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Optimization of barge handling with priority service in the Port of Rotterdam

by

Christodoulou Ioanna

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Abstract

Liner shipping accounts for 60 percent of the value of the goods transported by sea. The emergence of intermodal transportation has increased the importance of inland waterways and the use of barges. However, the increase of global trade throughput has created serious challenges for the barge transportation. Economies of scale, communication problems and the lack of contractual relationships contribute to an ever-increasing congestion problem in the major container terminals and especially in the port of Rotterdam. The increase of the minimum call size of the barges consists one of the proposed solutions while vessels are treated with different priority according to their cargo and size. Given the effort of all actors of the chain to increase the effectiveness in the terminals, this study examines the following research question: To what extend can the optimal handling of the barges in the port of Rotterdam be achieved by increasing their minimum call size while taking into account the priority service given to each type of vessel? To do so, after collecting real-time data from a terminal in the port, a discrete event simulation model in a programming environment is used to analyze several approaches which are based on the effect of an increasing call size of the barges given the priority service scheduling that the vessels have. The results indicate that increasing the minimum call size has a positive effect on the waiting times of the vessels in total, especially in barge transportation in all priority service approaches envisaged. An increasing call size may have negative effects as well, but the actors can work together to offset them partially or totally. Thus, this study provides a framework to identify how the increasing call size can indeed benefit the handling of the barges and eventually increase the efficiency of the container terminals in terms of waiting lines.

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List of Abbreviations

DES	Discrete event simulations
Deep-sea	Deep-sea vessels
MWT	Mean waiting time
HRS	Hours
NoPrio47	Approach 1: No priority using 47 moves
Prio47	Approach 2: Non preemptive priority scheduling using 47 moves
PreemptPrio47	Approach 3: Preemptive priority scheduling using 47 moves
Incr.CallSize58	Approach 4: Increasing the call size of barges to 58 moves with preemptive priority scheduling
Incr.CallSize69	Approach 4: Increasing the call size of barges to 69 moves with preemptive priority scheduling
LessBerth47	Approach 5: Decreasing the number of berths by one and preemptive priority scheduling with 47 moves
LessBerth58	Approach 5: Decreasing the number of berths by one and preemptive priority scheduling with an increasing call size for barges at 58 moves
LessBerth69	Approach 5: Decreasing the number of berths by one and preemptive priority scheduling with an increasing call size for barges at 69 moves
Cutoff	Approach 6: Increasing the call size of barges by cutting off low values of their handling time

Chapter 1: Introduction

1.1: Background information and problem description

Container liner shipping gains its importance from the fact that it is the conduit of world trade and it consists an efficient mode of transport. Liner shipping carries around 60 percent of the value of the goods which are transported by sea (Worldshipping, 2020).

Hinterland transportation contributes to the accessibility of a port for product exchange and determines its performance especially for containers. With the emergence of intermodal transportation, the importance of inland waterways has become apparent. Barges are commonly used in inland waterways and consist the most important mode of transportation given its ability to be safer, more environmentally friendly, and able to reduce congestion.

According to (UNCTAD, 2019), in 2018, there was an increase of 4.7 percent in global container port throughput which enabled an increase of 35.3 million TEUs over 2017. Asia has a central role in the growth that container liner shipping is experiencing today, while at the same time, container cargo handling tends to concentrate to specific ports mainly located in Asia with Rotterdam, Antwerp and Hamburg being some of the exceptions.

This increasing volume in trade, has caused congestion problems in many ports and serious challenges for barge transportation. The time factor has a central role in liner shipping and the operators demand high levels of effectiveness on their service. To keep carriers satisfied, container terminal operations need to constantly improve in order to cope with the changes. The need to be operating effective, led to the emergence of ever larger containerships. Pressure is being put to container terminals due to the larger size of vessels with fewer calls that cause longer times at the port. The benefits of the economies of scale are widely known since as the capacity of the vessel increases, the costs per TEU decrease. Nonetheless, this phenomenon can cause diseconomies of scale in various aspects such as the fact that more containers are forced to be shipped over a shorter period of time in order to maintain the port schedule.

Communication is an essential element in barge transportation. The high level of barge congestion in the ports has caused inefficiencies in the handling times therefore affecting the reliability and the waiting time of the vessels. This problem has caused wide uncertainty over the ports and the actors have tried to find solutions to cope with it. For this matter, finding an optimal way to handle the barges to reduce waiting times has become a necessity. One of the measures that ports have taken to ensure efficiency in barge transport is to increase the call size of the barges in an effort to reduce the number of calls in the port. Moreover, depending on the cargo and the size of the vessels, the waiting time may be more expensive for deep-sea vessels than that of the barges. This issue brings to the surface the importance of the priority that is given to the service of each type of vessel. Thus, the question is: To what extend can the optimal handling of the barges in the port of Rotterdam be achieved by increasing their minimum call size while taking into account the priority service given to each type of vessel?

1.2: Purpose of the research

This research comes up with the idea to model the way barge handling can be optimized so as to reduce the waiting times and eliminate the congestion problem that exists with specific attention to the port of Rotterdam. Given the location of Rotterdam and the size of vessels that need to be served but also the connections that the port provides, its competitive position is obvious. However, port of Rotterdam is experiencing serious problems regarding congestion especially with congestion in container barges being an increasing problem the past few years (Rotterdam, 2020). Increasing transshipment volumes due to the hub position of Rotterdam in North Europe together with pressures on terminal capacity further highlight the problems that the port is facing. To enable growth in transportation new options about barge and vessel operations are needed. Many ports like Antwerp and Rotterdam have introduced the so-called minimum call size as a potential solution to the problem while the priority service of each vessel should also be considered as it differs according to the size of the vessel. In this respect, investigating how an increasing call size can optimize the barge handling in the port Rotterdam given the priority of each vessel, gives us some valuable insights.

1.3: Research questions

Based on the problem description and purpose of research we are able to develop the following main research question:

Main research question: To what extend can the optimal handling of the barges in the port of Rotterdam be achieved by increasing their minimum call size while taking into account the priority service given to each type of vessel?

In order to adequately address the above research question, the following sub-research questions are needed:

Sub-research questions:

1. Which are the root causes and solutions of barge congestion?
2. What is the current situation in container terminals in the port of Rotterdam?
3. What is the effect of a minimum call size?
4. Which model can be used to analyze the way that the handling of barges can be optimized in the port of Rotterdam?
5. What approaches can we envisage regarding the priority service and minimum call size of the barges?
6. Which proposed approach best solves the congestion problem?

1.4: Relevance of the research

We will investigate the way the barges can be handled in a way that optimizes the waiting times by increasing their minimum call size and differentiating the priority in service. Most of the barge handling literature focuses on analyzing the reasons behind this problem and finding empirical solutions to it. Other papers have also tried to better capture the reality through quantitative approaches. These studies focus on finding the optimal solution for barge congestion without giving much attention to the priority that barges have in contrast to the deep-sea vessels or the effect of an increasing call size. In that sense, this research tries to fill this research gap for the case of port of Rotterdam by treating barges with different approaches regarding their priority service and call size. We will assess these approaches using a discrete event simulation method in a programming environment to better capture the reality. The study aims to provide knowledge and insights to all actors of the port of Rotterdam that can be used to mitigate the issue that has emerged.

1.5: Structure

The research paper is structured as follows. Chapter 2 reviews relevant literature related to barge handling and the congestion problem and can be considered as an introduction to the problem statement. Sub-research questions 1-3 are answered in this chapter. Chapter 3 presents the methodological approach that will be used in the research and the appropriate programming language chosen and responds to sub-research question 4 and 5. Chapter 4 provides the necessary data required for the research. Chapter 5 analyses the results of the study and compares the approaches envisaged ending up in providing an answer for sub-research question 6. Chapter 6 provides a discussion about the limitations of the research and the generality of the results while Chapter 7 summarizes the main findings of this study and highlights areas for further research.

Chapter 2: Literature Review

The increase in international trade along with the port competition has increased the importance of hinterland infrastructure. Efficient transportation and availability of services is nowadays crucial especially for rail and barge transport which are considered the more sustainable modes. Nonetheless, container barging is battling with inefficiencies that hinder its potential to grow as a mode. What are the causes of this inefficiency? How can we improve the current situation? What is the impact for the largest container port in Europe?

This chapter ponders these issues by reviewing related literature regarding barge handling. First of all, this chapter highlights the modal split of inland, sea and air freight transport (Section 2.1.). After that, the different types of freight transportation are discussed in order to show the evolution that has been done (Section 2.2). Interdependencies in the transportation chain hide serious performance problems. Section 2.3 provides the causes of performance and congestion problems in container barging, namely coordination issues, absence of contractual relationships and economies of scale. The research is then focused on the container transport by barge in the port of Rotterdam given that it is the largest container port in the northwest Europe (Section 2.4). Last but not least, potential solutions to the congestion problem of barges is discussed (Section 2.5). In that way, we are able to answer the first three of our sub-research questions.

2.1 Inter and Multimodal freight transportation

Among road, rail and inland waterway transport, road provides less efficiency when it comes to energy and emission production. The environmental and social impacts of road transport such as pollution and accident rate are then obviously higher compared to rail or inland waterways. Given the huge rise in the road transportation and the percentage share that it has in freight transport, some progress is needed to shift cargo from road to other, more sustainable modes. With the proper policies, less environmentally polluting and more efficient modes can be encouraged to be used in order to mitigate the impact. The necessity of the modal shift can also be understood given the IMO 2050 mandate of reducing the greenhouse gas emissions by at least 50%. The evolution of different types of transportation that exist includes unimodal, intermodal, multimodal and synchro modal transportation which have all given rise to the use of rail and inland waterways.

2.1.1 Unimodal transportation

Unimodal transportation concerns the transportation which is done only with a single mode of transport such as road, rail, inland waterways, sea and air (Asean, 2014). The sea transport is being done either directly between ports or with transshipment. Unimodal transportation is ideal for shipping goods in short distances and it consists the least expensive option when the point of origin and destination can be reached through land (Spolaor and Spolaor, 2020). The main mode used in this category is road, mainly due to the efficiency that it provides. Therefore, the greenhouse emissions associated with this kind of transportation is relatively high while at the same time, for shipments that require long distances, the time needed is increased (Spolaor and Spolaor, 2020). Another possible drawback is the lack of physical linkage between the point of origin and destination since the road cannot be used in this case. Figure 1 provides an overview of the flows between hinterlands parties in unimodal transportation.

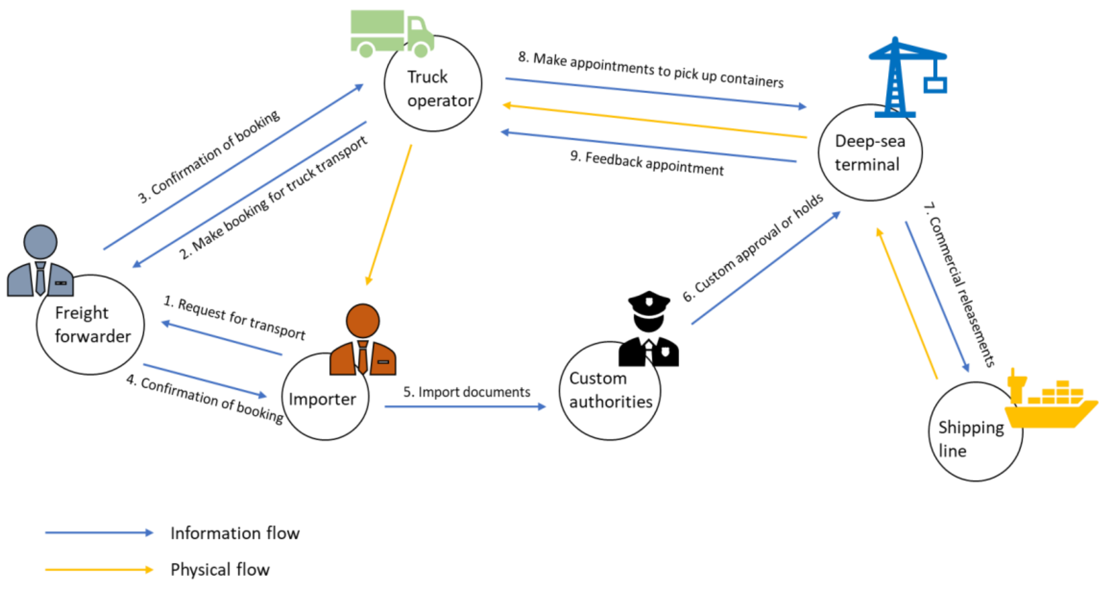


Figure 1: Flows between hinterland parties- Unimodal transportation, Source: Author's creation based on (Menger, 2016)

Overall, unimodal transportation does not consist the most efficient possible way of transporting products especially when the delivery does not only include port to port or terminal to terminal routes. Two or more types of transport can be combined in order to increase the quality of transport. This kind of transportation can be distinguished between intermodal and multimodal.

2.1.2 Intermodal transportation

Intermodal freight transport is a vital way of transporting goods especially for longer distances. It is one of the transportation types that enables the transport of goods between the shipper and the consignee by using at least two modes of transport (road, rail, inland waterways, shortsea shipping) without the need to reload the goods when changing the mode. The goods are being moved in the same load unit. This kind of transportation gives the opportunity to consolidate loads of goods before they reach their final destination. In this case, each segment needs to be considered as separate, having its own contract and carrier (Spolaor and Spolaor, 2020). Thus, on the one hand more logistic efforts and coordination is needed but on the other hand, negotiations can be made between the sender and each provider.

Intermodal freight terminals are composed of three stages namely the main haulage performed either by inland waterways or rail, the terminal handling (transshipment) and the pre and end haulage performed by trucks (Wiegmans and Konings, 2015). Since other modes besides road are also used, the environmental and social impact is reduced, therefore consisting a more sustainable way of transportation. The main motive behind the use of such a transportation is the cost performance that it offers in contrast to purely road transport. Moreover, due to the separate agreements that exist, it is easy for the delivery to be stopped at any point if needed.

Intermodal transportation allows barges and railways to penetrate the market and increase the reliability of the services which is extremely valuable given the high levels of congestion in road transport. Furthermore, when it comes to inland waterways, economies of scale are easier to be achieved than in railways, giving inland waterways the advantage of being more cost effective to road transport (Wiegmans and Konings, 2015).

For intermodality to work, cooperation plays a vital role in performing the tasks according to the schedule. Transport agents need to cooperate with each other to improve the relations and the operations between them. Intramodality highly depends on the proper division and synchronization of tasks. At the same time, the existing competition between transport agents in the market, makes them not willing to improve their cooperation. During the past 15 years, a lot of attention has been given to intermodal transport and the processes that it involves. Figure 2 provides an overview of the flows between hinterlands parties in intermodal transportation.

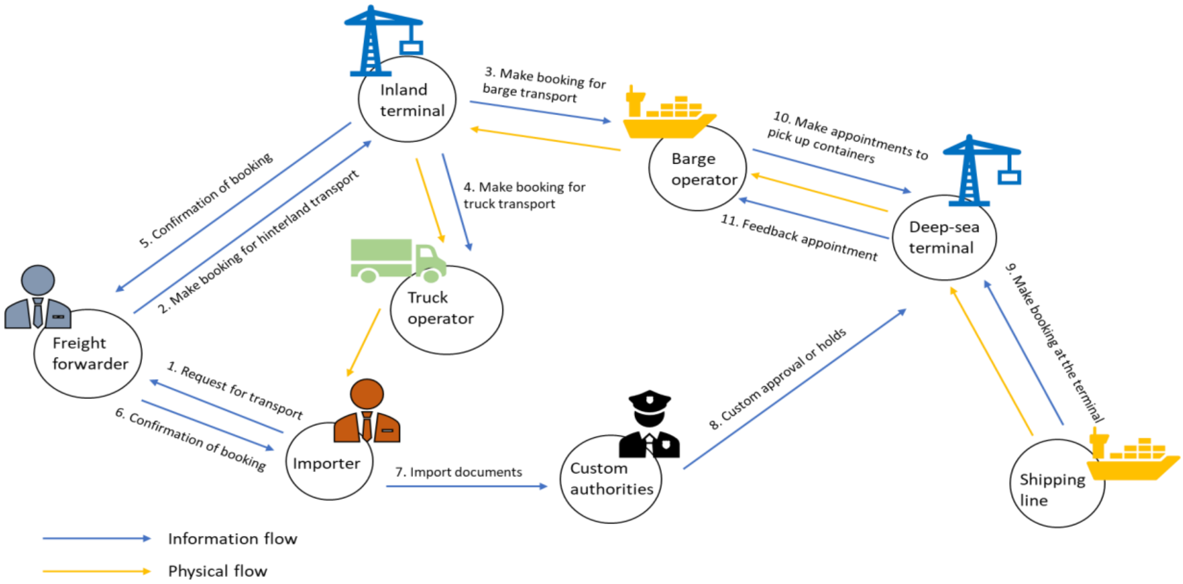


Figure 2: Flows between hinterlands parties-Intermodal transportation, Source: Author's creation based on (Menger, 2016)

2.1.3 Multimodal transportation

Multimodal transportation is the second type of transport that enables the delivery of goods from the shipper to the consignee by using at least two modes of transport (road, rail, inland waterways, shortsea shipping). The difference with intermodality is the fact that companies who choose this type, are required to have a single contract with only one provider (Spolaor and Spolaor, 2020). The provider is then responsible for every part of the shipment including any problems such as delays or tracking even if sub-carriers exist (Spolaor and Spolaor, 2020). The need for coordination is minimized in this case since a single provider has to deal with the entire transport. Furthermore, the logistic effort needed by the sender is less while the combination of modes makes once again the delivery faster and with less environmental and social impact. On the contrary, negotiations are not possible with multimodal transportation and there is always the risk of not finding the appropriate sub-carrier when needed.

2.1.4 Synchromodal transportation

Synchromodality is the supply of efficient and sustainable services which is feasible via the constant coordination of every operation among one or more supply chains (Giusti, Manerba , Bruno , Tadei, 2019). This cooperation can be done with the use of communication and intelligent transportation system technologies. Synchromodal transportation can be considered as an evolution of the transportation paradigms mentioned above and is a logistic concept that emerged the last decade. This kind of logistics is able to provide more integrated modes of transport with the goal of enabling an optimized resource utilization with minimum environmental impact. It considers the interests of every actor in the chain and not only a specific shipment as in intermodality.

Real time information, cooperation, flexibility and synchronization are vital elements for this kind of transportation (Giusti, Manerba , Bruno , Tadei, 2019). Real time information enables stakeholders to have a clear view of the impact of their actions and react quickly when unexpected events occur. Flexibility refers to the customers who are letting the logistic providers to optimize the operations based on the circumstances. This means that the mode of transport and the route is not predefined but instead, the providers are able to switch modes in order to be more efficient and eliminate disruptions. The importance of cooperation can be understood given its significance in building the network. While intermodality only requires vertical integration, synchromodality also depends on horizontal integration. Therefore, coordination is necessary, and it is also depended on the sharing of information among the actors of the chain. In that way synchronization is achieved in order to optimize the use of the resources.

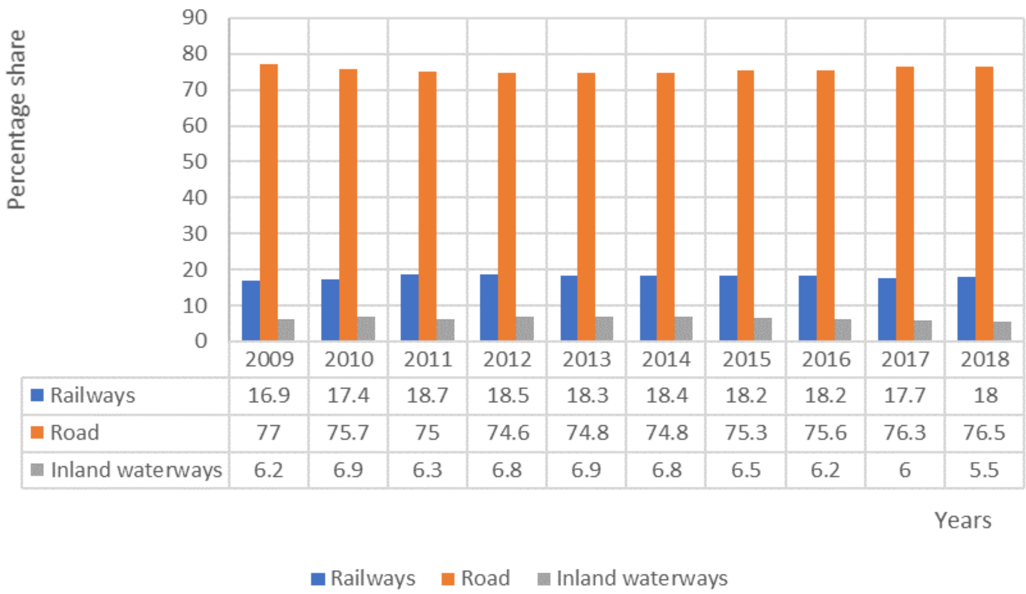
Synchromodality is the optimum way of transporting goods by being able to reroute, reschedule and switch modes of transport when needed. Obviously, managing this kind of logistics transportation requires all actors to be actively engaged in sharing information and cooperating with one another. With these elements, logistics can be improved and synchromodality can be characterized as the transportation of the future.

2.2 Modal split of the EU

2.2.1 Modal Split of inland freight transport

The modal split of freight transport is an indicator which is consisted of the percentage share of each mode in the total inland transport. This indicator is measured in tonne-kilometres. When we refer to inland freight transport, this includes road, rail and inland waterways. The reason why there is no focus on sea and air transport is because of the absence of conceptual coherence between these kinds of transport and inland modes also given the international nature of sea and air transport.

Figure 3 below shows the modal split of freight transport for EU28 between 2009-2018. Road transport seems to have the biggest share of EU28 freight transport between road, rail and inland transport. There is a steady increase of the percentage share of road transport from 2012-2018, with 2018 reaching a percentage of 76.5. Transport through railways has the second highest share in the modal split which was also relatively steady between 2011-2016 at around 18.4%. In 2017, there was a slight decrease which was then again increased in 2018. Inland transport has the lowest share over the years with the percentage ranging from 6.9 (2013) to 5.5 (2018).



	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Railways	16.9	17.4	18.7	18.5	18.3	18.4	18.2	18.2	17.7	18
Road	77	75.7	75	74.6	74.8	74.8	75.3	75.6	76.3	76.5
Inland waterways	6.2	6.9	6.3	6.8	6.9	6.8	6.5	6.2	6	5.5

Figure 3: Modal split of freight transport for EU28, 2009-2018, Author's creation based on (Modal split of freight transport – Eurostat, 2020)

It should be noted that the data regarding railways and inland waterways are given based on transport in the national territory with no restriction on the nationality of the haulier whereas for road transport the data are given based on the nationality of the haulier with no restriction on the territory.

2.2.2 Modal split including sea and air transport

Figure 4 below shows the modal split including sea and air transport for EU27 between 2013 to 2018. We can see that even when adding the additional transport modes, road transport is still in the first position, followed by sea transport. Again, the modal split is measured in percentage share in tonne-kilometres. In the most recent findings, road transport accounts for 52.4% with maritime transport having a share of 30%, being in the second position. Inland waterways accounted for 4.1%. Air transport has the lowest position with only 0.4%. We can also observe that the shares of sea, rail and road transport increased during this period whereas inland waterways were decreased, and air transport remained unchanged.

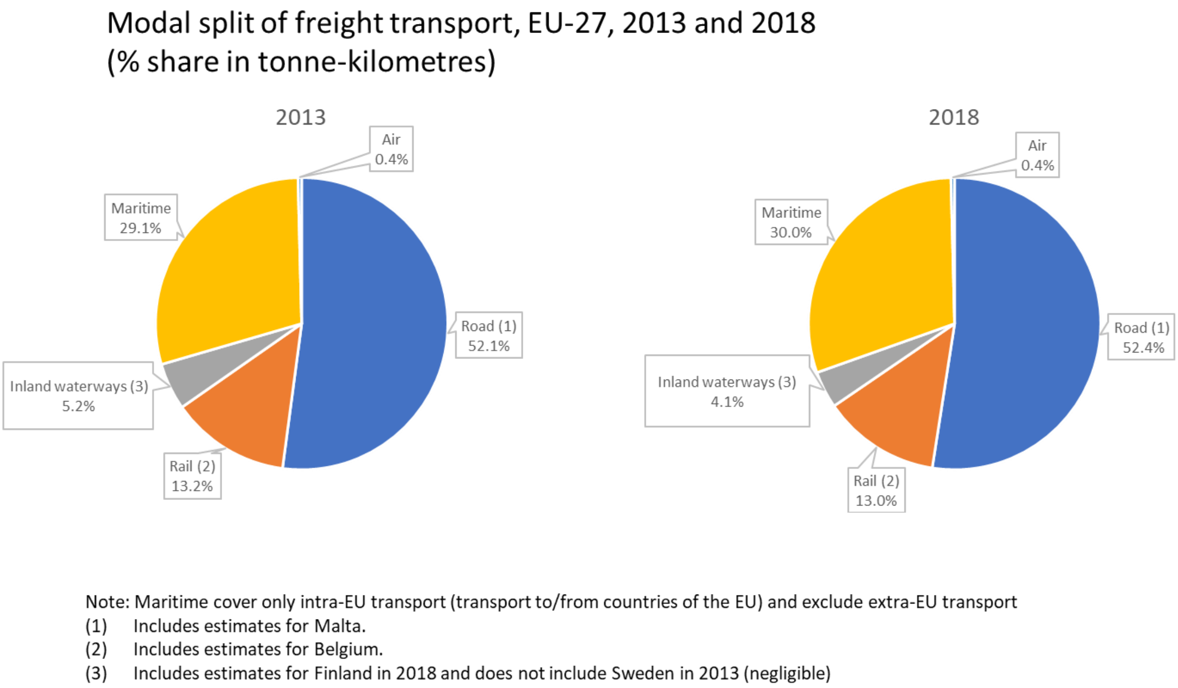


Figure 4: Modal split of freight transport, 2013-2018, Source: Author's creation based on (Eurostat, 2020a)

2.2.3 Modal split of the Netherlands

If we take a closer look into the modal split evolution for the Netherlands, we can observe that it is the country with the highest share in inland waterways, consisting almost half its total freight transport. Figure 5 shows the comparison of the EU countries per mode of transport for the period 2013-2018 while Figure 6 focuses on the modal split of the Netherlands during the period 2009-2018.

TIME	2013			2014			2015			2016			2017			2018		
GEO (Labels)	Roads	Railways	Inland waterways	Roads	Railways	Inland waterways	Roads	Railways	Inland waterways	Roads	Railways	Inland waterways	Roads	Railways	Inland waterways	Roads	Railways	Inland waterways
Belgium	73.1	11	15.9	73	11	15.9	73.6	11	15.2	74.3	11	14.7	73.6	11	15.7	72.1	11.7	16.1
Bulgaria	56	17	27.5	54.9	18	26.9	54.7	18	27.4	55.6	17	27.3	56.6	19	24.8	56.2	19.3	24.5
Czechia	71.7	28	0.1	71.7	28	0.1	73.6	26	0.1	73.5	27	0.1	73.1	27	0	72.4	27.6	0
Denmark	88.7	11	:	88.8	11	:	88	12	:	88.7	11	:	88.5	12	:	88.2	11.8	:
Germany	70.7	19	10.2	71.3	19	9.9	71.6	19	9.1	70.5	21	8.6	72.1	19	8.6	72.8	19.8	7.4
Estonia	36.3	64	:	44.8	55	:	47.6	52	:	57.1	43	:	55.6	44	:	53.8	46.2	:
Ireland	98.9	1	:	98.9	1	:	99	1	:	99.1	1	:	99.1	1	:	99.2	0.8	:
Greece	98.5	2	:	98.3	2	:	98.4	2	:	98.7	1	:	98.2	2	:	97.9	2.1	:
Spain	94.7	5	:	94.1	6	:	94.2	6	:	94.7	5	:	94.9	5	:	95	5	:
France	86.4	11	3	86.3	11	2.9	85.5	12	2.9	86.3	11	2.8	87.2	11	2.4	87.8	9.9	2.3
Croatia	72.9	20	7.3	72.7	20	6.9	72.9	19	7.8	73.4	19	7.4	73.6	20	6.3	73.6	21.2	5.2
Italy	88.1	12	0.1	86.8	13	0	86.5	13	0	85.3	15	0	86.4	14	0	86.8	13.1	0
Cyprus	100	:	:	100	:	:	100	:	:	100	:	:	100	:	:	100	:	:
Latvia	18.8	81	:	18.8	81	:	20.2	80	:	23.4	77	:	26	74	:	24.2	75.8	:
Lithuania	33.4	67	0	31.9	68	0	34.1	66	0	35	65	0	33.3	67	0	32.1	67.9	0
Luxembourg	82.2	7	10.5	85.5	6	8.4	84.9	7	8	87.3	7	6.2	87	7	6.2	84.3	8.2	7.5
Hungary	63.3	31	6.1	63.4	31	5.5	65.1	30	5.4	66.1	29	5.4	62.7	32	4.8	68.9	27.	4.1
Malta	100	:	:	100	:	:	100	:	:	100	:	:	100	:	:	100	:	:
Netherlands	48.2	6	46	48.2	6	46.1	48.4	6	45.4	49.7	6	44.3	49.4	6	44.7	50.4	6.4	43.2
Austria	64	32	3.9	63.4	33	3.5	64.7	33	2.8	64.9	32	3	65.4	32	2.9	66.3	31.5	2.1
Poland	73.5	26	0	73.4	27	0.1	74.4	26	0	75.2	25	0.1	76	24	0.1	73.1	26.8	0.1
Portugal	87.3	13	:	87.2	13	:	85.9	14	:	85.5	15	:	85.9	14	:	85.8	14.2	:
Romania	40.3	31	29	40.8	30	29	38	32	30.4	40.3	30	29.4	42.4	30	27.4	44	29	27.1
Slovenia	65.2	35	:	64	36	:	65	35	:	66.1	34	:	64.5	36	:	64.7	35.3	:
Slovakia	56.4	39	4.6	57.1	39	4	60.2	37	3.2	61.7	35	3.7	63.5	33	3.6	64.4	32.6	3
Finland	69.5	30	0.4	68.8	31	0.4	72.6	27	0.4	72.9	27	0.3	72.4	27	0.3	70.7	29.	0.4
Sweden	66.3	34	:	69.6	30	:	70.5	30	:	70.5	30	0	69.8	30	0	68.9	31.1	0
United Kingdom	86.5	13	0.1	86.4	14	0.1	89	11	0.1	90.5	9	0.1	90.4	10	0.1	90.5	9.4	0.1
Iceland	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:	:
Norway	86.7	13	:	86.3	14	:	87.1	13	:	87	13	:	84.8	15	:	84.5	15.5	:
Switzerland	63.7	36	0.1	63.7	36	0.1	62.5	37	0.1	62.4	38	0.1	65.1	35	0.1	65.2	34.7	0.1

Figure 5: Modal split for EU countries, 2013-2018, Author's creation based on (Eurostat, 2020b)

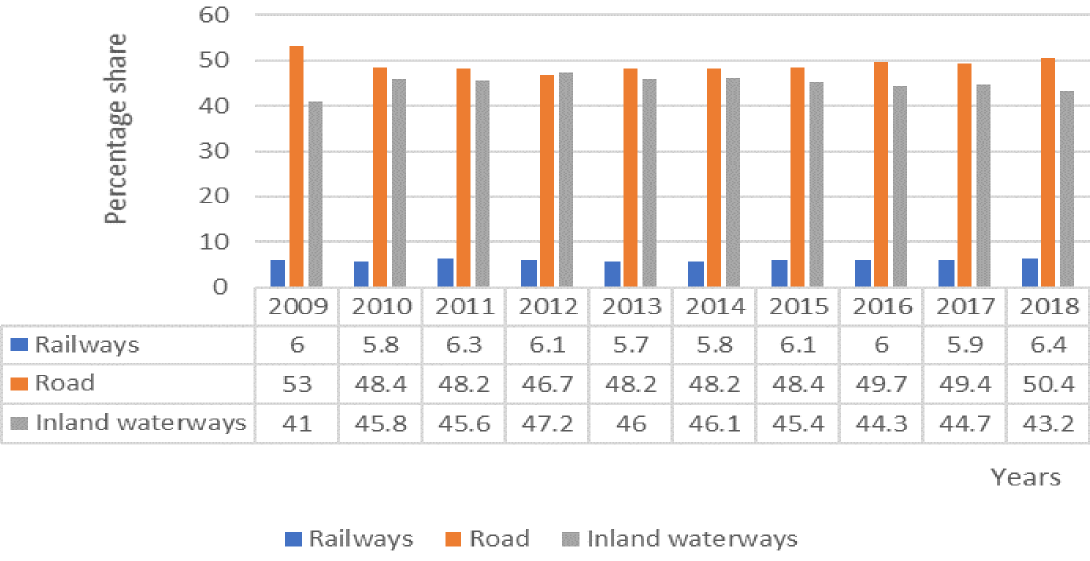


Figure 6: Modal split for the Netherlands, 2009-2018, Author's creation based on (Modal split of freight transport – Eurostat, 2020)

The figures for inland waterways seem to drop over the years but the percentage change is low. In 2018, the Netherlands had a percentage of 43.2 for inland waterways. It is important to note that road transport remains the highest ranked option with 50.4% share.

The length of the inland waterway system in the Netherlands is more than 6000 kilometers out of the 41000 total in the EU, being in the third place after Finland and Germany (CBS, 2009). From this 6000, 500 kilometers consist the main transport waterways for the heavy transport between Rotterdam, Amsterdam, Germany and Belgium (CBS, 2009). Main waterways such as Maas, Lek and IJssel and the Ijsselmeer consist almost 900 kilometers. Thus, even though inland waterways are a minority for the rest of the EU, they are one of the most important modes of transport for the Netherlands.

2.3 Causes of congestion in inland transportation

Nowadays, inland waterways and railways have become the keystone in cargo transportation due to the more sustainable and efficient operations that they offer. The level of competition between ports is constantly increasing mainly due to the growth of international trade (Van der Horst, Kort, Kuipers& Geerlings, 2019). In this framework, having efficient port related transport services is of paramount importance. Due to the interdependencies in intermodal transportation, many problems that hinder the performance of the modes and container barging still exist. This lagging in performance makes container barging unable to have the dominant position in the hinterland transportation.

2.3.1 The coordination problem

Hinterland transport involves several actors which are distinguished as private such as shipping lines, inland terminal operators and freight forwarders but also public such as customs and port authorities. The effectiveness of hinterland transport strongly relies on the coordination between these actors in order to ensure good information flow and contractual relationships.

Before analyzing the coordination problems in container barging, it is important to mention the reasons why there are no extensive efforts to resolve coordination problems. The first reason is the uneven distribution of the benefits and costs associated with coordination (Van der Horst, De Langen, 2008). Some actors may not be willing to invest in mechanisms that promote coordination (i.e. ICT systems) if they know that the other actors will not do the same but will only gain the benefits. The lack of resources or readiness to make investments from at least one actor in the chain can be considered as another reason for the coordination problems (Van der Horst, De Langen, 2008). Although, investments are proven to be valuable, not many firms are open in investing either in technology or management systems. In addition, many companies may be unwilling to improve coordination if they know that this will be in favor of their competitors. Especially in markets with high competition, this issue is easy to emerge. Furthermore, the existence of a dominant firm in the supply chain is able to improve coordination since it can have an impact in the structure of the chain. An absence of such a firm, creates additional problems. Finally, many companies may be reluctant in engaging with risky and time-consuming processes that deal with coordination (Van der Horst, De Langen, 2008). This behavior further extends the cooperation and coordination problems.

Although in the maritime container transport the importance of coordination is well known, little attention has been paid to it when it comes to hinterland container transport. According to Van der Horst and De Langen (2008), there are three main coordination problems when dealing with container barging.

The first issue is the long duration of barge handling due to the fact that they have a high number of calls per port with small call sizes. Better coordination in this case would ensure fewer calls. The second issue is that both deep-sea vessels and barges lack of a proper terminal and quay planning. For over 20 years now, the waiting and sailing time of the barges are significantly higher than the actual time of loading/unloading, making impossible to avoid congestion. Since then, no improvements have been made and tight planning has become a possible solution. This lack in coordination can be attributed to the lack of contracts that exist between the terminal operating companies and the barge operators. This fact hinders the barge operators from having an actual impact on the terminal planning since priority is given to seagoing vessels. The third and final coordination issue is the exchanged amount of cargo which is small. A higher amount of cargo would enable fewer port calls with larger vessels.

2.3.2 The absence of contractual relationship between deep-sea terminals and barge operators

The intermodal logistics supply chain has a role of distributing the goods in the least amount of time and cost. This chain has various links all of which are interdependent and relations between the actors have a vital role in building the level of integration. Nonetheless, there seems to be no commercial relationship between deep-sea operators and barge operators, which causes coordination problems for the movement of containers as already mentioned. This link of the chain deviates from the integrated philosophy thus creating intermodal disintegration.

Figure 7 depicts all contractual relationships between the actors in the chain for container barges. The container stevedore has a contract with the shipping line in order to arrange the handling charges. The contract includes actions related to the transfer of goods from the deep-sea vessel to the stack, the storage of containers at the stack and the transportation to the hinterland network (railway, truck or barges). It is important to notice, that there is not contractual relationship between the barge operator and the deep-sea operator. Therefore, the quay planning of the stevedore is not able to match the planning of the barge operator. According to Van der Horst, Kort, Kuipers& Geerlings (2019), this absence of contractual relationship as well as the fact that shipping lines always get priority does not enable the proper handling of barges.

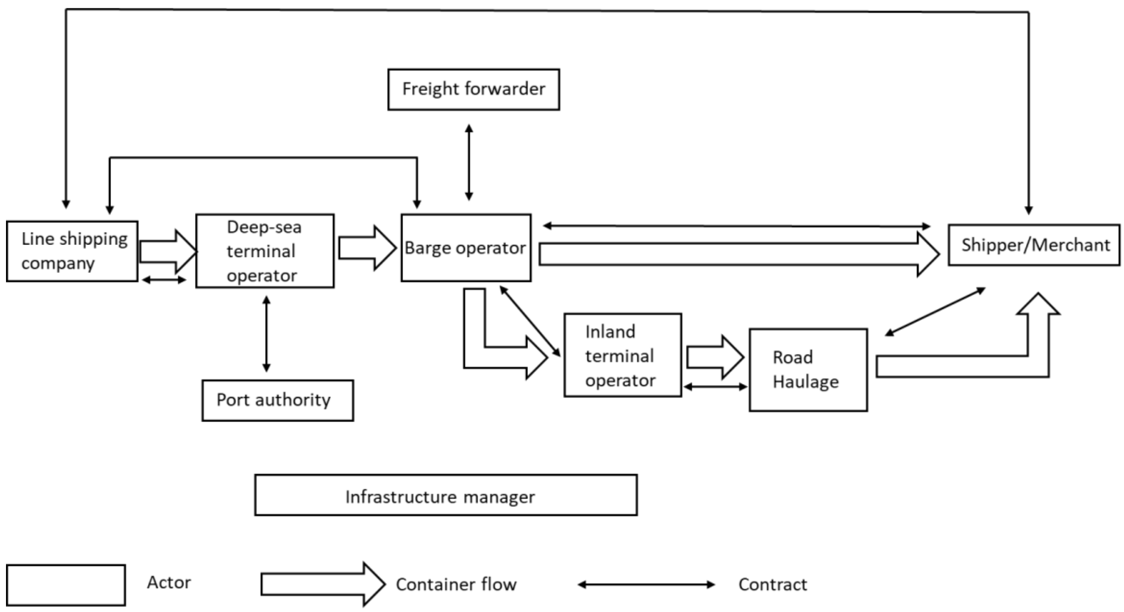


Figure 7: Contractual relationships between the actors of the chain, Source: Author's creation based on Van der Horst M., Kort M., Kuipers B. & Geerlings H. (2019)

On top of that, container barges are primarily handled in the same quay as deep-sea vessels. Based on the figure, there is also no formal relationship between the barge operator and the infrastructure manager so as to use the waterway at a specific time frame. The reason for no contracts between these actors is the Mannheim Convention on Navigation on the Rhine from 1868 which declares the freedom of navigation for ships of estuary nations and the equality of domestic and foreign vessels when it comes to administration and general treatment (Van der Horst, Kort, Kuipers& Geerlings, 2019). All tolls applied for the right to navigate are also not applicable. A more efficient use of the infrastructure of the port is therefore not possible. This absence of contractual relationship does not exist in railways.

Lack of contracts is a main cause of congestion in ports. In reality, there should be a common interest that would ensure timely movement of cargo. The absence of contractual relation between the deep-sea terminals and the barge operators definitely has implications for the whole chain. The lack of contracts gives the parties the possibility to make changes to the schedule whenever they want without any financial consequences (EY-Parthenon B.V., 2018). In that way, they do not have a motive to care about the time factor when handling containers. In addition, the handling costs are not paid directly but through the shipping line which usually shares capacity with the barges (EY-Parthenon B.V., 2018). A direct contract does not even exist for shippers and deep-sea terminals as well as barge operators and infrastructure managers. Disintegration adds up to the congestion problem and makes supply chain actors to not care about the reliability of their moves.

2.3.3 Economies of scale

Container shipping benefits from economies of scale when it comes to maritime shipping, transshipment and inland transportation (The Geography of Transport Systems, 2020). Shipping companies are always seeking to reduce their costs and the ever-larger ships are the way to do so, since increase in capacity means lower costs per TEU. The fact that the service is not easily differentiated, leaves companies with no choice but to increase the scale of their container ships to be competitive. However, this new trend may hinder the risk of reaching diseconomies of scale as show in Figure 8.

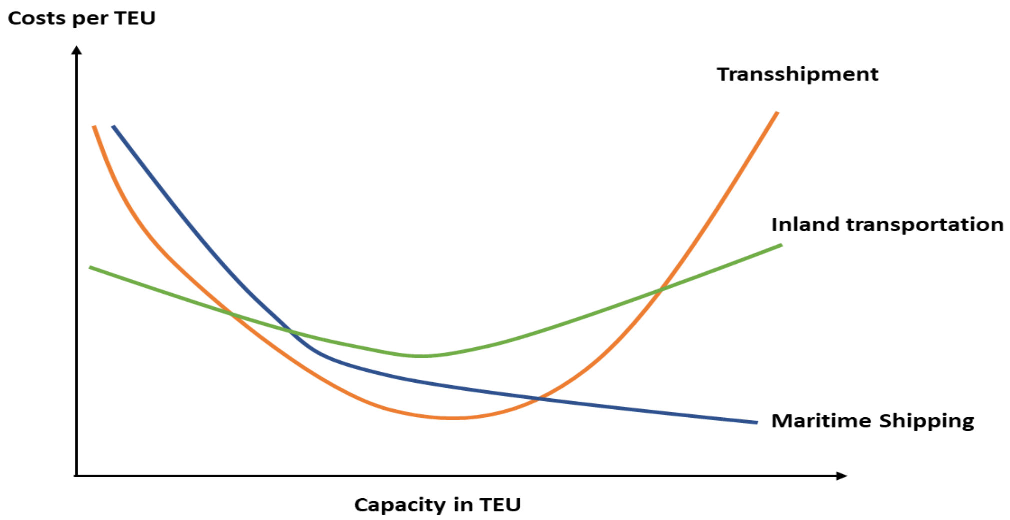


Figure 8: Economies and diseconomies of scale, Source: Author's creation based on (The Geography of Transport Systems, 2020)

When it comes to port terminals, an increase in the capacity of vessels leads to extensive growth in the cargo that needs to be transshipped in a limited period. Shipping companies are seeking to reduce their port time, and this creates a challenge for the terminal operators. The larger cranes and infrastructure needed can end up causing diseconomies of scale due to the costs associated with them (The Geography of Transport Systems, 2020). In addition, the growing capacity of the vessels adds up to the congestion problem faced by inland transportation. Given that nowadays technological innovations have enabled us to move from trucking to railway and inland waterways as already discussed, there is a fine line between economies and diseconomies of scale. Overall, diseconomies of scale is a risk that affects all parts of the chain.

Although studies like Malchow (2017), have shown that a further increase in the size of the vessels will no longer be profitable, the facts show that the scale of the vessels will continue to grow and according to McKinsey (2018), by 2066 the vessels are expected to grow to 50000 TEU (SWZ|Maritime, 2020b). Nobody knows what the maximum capacity will be but for now the scale of the vessels continues to grow.

This increase in scale has an impact on the operations of the deep-sea terminals. The larger cranes and infrastructure needed can end up causing diseconomies of scale due to the costs associated with them (The Geography of Transport Systems, 2020). Moreover, an increase in the capacity of the vessels leads to extensive growth in the cargo that needs to be transshipped in a limited period of time. Shipping companies are seeking to reduce their port time, and this creates a challenge for the terminal operators. The call sizes have increased while the punctuality of the vessels has not improved. Terminals are forced to handle more containers at the same time which results in delays.

The consequences of these delays expand to the hinterland transportation as the growing capacity of the vessels adds up to the congestion problem that it faces. This issue emerges from the fact that inland vessels are in most cases handled at the same quay with deep-sea vessels. In case the deep-sea vessel has a delay caused by the increase in call sizes, the inland vessel consequently has a delay as well. Some terminals have a different quay for inland vessels but that is far from the reality that exists in the rest of the world. In addition, given that the impact of the delay of a deep-sea vessel in the chain is bigger than that of an inland vessel, the latter is always being moved to another spot when a deep-sea vessel arrives. That causes even more congestion to the port. Since technological innovations has enabled us to move from trucking to railway and inland waterways as already discussed, there is a fine line between economies and diseconomies of scale due to the lack of finding the optimal capacity for each mode.

Furthermore, deep-sea terminals always seek to satisfy the needs of the ship owners and not the inland waterway vessels. That is due to the lack of contractual relationship between those two. One of the consequences of that is the fact that sea vessels tend to always have priority over the barges. As a result, the focus of the terminal operators is concentrated on the handling of the sea vessels, which affects the rate at which barges are handled. As the cranes wait to be distributed among the vessels, barges are left with no cranes since they do not have priority over bigger vessels. The barges are left in the system while at the same time new barges enter without any barge managing to leave the system. It is only until too much congestion occurs, that barges are finally being handled. After that, attention is again given to the sea vessels. The lack of priority when it comes to barges, seriously affects the waiting times and creates congestion problems as new barges continue entering the system.

The consequences that economies of scale have on the barges lie also to the fact that we observe the so-called reverse modal split. Many shippers switch from inland transport to trucking because of the problems caused in inland waterways. According to (SWZ|Maritime, 2020b), statistics from port of Rotterdam have showed that in 2016, truck transport had an increase of 0.7% in share whereas the share of inland shipping decreased by 0.6%. The uncertainty about the delivery of the containers caused many shipping lines and forwarders to move to trucking. Reverse modal split has affected the whole society since normally inland shipping transportation is cleaner than transportation by truck. Moreover, many public investments have been done in inland shipping that cannot be fully exploited if the share is declining. Finally, the cost per container goes up which will end up being a drawback to the consumers themselves.

2.4 The situation in the port of Rotterdam

As already shown, the Netherlands have the highest share when it comes to using inland waterways for the hinterland transportation. Due to the environmental benefits of the use of Inland Waterway Transport (IWT) and the given infrastructure, the Dutch government and the port of Rotterdam have decided to undergo a modal shift by using inland waterways (Van der Horst, Kort, Kuipers& Geerlings, 2019). Nonetheless, the performance of container barging in the port is rather inefficient. Container barges do not leave the port on time making them unpredictable. More specifically, 62% of the barges in port of Rotterdam show a delay (Van der Horst, De Langen, 2008).

Every year, inland vessels transport approximately 2.500.000 containers either between the port and the hinterland or within the range of the port (Nextlogic, 2020). 70% of the containers (8.5 million TEU) have an origin or destination in the hinterland of the port (Van der Horst, Kort, Kuipers& Geerlings, 2019). The contribution of inland shipping is then vital for the success of the port of Rotterdam. With so many containers being moved, having the right planning is important. The authority of the port has created a strategic plan called “Port Vision 2030” which reveals the desire to formulate a modal split where container barging will account for 45% of the total Maasvlakte port area by 2030 (Van der Horst, Kort, Kuipers& Geerlings, 2019).

High levels of coordination exist during the operations of inland shipping. However, since they only have an overview of their own planning and capacity, they often fail to match supply with demand. Despite the good location of the port (in the estuary of Rhine) and the increasing cargo volumes, the problems in container barging mentioned in the previous sections do not allow Rotterdam to fulfill its vision.

Container barges face congestion in many terminals of the port of Rotterdam. This issue causes extra costs, unreliable schedules and reverse modal split. Between 70%-80% of container hinterland transport in Rotterdam is arranged by a forwarder (Van der Horst, Kort, Kuipers& Geerlings, 2019). The forwarder does not have a huge impact on the performance of the stevedore or barge operator. That is called a merchant haulage. If a carrier haulage occurs, container shipping would be able to increase the performance of the operator and the stevedore.

The ever-larger containerships not only impact the terminals but also the reliability of inland transportation. In Rotterdam, the port authority keeps a barge performance monitor in order to have an overview of the delay at each week of the year. In Figure 9 below we can observe the performance of the handling of barges. Green indicates that the handling was according to the plan, orange indicates that a small delay occurred whereas red indicates a huge delay. The performance can be characterized as rather poor especially on the 12th week of 2019 where large delay is indicated for more than half of the vessels. Since the system resets to zero after the delay exceeds the 24 hours, we can expect that the actual delay is even higher than that observed in the figure. According to (Barge Terminal Born, 2019), in 2019, waiting times varied between 24 and 96 hours.

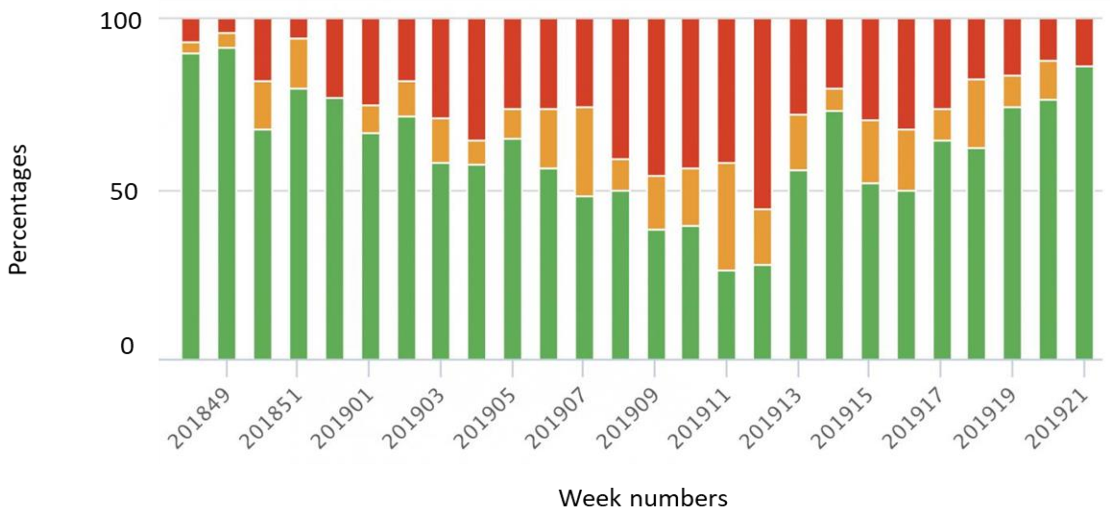


Figure 9: Indications of barge performance monitor. Source: Author's creation based on (SWZ|Maritime, 2020b)

2.5 Potential solutions to the congestion problem

There is no single solution to eliminate the congestion problem that big hubs like Rotterdam and Antwerp are facing. However, several solutions have been proposed.

According to the port authority of port of Antwerp, one of the measures they take is the effort to increase their barge capacity. Since deep-sea vessels always have priority over the barges, a dedicated terminal would be useful in order to cope with the congestion that has emerged. To do that, all actors of the supply chain should be involved. One main reason of the trend towards dedicated terminals is the better possibility to integrate the operations of the entire chain. On the contrary, although Rotterdam already had dedicated terminals it was confirmed that, during off peak times, the operation of those terminals was difficult. Dedicated terminals come with more transport and transshipment requirements that remain unutilized during off peak periods. That being said, finding the optimum point is a challenge. The bundling of containers is also considered as a possible solution. Overflow hubs can be developed in order to combine smaller call sizes into a large one. Despite the fact that this option seems promising, large distances between the terminals brings financial issues into the surface (SWZ|Maritime, 2020b). Another measure that port of Rotterdam is considering is working with time slots. That means that the handling of the vessels can be done in specific periods of time. Still, the ability to eliminate congestion seems difficult and the measures taken may not be enough.

2.5.1 The effect of a minimum call size

Ports are taking measures to ensure efficiency in barge transport. One of these is the so-called minimum call size, meaning a minimum quantity of containers per barge.

In the hope of solving the congestion problems, the actors of the chain have suggested increasing the call size of the vessels. With this action, the container barge sector focuses on reducing the number of calls while increasing their size. By doing so, we achieve a smaller number of vessels with higher call size and therefore reduced waiting times. In that way, even if the productivity remains the same, we have a decrease in berth occupancy. Berth productivity is also increased as a result of increasing vessel size while the equipment utilization is decreasing when the total volume remains the same. The fixed time required for the handling of each vessel is decreasing on average as a result of the call size of the vessel.

In this case, the idea of consolidating small call sizes is vital in an effort to combine the calls that do not satisfy the minimum requirements. Smaller calls may also need to call specific hubs to be treated. In port of Antwerp, the minimum call size was thirty lifts (SWZ|Maritime, 2020a). Due to low waters on the Rhine, barges are not able to be fully loaded so as to restrict the draft. That affects the minimum call size and it is the reason why the port authority in Antwerp lowered the minimum call size to twenty lifts (SWZ|Maritime, 2020a). The result of that was that the average call size increased by 25% whereas the number of calls decreased by 40% (SWZ|Maritime, 2020a). It is important to note that barge operators should not abuse the low level of waters in order to carry less containers since that may cause even more congestion.

In the port of Rotterdam, the minimum call size varies according to the terminal. In Rotterdam's World Gateway Terminal (RWG) the minimum number is 15 containers (lloydsloadinglist, 2020). The RWG terminal hardly ever makes exceptions by taking into account the lower water levels. ECT Delta DDE terminal has a minimum call-size of 175 moves while ECT Euromax terminal has a minimum call-size of 150 moves (Hutchison Ports ECT Rotterdam, 2019). These numbers are allowed to deviate by 10%.

2.5.2 Nextlogic

Rotterdam is also introducing Nextlogic, an integrated planning based on which barge calls will be handled more efficiently (Nextlogic, 2020). With this platform, inland and deep-sea terminals will have the chance to exchange information with all actors of the chain. Information exchange is a necessity for the integrated planning and therefore for the improvement of inland transportation. According to Nextlogic, extensive information exchange is vital for optimizing operational processes in the chain. This system will be optimized based on real time facts. The aim is to provide optimal services for inland container shipping.

The integrated planning offered by Nextlogic contributes to the optimal use of assets and is appropriate for all parties (Nextlogic, 2020). The specified rotation time of each container is maintained through the proper planning of their delivery and pick up (Nextlogic, 2020). The cranes are used in a smart way based on their availability and the whole system is continuously optimized based on real-time data. This brings information exchange to the foreground and all actors should make sure that information is always on time and complete for all parties involved. Mutual respect and understanding are also important for the parties. The improvement of inland containers is highly depended on efficient integrated planning and therefore good data exchange.

The added value that Nextlogic offers cannot be overseen. It has a positive impact to the modal shift ambitions of the port of Rotterdam as already discussed while it strengthens the competitive position of the port (Nextlogic, 2020). Waiting times, peak factors and no-shows are optimized to satisfy all actors of the chain. Disruptions may occur quite often and unexpectedly for example due to weather conditions or delayed ships. Nextlogic can shorten the recovery periods by optimally deploying the existing assets (Nextlogic, 2020). Thus, financial damages are minimized. Utilization rates of ships and cranes as well as overtime are optimized among others to ensure an efficient inland transportation.

All chain parties involved, can highly benefit from this initiative. Shippers acquire reliability when transporting containers to and from the hinterland. Shipping companies are able to better connect with deep sea and always have containers when needed according to the plan. For barge operators, Nextlogic not only offers better service to their customers but also competent distribution and utilization of ships. Turnaround times are also quicker and more reliable. Finally, the terminal benefits from the better logistics and stacking operations as well as the optimal use of quays and cranes.

However, one should be critical on whether Nextlogic is fully ready to be operational. Nextlogic is about collaboration of different parties in the chain in order to work together towards achieving more reliable and efficient inland container shipping. This goal is not easy to realize. We first have to make sure that everyone involved will be dedicated enough in order to put the common interest forward and not to act based on their individual priorities. Any occasional differences must be eliminated. Given the importance of information exchange between the parties, the quality should be protected to ensure the right flow of information and the appropriate actions. Thus, the quality of the data is a major issue and the everyone should ensure that the information given is not optimistic but realistic.

2.5.3 Container Exchange Route (CER)

Rotterdam is also building a Container Exchange Route (CER) that will connect terminals via road, bringing intra port cooperation to a new level (Container Exchange Route (CER), 2020). What CER does is that it bundles flows of containers from train, barges and feeder ships in order to not have different terminals (Container Exchange Route (CER), 2020). In that way, they hope to ensure high level of reliability and save time and costs. Inland vessels would then need to have less amount of exchange costs and the competitive position of the port as a hub is strengthened.

CER offers better connectivity and less residence time. Containers will be able to enter CER via dedicated exchange points and be moved to various locations where they can be bundled and loaded to other modes so as to reach their final destination. That means that trains and inland vessels no longer have to go to different terminals. This new advanced system uses IT systems and infrastructure between terminals and empty depots in order to fulfill its purpose. They expect that over 1 million containers per year will be exchanged in this way in the future (Container Exchange Route (CER), 2020).

However, it is obvious that more needs to be done. All actors of the chain should meet regularly to discuss the challenges that come up. At the same time, they should think of other possible solutions that would be proven helpful.

To sum up, the challenges that container barges are facing are many while at the same time the potential growth and the advantages that inland waterways have are profound. Port of Rotterdam is an important hub for transport to and from the hinterland. This hinterland extends from the Netherlands to Belgium, Germany and Switzerland. However, peak loads due to increased call sizes, and a lack of insight due to visits and unloading times at multiple terminals cause inefficiencies and delays in the transport chain. Given the various perspectives that exist, one can understand that an optimal solution is not yet found but it is needed so as to eliminate congestion in ports. Key aspects on that would be new technologies, proper management, and an open mindset. The following sections of this research are aiming to find possible solutions to the barge handling issues that have emerged by simulating the impact of different priority service approaches of the vessels while examining the effect of an increasing call size of the barges as explained in section 2.5.1.

Chapter 3: Methodology

In this chapter we analyze the choice of the model and programming environment used and the benefits that it offers when it comes to our research question. We also specify the approaches that will be taken into account so as to capture the different priority service scheduling and the increasing call size which will provide an answer to our fourth and fifth sub-research questions.

3.1 The choice of simulations in R as methodological tool to develop the research

Despite the ability of mathematical analysis to provide accurate results, the complexity of real-life processes makes them more easily described and analyzed through simulation methods. Simulations are a powerful tool as it gives us a better understanding of the real-life data we collect, by giving us the opportunity to mimic the outcome of the data we wish to collect. At the same time, it offers an insight into the algorithms used to end up to our model analysis. To react to our main research question, we are going to conduct discrete event simulations (DES) in the R programming environment. DES is a way of simulating the performance of “real-data” and it is widely used in logistics and supply chain management as decision support tools (Allen, Spencer, Gibson, et al., 2015). This method uses an order of well-defined events to codify the performance of complex systems (Allen, Spencer, Gibson, et al., 2015). It can also consider the stochastic nature of certain events while being able to predict the behavior and outcome that we wish to examine.

The R programming environment is a platform where simulations can be performed. It gives us the ability to incorporate sophisticated procedures to plot our data and offers many packages that allow proper modeling of the data we are going to use (Hallgren, 2013). By using R, researchers are able to include features that exist in all programming environments such as random number generators, branching and writing of data in order to generate new data through repetitive techniques which are required in simulations (Hallgren, 2013). Simulations often offer solutions to real-world problems in an understandable and accurate way. They are applied for several planning and operational purposes in container handling. They form tools based on which several decisions can be made in the ports. Since we want to examine the extend at which the optimality of barge handling can be achieved and given our sub-research questions as mentioned in section 1.3 we can understand that this kind of questions cannot easily be answered using econometric or mathematic modelling, due to the lack of available data on the topic. Restating, the behavior of barges and vessels in general can be better recorded through DES performed in R. In our model we will include several approaches to better capture the reality and be able to gradually apply changes to our model in order to optimize the result namely the waiting times of the vessels.

3.2 The Gamma Distribution

The gamma distribution can be used in many physical quantities and it is also related to distributions such as Poisson, Erlang, chi-square and others (Mun,2008). It is also applied when calculating the time between events even when these are not completely random. It is commonly used in measuring the amount of time until the rth occurrence of an event following a Poisson process (Mun,2008). In this case, the following three conditions apply:

1. The possible occurrences in any time unit is not limited to a fixed number.

2. The occurrences are independent.

3. The average number of occurrences must remain the same from unit to unit.

The formulas used in gamma distribution are the following:

$$f(x) = \frac{(\frac{x}{\beta})^{\alpha-1} * e^{\frac{-x}{\beta}}}{\Gamma(\alpha)\beta} \; with\, \alpha, \beta > 0 \qquad (1)$$

$$mean = \alpha * \beta \qquad (2)$$

$$standard\ deviation = \sqrt{a\beta^2} \qquad (3)$$

Coefficient of variation = standard deviation / mean = 1/ sqrt(α) (4)

Hence,

$$\text{shape } (\alpha) = 1/\text{ squared coefficient of variation} \qquad (5)$$

scale (β)=mean/shape= mean*squared coefficient of variation (6)

Alpha (α) and beta (β) are the parameters of the distribution with alpha being the shape parameter and beta the scale parameter. When alpha is a positive integer, we have the Erlang distribution with is used to predict waiting times in queuing models. Erlang distribution is then the sum of random variables that are independent and identically distributed which have an exponential distribution which has the memoryless property (Mun,2008).

If we let n denote the number of these variables, the formula in this case is:

$$f(x) = \frac{x^{n-1} * e^{-x}}{(n-1)!} \text{ with x>0 and n positive integers} \quad (7)$$

Beta parameter: Any positive value above or equal to zero.

Alpha parameter: Any positive value above or equal to 0.05.

3.3 The approaches used in the model

Our primary goal is to see what will happen in the waiting time of barges and vessels given the priority service approaches that we can envisage while we increase the minimum call size of the barges.

Approach 1: For this approach we assume that no vessels have priority. That means that both barges and deep-sea vessels are treated as equally important and they are treated on a first come first served basis. Different kind of vessels cannot interrupt one another meaning that the size or the importance of the vessel does not matter. Of course, this approach does not capture the reality, but it consists a good base for building up our model and it can serve in comparisons.

Approach 2: In this approach we have a more realistic view since the arrival time of the ships is known even sometimes days before the ship reaches at the berth. In this approach we therefore assume that deep sea vessels will be treated as priority vessels. The reason behind that is the fact that depending on the cargo and the size of the vessels, their waiting time may be more expensive than that of the smaller vessels (barges). In this study, we only assume two priority classes (either the ship has or does not have priority), in which barges have no priority whereas deep-sea do have priority. The berth allocation then will proceed as follows. When both a high-priority vessel and a low priority vessel arrives at the terminal, the high priority one will be served first so it would first be assigned to a free berth. The low priority one will then enter the queue and wait to be treated. However, if the low priority vessel approaches first the terminal while no high priority vessel is waiting in the queue, it will be served and therefore it will reserve a slot. In this approach, we assume that there is no preemptive priority scheduling meaning that the high priority vessel cannot interrupt the service of a low priority one if the latter has already started being served at the berth. Preemptive priority scheduling is examined in later approaches.

Approach 3: This approach has the purpose of adding one more element to our model which is preemptive priority scheduling. In this case, each time a vessel arrives at the queue, its priority will be compared to the one of the other vessels which are served at that time as well as with the other vessels in the queue itself. The vessel with the highest priority will be served first. That means that the service of the vessels can be interrupted. Again, a high priority is given to the deep-sea vessel. If a vessel of high priority arrives, then the service of the low priority (in our case of the barge) will stop whereas if a low priority vessel arrives it does not have the right to stop the service of the high priority vessel. When a high priority vessel interrupts the service of the others, it is understandable that the latter can then either resume its service after the high priority vessel has finished or restart its service completely after the completion of the service of the high priority vessel. Resume means that the vessel that will be interrupted will continue its service from the point it was left before it was interrupted. Restart means that it has to start its service from the beginning. In this approach we will examine both the restart and the resume possibility and see the differences that occur in the waiting times of the vessels.

Approach 4: As already discussed in the literature review, one measure to ensure efficiency in the ports when it comes to barge transport is to set a minimum call size. This approach aims at examining the effect of increasing the minimum call size of the barges even more to test the efficiency of bigger barges and see whether in this way the waiting time can be reduced. In this case, we aim at decreasing the number of barges as the minimum call size increases. The total number of containers will remain the same while the containers per time unit will increase. In this approach we incorporate the assumptions made under approach 3 meaning that there is preemptive priority scheduling either with restart or with resume and that a high priority is given to the deep-sea vessel.

Approach 5: Due to the Covid19 virus, which was spread in 2020, we expect that the arrivals of all types of vessels were decreased. Therefore, the waiting times of the vessels is expected to be found in low levels, compared to what would occur in reality. The data collected may therefore differ to those that we would have, if the research had been done in another year. In 2020, less containers and thus less ships were reported, a fact which we have to take into account when making the calculations. In an effort to capture this issue and take it into consideration in our model, we will assume that we have one less berth than the number of berths we will use in the previous approaches in order to increase the utilization rate and eliminate the adverse effect that Covid19 has on the number of ships and on the waiting times. Approach 5 will therefore have the same base as approaches 3 and 4, with the only difference being that we will have one less berth. That means that we will incorporate the assumption of preemptive priority scheduling and later increase the minimum call size to again see the effect.

<u>Approach 6:</u> While approach 4 measures the effect of increasing the minimum call size, in reality, call size has a distribution as not all barges have the same number of containers. By cutting off the low values of the handling time of the barges we will again be able to increase the mean handling time while decreasing the number of barges. In that way we will have the same effect as in approach 4. Approach 6 will therefore examine this possibility to explore different ways of increasing the call size by taking into account the different number of containers that each barge has and the distribution that the call size follows. This approach follows the same priority scheduling as approach 4.

Chapter 4: Data and Model

In this chapter we are first going to specify the data assumptions which will be incorporated in our calculations in the following sections. After that, we specify the data that were used to conduct the simulations and the way we obtained them. The model specifications are also described in this chapter and they give an overview of how we translated the data into inputs for our model.

4.1 Data

The data used will be measured in days so as for the reader to follow the calculations easier. If the data were in hours or years, the figures would be too small.

4.1.1 Data assumptions

In order to design our model and given the lack of data that exists in this field, some assumptions are vital in order to formulate the code that we will use on the programming environment. For this purpose, we will include the following reasonable assumptions in our model:

1) The interarrival time and the service time follows a gamma distribution (we are proving that in section 4.2.1 with distribution fitting).
2) The data collected in a period of 4 weeks from ECT Delta terminal can be generalized and used in drawing conclusions about the waiting times in the port.
3) The length of a deep-sea vessel is considered to be 400m, adding 50m for cables (in total).
4) We assume that the barges need 0.5 hours until the ropes are attached while the deep-sea vessels are assumed to require 2 hours.
5) We assume that the times provided by ECT terminal include mooring time.
6) We consider that there is only one waiting queue for our vessels.
7) We apply 20 moves per hour per crane (Nieuwsblad Transport, 2020).

4.1.2 Interarrival time of barges and deep-sea

For the purpose of collecting data about the interarrival time of barges and deep-sea, we monitored the arrivals at ECT Delta terminal in Rotterdam for a period of four weeks (1/6/2020-28/6/2020) from (ECT, 2020b). Based on the observed data, during the period of one-month 609 barges and 79 deep-sea were recorded in total.

4.1.3 Service time of barges

When it comes to the service of barges according to ECT Delta terminal (ECT, 2020b), the average time a barge spends at this terminal is 0.12 days which equals to 2.88 hours (see also Table 1 in section 4.1.7). Based on the data from the terminal we cannot be sure whether mooring and unmooring times are included in the times provided. We therefore assume that those time are included so we have to decrease the mooring time from the 0.12 days in order to obtain the real service time. If we take into consideration the mooring and unmooring times, we can subtract 0.5 hours=0.0208 days, ending up in 2.38 hours=0.0992 days of service time.

4.1.4 Service time of deep-sea

When it comes to the service of deep-sea vessels according to ECT Delta terminal (ECT, 2020b), the average time a deep-sea vessel spends at this terminal is 1 day which equals to 24 hours (see also Table 2 in section 4.1.7). Based on the data from the terminal we cannot be sure whether mooring and unmooring times are included in the times provided. We therefore assume that those times are included so we have to decrease the mooring from the 1 day in order to obtain the real service time. If we take into consideration the mooring and unmooring times, we can subtract 2 hours=0.0833 days, ending up in 22 hours=0.9167 days of service time.

4.1.5 Multiple servers

Since in all of our approaches we examine the case of having multiple servers as it better captures the reality, we have to find the appropriate number of servers (berths) we will use. According to (ECT, 2020a), the quay length of ECT Delta Terminal is 3.6km. Based on the third assumption that we made under section 4.1.1, the total length of a deep-sea vessel is considered to be 450m. To find the number of berths of the terminal we follow the formula:

$$\text{No of berths} = \frac{Quay\ length}{Length\ of\ the\ ship} = \frac{3600}{450} = 8\ \text{berths} \tag{8}$$

Thus, for the approaches 1-4 and 6 we will use 8 berths in our simulations whereas for approach 5 we will use 7 berths.

4.1.6 Utilization rate

Given the arrival rate and the service rate of barges and deep-sea vessels as described in the above sections, as well as the number of berths we can calculate the utilization rate based on the formula:

$$\rho = \frac{\lambda}{k * \mu} \tag{9}$$

Where k is the number of servers (berths) as analyzed under section 4.1.5.

The utilization rate for each approach will later be calculated based on equation (9) in the results and analysis (chapter 5) as a performance measure after having calculated the parameters that we need in each case. For now, it will be used for the vessels which were monitored during the period of 4 weeks while we consider the start and end time to be the time that the first and the last monitored vessel arrives at the terminal accordingly.

4.1.7 Data statistics

Tables 1 and 2 of this section summarize the statistics for the interarrival and handling time of barges and deep-sea vessels respectively, not only for the period of one month but also during each one of the four weeks. We calculate these statistics with the objective to find the shape and scale of our data which we will later incorporate into the R-script to obtain the waiting times per approach. We will first explain what is measured and how it is calculated.

We can calculate the interarrival time as:

Interarrival time=arrival date(i+1) – arrival date (i), where i is the vessel (10)

The total handling time (including mooring) can be calculated as:

Handling time= departure time (i)-arrival date (i) (11)

We are then able to calculate the total interarrival time and handling time as the sum per week or month.

The number of arrivals is the sum of barges/deep-sea vessels that were monitored during each week and during the whole month. In order to get the total handling time at the end of the month excluding mooring we assume that 0.5 hours=0.0208 days are dedicated to mooring and we subtract 609*0.5/24=304.5/24=12.69 days ending up in: total handling time-mooring time= 70.82-12.69=58.13 days for the barges whereas for the deep-sea vessels assuming 2 hours of mooring time and given the total of 79 vessels that were observed we will have 79*2/24=6.58 days of mooring ending up in: total handling time-mooring time= 78.97-6.58=72.39 days. Tables 1 and 2 include only the total handling time including mooring.

The next two measures that are calculated is the average total handling time and the average service rate as follows:

Average total handling time= sum of handling time including mooring/ no of arrivals (12)

Average service rate (ships per day) =1/ average total handling time (13)

Average service rate (ships per week)= average service rate (ships per day)*7 (14)

Average service rate (ships per month)= average service rate (ships per day)*30 (15)

The utilization rate is calculated based on equation (9) given under section 4.1.6.

The mean interarrival time is considered to be the average of the observed interarrival times (per week or per month respectively) whereas the standard deviation of the interarrival time and handling time is calculated based on the excel formula st.dev of the observed data. Using these data, we are now able to calculate the coefficient of variation as follows:

Coefficient of variation(interarrivals)= Standard deviation of interarrivals/ Mean interarrival time (16)

Coefficient of variation (handling time)= Standard deviation of handling time/Mean handling time (17)

The final step is to calculate the scale and shape of our data according to equations 5 and 6 from section 3.2. Tables 1 and 2 below summarize the results of the equations 5,6,10-17 as explained above.

Table 1: Statistics for Barges, Source: Author's creation

	Week 1	**Week 2**	**Week 3**	**Week 4**	**Month**
Total handling time incl. mooring (days per month)	16.92	16.03	16.80	21.08	70.82
No of arrivals	153.00	146.00	149	161	609.00
Mean total handling time (days per ship)	0.11	0.11	0.11	0.13	0.12
Average service rate (ships per day)	9.04	9.11	8.87	7.64	8.60
Average service rate (ships per week-month)	63.30	63.76	62.09	53.48	257.98
No of berths	8.00	8.00	8.00	8.00	8.00
Utilization rate	0.30	0.29	0.30	0.38	0.30
Mean interarrival time (days)	0.04	0.05	0.05	0.04	0.05
St.dev of interarrival time (days)	0.04	0.04	0.05	0.04	0.04

St.dev of handling time (days)	0.10	0.11	0.10	0.11	0.10
Coefficient of variation (interarrivals)	1.027	0.895	0.96	0.86	0.94
Coefficient of variation (handling time)	0.905	0.966	0.919	0.823	0.899
shape (alpha) for interarrivals	0.95	1.25	1.08	1.36	1.14
shape (alpha) for handling time	1.22	1.07	1.18	1.48	1.24
scale (beta) for interarrivals	0.05	0.04	0.04	0.03	0.04
scale (beta) for handling time	0.09	0.10	0.10	0.09	0.09

Table 2: Statistics for deep sea vessels, Source: Author's creation

	Week 1	**Week 2**	**Week 3**	**Week 4**	**Month**
Total handling time incl. mooring (days per month)	23.03	15.51	24.38	16.05	78.97
No of arrivals	21.00	18.00	25.00	15	79.00
Mean total handling time (days per ship)	1.10	0.86	0.98	1.07	1.00
Average service rate (ships per day)	0.91	1.16	1.03	0.93	1.00
Average service rate (ships per week-month)	6.38	8.12	7.18	6.54	30.01
No of berths	8.00	8.00	8.00	8.00	8.00
Utilization rate	0.41	0.28	0.44	0.29	0.33
Mean interarrival time (days)	0.31	0.38	0.27	0.38	0.34
St.dev of interarrival time (days)	0.23	0.39	0.18	0.32	0.28
St.dev of handling time (days)	0.78	0.56	0.61	0.50	0.63
Coefficient of variation (interarrivals)	0.73	1.02	0.65	0.85	0.83
Coefficient of variation (handling time)	0.72	0.65	0.63	0.47	0.63
shape (alpha) for interarrivals	1.86	0.96	2.35	1.38	1.47
shape (alpha) for handling time	1.95	2.40	2.52	4.54	2.53
scale (beta) for interarrivals	0.17	0.40	0.12	0.27	0.23
scale (beta) for handling time	0.56	0.36	0.39	0.24	0.40

4.1.8 Increasing the minimum call size of barges

This section refers to approaches 4 and 5, where we increase the minimum call size of the barges in an attempt to test whether the waiting time of the vessels can be decreased. From section 4.1.3 we know that the average service time of barges is 2.8 hours=0.12 days out of which we subtract 0.5 hours=0.0208 days for mooring since based on our assumptions, the data collected from ECT terminal include mooring time. Based on our seventh assumption in section 4.1.1 we can apply 20 moves per hour per crane=480 moves per day per crane to find the number of moves per barge. We thus end up with: (0.12-0.0208) *480= 47 moves per barge. If we take the TEU factor to be 1.8 we end up with 1.8*47=84 TEU (note that is the sum of the loaded and unloaded number of containers). In this study we define the call size as the moves per barge for every approach and we then apply the following formula in each case to calculate the new number of barges:

original call size (TEU)*number of barges= new call size (TEU)* new number of barges (18)

Given equation (18), we already know that the original call size is 47 moves as stated above and the total number of barges as monitored during the four weeks was 609 barges. We are now able to increase and vary the new call size of the barges to find the new number of barges in the terminal. We keep in mind that we will have the same total number of containers but the number of containers per barge will increase meaning that the number of barges needed will decrease.

After that, the service time of barges should be recalculated as it will increase given the higher number of containers per barge. To incorporate this change to our simulations, we scale up the handling time of barges. To do so, we use equation (6) for the scale where we will keep the coefficient of variation constant and we increase the mean.

Increasing the call size from 47 to 58 moves

In this part of approaches 4 and 5, we assume that we are able to increase the call size from 47 to 58 moves. If we again take the TEU factor to be 1.8 we end up with 1.8*58=104 TEU per barge. We can then apply equation (18) as follows:

original call size*number of barges= new call size* new number of barges ⇔47*609=58*new number of barges ⇔ new number of barges=493

We are now able to calculate the crane time at 480 moves per day which will be 58/480=0.1208 days. If we also add the 0.5 hour=0.0208 days for mooring time, we end up with 0.1416 days as the total time per barge.

We now have to scale up the handling time of barges meaning that we increase the mean while we hold the coefficient of variation constant. From Table 1 above, we know that the coefficient of variation for the handling time of barges is 0.899. We also know that the initial number of barges is 609 and the total handling time is 70.82 days=1700 hours (including mooring time) which equals to 1395.2 crane hours= 1395.2*20 moves per crane=27904 moves. By using the new number of barges to be 493 we get 27904/493=56.6 moves per barge=56.6/20=2.83 hours=0.1179 days. If we also add the mooring time which is 0.5 hours = 0.0208 days we get a total of 3.33 hours per barge=0.1387 days. We summarize the results as follows:

Table 3: Increasing call size to 58 moves, Source: Author's creation

Call size from 47 to 58 moves	
Total handling time (including mooring) in days	70.82
Handling time (excluding mooring) in days	58.11
Initial number of barges	609
New number of barges	493
Coefficient of variation	0.899
Mean handling time including mooring (days)	0.1387
Scale of handling time (days)	0.1121

As we can see, the mean handling time increased from 0.12 days to 0.1387 days while the scale increased from 0.09 days to 0.1121 days.

Increasing the call size from 47 to 69 moves

In this part of approaches 4 and 5, we assume that we are able to increase the call size from 47 to even 69 moves. If we take the TEU factor to be 1.8 we end up with 1.8*69=124 TEU. We can then apply the formula:

original call size*number of barges= new call size* new number of barges ⇔47*609=69*new number of barges ⇔ new number of barges=414

We are now able to calculate the crane time at 20 moves per hour = 480 moves per day which will be 69/480=0.14375 days. If we also add the 0.5 hour =0.0208 days for mooring time, we end up with 0.16455 days as the total time per barge.

We now have to scale up the handling time of barges meaning that we increase the mean while we hold the coefficient of variation constant. From Table 1 above, we know that the coefficient of variation for the handling time of barges is 0.899. We also know that the initial number of barges is 609 and the total handling time is 70.82 days=1700 hours (including mooring time) which equals to 1395.2 crane hours= 1395.2*20=27904 moves. By using the new number of barges to be 407 we get 27904/407=68.56 moves per barge=68.56/20=3.43 hours=0.1429 days. If we also add the mooring time which is 0.5 hour=0.0208 days we get a total of 3.93 hours per barge=0.164 days.

We summarize the results as follows:

Table 4: Increasing call size to 69 moves, Source: Author's creation

Call size from 47 to 69 moves	
Total handling time (including mooring) in days	70.82
Handling time (excluding mooring) in days	58.11
Initial number of barges	609
New number of barges	414
Coefficient of variation	0.899
Mean handling time including mooring (days)	0.164
Scale of handling time (days)	0.13254

As we can see, the mean handling time increased from 0.12 days to 0.164 days while the scale increased from 0.09 days to 0.13254 days.

4.2 Data Analysis

4.2.1 Distribution Fitting

To simulate the waiting times of the vessels, we have to find the appropriate distribution for our data. To evaluate which distribution best fits to the interarrival and handling times of both barges and deep-sea vessels we create QQ-plots in R to test each distribution. QQ-plots (quantile-quantile plots) is a tool that enables us to understand whether the set of data that we are using come from a theoretical distribution such as the normal, exponential or gamma. What QQ-plots do is that they sort our interarrival and handling times in each case versus quantiles which are taken from the theoretical distribution (either normal, exponential or gamma). R mainly uses functions qqnorm and qqplot to make these QQ-plots. The R script that was used to create the figures below are depicted in the Appendix (Figure 36). Figures 10-13 show the fitting in case of a normal distribution, Figures 14-17 show the fitting in case of a gamma distribution while Figures 18-21 show the fitting in case of an exponential distribution. At the end we are able to conclude which distribution best fits our data.

Normal distribution

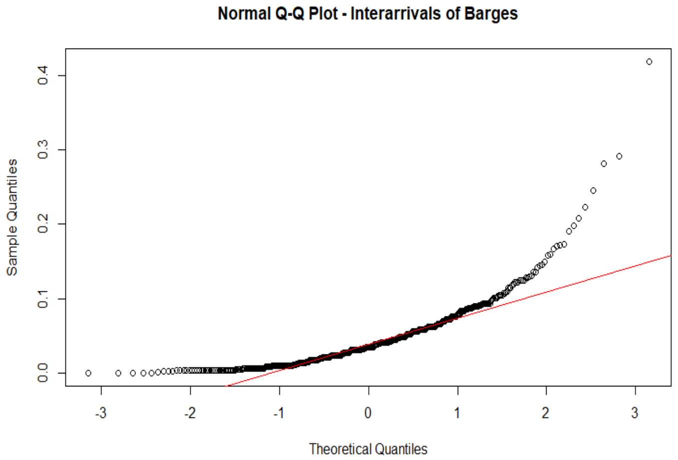


Figure 10: Normal QQ plot Interarrival time of barges, Source: Author's creation

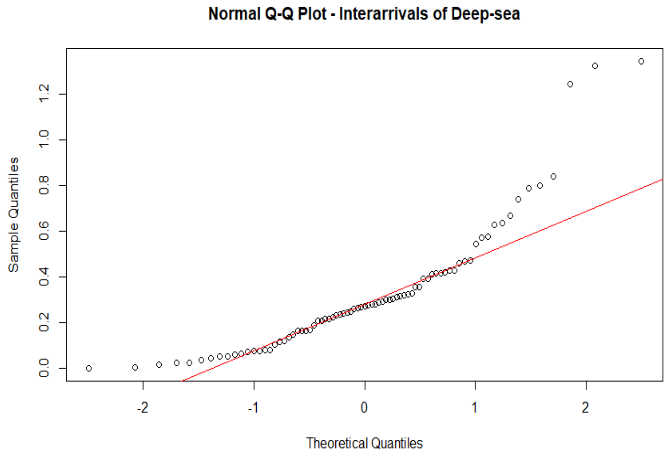


Figure 11: Normal QQ plot Interarrival time of deep-sea, Source: Author's creation

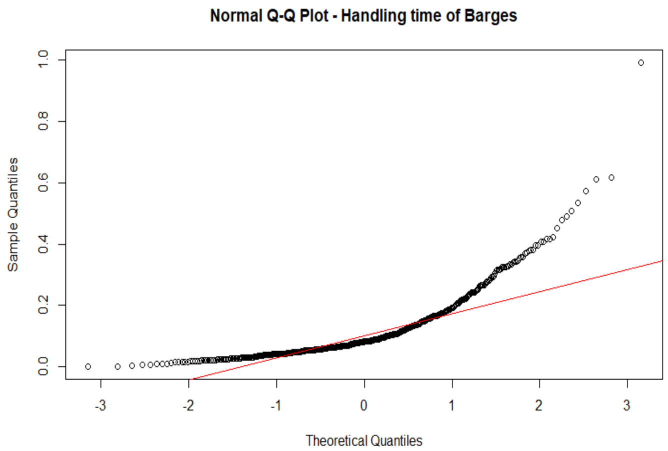


Figure 12: Normal QQ plot Handling time of barges, Source: Author's creation

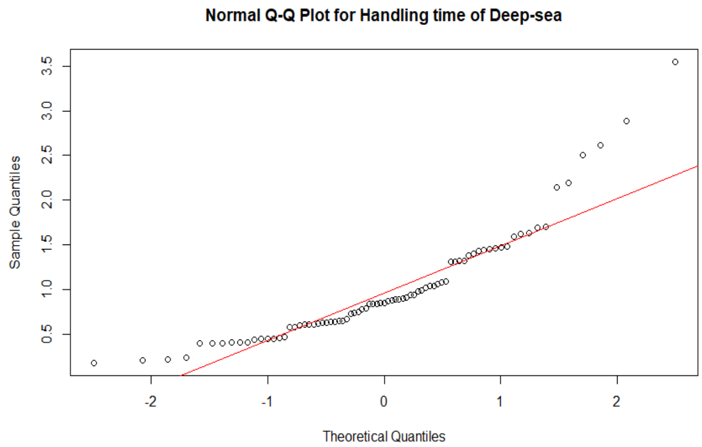


Figure 13: Normal QQ plot Handling time of deep-sea, Source: Author's creation

The Figures above show the fitting of the interarrival and handling times of our vessels in case we assume a normal distribution. The red line (qqline) is a line added to the theoretical QQ-plot, which by default is normal and goes through the first and third quartiles. The dots represent our interarrival and handling times of the vessels accordingly. When the values lie along with the red line, that means that our data have the same shape and scale with the data of the distribution that we have assumed. In this case, as we can see from Figures 10-13 above, the observations follow an upward curve shape which indicates a positive skewness (right skew). That means that the normal distribution is not appropriate in this case and we should examine the exponential and the gamma distribution.

Gamma distribution

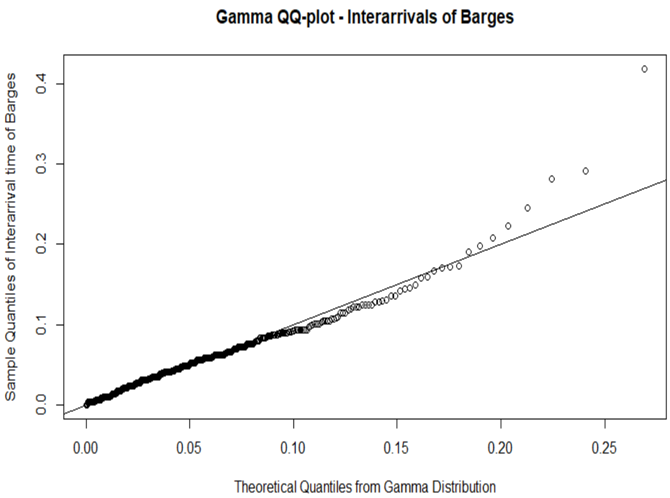


Figure 14: Gamma QQ plot for Interarrival time of barges, Source: Author's creation

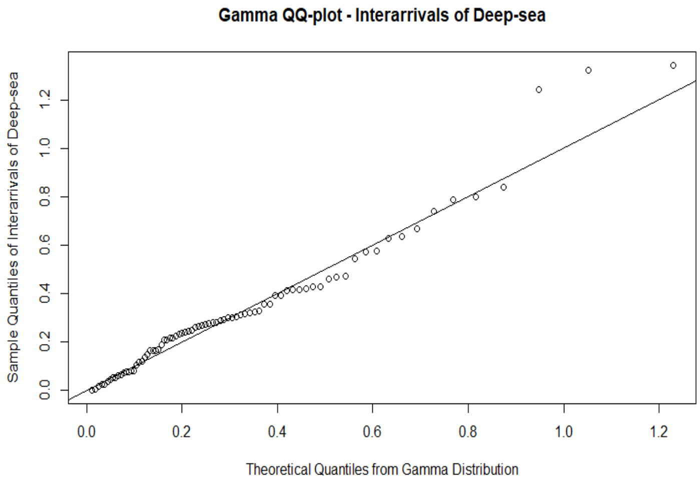


Figure 15: Gamma QQ plot for Interarrival time of deep-sea, Source: Author's creation

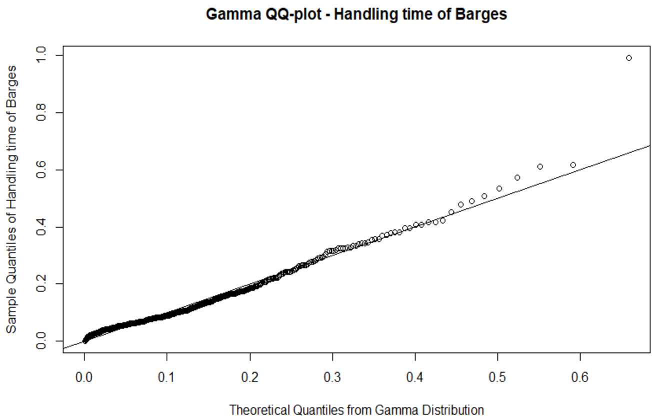


Figure 16: Gamma QQ plot for Handling time of barges, Source: Author's creation

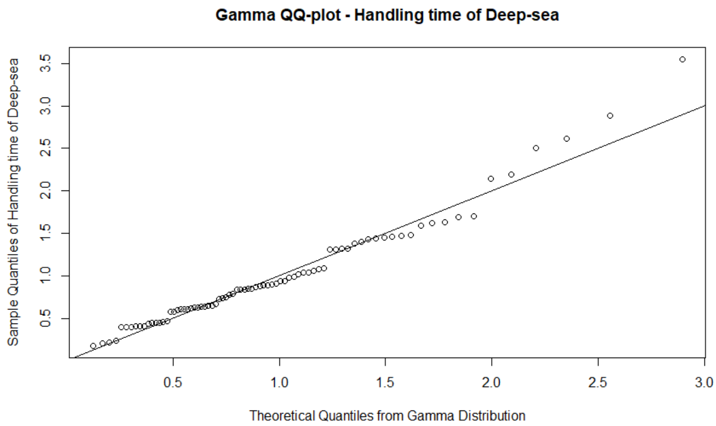


Figure 17: Gamma QQ plot for Handling time of deep-sea, Source: Author's creation

The Figures above show the fitting of our data in case we assume a gamma distribution. The straight line is a line added to the theoretical QQ-plot, which by default is gamma distributed. The dots represent our interarrival and handling times of the vessels accordingly. Similarly, when the values lie along with the straight line, that means that our data have the same shape and scale with the data of the distribution that we have assumed. In this case, as we can see from Figures 14-17 above, the observations seem to follow the straight gamma distributed line with the only deviations being in higher observations. The handling time of deep-sea vessels seem to depict a stepwise pattern in some cases which can perhaps be attributed to the opening hours of the terminal. Overall, the gamma distribution fits our data well.

Exponential distribution

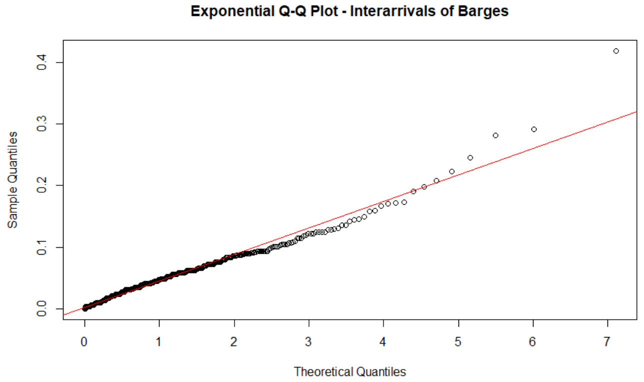


Figure 18: Exponential QQ plot Interarrival time of barges, Source: Author's creation

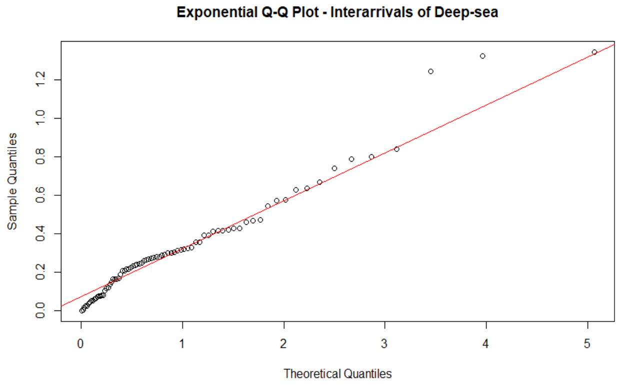


Figure 19: Exponential QQ plot Interarrival time of deep-sea, Source: Author's creation

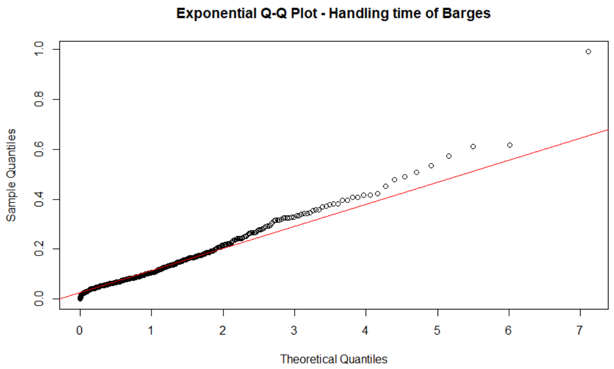


Figure 20: Exponential QQ plot Handling time of barges, Source: Author's creation

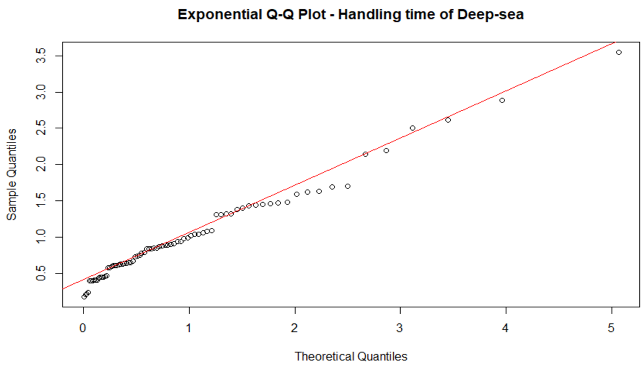


Figure 21: Exponential QQ plot Handling time of deep-sea, Source: Author's creation

The Figures above show the fitting of our data in case we assume an exponential distribution. The red line is a line added to the theoretical QQ-plot, which by default is exponentially distributed. The dots represent our interarrival and handling times of the vessels accordingly. Similarly, when the values lie along with the red line, that means that our data have the same shape and scale with the data of the distribution that we have assumed. In this case, as we can see from Figures 18-21 above, while the observations follow the red exponentially distributed line quite well, we observe slightly higher deviations that the ones we saw under the gamma distributed QQ plots. This fact enables us to conclude that the best distribution for our data is the gamma distribution which we will use in the later sections.

4.2.2 Model specifications

The simmer model used in the simulations in R will now be specified to understand how it works. The functions and inputs used for the needs of our model as well as the theory behind them is given in the Appendix (Model Specifications). The inputs for the gamma distribution are mentioned in this section since they require some altering of the way we describe our data.

Gamma distribution: Since our data are gamma distributed, we use the command rgamma which generates realizations from gamma distribution in R and takes the following inputs:

rgamma(n, shape, rate, scale)

In R, we only need to provide either the rate or the scale of the distribution. Given the fact that R recognizes the scale as defined in section 3.2 as rate=1/scale, we have to convert the scale values as calculated in section 4.1 in order to be expressed as rates (=scale in R) and we are going to use those rates as an input for our model. In Section 4.1.7, Tables 1 and 2 depicted the following results in scale which can be converted in the proper rate for R:

Table 5: Scale in R, Source: Author's creation

	Scale (days) (Tables 1 & 2)	Rate (=Scale) in R (1/days)
Handling time of barges	0.09	1/0.09=11.1111
Handling time of deep-sea	0.4	1/0.4=2.5
Interarrivals of barges	0.04	1/0.04=25
Interarrivals of deep sea	0.23	1/0.23=4.3478

In section 4.1.8 we mentioned that we are going to increase the call size of barges in an effort to examine the effect that it has on the waiting times. To do so, we scaled up the handling time of barges. To express this in R, we have to scale up the rate input. We are going to increase the rate in R by the same percentage increase as the increase in scale as calculated in section 4.1.8. We therefore have the following results:

Table 6: New rates for Approaches 4 and 5, Source: Author's creation

	Initial scale of barges (days)	New scale (section 4.1.8)	% increase	Rate (=Scale) in R (1/days)
From 47 to 58 moves	0.09	0.1121	24.55%	11.1111(1+0.2455)= =13.8394
From 47 to 69 moves	0.09	0.13254	47.27%	11.1111(1+0.4727)= =16.3633

We are thus going to use these new rates as inputs in our fourth and fifth approach where we examine the effect of the increasing call size both in preemptive restart and preemptive resume scheduling.

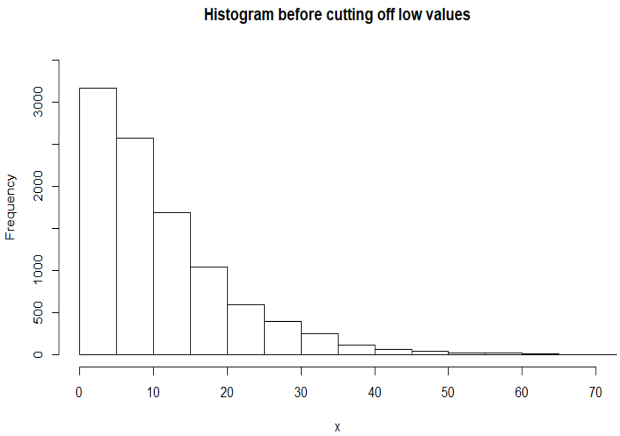
The rest of the functions are the trajectory, the timeout function, the add-resource function, the add-generator function and the get monitored arrivals. The inputs for our model and the description of these functions are given in the Appendix.

4.2.3 Cutting off low values of the handling time of barges

The calculations of this section will be used in our final approach (approach 6). In our calculations so far, we assume that all call sizes increase. In reality, call size has a distribution as not all barges have the same number of containers. If we cut off the low values of the handling time of the barges, then the mean will increase, and we will have the same effect as before namely decreasing the waiting times of our vessels.

To be able to increase the mean call size we will run the following loop in R as shown in Figure 37 in the Appendix which concerns the handling time of barges. We use the initial rate=11.1111 days as found under section 4.2.2 and we run a loop for 10000 times. The shape parameter remains the same meaning 1.24 days for our barges. We multiply the rgamma distribution with 100 to better visualize the effect on the histograms we will later create. That means that the mean handling time that will be calculated is multiplied by 100.

We then run the same loop with the only difference being that we set a minimum value of handling time which in this case will be 0.05 days in order to cut off low values and see the effect that it has on the mean. We also present the histograms to visualize the effect that we are achieving.



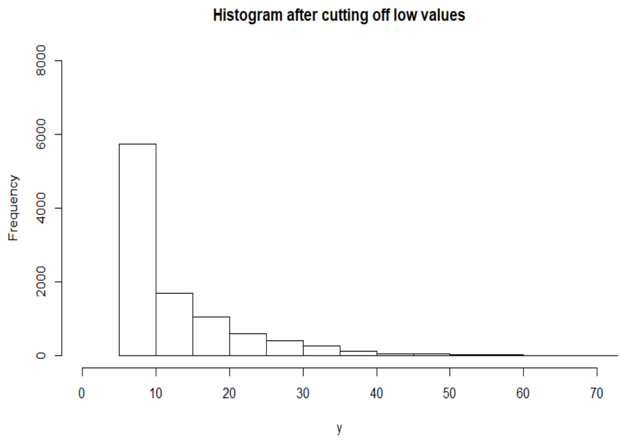


Figure 22: Histogram before cutting off low values, Source: Author's creation

Figure 23: Histogram after cutting off low values, Source: Author's creation

Figure 37 in the Appendix shows the R script used in order to calculate the new mean. The initial mean handling time was found to be 0.1112 days while the new mean handling time after setting the minimum handling time to be 0.05 days was found to be 0.1189 days. Figure 22 demonstrates the mean handling time before we cut off the low values whereas Figure 23 shows the situation after we cut off the low values. The histograms show the increasing mean given the higher frequency that occurs in Figure 23.

We now use equation (18) from section 4.1.8 to find the new number of barges. We already know that the initial number of barges is 609, which means that we will have:

0.1112*609=0.1189* new number of barges ⇔ new number of barges= 569 barges

That means that we were able to decrease the number of barges from 609 to 569.

From Table 1 we know that the coefficient of variation for the handling time of barges is 0.899 days. We are now able to calculate the new scale for our barges and incorporate it to our model.

The scale will now be: scale= new mean*(coefficient of variation)^2= 0.1189*(0.899)^2=0.096 days

Since the initial scale was 0.09 days as found in Table 1, that means that we have an increase of (0.096-0.09)/0.09=0.0666 or 6.66%. In the R script that translates into an 6.66% increase in rate (which was 11.1111 days as mentioned in section 4.2.2) so we end up with rate=11.1111*(1+0.0666)=11.8510. We apply these calculations both on preemptive priority with restart and preemptive priority with resume to see if the waiting times will be reduced.

Chapter 5: Results and analysis

In this chapter we will demonstrate the results of the simulations and we will analyze the outcome to see whether and how an optimization in the waiting times of the vessels can occur. To do so, a summary of the results will be presented in a table for each approach and we will then compare the approaches to see the differences that occur in each case. In each one of the following approaches, approximately 12500 vessels were simulated in total out of which approximately 11000 were barges and 1500 were deep-sea vessels (deep-sea). Given that our total monitored vessels were 688, this means that we simulated approximately 12500/(688*12)=1.5 year so we consider that the warm up effect has disappeared.

5.1 Results and analysis of Approach 1: No priority with 47 moves (NoPrio47)

As discussed in section 3.3, this approach deals with the assumption that no vessels have priority. Regardless of whether a barge or a deep-sea vessel arrives at the berth or the queue, it will be served on a first come first serve basis. This was a simplification of what happens in reality, and its purpose is to start implementing our model. The R-script which was created to simulate the waiting times of the vessels in this case is given in the Appendix (Figure 38) where we use the inputs as elaborated in chapters 3 and 4 above.

<u>The accuracy of the results</u>

What is important when presenting our results, is to determine how many decimals are accurate enough. To do so, we will use the batch means method to calculate the 95% confidence interval of the estimated mean waiting times (MWT). The results of this calculation can be considered the same for the following approaches since they are comparable.

We first divide the simulation in N=10 batches to obtain reliable results. Given that the total simulated vessels in the first approach were 12423, each batch will have approximately n=12423/10=1242 observations.

According to (Netlab.tkk.fi., 2020), the confidence interval can be calculated using the following steps:

The sample average of each batch (where X is the total waiting time, i is the batch and j is the number of observation) will be:

$$\overline{X_\iota} = \frac{1}{n}\sum_{j=1}^{n} X_{ij} \quad (19)$$

The sample average of the whole simulation will then be calculated as:

$$\widehat{\mu_N} = \frac{1}{N}\sum_{i=1}^{N} \overline{X_\iota} \quad (20)$$

We assume that the batches are long enough so the sample averages $\overline{X_\iota}$ of the batches are considered approximately independent. The sample variance is then calculated as follows:

$$S^2 = \frac{1}{N-1}\sum_{i=1}^{N} (\overline{X_\iota} - \widehat{\mu_N})^2 \quad (21)$$

Finally, we are able to obtain the confidence interval (at confidence level 95%) as:

$$\widehat{\mu_N} \pm Z_{1-a/2}\frac{S}{\sqrt{N}}\ where\ a = 0.05 \quad (20)$$

Table 7 summarizes the results (in HRS) from equations 19-21.

Table 7: Confidence interval, Source: Author's own

Batch number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
$\overline{X_\iota}$	0.76	0.16	0.68	0.20	0.43	0.26	0.65	0.37	0.52	0.33
$\widehat{\mu_N}$	0.44									
$(\overline{X_\iota} - \widehat{\mu_N})^2$	0.11	0.08	0.06	0.05	0.00	0.03	0.04	0.00	0.01	0.01
S^2	0.04									
Confidence interval	0.44±0.13									

Since the 95% confidence interval turned out to be 0.44±0.13 hours, and the random numbers of the model are not preserved for the same things in the process (meaning handling and arrivals of the same ship), we can imply that only 2 digits will be reliable when presenting our results. We consider having the same effect for our later approaches.

Table 8 below shows the results of the MWT in hours (HRS) that our model calculated for the total number of vessels but also for each type of vessel separately.

Table 8: MWT NoPrio47, Source: Author's creation

	Total	**Barges**	**Deep sea**
MWT (HRS)	0.44	0.45	0.38

In this approach, we can see that although the waiting time of the deep-sea vessels seems to be the lowest, overall, all types of vessels have approximately the same mean waiting time. The reason for that is that both are treated as equal since no priority is given based on their size or their importance. We can see that the MWT is low compared to what someone would expect and the reason for that may be the Covid19 virus as already mentioned. Approach 5 will take this into account and will give a better overview of the reality in times before Covid19.

Distribution of waiting times

What is also important to consider is the distribution of the waiting times of our vessels. Figures 24-29 below, show the result of the QQ plots made based on the waiting times of the simulated vessels (barges and deep sea) so as to see which distribution fits to the waiting time of the vessels in this approach. The QQ plots were made in R by following the same procedure as in section 4.2.1. For each type of vessel, we present the normal, the exponential and the gamma distributed fitting.

Distribution of waiting time of barges: NoPrio47

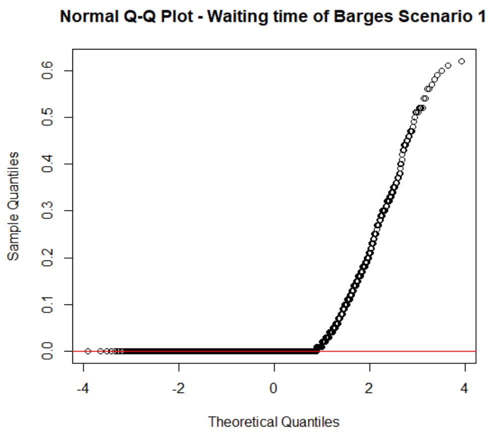


Figure 24: Normal QQ plot Barges NoPrio47, Source: Author’s creation

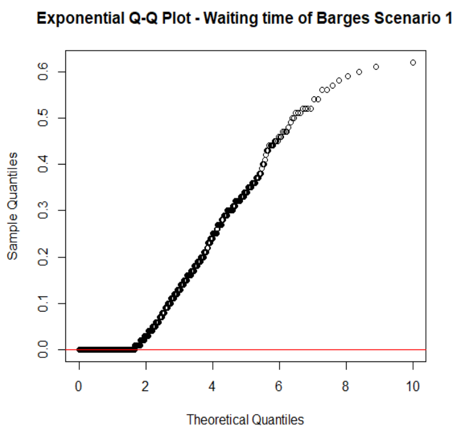


Figure 25: Exponential QQ plot Barges NoPrio47, Source: Author’s creation

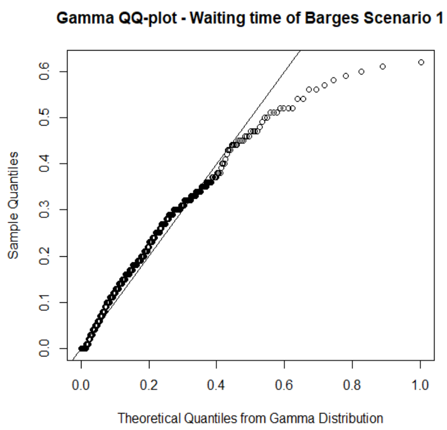


Figure 26: Gamma QQ plot Barges NoPrio47, Source: Author’s creation

Distribution of waiting time of deep-sea vessels: NoPrio47

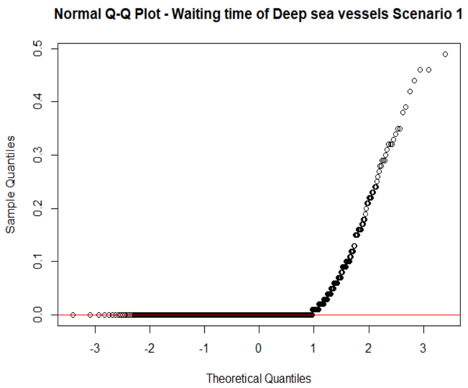


Figure 27: Normal QQ plot deep-sea NoPrio47, Source: Author's creation

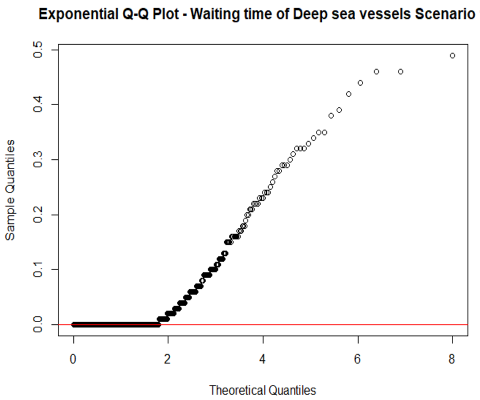


Figure 28: Exponential QQ plot deep-sea NoPrio47, Source: Author's creation

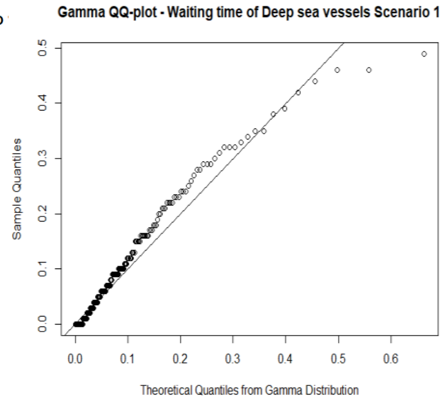


Figure 29: Gamma QQ plot deep-sea NoPrio47, Source: Author's creation

An important element to note, is that the normal and exponential QQ plots do not depict the 45 degrees theoretical line that one would expect. That is because in case the 1st and 3rd quartiles did not match the distribution then the line will not be 45 degrees showing that the distribution is not a good fit. The deviations in Figures 27 and 28 are high and we therefore conclude that the waiting times are gamma distributed. Some deviations in the gamma distribution should however be noted since in case of the barges, we see that in higher waiting times the distribution tends to be skewed. Moreover, in the case of deep-sea, we see that for some observations the theoretical quantile is not exactly in line. However, it is quite clear that the distribution the waiting times of the vessels in this approach follow, is the gamma distribution given that the theoretical quantiles mainly fall in line with the sample quantiles.

Utilization of berth

We are now able to calculate the utilization rate for this approach based on equation (9) as explained under section 4.1.6.

Table 9 depicts the results of the utilization rate in this approach based on the data that we have collected for the whole month. Equations (14)-(17) as explained under section 4.1.7 are used in order to find the service rate of the vessels with the only difference being that instead of one month, we now have 500 days of simulated arrivals. We use the data as given by the results of the simulation which was exported in excel.

Table 9: Utilization rate NoPrio47, Source: Author's creation

	Barges	Deep sea
Total handling time (days per month)	1210.23	1488.80
No of arrivals	10920	1499
Mean total handling time (days per ship)	0.11	0.99
Average service rate (ships per day)	9.02	1.01
Average service rate (ships per period of 500 days)	4511.54	503.43
No of berths	8.00	8.00
Utilization rate	**0.30**	**0.37**

As we can see, the utilization rate for barges turned out to be 0.3=30% whereas the utilization rate for deep-sea vessels turned out to be 0.37=37%. We are then able to calculate the total utilization as:

Total utilization= Utilization of barges+ Utilization of deep-sea vessels=0.67=67%. The utilization appears to be the same as the one we derived from the data we collected over the period of one month from ECT Delta terminal.

5.2 Results and analysis for Approach 2: Non preemptive priority with 47 moves (Prio47)

As earlier discussed in section 3.3, in this approach we assume that deep-sea have a non-preemptive priority over barges which means that if the berth is free, the deep-sea will be served first but if the berth is occupied by a barge, they are not able to stop the service of the barge. The R-script which was created to simulate the waiting times of the vessels in this case is given in the Appendix (Figure 39) where we use the inputs as elaborated in chapters 3 and 4 above.

Table 10 below shows the results of the MWT in HRS for the first and second approach that our model calculated.

Table 10: MWT NoPrio47 and Prio47, Source: Author's creation

	Total (HRS)	Barges (HRS)	Deep sea (HRS)
NoPrio47	0.44	0.45	0.38
Prio47	0.70	0.77	0.16

We can see that the difference in the MWT of the two types of vessels has now increased compared to NoPrio47, which can be understood since this approach does not treat all kinds of vessels as equal but assumes priority. We see that the MWT of the deep-sea is now reduced because of the high priority given to them while the barges have an increased MWT due to the low priority they have over the deep-sea.

Distribution of waiting times

The distribution of the waiting times of our vessels is again plotted against QQ plot with the purpose to find what distribution is followed in this approach. Following the same method as in NoPrio47, Figures 54-59 in the electronic pdf file in the Appendix depict these plots which show almost the same pattern as in the first approach meaning that once again, the waiting times of both vessels are gamma distributed.

Utilization of berth

We are again able to calculate the utilization rate for this approach based on equation (9). Table 11 depicts the results of the utilization rate in this case based on the data that we have collected with the only difference being that instead of one month, we now have 500 days of simulated arrivals. We use the data as given by the results of the simulation which was exported in excel.

Table 11: Utilization rate Prio47, Source: Author's creation

	Barges	**Deep-sea**
Total handling time (days per month)	1206.41	1554.64
No of arrivals	10885	1528
Mean total handling time (days per ship)	0.11	1.02
Average service rate (ships per day)	9.02	0.98
Average service rate (ships per period of 500 days)	4511.31	491.43
No of berths	8.00	8.00
Utilization rate	**0.30**	**0.39**

As we can see, the utilization rate for barges turned out to be 0.3=30% whereas the utilization rate for deep-sea vessels turned out to be 0.39=39%. We are then able to calculate the total utilization as:

Total utilization= Utilization of barges+ Utilization of deep-sea vessels=0.69=69%.

The utilization of the deep-sea vessels seems to have slightly increased after giving them high priority while the utilization of the barges was kept the same. That means that giving prioritization to the vessels increases the utilization of the berth.

5.3 Results and Analysis for Approach 3: Preemptive priority scheduling with 47 moves (PreemptPrio47)

In NoPreemptPrio47, we analyzed the case of non-preemptive priority scheduling which does not enable a high priority vessel to interrupt the service of a low priority one if the latter has reserved the slot. In approach 3 (PreemptPrio47), we examine the case of preemptive priority scheduling where high priority vessels are given a preemptive right to be served over non-priority vessels. We both examine preemptive priority with resume and preemptive priority with restart meaning that the vessel which is interrupted, can later either resume its service from where it was left or restart it. The R-script which was created in order to simulate the waiting times of the vessels in the case of preemptive priority with resume and restart is given in the Appendix (Figures 40-41) where we use the inputs as elaborated in chapters 3 and 4 above.

Table 12 below shows the results of the MWT in HRS that our model calculated. We also include the findings from the other approaches so far.

Table 12: MWT NoPrio47, Prio47, PreemptPrio47, Source: Author's creation

		Total (HRS)	**Barges (HRS)**	**Deep-sea (HRS)**
NoPrio47		0.44	0.45	0.38
Prio47		0.70	0.77	0.16
PreemptPrio47	Resume	0.75	0.85	0.01
	Restart	0.90	1.01	0.03

We can see that the difference in the MWT of the two types of vessels has now further increased compared to NoPrio47 and Prio47, because of the priority given to deep sea but also since the service of the barges can now be interrupted. While the MWT of barges has now increased, the MWT of the deep-sea has almost been eliminated. Again, that can be attributed to the fact that now high priority vessels are able to interrupt the process. What is also important to note is that in case of restart, the average waiting time of both types of vessels seems to increase which can be explained by the fact that they need to start their service from the beginning each time they are interrupted.

Distribution of waiting times

Following the same steps as before, we will again examine the distribution of the waiting times of our vessels through the QQ plots. Figures 60-65 in the electronic pdf file in the Appendix, show the result of the QQ plots made based on the waiting times of the simulated barges. In this case, we distinguish between preemptive priority with resume and restart. Once again, the waiting times of the barges appear to be gamma distributed with a slightly increased skewness.

The QQ plots concerning the waiting times of deep-sea in PreemptPrio47 with resume and restart tend to show a different result than the one we have observed so far. When it comes to deep-sea, the gamma distribution that we have seen so far to be the best fit does not seem to fit the waiting times at all. On the other hand, the normal and exponential distribution seem to be a better fit and especially for the lower values of the waiting times the fit is perfect. With slight differences, the normal distribution seems to fit the data better than the exponential one given the higher deviations in the larger observations of the deep-sea vessels. Thus, we can conclude that the waiting time of the deep-sea vessels in this approach are normally distributed not only in the resume but also in the restart case which indicates that when preemptive priority is introduced, the waiting times of the deep-sea are no longer gamma distributed. Figures 30-35 depict the results of the QQ plots.

Distribution of waiting time of deep-sea vessels: PreemptPrio47 Resume

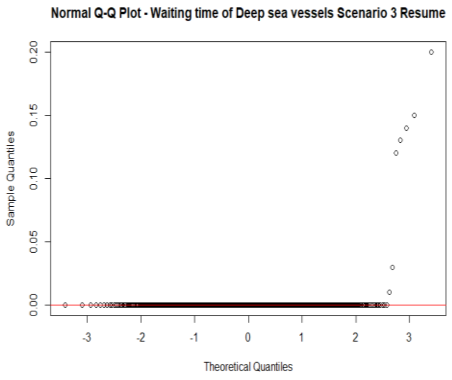


Figure 30: Normal QQ plot deep-sea PreemptPrio47 Resume, Source: Author's creation

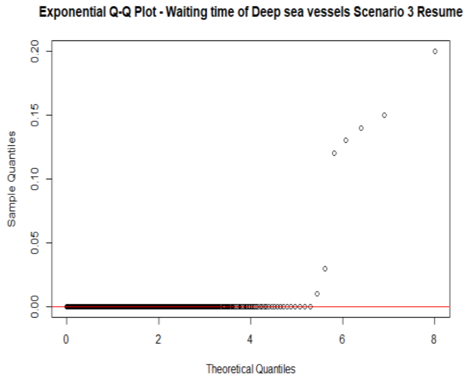


Figure 31: Exponential QQ plot deep-sea PreemptPrio47 Resume, Source: Author's creation

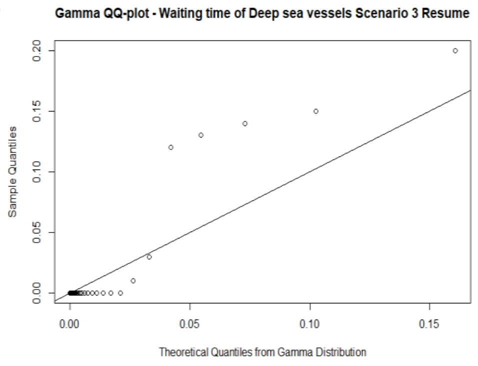


Figure 32: Gamma QQ plot deep-sea PreemptPrio47 Resume, Source: Author's creation

Distribution of waiting time of deep-sea vessels: PreemptPrio47 Restart

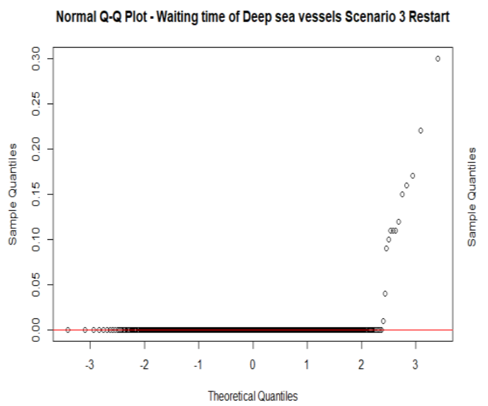


Figure 33: Normal QQ plot deep-sea PreemptPrio47 Restart, Source: Author's creation

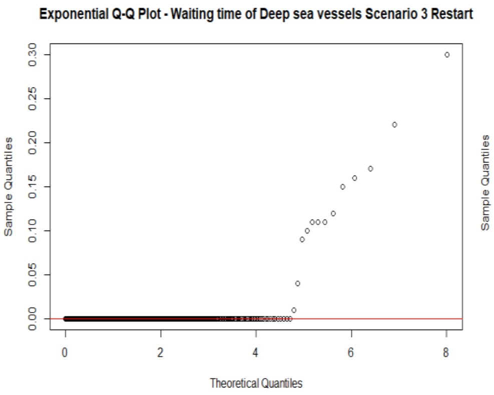


Figure 34: Exponential QQ plot deep-sea PreemptPrio47 Restart, Source: Author's creation

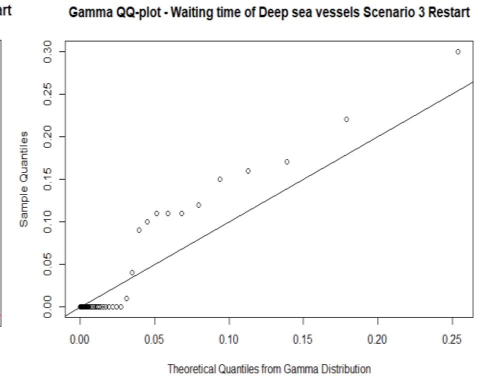


Figure 35: Gamma QQ plot deep-sea PreemptPrio47 Restart, Source: Author's creation

Utilization of berth

Following the same procedure as in the previous approaches, Table 13 depicts the results of the utilization rate in case of preemptive priority with resume where equation (9) is again used. The utilization rate is considered the same for preemptive priority with restart.

Table 13: Utilization rate PreemptPrio47, Source: Author's creation

	Barges	**Deep sea**
Sum of Handling time (days per month)	1206.03	1498.94
No of arrivals	10866	1509
Average (mean) total handling time (days per ship)	0.11	0.99
Average service rate (ships per day)	9.01	1.01
Average service rate (ships per period of 500 days)	4504.85	503.36
No of berths	8.00	8.00
Utilization rate	**0.30**	**0.37**

As we can see, the utilization rate for barges for turned out to be 0.3=30% whereas the utilization rate for deep-sea vessels turned out to be 0.37=37%. We are then able to calculate the total utilization as:

Total utilization= Utilization of barges+ Utilization of deep-sea vessels=0.67=67% in case of resume and 68% in case of restart.

The utilization of the deep-sea seems to have decreased to the levels of NoPrio47, which also brought the overall utilization in the same levels. This means that setting a preemptive priority scheduling can decrease slightly the utilization of the berth.

5.4 Results and Analysis for Approach 4: Increasing the minimum call size

This approach dealt with the primary goal of this paper which is to reduce the waiting times of the vessels at the terminal by increasing the minimum call size of the barges. We again assume preemptive priority either with restart or with resume and we vary the call size while the number of barges decreases. We tested this approach by first increasing the call size from 47 to 58 moves per barge and later to 69 moves to see a bigger effect. By steadily increasing the minimum call size we see whether the waiting times are eliminated which means that the efficiency of the terminal is increased.

Increasing the call size to 58 moves (Incr.CallSize58)

The R-script which was created in order to simulate the waiting times of the vessels in the case of increasing the call size to 58 moves is given in the Appendix (Figures 42-43). Table 14 below shows the results of the MWT in HRS that our model calculated in the case where the call size is increased from 47 to 58 moves. We also include the findings from the other approaches so far.

Table 14: MWT NoPrio47, Prio47, PreemptPrio47, Incr.CallSize58, Source: Author's creation

		Total (HRS)	**Barges (HRS)**	**Deepsea (HRS)**
NoPrio47		0.44	0.45	0.38
Prio47		0.70	0.77	0.16
PreemptPrio47	Resume	0.75	0.85	0.01
	Restart	0.90	1.01	0.03
Incr.CallSize58	Resume	0.60	0.68	0.01
	Restart	0.88	0.99	0.03

To see whether our goal was achieved, we need to compare these results to the ones observed under PreemptPrio47. We observe that the total MWT indeed did decrease. We will further expand on these results in section 5.7 where we will compare the approaches.

Distribution of waiting times

Once again, it is interesting to see what distribution the waiting times of our vessels follow in this approach based on their QQ plots. The plots are given in figures 66-77 in the electronic pdf file in the Appendix, where we observe that the waiting times of the barges and deep-sea in Incr.Callsize58, follow a similar distribution pattern to PreemptPrio47 since once again, the waiting times of the barges are gamma distributed although an important deviation occurs in the case of restart in the point where the sample quantiles are between 0.5 and 1. When it comes to the deep-sea, although some deviations occur for the larger observations, it is clear that the majority of the waiting times are exactly in line with the normal quantiles.

Increasing the call size to 69 moves (Incr.CallSize69)

After having examined the possibility to increase the call size and since we want to see a bigger effect in our results, we proceed by further increasing the call size to 69 moves this time. The R-script which was created in order to simulate the waiting times of the vessels in the case of increasing the call size to 69 moves is given in the Appendix (Figures 44-45).

Table 15 below shows the results of the MWT in HRS that our model calculated in the case where the call size is increased from 47 to 69 moves. We also include the findings from the other approaches so far.

Table 15: MWT NoPrio47, Prio47, PreemptPrio47, Incr.CallSize58, Incr.CallSize69, Source: Author's creation

		Total (HRS)	**Barges (HRS)**	**Deepsea (HRS)**
NoPrio47		0.44	0.45	0.38
Prio47		0.70	0.77	0.16
PreemptPrio47	Resume	0.75	0.85	0.01
	Restart	0.90	1.01	0.03
Incr.CallSize58	Resume	0.60	0.68	0.01
	Restart	0.88	0.99	0.03
Incr.CallSize69	Resume	0.28	0.32	0.01
	Restart	0.19	0.22	0

To see whether we further decreased the waiting times of our vessels, we need to compare these results to the ones observed under PreemptPrio47 but also under Incr.CallSize58. We observe that the total MWT indeed did decrease even more compared to using 58 moves. We will further expand on these results in section 5.7 where we will compare the approaches.

Distribution of waiting times

We again perform QQ plots for the three most common distributions: normal, exponential and gamma. The results are depicted in figures 78-89 in the electronic pdf file in the Appendix.

In the case of increasing the call size to 69 moves, the QQ plots enable us to notice that despite the higher deviations in the larger observations of our dataset, the waiting time of barges in both preemptive priority with resume and restart seems to follow a gamma distribution as they did in all previous approaches. On the other hand, the waiting times of the deep-sea once again best fit to a normal distribution. It is worth noting that in case of preemptive priority with restart, the deviations are almost none, which means that the normal distribution fits the waiting times well.

Utilization of berth

We will again use equation (9) to calculate the utilization rate of each type of vessel.

Tables 16 and 17 depict the results of the utilization rate in this approach based on the excel file exported after the simulation. Table 16 is concerned with the utilization rate in case of increasing the call size to 58 moves while Table 17 depicts the results in case of increasing the call size to 69 moves.

Table 16: Utilization rate Incr.CallSize58, Source: Author's creation

	Barges	**Deep sea**
Total handling time (days per month)	983.94	1545.46
No of arrivals	10987	1535
Mean total handling time (days per ship)	0.09	1.01
Average service rate (ships per day)	11.17	0.99
Average service rate (ships per week-month)	5583.19	496.62
No of berths	8.00	8.00
Utilization rate	**0.25**	**0.39**

Table 17: Utilization rate Incr.CallSize69, Source: Author's creation

	Barges	**Deep sea**
Total handling time (days per month)	847.72	1487.46
No of arrivals	11090	1484
Mean total handling time (days per ship)	0.08	1.00
Average service rate (ships per day)	13.08	1.00
Average service rate (ships per week-month)	6541.04	498.84
No of berths	8.00	8.00
Utilization rate	**0.21**	**0.37**

Given the increasing call size of the barges which in this approach has caused a decrease in the number of barges, we see that their utilization rate has significantly dropped whereas the utilization rate of the deep-sea remains rather constant since their arrival rate remains the same. In the case of an increasing call size to 58 moves, the utilization rate of the barges has decreased to 25% with the total being 25%+39%=64% while in case of an increasing call size to 69 moves, barges have a rate of 21% while the total utilization adds up to 21%+37%=58% which is the lowest so far. The reason for the reduction is the decreased number of barges that need to be served which alleviates the pressure from the terminal as the service rate increases.

5.5 Results and Analysis for Approach 5: One less berth

This approach aimed at giving a more realistic overview of what is happening in the terminal under normal circumstances meaning without the impact that Covid19 had in 2020. To do so, one less berth was considered in this case so as to increase the waiting time at the levels it is expected to be, given the higher arrival rate of vessels that exists. The berths in this case are 7 instead of 8 and we conduct the same procedure as in PreemptPrio47 and Incr.CallSize meaning we assumed preemptive priority scheduling with restart and resume and after that we increased the call size to see the effect.

PreemptPrio47 with one less berth (LessBerth47)

The R-script which was created in order to simulate the waiting times of the vessels in the case of one less berth is given in the Appendix (Figures 46-47) where we use the inputs as elaborated in chapters 3 and 4 above and we decrease the berths to 7.

Table 18 below shows the results of the MWT in HRS that our model calculated. We also include the findings from the other approaches so far.

Table 18: MWT NoPrio47, Prio47, PreemptPrio47, Incr.CallSize58, Incr.CallSize69, LessBerth47, Source: Author's creation

		Total (HRS)	Barges (HRS)	Deep-sea (HRS)
NoPrio47		0.44	0.45	0.38
Prio47		0.70	0.77	0.16
PreemptPrio47	*Resume*	0.75	0.85	0.01
	Restart	0.90	1.01	0.03
Incr.CallSize58	*Resume*	0.60	0.68	0.01
	Restart	0.88	0.99	0.03
Incr.CallSize69	*Resume*	0.28	0.32	0.01
	Restart	0.19	0.22	0
LessBerth47	*Resume*	2.65	3.01	0.08
	Restart	3.99	4.52	0.12

As we can see, the waiting times now are indeed higher than those of PreemptPrio47 which is understandable given that we now have one less server for our vessels. We will further compare LessBerth47 with PreemptPrio47 in section 5.7.

Distribution of waiting times

Once again, finding the distribution that these waiting times follow is important. We conduct the QQ plots again for the barges and deep-sea both for preemptive priority with resume and restart. Figures 90-101 in the electronic pdf file in the Appendix depict the plots. Again, the waiting times of the barges follow a gamma distribution with even less deviations than before. When it comes to the deep-sea, while lower waiting times are normally distributed, higher waiting times tend to follow the gamma distribution. This indicates that when we decrease the servers, the distribution of the deep-sea changes and becomes a combination of the distributions we have seen so far.

Utilization of berth

Table 19 presents the utilization rate in this approach based on the data that we have simulated and equation (9). We use the same calculations as we did in the previous approaches.

Table 19: Utilization rate LessBerth47, Source: Author's creation

	Barges	**Deep sea**
Total handling time (days per month)	1208.44	1482.98
No of arrivals	10877	1521
Average (mean) total handling time (days per ship)	0.11	0.98
Average service rate (ships per day)	9.00	1.03
Average service rate (ships per period of 500 days)	4500.42	512.82
No of berths	8.00	8.00
Utilization rate	**0.30**	**0.37**

The results in this case appear to be quite similar to those in PreemptPrio47, given that the number of arrivals is the same which creates a utilization rate of 30% for the barges and 37% for the deep-sea vessels. The overall utilization is now brought back to 67% as it was before.

Incr.CallSize with one less berth

Increasing call size to 58 moves (LessBerth58)

The R-script which was created in order to simulate the waiting times of the vessels in this case is given in the Appendix (Figures 48-49) where we use the inputs as elaborated in chapters 3 and 4 above while we decrease the berths to 7.

Table 20 below shows the results of the MWT in HRS that our model calculated. We also include the findings from the other approaches so far.

Table 20: MWT NoPrio47, Prio47, PreemptPrio47, Incr.CallSize58, Incr.CallSize69, LessBerth47, LessBerth58, Source: Author's creation

		Total (HRS)	**Barges (HRS)**	**Deep-sea (HRS)**
NoPrio47		0.44	0.45	0.38
Prio47		0.70	0.77	0.16
PreemptPrio47	*Resume*	0.75	0.85	0.01
	Restart	0.90	1.01	0.03
Incr.CallSize58	*Resume*	0.60	0.68	0.01
	Restart	0.88	0.99	0.03
Incr.CallSize69	*Resume*	0.28	0.32	0.01
	Restart	0.19	0.22	0
LessBerth47	*Resume*	2.65	3.01	0.08

	Restart	3.99	4.52	0.12
LessBerth58	*Resume*	2.30	2.59	0.13
	Restart	1.78	2.00	0.13

By comparing LessBerth58 with LessBerth47 we again see the effect that an increasing call size has on the waiting times of the vessels, meaning that they are reduced. We will further expand on these results in section 5.7 where we will compare the approaches.

Distribution of waiting times

When it comes to the distribution of the waiting times of the vessels, the QQ plots show that the barges seem to follow the same pattern as in all other approaches, meaning that they are gamma distributed while some deviations occur for the larger observations. When it comes to the waiting times of the deep-sea, the observations tend to have bigger deviations in all distributions. One can say that for lower observations, the normal distribution is a better fit while for larger observations the gamma distribution is appropriate given that it has the least deviations. This indicates that as the waiting times become higher and we have one less server, their normality lessens. The QQ plots can be depicted in figures 102-113 in the electronic pdf file in the Appendix.

Increasing call size to 69 moves (LessBerth69)

We proceed by further increasing the call size to 69 moves this time. The R-script which was created in order to simulate the waiting times of the vessels in this case is given in the Appendix (Figures 50-51) where we use the inputs as elaborated in chapters 3 and 4 above and we decrease the berths to 7. Table 21 below shows the results of the MWT in HRS. We also include the findings from the other approaches so far.

Table 21: MWT NoPrio47, Prio47, PreemptPrio47, Incr.CallSize58, Incr.CallSize69, LessBerth47, LessBerth58, LessBerth69, Source: Author's creation

		Total (HRS)	Barges (HRS)	Deep-sea (HRS)
NoPrio47		0.44	0.45	0.38
Prio47		0.70	0.77	0.16
PreemptPrio47	*Resume*	0.75	0.85	0.01

	Restart	0.90	1.01	0.03
Incr.CallSize58	*Resume*	0.60	0.68	0.01
	Restart	0.88	0.99	0.03
Incr.CallSize69	*Resume*	0.28	0.32	0.01
	Restart	0.19	0.22	0
LessBerth47	*Resume*	2.65	3.01	0.08
	Restart	3.99	4.52	0.12
LessBerth58	*Resume*	2.30	2.59	0.13
	Restart	1.78	2.00	0.13
LessBerth69	*Resume*	1.26	1.42	0.10
	Restart	1.25	1.40	0.15

By comparing LessBerth69 with LessBerth47 and LessBerth58 we once again see the effect of decreasing waiting times as the call size of the barges increases. We will further expand on these results in section 5.7 where we will compare all the approaches.

Distribution of waiting times

After creating the QQ plots for the waiting times of the vessels (depicted in figures 114-125 in the electronic file in the Appendix), we can realize that once again the waiting times of the barges appear to follow the gamma distribution as in all previous approaches. Decreasing the number of berths by one seems to create smaller deviations from the theoretical quantiles than in case of 8 berths. Nonetheless, some outliers exist again for larger observations.

As for the deep-sea, similarly to the LessBerth47 and LessBerth58, lower observations of the waiting times tend to keep the normality that we saw in previous approaches but as the observations become larger, the deviation from the theoretical quantiles deteriorates and the gamma distribution becomes more appropriate. It should also be noted that in this case, the deviations from the gamma distribution tend to be less.

Utilization of berth

Tables 22 and 23 depict the results of the utilization rate in this approach based on equation (11) and following the same calculations as in previous approaches. Table 22 is concerned with the utilization rate in case of increasing the call size to 58 moves while Table 23 depicts the results in case of increasing the call size to 69 moves.

Table 22: Utilization rate LessBerth58, Source: Author's creation

	Barges	**Deep sea**
Total handling time (days per month)	986.27	1530.13
No of arrivals	11015	1516
Mean total handling time (days per ship)	0.09	1.01
Average service rate (ships per day)	11.17	0.99
Average service rate (ships per week-month)	5584.17	495.38
No of berths	8.00	8.00
Utilization rate	**0.25**	**0.38**

Table 23: Utilization rate LessBerth69, Source: Author's creation

	Barges	**Deep sea**
Total handling time (days per month)	840.56	1557.75
No of arrivals	11031	1538
Mean total handling time (days per ship)	0.08	1.01
Average service rate (ships per day)	13.12	0.99
Average service rate (ships per week-month)	6561.66	493.66
No of berths	8.00	8.00
Utilization rate	**0.21**	**0.39**

Same as in Incr.Callsize58 and Incr.CallSize69, the utilization rate of the barges is decreased as the call size increases. In the case of an increasing call size to 58 moves, the utilization rate of the barges has decreased to 25% with the total being 25%+39%=64% while in case of an increasing call size to 69 moves, barges have a rate of 21% while the total utilization adds up to 21%+39%=60% which is the second lowest so far. The reason for the reduction is of course the decreased number of barges that need to be served which alleviates the pressure from the terminal as the service rate increases.

5.6 Results and Analysis for Approach 6: Cutting off low values of the handling time of the barges (Cutoff)

This approach aimed at examining another way of increasing the call size of the barges by taking into account that this call size follows a distribution and that each barge does not carry the same number of containers. We considered the preemptive priority with resume and restart as in the previous approaches and we cut off the low values of the handling time of barges in order to increase their mean handling time. The goal was to reduce the waiting time as we did in approach 4.

The R-script which was created in order to simulate the waiting times of the vessels in this case is given in the Appendix (Figures 52-53) where we use the inputs as elaborated in section 4 above.

Table 24 below shows the results of the MWT in HRS. We also include the findings from the other approaches so far.

Table 24: MWT - All Approaches, Source: Author's creation

		Total (HRS)	**Barges (HRS)**	**Deep-sea (HRS)**
NoPrio47		0.44	0.45	0.38
Prio47		0.70	0.77	0.16
PreemptPrio47	*Resume*	0.75	0.85	0.01
	Restart	0.90	1.01	0.03
Incr.CallSize58	*Resume*	0.60	0.68	0.01
	Restart	0.88	0.99	0.03
Incr.CallSize69	*Resume*	0.28	0.32	0.01
	Restart	0.19	0.22	0
LessBerth47	*Resume*	2.65	3.01	0.08
	Restart	3.99	4.52	0.12
LessBerth58	*Resume*	2.30	2.59	0.13
	Restart	1.78	2.00	0.13
LessBerth69	*Resume*	1.26	1.42	0.10
	Restart	1.25	1.40	0.15
Cutoff	*Resume*	0.71	0.80	0.03
	Restart	0.77	0.88	0.01

It is useful to compare the Cutoff results with the ones obtained from PreemptPrio47 to see whether we managed to again decrease the waiting times by cutting off the low values of handling time and therefore increasing the call size. We compare the findings in section 5.7, but we can already see that the waiting times did decrease, which indicates that the goal was achieved.

Distribution of waiting times

The distribution of the waiting times of the vessels follow the same pattern as LessBerth47, LessBerth58 and LessBerth69, which is proven by the QQ plots in figures 126-137 in the electronic pdf file in the Appendix. The waiting times of the barges fit rather well into the gamma distribution with some deviations for the larger observations while for the deep-sea, lower waiting times present normality and as the waiting times become higher they tend to be gamma distributed although deviations are still apparent.

Utilization of berth

Table 25 shows of the utilization rate in this approach based on equation (11).

Table 25: Utilization rate Cutoff, Source: Author's creation

	Barges	**Deep sea**
Total handling time (days per month)	1136.00	1512.23
No of arrivals	10905	1521
Mean total handling time (days per ship)	0.10	0.99
Average service rate (ships per day)	9.60	1.01
Average service rate (ships per week-month)	4799.72	502.90
No of berths	8.00	8.00
Utilization rate	**0.28**	**0.38**

Due to the fact that in this approach we are again trying to increase the call size of the barges but in a different way, we see that the effect on the utilization rate is the same as in Incr.CallSize58, Incr.CallSize69, LessBerth58 and LessBerth69, meaning a rather similar utilization rate for the deep-sea while the utilization rate for the barges reduces significantly. The total utilization of the berth is now 28%+38%=64%.

5.7 Comparison of all approaches

For illustration purposes, the cumulative Table 24 of all the results (MWT) as presented in section 5.6 is again depicted below (named Table 26) while a cumulative table of the utilization rates is depicted in Table 28. We are now able to compare the approaches and see in which case we achieve the least MWT for the vessels and therefore the highest efficiency in terms of waiting time for the terminal as well as the levels of utilization in each case. The 90th percentile of the waiting times of our vessels is also given in Table 27 to detect any extreme values in our data.

Table 26: MWT- All Approaches, Source: Author's creation

		Total (HRS)	Barges (HRS)	Deep-sea (HRS)
NoPrio47		0.44	0.45	0.38
Prio47		0.70	0.77	0.16
PreemptPrio47	*Resume*	0.75	0.85	0.01
	Restart	0.90	1.01	0.03
Incr.CallSize58	*Resume*	0.60	0.68	0.01
	Restart	0.88	0.99	0.03
Incr.CallSize69	*Resume*	0.28	0.32	0.01
	Restart	0.19	0.22	0
LessBerth47	*Resume*	2.65	3.01	0.08
	Restart	3.99	4.52	0.12
LessBerth58	*Resume*	2.30	2.59	0.13
	Restart	1.78	2.00	0.13
LessBerth69	*Resume*	1.26	1.42	0.10
	Restart	1.25	1.40	0.15
Cutoff	*Resume*	0.71	0.80	0.03
	Restart	0.77	0.88	0.01

The first approach (NoPrio47) which assumed that there is no priority while the number of moves was kept at 47, depicts low waiting times due to the fact that it does not take into account the priority that vessels have in reality. Once priority is considered (Prio47), we see that the waiting times do increase while preemptive priority (PreemptPrio) increases the total MWT even more especially in case of preemptive priority with restart. The increase in the MWT is caused by the waiting times of the barges while the deep-sea seem to be able to decrease their waiting times which is attributed to the high priority they have.

The results of Incr.CallSize58 and Incr.CallSize69 prove that by increasing the call size of the barges, we achieve a positive effect on the total waiting time of the vessels given that the number of barges in this case declines. The effect is bigger on the waiting times of the barges while the deep-sea require a high increase in the call size of the barges for their waiting times to be affected. Nonetheless, we see that in case of increasing the call size to 69 moves, the deep-sea manage to eliminate their waiting time as well.

By decreasing the number of berths by one (LessBerth47), in an effort to have a more realistic view in the situation of the waiting times in the years before the Covid19, we see that indeed the waiting times are higher which is reasonable given the lower number of servers for our vessels. This highlights the impact that Covid19 had on the arrival rate of the vessels and how the situation is in real life. Again, LessBerth58 and LessBerth69 show that the total waiting times are reduced as the call size of the barges increases. However, it should be noted that in case of one less berth, the waiting times of the deep-sea are negatively impacted in contrast to Incr.CallSize69. This result indicates that when we have higher initial waiting times there is the possibility that we need to further increase the call size of the barges in order to be able to see the effect on the waiting times of the deep-sea as well. However, since the waiting times of the deep-sea are relatively low, this finding should not consist a concern. The overall waiting time of the vessels has been reduced which shows the higher efficiency that an increasing call size brings to the terminal.

By cutting off the low values of the handling time of the barges (Cutoff) as a way of increasing their call size is proven to be a successful way of reducing the waiting times of all types of vessels which can be seen if we compare it with PreemptPrio47. Finally, it should be noted that the restart case is expected to provide the most realistic view in all approaches.

Extreme values: 90th percentile

The result of the 90th percentile refers to 90% of the waiting times found at or below this value. After having examined the MWT it is useful to add this measure as well to detect any extreme values in our simulated vessels. For the 90th percentile of the waiting times we use the R function: quantile(waiting, probs=c(0.90)). Waiting refers to the waiting time of our vessels (all vessels, barges or deep-sea) and we use this function for both types of vessels and each approach separately. Since the result will be in days, we multiply it by 24 to obtain the 90th percentile in hours. Table 27 presents the findings.

Table 27: 90th percentile- All Approaches, Source: Author's own

		All vessels (HRS)	Barges (HRS)	Deep-sea (HRS)
NoPrio47		1.2	1.44	0.96
Prio47		1.92	2.16	0.48
PreemptPrio47	*Resume*	1.92	2.4	**0**
	Restart	1.92	2.64	**0**

Incr.CallSize58	*Resume*	1.2	1.68	**0**
	Restart	**0.72**	**0.96**	**0**
Incr.CallSize69	*Resume*	**0**	**0.242**	**$1.839e^{-14}$**
	Restart	**0**	**$6.817e^{-13}$**	$1.711e^{-14}$
LessBerth47	*Resume*	9.12	10.8	**0**
	Restart	15.84	18.24	**0**
LessBerth58	*Resume*	6.24	7.68	**$1.854e^{-14}$**
	Restart	4.56	5.52	**$1.907e^{-14}$**
LessBerth69	*Resume*	2.64	3.12	**0**
	Restart	3.36	4.08	**0**
Cutoff	*Resume*	1.44	1.92	**$4.008e^{-13}$**
	Restart	1.68	2.16	**$1.508e^{-14}$**

Since the MWT is considered to be the 50th percentile of our data, one would expect the 90th percentile to always be higher. By comparing Tables 26 and 27 however, we can see that in some cases, the 90th percentile depicts a lower value than the mean (marked with red in Table 27). This fact indicates that almost in all cases for the deep-sea and also for all types of vessels in Incr.CallSize58 Restart and Incr.CallSize69, we have a small chance of getting a very high MWT, which is distorting the average. On the other hand, since the high MWT happens less than 10% of the time, it is not changing the 90th percentile. We can also see that in these cases the differences between the MWT and the 90th percentile is not big.

For the rest of our approaches, we can see that the 90th percentile is higher than the MWT which gives us an indication about the extreme values per approach. We can see that the highest extremes can be found in case we reduce the number of berths from 8 to 7 (LessBerth47, LessBerth58 and LessBerth69) with the biggest difference being in LessBerth47 with Restart. Thus, in case we have one less server and without increasing the call size of our barges, the MWT of our vessels and especially of the barges show extreme values with 18.24 hours being the highest. Within the 90% of our barges, we therefore have extreme values which highlight the need to increase the call size to achieve less MWT overall.

Table 28: Utilization rate- All Approaches, Source: Author's own

	Utilization rate Barges	**Utilization rate Deep-sea**
NoPrio47	30%	37%
Prio47	30%	39%
PreemptPrio47	30%	37%
Incr.CallSize58	25%	39%
Incr.CallSize69	21%	37%
LessBerth47	30%	37%
LessBerth58	25%	38%
LessBerth69	21%	39%
Cutoff	28%	38%

As we can derive from Table 28, the utilization rate in case of deep-sea remains stable over all approaches. No matter what priority scheduling we choose or what call size the barges will have, the utilization of berth in case of the high priority vessels ranges between 37%-39%. On the contrary, we see that the utilization rate in case of the barges is highly affected in case we increase their call size (Incr.CallSize58, Incr.CallSize69, LessBerth58, LessBerth69 and Cutoff). The reason behind that is the fact that as the call size increases, the number of barges is reduced, which further increases their service rate.

Distribution of waiting times

As for the waiting times of our vessels, when it comes to barges, they seem to always follow the gamma distribution whereas for the deep-sea depending on the approach, the waiting times are either normally or gamma distributed. For the approaches which assumed no preemptive priority (NoPrio47 and Prio47), the waiting times of the deep-sea where gamma distributed. On the other hand, preemptive priority with or without an increasing call size and assuming 8 berths (PreemptPrio47, Incr.CallSize58, Incr.CallSize69) seems to cause a change in the distribution of the waiting times of the deep-sea as they become normal. Finally, approaches LessBerth and Cutoff revealed a mixed distribution pattern as the lower waiting times of the deep-sea are normally distributed whereas the higher ones are gamma distributed.

Chapter 6: Discussion

In this chapter we dive into the limitations of this research, the generality of our results and we have a critical view over our findings.

To start with, the time availability to conduct the research is a limitation which affected the data that we collected for the arrival times of the vessels. As already discussed, the data arise from a period of four weeks from ECT Delta terminal in Rotterdam. If the time period in which the research was conducted was longer, we would have been able to collect data over a longer period which would make our results more valid since the size of our sample would be bigger. In addition, given the Covid19 virus, our data are affected by the smaller number of arrivals in the port which results in less waiting times. The number of berths was derived based on calculations made upon the assumption regarding the length of our vessels, but it can be considered as a rather realistic number. Reducing the number of servers enables us to include partially the possible effect that we would see in a more realistic case where increased waiting times would occur. Moreover, it should be mentioned that since we did not have any data about the real waiting times in the port, we can only drive conclusions based on the simulated waiting times. This issue led us conclude that the results may be more general than expected but despite that, the significance of this research should not be undermined.

Besides the limitations faced during the study, the direction of the effects, meaning the decrease of the waiting times as the call size of the barges increases, is as expected from the theory. The only aspect which is affected is the size of that effect which depends on the data and how congested the terminal is. Since the case is limited, we are obliged to claim generality, but the effect will nonetheless hold for other terminals as the results are general effects which are expected. Given the increased call size of the barges, the vessels lose less time in mooring and unmooring (which is unproductive time) given the lower number of ships at the terminal. The total number of moves is the same so the time per move also remains constant resulting in the same efficiency in loading-unloading. The effect is thus on the efficiency of the waiting lines.

More attention should be given to the approaches which assume preemptive priority with restart rather than resume since it is a more realistic case. The highest waiting times of the LessBerth approach especially in preemptive priority with restart should be taken into account also given the extreme values as seen from the 90th percentile. In this case, we also saw a big effect by increasing the minimum call size of the barges.

The assumptions made under section 4.1.1. of the research can be considered necessary and reasonable given the lack of real data in this field. The research question of this study: “To what extend can the optimal handling of the barges in the port of Rotterdam be achieved by increasing their minimum call size while taking into account the priority service given to each type of vessel?” is answered by showing the reduction in the waiting times of the vessels and especially the barges that can be achieved with an increasing call size also taking into consideration the priority service of the vessels.

Despite the positive aspects of increasing the minimum call size of the barges, one would be remiss not to discuss the challenges associated with such a measure. First, many barge owners prefer to use small quantities of cargo in their operations in a way of maintaining their independence and work as a family business (Shobayo, van Hassel, 2019). In addition, the scheduling of the shipment is another challenge that emerges. Given the fact that an increasing call size would mean that freight should be consolidated, the complexity of the scheduling is increased and a lot of communication between carriers and shippers is needed (Point to Point ,2020). However, the more planning is done, the easier it will be to build a system that will serve the scheduling is a simple way. One of the most difficult downsides of increasing the call size and therefore having to consolidate the cargo of barges is the short lead times that exist on shipments. Consumer demand is high, and shippers need to work together to ensure that consolidation will be done quickly and with limited costs (Point to Point ,2020). Finally, given the increase of e-commerce, reverse logistics may also create a challenge as a wave of commerce returns may be proven hard to handle when consolidating the cargo of the barges (Point to Point ,2020).

Nonetheless, all the aforementioned challenges can be partially or wholly resolved with the proper collaboration between the actors of the chain in order to take advantage of the positive effects of an increasing call size as much as they can.

Chapter 7: Conclusion

7.1 Concluding remarks

Nowadays, many of the goods carried by sea use container liner shipping as a mode of transport. Under this framework, hinterland transportation and especially inland waterways become more and more necessary given the efficiency they can provide. The increase in global container throughput has caused serious challenges for barge transportation in terms of congestion problems in many ports, especially the port of Rotterdam. Inefficiencies in the handling times of the vessels are apparent and all actors of the chain are trying to constantly optimize terminal operations in an effort to reduce uncertainty. The minimum call size consists one of the measures that the ports have taken to reduce the number of calls at the port. At the same time, the priority of each vessel differs according to its size and cargo and should be considered.

Concerning that problem, this research has the objective to increase the efficiency in the port of Rotterdam in terms of the waiting times, by producing a model that optimizes the handling of the barges by increasing their call size while taking into account the priority service of each vessel. The main research question is thus set as follows: "To what extend can the optimal handling of the barges in the port of Rotterdam be achieved by increasing their minimum call size while taking into account the priority service given to each type of vessel?"

The literature review (Chapter 2) has laid the foundation about the root causes and solutions of the congestion in barge transport, the current situation in the port of Rotterdam and the effect of a minimum call size, corresponding to sub-research questions 1,2 and 3. In a nutshell, coordination problems, the absence of contractual relationship between deep-sea terminals and barge operators as well as economies of scale are the major causes of the congestion problem. These problems are apparent in the current situation of the port of Rotterdam given the rather inefficient performance of container barge handling at deep-sea container terminals. The significance of inland shipping for the port is undeniable and the delays caused by the barges should be eliminated. Under these circumstances, Nextlogic and the Container Exchange Route are trying to mitigate the problem while a minimum call size would guarantee fewer calls and thus reduced waiting times.

Chapter 3 identified the appropriate methodology by drawing a line between the literature review and the objective of this research. The effect of an increasing minimum call size of the barges as explained in Chapter 2 is examined. This chapter enables us to answer sub-research question 4, by deciding to apply a discrete event simulation model in the R programming environment to test and analyze the way that the handling of barges can be optimized in the port of Rotterdam. At the same time, considering different priority scheduling and call sizes, we are able to identify the necessary approaches for our model which provides the answer to sub-research question 5. The initial approach is considered to be the one where vessels have no priority. We then build up our model and compare it with approaches that examine either preemptive or non-preemptive priority while the call size of the barges fluctuates between 47 and 69 moves.

Chapter 4 provides an overview of the data collected from ECT Delta terminal as well as how these data were processed to give the necessary inputs for the simulation model used in this research.

The remaining sub-research question which concerns the best approach that can be used, is answered in Chapter 5 where the model is implemented, and we are able to see which call size approach best resolves the congestion problem that the port is facing as well as what the effect of the increasing call size is. From the findings presented in this chapter, we are able to conclude that the waiting times of the vessels are able to decrease, as the call size of the barges increases given the reduced number of vessels that results in this case. Under this framework, the approaches which assumed 69 moves were considered the best (Incr.CallSize69 and LessBerth69). The utilization rate served as a performance measure which revealed that the utilization of the berth decreases as the call size increases. Meanwhile, the distribution of the waiting times seems to be gamma distributed for the barges while for the deep-sea they appear to be either normal or gamma distributed depending on the approach.

Increasing the call size provides a level of optimality for the barge handling in the port of Rotterdam, which is proven by the decreasing waiting times, therefore answering our main research question. The effect would be even higher if the waiting times were not affected by Covid19. At the same time, we should remain cautious about the level at which we are able to increase the call size given the downsides of this measure such as the complexity of scheduling and short lead times.

In conclusion, we can achieve to some extend more optimal handling of the barges in the port of Rotterdam and thus reduced waiting times for all types of vessels by deploying discrete event simulations and increasing the call size of the barges. To enhance the reliability of the results, some approaches followed a different angle which incorporated the effect that Covid19 has on the arrival rate of the vessels given the timing of the dataset collected. At last, no matter which approach is followed, the waiting times manage to be reduced therefore highlighting the necessity of an increasing call size while all actors should try and minimize the negative aspects associated with this solution.

7.2 Recommendations for further research

The main obstacle when developing the model was the collection of the data as not many data are available when it comes to arrival times of vessels in the Port of Rotterdam. Thus, a follow-up research might be useful to validate the results of the waiting times given a larger sample that can be collected over a longer period. This research can also be broadened to include other ports that experience congestion problems such as the port of Antwerp since the effect of this study can be applied in other terminals. Finally, since the study assumes only one waiting queue for all the servers (berths), the model can be expanded to incorporate individual queues for each server.

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Appendix

Distribution fitting for interarrival and handling times

```
data <- read.csv('bargefit.csv', header = TRUE)
data2 <- read.csv('deepseafit.csv', header = TRUE)

#NORMAL QQPLOTS

#QQplot for Interarrivals of Barges
qqnorm(data$Interarrival.times,main="Normal Q-Q Plot - Interarrivals of Barges")
qqline(data$Interarrival.times,col='red')

#QQplot for Handling time of Barges
qqnorm(data$Handling.time, main="Normal Q-Q Plot - Handling time of Barges")
qqline(data$Handling.time,col='red')

#QQplot for Interarrivals of Deep-sea
qqnorm(data2$Interarrival.times, main="Normal Q-Q Plot - Interarrivals of Deep-sea")
qqline(data2$Interarrival.times,col='red')

#QQplot for Handling time of Deep-sea
qqnorm(data2$Handling.time, main="Normal Q-Q Plot for Handling time of Deep-sea")
qqline(data2$Handling.time,col='red')

#EXPONENTIAL QQ PLOTS
#QQplot for Interarrivals of Barges
qqplot(qexp(ppoints(length(data$Interarrival.times))), data$Interarrival.times, main="Exponential Q-Q Plot - Interarrivals of Barges",
       xlab="Theoretical Quantiles",ylab="Sample Quantiles")
qqline(data$Interarrival.times,distribution=qexp,col='red')

#QQplot for Handling time of Barges
qqplot(qexp(ppoints(length(data$Handling.time))), data$Handling.time, main="Exponential Q-Q Plot - Handling time of Barges",
       xlab="Theoretical Quantiles",ylab="Sample Quantiles")
qqline(data$Handling.time,distribution=qexp,col='red')

#QQplot for Interarrivals of Deep-sea
qqplot(qexp(ppoints(length(data2$Interarrival.times))), data2$Interarrival.times, main="Exponential Q-Q Plot - Interarrivals of Deep-sea",
       xlab="Theoretical Quantiles",ylab="Sample Quantiles")
qqline(data2$Interarrival.times,distribution=qexp,col='red')

#QQplot for Handling time of Deep-sea
qqplot(qexp(ppoints(length(data2$Handling.time))), data2$Handling.time, main="Exponential Q-Q Plot - Handling time of Deep-sea",
       xlab="Theoretical Quantiles",ylab="Sample Quantiles")
qqline(data2$Handling.time,distribution=qexp,col='red')

#GAMMA DISTRIBUTED QQPLOTS

#QQplot for Interarrivals of Barges
n=length(data$Interarrival.times)
mean.bargearrivals=mean(data$Interarrival.times)
var.bargearrivals=var(data$Interarrival.times)
sd.bargearrivals=sd(data$Interarrival.times)
probabilities = (1:n)/(n+1)
gamma.quantiles = qgamma(probabilities, shape = mean.bargearrivals^2/var.bargearrivals, scale = var.bargearrivals/mean.bargearrivals)
plot(sort(gamma.quantiles), sort(data$Interarrival.times), xlab = 'Theoretical Quantiles from Gamma Distribution',
     ylab = 'Sample Quantiles of Interarrival time of Barges', main = 'Gamma QQ-plot - Interarrivals of Barges')
abline(0,1)

#QQplot for Handling time of Barges
n=length(data$Handling.time)
mean.bargehandle=mean(data$Handling.time)
var.bargehandle=var(data$Handling.time)
sd.bargehandle=sd(data$Handling.time)
probabilities = (1:n)/(n+1)
gamma.quantiles = qgamma(probabilities, shape = mean.bargehandle^2/var.bargehandle, scale = var.bargehandle/mean.bargehandle)
plot(sort(gamma.quantiles), sort(data$Handling.time), xlab = 'Theoretical Quantiles from Gamma Distribution',
     ylab = 'Sample Quantiles of Handling time of Barges', main = 'Gamma QQ-plot - Handling time of Barges')
abline(0,1)

#QQplot for Interarrivals of Deep-sea
n=length(data2$Interarrival.times)
mean.deeparrivals=mean(data2$Interarrival.times)
var.deeparrivals=var(data2$Interarrival.times)
sd.deeparrivals=sd(data2$Interarrival.times)
probabilities = (1:n)/(n+1)
gamma.quantiles = qgamma(probabilities, shape = mean.deeparrivals^2/var.deeparrivals, scale = var.deeparrivals/mean.deeparrivals)
plot(sort(gamma.quantiles), sort(data2$Interarrival.times), xlab = 'Theoretical Quantiles from Gamma Distribution',
     ylab = 'Sample Quantiles of Interarrivals of Deep-sea', main = 'Gamma QQ-plot - Interarrivals of Deep-sea')
abline(0,1)

#QQplot for Handling time of Deep-sea
n=length(data2$Handling.time)
mean.deepseahandle=mean(data2$Handling.time)
var.deepseahandle=var(data2$Handling.time)
sd.deepseahandle=sd(data2$Handling.time)
probabilities = (1:n)/(n+1)
gamma.quantiles = qgamma(probabilities, shape = mean.deepseahandle^2/var.deepseahandle, scale = var.deepseahandle/mean.deepseahandle)
plot(sort(gamma.quantiles), sort(data2$Handling.time), xlab = 'Theoretical Quantiles from Gamma Distribution',
     ylab = 'Sample Quantiles of Handling time of Deep-sea', main = 'Gamma QQ-plot - Handling time of Deep-sea')
abline(0,1)
```

Figure 36: Distribution fitting, Source: Author's creation

```
set.seed(50)
x=NA
x[0]=0
for (i in 1:10000){
  x[i]=100*rgamma(1, shape=1.24,rate=11.1111)}
mean(x)
hist(x, ylim=c(0,3500),xlim=c(0,70),
     main="Histogram before cutting off low values")

set.seed(50)
y=NA
y[0]=1
for (i in 1:10000){
  y[i]=100*max(0.05,rgamma(1, shape=1.24,rate=11.1111))}

mean(y)
hist(y, ylim=c(0,8000),xlim=c(0,70),
     main="Histogram after cutting off low values")
```

Figure 37: R script for cutting off low values of mean handling time, Source: Author's creation

Model Specifications: Functions and inputs (as taken from R)

1. Gamma distribution:

n	number of observations. If length(n) > 1, the length is taken to be the number required.
shape, scale	shape and scale parameters. Must be positive, scale strictly.
rate	an alternative way to specify the scale

The rest of the functions are the trajectory, the timeout function, the add-resource function, the add-generator function and the get monitored arrivals. The inputs for our model and the description of these functions are given in the Appendix.

For the first and the second approach we use the formula: add_resource("berth", 8) where 8 denotes the number of berths.

For the third, fourth and sixth approach we add the input "preemptive=TRUE" in order to denote that in this case we have preemptive priority. We will therefore have: add_resource("berth", 8, preemptive=TRUE). For the fifth approach, since the number of berths decreases by one, we will have: add_resource("berth", 7, preemptive=TRUE)

2. Trajectory: This function creates a chain of activities that can be attached to a generator.

   trajectory(name = "anonymous", verbose = FALSE) name the name of the trajectory.

verbose enable showing additional information.

In our models we use two trajectories: one for the barges which we name “barge” and one for the deep-sea vessels which we name “deepsea”.

3. Timeout function: This function creates gamma distributed service times for the barges and the deep-sea vessels. We use the following formula:

```
timeout(.trj, task)
```

.trj the trajectory object.

task the timeout duration supplied by either passing a numeric or a callable object (a function) which must return a numeric (negative values are automatically coerced to positive).

Since the service time is gamma distributed, the task input will be the rgamma function as described above. We will therefore have:

```
timeout(function() {rgamma(1, shape,rate)})
```

We use this formula for the case of barges and for the case of deep-sea vessels. In approach 6, where we set a minimum handling time in order to cut off low the values, we modify the timeout function for the barges to be:

```
timeout(function() {max(minimum value, rgamma(1, shape,rate))})
```

4. Add resource function: This function creates servers (berths) for the vessels.

```
add_resource(name, capacity = 1, queue_size = Inf, mon = TRUE,
  preemptive = FALSE, preempt_order = c("fifo", "lifo"),
  queue_size_strict = FALSE, queue_priority = c(0, Inf))
```

name the name of the resource. If several names are provided, several resources will be defined with the same parameters.

capacity	the capacity of the server, either an integer or a schedule, so that the value may change during the simulation.
queue_size	the maximum size of the queue, either an integer or a schedule, so that the value may change during the simulation.
mon	whether the simulator must monitor this resource or not.
preemptive	whether arrivals in the server can be preempted or not based on seize priorities.
preempt_order	if preemptive=TRUE and several arrivals are preempted, this parameter defines which arrival should be preempted first. Either fifo (First In First Out: older preemptible tasks are preempted first) or lifo (Last In First Out: newer preemptible tasks are preempted first).
queue_size_strict	whether the queue_size is a hard limit (see details).
queue_priority	the priority range required to be able to access the queue if there is no room in the server (if a single value is provided, it is treated as the minimum priority). By default, all arrivals can be enqueued.

For the first and the second approach we use the formula: add_resource("berth", 8) where 8 denotes the number of berths.
For the third, fourth and sixth approach we add the input “preemptive=TRUE” in order to denote that in this case we have preemptive priority. We will therefore have: add_resource("berth", 8, preemptive=TRUE). For the fifth approach, since the number of berths decreases by one, we will have: add_resource("berth", 7, preemptive=TRUE)

5. <u>Add generator function:</u>
   add_generator(.env, name_prefix, trajectory, distribution, mon = 1,

priority = 0, preemptible = priority, restart = FALSE)

.env	the simulation environment.
name_prefix	the name prefix of the generated arrivals. If several names are provided, several generators will be defined with the same parameters.
trajectory	the trajectory that the generated arrivals will follow
distribution	a function modelling the interarrival times (returning a negative value stops the generator).
mon	whether the simulator must monitor the generated arrivals or not (0 = no monitoring, 1 = simple arrival monitoring, 2 = level 1 + arrival attribute monitoring)
priority	the priority of each arrival (a higher integer equals higher priority; defaults to the minimum priority, which is 0).
preemptible	if a seize occurs in a preemptive resource, this parameter establishes the minimum incoming priority that can preempt these arrivals (an arrival with a priority greater than preemptible gains the resource). In any case, preemptible must be equal or greater than priority, and thus only higher priority arrivals can trigger preemption.
restart	whether the activity must be restarted after being preempted

6. Get monitored arrivals: With this function we obtain monitored data about arrivals, attributes and resources. We use the following formula:

get_mon_arrivals(.envs, per_resource = FALSE, ongoing = FALSE)

.envs	the simulation environment (or a list of environments).

per_resource	if TRUE, statistics will be reported on a per-resource basis.
ongoing	if TRUE, ongoing arrivals will be reported. The columns end_time and finished of these arrivals are reported as NAs

For the needs of all of our approaches in our model we use the formula as: get_mon_arrivals()

R scripts

```r
#Vessels with no priority

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=11.1111)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=FALSE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79,shape=1.47,rate=4.3478))}) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(609,shape=1.14,rate=25))}) %>%
  run(until = 500)

scenario1=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario1,'scenario1.csv',row.names = F)
```

Figure 38: R script NoPrio47, Source: Author's creation

```r
#Deep-sea vessel has priority

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=11.1111)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=FALSE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79,shape=1.47,rate=4.3478))},priority=1) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(609,shape=1.14,rate=25))}) %>%
  run(until = 500)

scenario2=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario2,'scenario2.csv',row.names = F)
```

Figure 39: R script Prio47, Source: Author's creation

```
#Vessels with preemptive priority, with restart

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=11.1111)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=TRUE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(609,shape=1.14,rate=25))},priority=0, preemptible=0, restart=TRUE) %>%
  run(until = 500)

scenario3_restart=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario3_restart,'scenario3_restart.csv',row.names = F)
```

Figure 40: R script PreemptPrio47 Restart, Source: Author's creation

```
#Vessels with preemptive priority, with resume

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=11.1111)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=FALSE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(609,shape=1.14,rate=25))},priority=0,preemptible=0,restart=FALSE) %>%
  run(until = 500)

scenario3_resume=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario3_resume,'scenario3_resume.csv',row.names = F)
```

Figure 41: R script PreemptPrio47 Resume, Source: Author's creation

```r
#Increasing call size to 58 moves: Vessels with preemptive priority, with resume

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=13.8394)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=FALSE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(493,shape=1.14,rate=25))},priority=0,preemptible=0, restart=FALSE) %>%
  run(until = 500)

scenario4_resume58=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario4_resume58,'scenario4_resume58.csv',row.names = F)
```

Figure 42: R script Incr.CallSize58 Resume, Source: Author's creation

```r
#Increasing call size to 58 moves: Vessels with preemptive priority, with restart

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=13.8394)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=TRUE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(493,shape=1.14,rate=25))},priority=0,preemptible=0, restart=TRUE) %>%
  run(until = 500)

scenario4_restart58=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario4_restart58,'scenario4_restart58.csv',row.names = F)
```

Figure 43: R script Incr.CallSize58 Restart, Source: Author's creation

```r
#Increasing call size to 69 moves: Vessels with preemptive priority, with resume

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=16.3633)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1,restart=FALSE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(414,shape=1.14,rate=25))}, priority=0,preemptible=0, restart=FALSE) %>%
  run(until = 500)

scenario4_resume69=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario4_resume69,'scenario4_resume69.csv',row.names = F)
```

Figure 44: R script Incr.CallSize69 Resume, Source: Author's creation

```r
#Increasing call size to 69 moves: Vessels with preemptive priority, with restart

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=16.3633)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1,restart=TRUE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(414,shape=1.14,rate=25))}, priority=0,preemptible=0, restart=TRUE) %>%
  run(until = 500)

scenario4_restart69=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario4_restart69,'scenario4_restart69.csv',row.names = F)
```

Figure 45: R script Incr.CallSize69 Restart, Source: Author's creation

```
#Vessels with preemptive priority, with resume

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=11.1111)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",7,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=FALSE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(609,shape=1.14,rate=25))},priority=0,preemptible=0,restart=FALSE) %>%
  run(until = 500)

scenario5_resume=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario5_resume,'scenario5_resume.csv',row.names = F)
```

Figure 46: R script LessBerth47 Resume, Source: Author's creation

```
#Vessels with preemptive priority, with restart

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=11.1111)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",7,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=TRUE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(609,shape=1.14,rate=25))},priority=0, preemptible=0, restart=TRUE) %>%
  run(until = 500)

scenario5_restart=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario5_restart,'scenario5_restart.csv',row.names = F)
```

Figure 47: R script LessBerth47 Restart, Source: Author's creation

```
#Increasing call size to 58 moves: Vessels with preemptive priority, with restart

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=13.8394)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",7,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=TRUE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(493,shape=1.14,rate=25))},priority=0,preemptible=0, restart=TRUE) %>%
  run(until = 500)

scenario5_restart58=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario5_restart58,'scenario5_restart58.csv',row.names = F)
```

Figure 48: R script LessBerth58 Restart, Source: Author’s creation

```
#Increasing call size to 58 moves: Vessels with preemptive priority, with resume

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=13.8394)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",7,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=FALSE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(493,shape=1.14,rate=25))},priority=0,preemptible=0, restart=FALSE) %>%
  run(until = 500)

scenario5_resume58=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario5_resume58,'scenario5_resume58.csv',row.names = F)
```

Figure 49: R script LessBerth58 Resume, Source: Author’s creation

```
#Increasing call size to 69 moves: Vessels with preemptive priority, with resume

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=16.3633)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",7,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1,restart=FALSE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(414,shape=1.14,rate=25))}, priority=0,preemptible=0, restart=FALSE) %>%
  run(until = 500)

scenario5_resume69=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario5_resume69,'scenario5_resume69.csv',row.names = F)
```

Figure 50: R script LessBerth69 Resume, Source: Author's creation

```
#Increasing call size to 69 moves: Vessels with preemptive priority, with restart

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=16.3633)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",7,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1,restart=TRUE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(414,shape=1.14,rate=25))}, priority=0,preemptible=0, restart=TRUE) %>%
  run(until = 500)

scenario5_restart69=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario5_restart69,'scenario5_restart69.csv',row.names = F)
```

Figure 51: R script LessBerth69 Restart, Source: Author's creation

```r
#Cutting off low values of the handling time of barges: Vessels with preemptive priority, with resume

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=11.8510)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=FALSE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(569,shape=1.14,rate=25))},priority=0,preemptible=0, restart=FALSE) %>%
  run(until = 500)

scenario6_resume=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario6_resume,'scenario6_resume.csv',row.names = F)
```

Figure 52: R script Cutoff Resume, Source: Author's creation

```r
#Cutting off low values of the handling time of barges: Vessels with preemptive priority, with restart

library(simmer)

set.seed(1269)

terminal <- simmer("terminal")

deepsea <-
  trajectory("Deep sea path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  timeout(function() {rgamma(1,shape=2.53,rate=2.5)}) %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})


barge <-
  trajectory("Barge path") %>%
  log_("Here I am") %>%
  set_attribute("start_time", function() {now(terminal)}) %>%
  seize("berth") %>%
  #  log_(function() {paste("Waited: ", now(terminal) - get_attribute(terminal, "start_time"))}) %>%
  timeout(function() {rgamma(1, shape=1.24,rate=11.8510)}) %>%
  release("berth") %>%
  log_(function() {paste("Finished: ", now(terminal))})

terminal <-
  simmer("terminal") %>%
  add_resource("berth",8,preemptive=TRUE) %>%
  add_generator("Deep sea vessel", deepsea, function() {c(0, rgamma(79, shape=1.47,rate=4.3478))},priority=1,preemptible = 1, restart=TRUE) %>%
  add_generator("Barge", barge, function() {c(0, rgamma(569,shape=1.14,rate=25))},priority=0,preemptible=0, restart=TRUE) %>%
  run(until = 500)

scenario6_restart=terminal %>%
  get_mon_arrivals() %>%
  transform(waiting_time = end_time - start_time - activity_time)%>%
  transform (start_service_time= start_time + waiting_time)

write.csv(scenario6_restart,'scenario6_restart.csv',row.names = F)
```

Figure 53: R script Cutoff Restart, Source: Author's creation

Distribution of waiting times per app