the damage status of the fleet.

Since the gate lane allocation hardly requires any structural changes in the gate system and the operation is also estimated to be less complex, low investment and operating costs can be assumed here. This approach can reduce the average throughput times and queues. Gate lane allocation can also increase on-time performance by allowing loading units to reach the booked RoRo vessel even if they arrive late at the terminal. A malus rule for long idle times can be used to obtain a speedy truck pick-up after the loading unit has been unloaded at the terminal on the ship side, thus reducing intermediate storage times and relieving limited storage space.

6 Discussion

The study has revealed barriers and benefits based on the measures transferred from container to RoRo terminals. The implementation of measures from container terminals can be seen as an advantage since it is based on an area in maritime logistics that is considered the best researched. The mentioned characteristics of unaccompanied units in the inlet of RoRo terminals are similar to those of containers on chassis. From this point of view, the developed approaches can be promising. The identified connecting points are based on the approaches highlighted in the literature.

However, the precarious situation around the technical literature has a disadvantage, which has to be mentioned explicitly. Moreover, the term RoRo cannot be assigned to the rolling handling of accompanied or unaccompanied units but can also be assigned to automobile handling, which differs rudimentarily from RoRo handling and further restricts the literature. Furthermore, it is sometimes impossible to speak of a holistic approach since the existing problem of inefficiencies at terminal gates has been considered in this work exclusively from the perspective of the terminal operators. The perspective of freight forwarders and shipowners has been missing so far. In addition, there are no KPIs for evaluating gate performance from the terminal side in the literature analyzed.

The relevance of the highlighted measures has to be confirmed by discussions with practice partners. Furthermore, it must be pointed out that the approaches used to require the measurement of variables necessary for calculating KPIs.

7 Conclusions, Limitations and further Research

This study aimed to examine systemic potentials in transferring from container terminals to RoRo terminals. For this purpose, a systematic literature review was conducted to identify similar characteristics of both types of terminals. In this context, 35 papers were identified which could be used as a basis for the transfer. The gate system was identified as the main weak point of a RoRo terminal, as it proves to be a significant bottleneck and affects the overall efficiency of a terminal and was therefore chosen for further

Potential of Container Terminal Operations for RoRo Terminals

consideration. After the introduction of four measures to increase performance and evaluation of the following measures (1) Truck Appointment System, (2) reversible Gate Lanes, (3) Automation of Gate Lanes, and (4) Vessel specific Gate Lanes were conducted.

The study was constrained by limited access to current literature since the subject area of "RoRo" has so far received little attention. Therefore, the problems identified may be far less severe in practice due to technological advances. Furthermore, it cannot be excluded that after focusing on the gate processes, other well-transferable solutions do not exist in other functional areas of RoRo terminals. Due to a lack of data, we cannot test our measures. Therefore, there is an acute need for research here. Furthermore, due to the different land availability on-site at the terminals, the possibility of implementing measures can vary significantly from terminal to terminal.

The study can be used as a knowledge base for different research approaches. The work reflects the current status of the literature, but it also offers opportunities for further analysis of RoRo terminals in terms of adaptation and further development of structures and processes. Avoiding unannounced units at the terminal is considered essential and requires further research, as this is seen as a cause of congestion and capacity bottlenecks. Furthermore, the situation around track and trace of trailers is an aspect that needs to be explored to make the information situation more transparent and to reduce inefficiencies.

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Potential of Container Terminal Operations for RoRo Terminals

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