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Published in:
Computational Logistics

DOI:
10.1007/978-3-030-31140-7_8

Publication date:
2019

Document Version
Peer reviewed version

Citation for published version (APA):
Jia, B., Rytter, N. G., Reinhardt, L., Haulot, G., & Billesøe, M. B. (2019). Estimating Discharge Time of Cargo Units: A Case of Ro-Ro Shipping. In C. Paternina-Arboleda, & S. Voß (Eds.), Computational Logistics: 10th International Conference, ICCL 2019, Barranquilla, Colombia, September 30 – October 2, 2019, Proceedings (pp. 122-135). Springer. https://doi.org/10.1007/978-3-030-31140-7_8

Estimating Discharge Time of Cargo Units

– A Case of Ro-Ro Shipping

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Abstract. Ro-Ro shipping is a dominant form of short sea freight transport. Ro-Ro ship operators are today unable to provide customers with precise information about when trailers are available for pick-up by customers on the terminal despite vessel arrival times being well known in due time. This results in reduced truck utilization, longer waiting time for drivers, less efficient yard space utilization, potential terminal congestion and dissatisfied customers. In this paper the cargo unit discharge time estimation problem of Ro-Ro shipping is solved in collaboration with a European short-sea Ro-Ro shipping company. A module-based framework using statistical analysis for estimating the discharge time is proposed and tested. The initial framework is able to estimate the earliest pick-up time of each individual truck or trailer within 1 hour accuracy for up to 70% of all cargo. The results of the study show potential for improving performance and accuracy. Further investigation and testing is currently ongoing by the case company based on the results from this study.

Keywords: Cargo Discharge Time Estimation, Short Sea Shipping, Terminal Operations, Integrated Logistics Chain, Industry Implementation.

1 Introduction

Roll-on/ Roll-off (Ro-Ro) shipping is a large part of the maritime freight transport of coastal communities and also deep sea due to the versatility of most Ro-Ro vessels. For over 1.8 billion tonnes of goods transported through short-sea shipping (SSS) in European Union in 2017, Ro-Ro units accounted for 13.6% with only 1% less than cargo transported through containers [1]. In Europe the Ro-Ro shipping is very dominant, due to the extensive coastal line compared to the landmass of Northern, Western and Southern Europe. The fact that this landmass consists of a large amount of peninsulas makes the short-sea Ro-Ro shipping an attractive alternative to land based and container transport and in some cases such as the British Isles there does not exist a land based alternative. Ro-Ro vessels consist of two major types: deep-sea going Ro-Ro vessels which are commonly car carriers traveling across continents, and short-sea Ro-Ro vessels that transport mostly trailers and heterogeneous cargo sometimes with a mixture of passengers as well. The short-sea vessels are in Europe strongly present between countries separated by sea but located closer to each other such as the North Sea, Baltic Sea and Mediterranean areas. Ro-Ro SSS like short-sea container transport generally operates with fixed schedules servicing often just two ports although in occasions the routes can include from 3 to 10 port calls in a round trip even though longer routes are more common in short-sea container transport. Although Ro-Ro vessels have a much smaller capacity than container vessels the Ro-Ro vessels have the advantage of a larger choice of ports due to container vessels crane requirement.

The main competitors for Ro-Ro vessels are road transportation and short-sea container shipping and it is important to remain competitive which implies offering client a short transit time and reliable schedules. However speeding up the vessels increases the bunker consumption significantly. Increasing the bunker consumption is both costly and also not applicable with the International Maritime Organization (IMO) announced goals for reducing CO_2 emission in maritime transportation with 50% by 2050.

The European Commission has set ambitions for enhancing the further development of SSS through three actions, one of which is improved integration of SSS in full logistics chains [2]. The integration includes among others the loading and discharge of Ro-Ro vessels. These processes can take up to long hours depending on the vessel size thus leaving a large time interval for the first trailer available for pick-up to the last one available at a given destination port. Lack of information can result in customers' trucks waiting around at the terminal for hours for a trailer or terminal congestion caused by trailers taking up the limited terminal space longer than actually required.

2 Background

Today the information about trailers availability for pick-up at the yard is often released after the discharge of all the cargo from the Ro-Ro vessel. In order to increase customer satisfaction without increasing operational costs, one option is to provide customers with the planned discharge time for their trailers or general cargo so that they can avoid waiting for the discharge of all the cargo before retrieving it. Being able to provide customers with information about availability of individual trailers for pick up at yard in due time, e.g. several hours before vessel ETA, can enable customers to increase the utilization of their logistics assets and resources. Moreover it can reduce the congestion at the gate and the surrounding road network as all customers are not arriving to the terminal to pick up their trailers at the same time. Meanwhile, reduced 'turnaround' time of trailers in the terminal means a better utilization of the yard with more throughput. However despite extensive effort spent on stowage planning and execution Ro-Ro shipping companies are today unable to produce and deliver this information to their clients.

Researchers have previously investigated the challenge of terminal congestion in relation to truck arrival, however most of the research so far has been focused on the segment of container shipping rather than the Ro-Ro sector. Moreover the focus of the research has been on investigating problems of terminal congestion due the unpredictable arrival time of trucks for pickup of import cargo, which impacts resource allocation at terminals and implies inefficiencies for ports and haulage companies. For container terminals, research on improving efficiency of landside drayage operations has proposed implementing Truck Appointment System (TAS), gate extended hours and pricing policies to control truck arrival rates to handle these challenges [3]. For example the impact of TAS on truck-related port emissions, turn-around time, congestion and air pollution has been studied extensively [4, 5]. Furthermore, there are some studies investigating the use of optimization methods to support TAS [6–8]. For example Phan and Kim have proposed a solution for negotiations of truck arrival time among trucking companies and terminal [9]. Reinhardt et al. applied several optimization techniques to solving the bottleneck of the inland transport of containers connecting customers and terminals for more efficient liner shipping operations [10, 11].

If we zoom out and consider the overall flow of logistics operations at terminals, it is interesting to observe that most research is focusing on TAS and truck arrivals. Thus investigating options for predicting discharge time of individual cargo units (containers) at terminals as a way forward attempting to improve terminal operations and customers' processes has been overlooked. In a situation where a ship operator or terminal is able to predict the available pick-up time of the individual cargo units, a TAS with better accuracy and reliability could be developed which would result in reduced terminal congestion. For container shipping, the challenge of predicting cargo availability for pickup might be difficult to embrace due to variability of stowage situations from ship to ship, however for Ro-Ro shipping this issue might be more addressable as loading and discharge procedures across decks, lane sections etc. can be assumed more regular and stable across voyages. In general, but in particular from the perspective of Ro-Ro shipping we consider estimating the discharge time of cargo units as an overlooked topic when solving terminal congestion problems and logistics efficiency problems. Quality estimation will enable TAS and truck arrival management systems to perform much better. It is also an issue so far not studied for Ro-Ro terminals, where we mainly identified a few studies focused on simulation and decision support for terminal capacity planning and operational execution [12–17].

In this paper we have in collaboration with a European short-sea Ro-Ro shipping company identified the discharge time estimation problem for Ro-Ro shipping, developed a module-based framework for estimating the time available for customers' pick-up of individual trailers. We have completed a subsequent evaluation of accuracy of the methods on data collected from actual discharge cases, and compared the results with different time windows.

The remaining of this paper continues with defining the discharge time problem for Ro-Ro vessels in section 3, followed by a description of the framework structure in section 4. In section 5, we present a case study on its application and discuss the results. Finally, we conclude the paper and point out directions for future research.

3 Problem Description

The Ro-Ro cargo unit discharge time problem is a challenge involving various stakeholders of the cargo logistics chain, as shown in **Fig. 1**. A cargo unit can be either unaccompanied or accompanied depending on if there is a truck and driver travelling with the cargo. Unaccompanied cargo requires tugs in order to be placed on/off board. All cargo are loaded under the instruction of a dispatcher (or foreman), who manually creates an overall stowage plan and controls cargo flows in an import/export terminal. When a vessel arrives at a terminal, a local dispatcher plans the discharge of the vessel for both types of cargo. Once all cargo is discharged from the vessel and onto the terminal, import customers are able to pick up their unaccompanied cargo and complete the rest of the logistics chain. One of the pain points for both terminals and customers is that the import customers do not have information of the available pick-up time for their cargo in advance as this is assumed difficult to provide by the Ro-Ro vessel operators for multiple reasons.

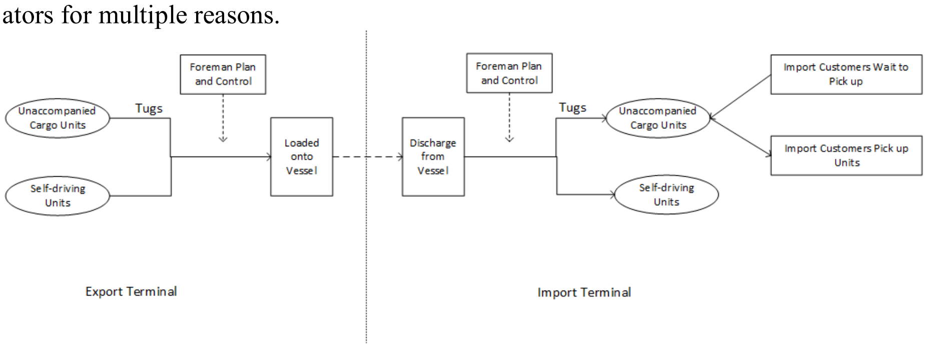

Fig. 1. Ro-Ro Cargo Logistics Chain at Terminal

First, different unit types require a different amount of time to be fastened to or be released from the vessel. For example, it’s faster to lock / unlock the trestles attached to standard trailers, whereas mafis and cassettes require longer time due to their special operational requirements (heavy weight, gooseneck, translifter, lashing etc.)

Besides this, general cargo, hazardous cargo, refrigerated cargo, livestock, bulk can also be transported. They have dedicated zones or warehouses where they are supposed to be discharged to inside the terminal. Refrigerated cargo must be plugged in, therefore the area where they are stored in the terminal is usually on the edge or furthest away. Same goes for bulk cargo, like steel and wood. Hence the cycle time is much longer for the above mentioned cargo, compared to standard trailers.

Where the unit is loaded onboard a vessel also influences the discharge time as a unit can be discharged only when all units which stand in front of it are discharged in order to make a path out. Moreover it requires more time for tugs to travel to the weather deck, which is the top deck of a vessel, than the time required to pick up a trailer on the main deck. Therefore, it is the relative position of a unit on a deck and the deck that determines the discharge time.

When a vessel arrives at a terminal, it also takes some time to set up the ramp and arrange tug masters before discharging the first unit. If the vessel is early or late according to the schedule, it will have an impact on the exact time when units is being discharged, and in the case where multiple vessels arrive in one time slot it will also have an impact on the schedule of the tug usage.

Tug availability is one of the most important factors determining the discharge speed of a vessel, hence, the discharge time. The more tug masters are assigned to the vessels, the faster the vessel gets discharged. However, depending on the day of the week and the number of vessels arriving, the tug availability fluctuates throughout the discharging process. Day of week is an external factor that has an impact on the number of tugs to be used. It indirectly influences the discharge speed by directly influencing the number of tugs scheduled for the discharge process. Weekends and weekdays with more vessels arrivals will have less tugs scheduled for each vessel's discharge, hence lowering down the speed. The tug availability is not a fixed number of workers as illness and other issues may affect the number of tugs available, thus making it difficult to model and plan.

Moreover, extreme weather requires extra lashing of the units for safety reasons during sailing. When it comes to the time of discharge, bad weather can slow down the tug masters' driving speed, and it requires extra time to release the lashing on the units before they can get discharged.

Having captured the influence of these factors or variables enables us to model the discharge time of each unit as a function of unit type or type group, cargo type, position, vessel arrival condition, tug availability, day of week, and weather condition.

$$\mathrm{EDT}_{unit} = F(t, c, p, v, n, d, w)$$

$\mathrm{EDT}_{unit} - discharge\ time\ per\ unit$

$t - unit\ type$

$c - carge\ type$

$p - position\ onboard$

$v - vessel\ arrival\ condition$

$n - tug\ availability$

$d - day\ of\ week$

$w - weather\ condition$

The factors influencing the discharge time of the unit are at the same time the challenges affecting the model of estimated discharge time (EDT). The challenges are of different risk types, as shown in the risk matrix in **Fig. 2**, depending on the availability of knowledge and the ease of control of the factors. As can be seen, the factors fall into two major quadrants by the time of vessel departure – known but uncontrollable; unknown but controllable.

Some information is known but uncontrollable, like day of week, cargo type, unit type, and weather condition. Regarding weather condition, one could argue that it is known through weather forecasts but it can also be considered slightly unknown due to inaccuracy or uncertainty of weather forecasts in general. It is for this study considered a piece of known information as operational efficiency is not sensitive to slight weather changes, and that weather forecast is sufficient to catch significant weather shifts. Whereas already by the time of loading, some of the factors are unknown, however still controllable which means that the information could be captured with certain degree of human intervention. This includes position on board, tug availability, and vessel arrival condition. These three factors have the highest influence on the discharge time of a unit. However the challenges in estimating the discharge time are, to the authors' knowledge, lack of traceability where the unit is loaded on board; shifting tug usage; and uncertain discharge sequence deck-wise but also position-wise within a deck. Furthermore, the challenges when implementing solutions to control these factors are the standardization of loading and discharge processes across routes and voyages with consideration of human participation and business complications stemmed from customer requirements.

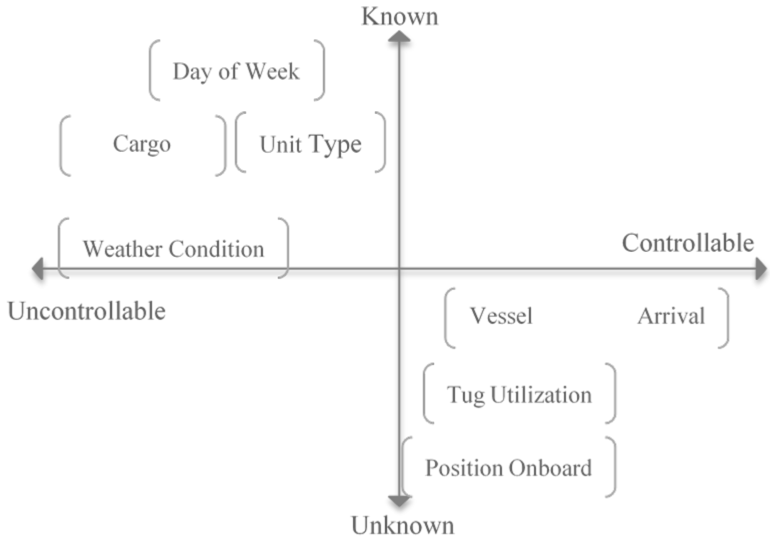

Fig. 2. Categorization of Potential Variables for Cargo Unit EDT

4 Framework

To estimate individual discharge times of the cargoes from the loading information, this paper propose a modular framework for the Ro-Ro cargo discharge time estimation problem (**Fig. 3**). The framework consists of basic statistical methods and logics combined in different modules to form the framework for delivering a good discharge time estimation. The framework consists of three modules:

Module 1. : The loading position is estimated from loading information such as loading timestamps, standardized loading sequence and its position (first in last out).

Module 2. : Estimates the discharge sequence from the estimated loading position provided by module 1 (furthest in last out).

Module 3. : Estimates the discharge time based on the discharge sequence generated in module 2 with certain discharge speed.

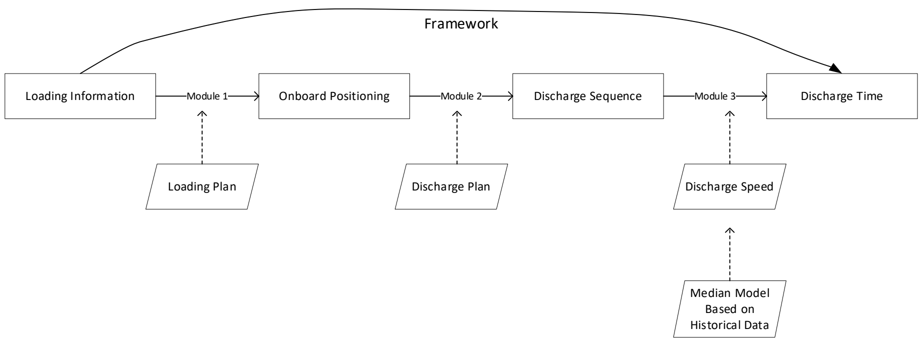

Fig. 3. The Modular Discharge Time Framework

The combination of three modules constitutes the Ro-Ro cargo discharge time estimation framework, and the overall accuracy depends on the performance of each module. Depending on what information is available in the operation, the discharge time estimation can be constructed with only one or two modules. For example, if the company makes a detailed stowage plan and executes accordingly, the first module will be omitted as real loading positions of cargoes will be available as input to module 2. In this paper, we are more interested in the cases where loading positions are not recorded when vessel departs and thus unknown, which is also close to situations experienced in real-life operations.

For the first two modules, a fixed loading and discharge plan is assumed, which means that the vessel loads and discharges in a specific sequence, however, a limited number of usually minor shifts in position in the plan is possible in reality. The third module estimates the discharge time based on the estimated discharge sequence and discharge speed which arose as a sub-problem.

4.1 Discharge Speed

As discussed in section 3, the discharge speed is influenced by various different factors. To find the discharge time in module 3 we have constructed a model which we call a situational median model to estimate discharge speed for different discharge situations. A situation is a combination of various factors that have a significant influence on the discharge speed, such as unit type, week day, tug availability and deck loaded. An example of a situation is illustrated in **Fig. 4**, and it is a situation where the discharge happens on a Wednesday, for trailers on the weather deck with four tugs working simultaneously.

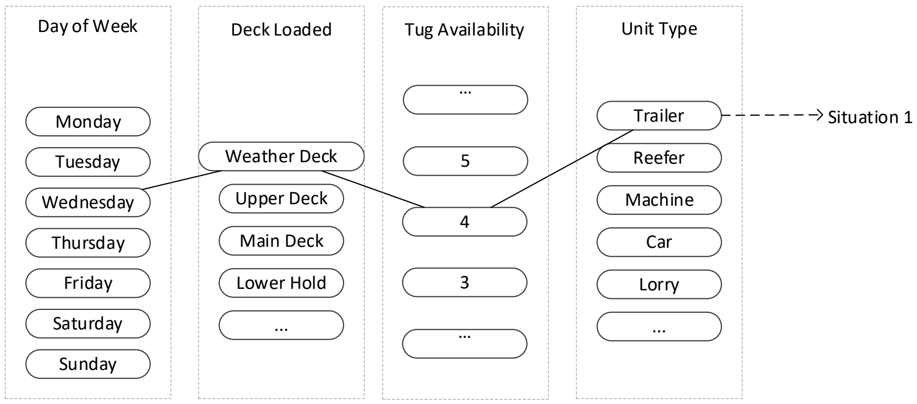

Fig. 4. Example of a Discharge Situation

Each situation is connected to a discharge speed based on historical data, assuming no significant changes of processes, equipment or systems in the relevant time horizon. Let S be the set of situations, and V be the set of discharge speed, where v_i in V is the discharge speed of situation i in S. The Binary variable x_{ni} equals to 1 if i is the situation of the n^{th} discharged unit, and 0 otherwise. Discharge time for one unit is defined as the time interval between the current discharging unit and the previously discharged unit. It is formulated as below:

$$\nabla^{i}_{EDT(n)} = DT^{i}_{n} - DT^{i'}_{n-1} \qquad \mathrm{i, i'} \in \mathrm{S} \ (1)$$

DT^{i}_{n} is the discharge timestamp of the n^{th} discharged unit, and $n-1$ is the previous unit in the discharge sequence. The situation i of ${\nabla^{i}}_{EDT(n)}$ is determined by the situation of the discharging unit n such as unit type, deck, weekday, and tug availability and is thus independent of the situation of unit $n-1$. This means that each discharge unit has its independent speed calculated from the situation i of the unit.

The situational median discharge speed equation is the median of discharge time intervals categorized by different situations from historical voyages. The discharge speed of situation i is irrelevant to the unit's discharge sequence n. Thus we can define the situational median speed v_i as:

$$v_i = median\left(\cup \nabla^{i}_{EDT}\right) \qquad i \in S \ (2)$$

The estimated discharge time of the n^{th} unit is the sum of the time needed to discharge individual unit from the first in the discharge sequence up until the n^{th}, based on the unit's situation. And it is formulated as:

$$EDT_n = \sum_{m=1}^{n} \sum_{i=1}^{|S|} v_i x_{mi} \qquad (3)$$

The framework is configured with more details from the industry case which is tested and evaluated with real data in the next section.

5 Case Study

5.1 Description of the Case Problem

The problem and the framework are further researched in a case study with a Ro-Ro shipping company that operates short-sea transportation in Europe. The chosen route of the study is a 15-hour voyage from Vlaardingen, the Netherlands to Immingham, England, with two identical vessels servicing a daily schedule.

A three-week data collection was conducted in collaboration with the company. Loading and discharging operations were instructed by foreman, based on the standardized sequence plans per deck. For module 1, an example of the loading sequence of main deck drawn by a foreman is given in **Fig. 5**. The first trailer loaded is estimated to be in position 1 and the last one loaded in position 63. If this were a discharge plan in module 2, position 63 would be estimated to be the first discharged and etc. Exact loading positions have been captured for framework validation. In addition, a nine-month historical data starting from January 2018 was retrieved from the company's database for the situational median discharge speed model. No significant changes in the process was made throughout the selected nine-month and three-week period.

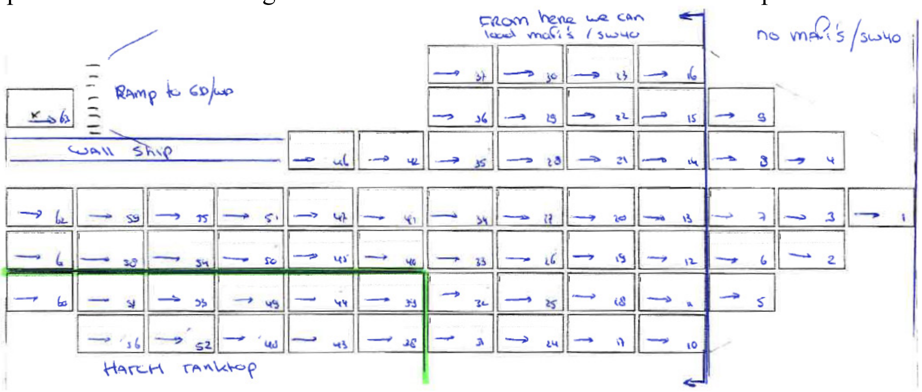

Fig. 5. Example of the loading plan of the main deck. Source: DFDS Vlaardingen

The majority of the data is automatically logged through booking and terminal management systems. For each unit, information on time of loading, time of discharging, deck loaded, unit type etc. is available. However due to changes in tug availability, it has been very difficult to determine the number of tugs available per deck at a certain time. Therefore, this information will not be considered and included in the framework for the present, and we assume the constant availability of tugs per deck every day. Unit type, as discussed above in the problem formulation, has an impact on the speed of discharge as well. However, based on analysis, the discharge process appears stable and units are evenly scattered over time, indicating that unit type is not a significant influencing factor, therefore it is not considered in this case. Lastly, vessel arrival conditions and weather are not included in the case study.

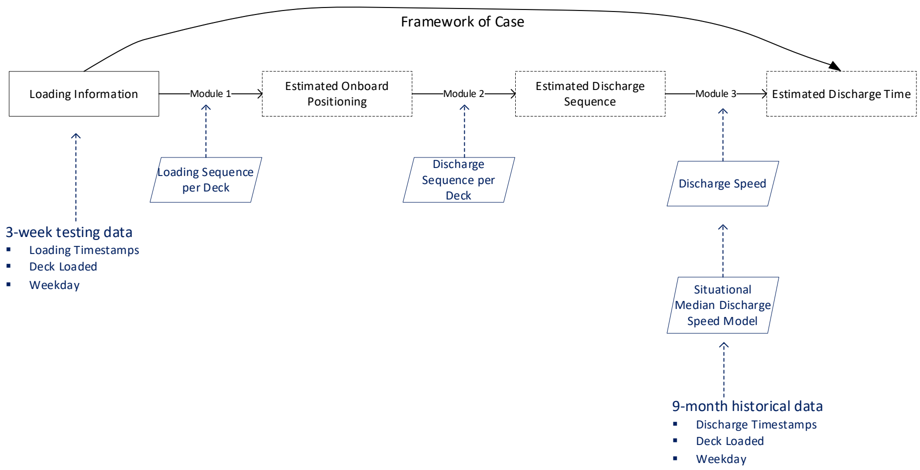

Fig. 6. Framework Configuration of Case Study

According to interviews with the company, foremen, managers among others, the study of the discharge speed is delimitated by the focus on loaded deck and day of week. This however also indicates the level of terminal activity and thus indirectly indicating the average number of tugs used. A diagram with data input and output for each module in the case study is illustrated in **Fig. 6**. Initial data input to the first module of the framework is the timestamp at which a unit was loaded onto the vessel and the deck the unit was loaded onto. Based on the actual sequence of loading the standardized loading sequence plan, the output of module 1 will be the estimated loaded position for each unit. In the second stage, the output of module 1 is fed into module 2 in order to estimate the discharge sequence based on the standardized discharge sequence plan. Lastly, the overall deliverable of the framework, which is the individual discharge time of a unit is estimated based on the discharge sequence and discharge speed, calculated as in equation (3).

5.2 Framework Evaluation

For a module-based framework, it is important to separate the individual module performance to understand the overall framework accuracy and to improve the performance if possible. Therefore it is important to look at individual module performance as well as combined performance. To achieve this, we have conducted three-week data collection where the company, terminal and crew were actively involved. Among other things, we have collected the onboard positioning of cargoes, actual discharge sequence and the actual discharge timestamp.

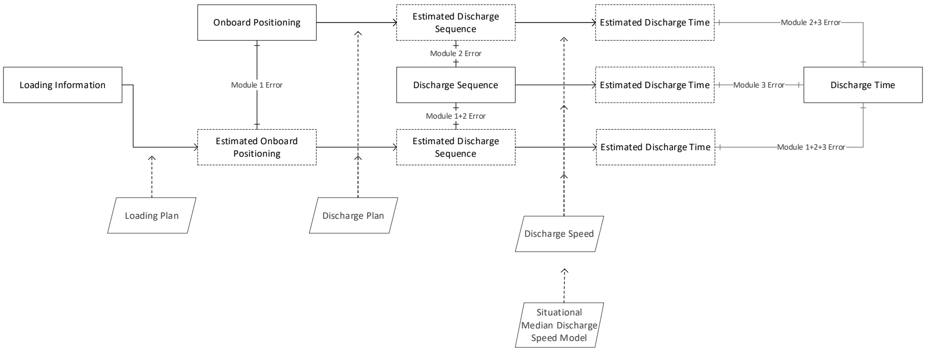

Fig. 7. Framework Evaluation Map

Individual module performance tells how well a module estimates given the input to the framework is real data instead of estimated. Illustrated in **Fig. 7**, the error of module 1 is the difference between estimated position and actual position; if the actual onboard positioning is known, the discharge sequence estimated from module 2 compared with actual discharge sequence is the individual performance of module 2, and the same logic applies to individual performance of module 3. Combined module performance is the result of a combination of two or more modules. A combined performance of all three modules makes the accuracy of the overall framework. By comparing combined performance to individual performance, we are able to tell how well modules can be integrated into one framework and what the accuracy loss is by predicting in a modular way. It also makes it possible for the company to see where with actual data would improve the discharge time estimations most.

5.3 Computational Results

The discharge speed was calculated in MySQL and fed into the overall framework, which was coded in excel. **Table 1** presents the results for individual modules, combined modules and the overall framework, with a 15-minute, 30-minute and 60-minute time window.

As mentioned in the previous section, individual performance for module 1 represents how well the module estimates loading positions from loading timestamps of units; for module 2 and 3, it is based on actual unit position on board and actual unit discharge sequence respectively. Actual data was gathered during the three-week data collection. Because of the nature of the data input and output in module 1 and 2, the errors are measured by the differences in the sequences. In order for the results to be comparable, we converted it into to a time estimate in minutes by multiplying errors in position by discharge speed. Combined performance of module 1 and 2 presents an integrated result when the input of module 2 is not actual data but predicted data from the output of module 1.

Table 1. Results of Framework Performance Evaluation

	% units <15min late			%units <30min late			% units <60min late		
	Individual Performance	Module 1+2	Overall Performance	Individual Performance	Module 1+2	Overall Performance	Individual Performance	Module 1+2	Overall Performance
Module 1	93.0%	90.3%	32.5%	95.0%	94.8%	43.2%	96.8%	98.3%	65.8%
Module 2	91.8%			95.0%			98.8%		
Module 3	32.4%	-		45.1%	-		67.2%	-	

Table 1 shows the computational results of each individual module of the framework and two different combinations of the modules. The overall result appears an undesirable accuracy of 32.5% with a 15-minute window late, 43.2% and 65.8% for 30-minute and 60-minute time window late respectively. When we compare the combined and overall results of modules to individual module performance, the difference in accuracy is relatively small. This means that the three modules they have little influence among each other and proves the robustness of the modular EDT framework.

From loading information to loading sequence (module 1), and from loading sequence to discharge sequence (module 2), we could predict the loading and discharge sequence with an accuracy of more than 90%. Furthermore, the combined result of module 1 and 2 does not show a significant drop in the accuracy. The robustness of the modules relies on the standardization of the loading and discharge procedures. From experience and practices, there already exist patterns of loading and discharge Ro-Ro vessels. Standardization of patterns is a challenge however, as the result shows, it is not impossible to overcome and acquire robust outcome out of it.

Module 3 has the lowest the accuracy – 32.4%, 45.1% and 67.2% predicted within 15, 30 and 60 minutes late respectively. This is the bottleneck of the framework since the overall accuracy follows closely the accuracy of module 3 with little difference. However this result is expected without pulling in tug availability and other factors discussed in section 3.

From a business perspective, almost 70% of the units can be estimated its discharge time with an hour time window. This means 70% of the customers get correct available pick-up time for their trailers, instead of hours after the ship's arrival and they can therefore avoid traffic jams around the terminal and time waste in general.

6 Concluding Remarks

This paper describes a currently unsolved problem for the Ro-Ro shipping industry – the estimation of discharge time for individual cargo units before vessel arrival - and proposes a data-driven module based approach for the problem. The motivation behind predicting cargo unit discharge times was that it enable ship and terminal operators to deliver a more efficient cargo supply chain for customers, a better utilization of the Ro-Ro terminal as well as a better service product from the shipping company.

The main idea of the proposed solution method is to approach the discharge time from loading information step by step, on a modular basis. With the input of instructed loading sequence plan, by ranking the timestamps when units are loaded, their positions on board are estimated. Based on the discharge sequence plan and position on board, a discharge sequence of all units is estimated. Then the discharge time of the individual unit can be estimated by incorporating the discharge speed, which was solved as a sub-problem where we introduced a situational median approach to find the discharge speed suitable for each unit.

The weak part of the framework is module 3, which was expected due to framework simplifications and limited data availability for tug usage, unit types, vessel arrival conditions and weather for the case study. Nevertheless, the overall results achieved with data obtained from real Ro-Ro cargo operations seem to verify the relevance and robustness of a modular and quantitative based approach. Compared to individual performance, combined and overall performance of modules deteriorate only to a trivial degree. The framework is widely applicable and customizable to different routes, ships and companies by tuning individual modules and adjusting the set of situations based on various influencing factors in Ro-Ro shipping. As for container terminals, it provides the framework and inspiration to potential research on discharge time of containers as input to TAS.

Further work could be focused on improving current solutions to calculating discharge speed or modelling discharge time against discharge sequence to improve the accuracy in module 3. Machine learning could also be an interesting investigation compared to the modular framework method, provided sufficient historical data. Another focus could be the problems related to cargo operations, for example, Ro-Ro stowage automation and optimization problems to be incorporated in module 1; dual cycling of loading and discharge operations, tugs planning and scheduling, and etc. which have a significant impact on discharge speed.

Acknowledgements

We would like to thank our industrial partner DFDS for its openness on problems and data sharing, and all the help and support from DFDS in Copenhagen, Vlaardingen and Immingham. The research is funded by EU Baltic Sea Interreg project – ECOPRODIGI, aiming at improving eco-efficiency in shipping industry processes through digitalization.

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