Analysis of the new container terminal at the Port of Leixões using a simulation approach

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ABSTRACT: The Port of Leixões currently possesses two container terminals, operating closely to its design capacity and although investments of time and money have been made to optimize, as far as possible, the throughput, a new terminal is dire, due to the predictable high degree of merchandise increase, due to the European Corridors project of the EU, moving more cargo from the countryside to the Port of Leixões. The aim of this work is to make the pre-dimensioning of the new terminal, located at the current location of the RO-RO Terminal, implying, in addition, a significant reduction of the fishing port facilities, with the appropriate accesses of road and rail, as well as, a Container Freight Station (CFS), and create a simulation model, using the commercial software ARENA, to study the flows of cargo and equipment along the terminal. The ultimate goal is to create a terminal capable of moving 600,000 TEU, while maintaining moderate utilization rates throughout the Infra-, Superstructure and Equipment, and validate the equations used for the pre-dimensioning, as well as, to determine the possible bottlenecks. To evaluate the terminal's performance, two additional scenarios, in addition to the proposed one, were studied, to study different parametric arrivals of ships. It was concluded that the terminal, under certain circumstances, can move the 600,000 TEU with reasonable values of utilization levels.

KEYWORDS: Container Terminal dimensioning, Discrete-event Simulation, Arena

1 INTRODUCTION

Historical Background

The Port of Leixões is the major port-infrastructure in the Northern Region of Portugal and of fundamental importance to the entire local industry, which once was, and still is, although in a reduced fashion, the major industrial region in Portugal. With the increased pressure on land vehicles, the EU found that it worthwhile to invest further in the Rail Network. Major cities such as Munich already have deep connections to the Port of Genova. The use of Road Networks is responsible for major pollution, but also its infrastructure has a high degree of maintenance and the transport itself has little transporting capacity. On the other hand, Rail Networks have the main advantage that multiple cargo can be transported at once, creating a scale economy, as well as reduce the amount of greenhouse gases, since all trains will be of electrical propulsion. Consequently, the project of the European Corridors was created, which implies that cargo will be arriving at more distant ports than the target market and will be transported through Rail Networks to the destination country. An example of this was presented earlier with Munich and the Port of Genova. But more connections will be made, as part of the PETI 3+ Project (Ministério da Economia 2014), and the Portuguese Ports are part of the 4th corridor, which will have two main connections and the Port of Leixões is included.

At present, the Port of Leixões has reached its maximum design capacity, so to further advance and to meet the expectations created by the EU, a new terminal is required, creating a need for a simulation study, to study the feasibility on what is intended. The terminal is to be of 600,000 TEU of capacity and is to be fitted with all necessary accesses, such as road, rail and maritime. Furthermore, a CFS will be designed for the same terminal, as to better understand the maximum viability of the new terminal, making use of the simulation software ARENA, a Rockwell Enterprise software.

Objectives and Structure

The objectives of this work are to properly design an entirely new container terminal, based on information already publicly available by (Brógueira Dias, Luis Estrada, and Passos Mealha 2011). From that point on, a preliminary design will be made, with all the equipment necessary, to have a starting point to implement in ARENA, which will be followed by an optimization of several variables, such as the number of quay cranes, yard trucks and so on. The ultimate objective is to study the optimum number of each component of the new terminal, to be able to handle the wanted number of TEUs/year. Also, the interactions with the other terminals will be considered in a succinct way, by implement two separate models, which will represent each of the existing terminals.

This work will be divided in 8 chapters. In the second chapter, the state-of-the-art works will be presented, as well as, the adopted theories from the information gathered. Thirdly, the need for a new terminal will be demonstrated and the available preliminary design, on which this work is based, will be presented. Moving on to chapter four, the modelling of the problem will be made with the necessary variables, formulations and the corresponding implications. In chapter number five, the pre-processing data for the simulation will be shown. Chapter six will present the results obtained as well as the methods used to verify and validate the implemented model. The last chapter, will show the conclusions taken from the work produced, along with recommendations and suggestions for future work to be developed.

2 STATE OF THE ART

With the increase in freight transportation and an ever-growing competition among ports, the importance of having an optimal performing port has led to a substantial increase in research on this subject. Consequently, a tremendous amount of publications have suggested methods to increase productivity and try to outperform the existing

models by better allocating the equipment, but also by improving management policies, for every aspect of the terminals. Up until now, there is no integrated solution, which solves all the problems related to operations inside a container terminal, rather optimizing models for the solution of local issues. Nevertheless, one could classify the research into two major categories: Container terminal simulation models and optimization models at container terminals.

Few models have focused on the use of a GST such as ARENA. (Lee, Park, and Lee 2003) considered a different approach for the Pusan East Container Terminal. The authors composed a model based on the ARENA software, where the terminal was modelled in accordance with several distributions for ship inter-arrival (Erlang), ship time at berth (Beta), crane container handling (Gamma) and so on; queues and other processes for the interactions among the multiple components of the the terminal, such as the berth-yard truck interaction. Moreover, the simulation was made in the view of SCM which consists of several interactions, as seen in Figure 2.2. The relationships and the impact of the supply chain characteristics are also discussed.

(Merkuryev et al. 1998) created an ARENA and SLX for the Container Terminal in Riga, where the aim was to regulate routes by segregating different traffic flows, to improve the layout of the terminal and analyse the impact of weather on the terminal. Little is known of the exact model created, nonetheless an interface showing different weather conditions, such as wind, temperature, visibility. The performance of the terminal was analysed by observing the impact of weather and the number of fork-lifts existing in the terminal. The use of cross-referencing between the weather conditions and the terminal performance was drawn from a database, which enabled the evaluation of this particular branch of the performance. The first study made about the Baltic Container Terminal was actually made by (Merkuryev et al. 1998). The Simulation made, was supported under the research program COPERNICUS 1994 of the EU. With this study, the authors aimed to determine how the increase in the level of automation of documentation management systems, as well how the introduction of automation in technological processes, in addition to the increase of working places at document processing points, would improve the terminal's performance. In a more recent work, (Merkuryev et al. n.d.) created a low-level model, to consider three separate terminal operations: Movement of containers between the Baltic Container Terminal and neighbouring ports, movement of containers at the terminal's quay, movement of containers inside the terminal. This way, it is possible to enable the full control of each separate resource unit. This approach allowed for a precise estimation of technological inefficiencies, which latter can be used by terminal managers for improvement. In fact, the work of Merkuryev deeply focuses on the optimization of the Baltic Container Terminal, being the main focus a progressive development of the basic model created in 1998, in order to consider multiple case scenarios. In this particular case, the authors calibrated their model by using real-time field measurements and thus being able to attain the results. Also, based on Kolmogorov-Smirnov statistical test, the validation was enabled. (Cortés et al. 2007) made a similar approach using the ARENA GST. In their study, the main target is related to the traffic flow inside the river port of Seville. By considering timetables, number of vessels in the system, the vessel time in the dock, the maximum capacity of terminals, queues for the docks, pilots, mooring, lock and, most importantly the existence of other products, such as bulk, a highly-detailed model is obtained. Nevertheless, the lack of spatial movement somewhat reduces the global quality of the software. (Silva and Soares 2007) created an ARENA based simulation model for the optimization of a intermodal terminal layout. In his work, (Silva and Soares 2007) aims to create the optimum terminal layout by varying parametrically several factors, such as the impact of the number of Reach Stackers and Forklifts existing in the terminal, among others. The model is validated by real-time data, provided by the Terminal XXI at the Port of Sines, Portugal. In Portugal, the integration of terminal pre-dimensioning and simulation was never attempted and even simulation studies are scarce, making it obvious that this thesis brings a breakthrough, what terminal design is concerned. As both terminal pre-dimensioning and simulation are going to be carried out in this thesis, a clear literature gap arises, validating the importance of this study.

3 PRE-DIMENSIONING OF THE TERMINAL

As a basis for this project, the available design made public by (Brógueira Dias et al. 2011) and (Silva et al. 2008). The new terminal is going to occupy the existing Multi-Purpose Terminal and landscape another portion, to achieve a terminal that should have the capability of receiving Post-Panamax vessels (2nd generation) and an annual throughput between 400,000 and 600,000 TEU. The area, where the terminal is to be built, is close to the existing Fishing Docks and the idea is to reduce the existing Fishing Docks, due to the little use of the current docks. Also, dredging will be needed to support the Post-Panamax vessels, that are supposed to arrive at this terminal.

3.1 *Arrival of Ships*

The lack of space is the primary issue of Port of Leixões, determining quite concretely which type of ships can arrive and be serviced at the new terminal, but also the area available, so a database was created. For that, a database of the existing ships arriving at the port was made, based on the AIS system. This database analysed the last three months of the year 2015, October to December. The basic data provided showed all the ships in port, so from these ones, Ro-Ro ships, Bulks and Tankers had to be removed. The division amongst container ships was made according to (Stopford 2009). There several regular lines present at the local terminals, for example, the Panamax line arrives every two months. All the others are replaced, in accordance with demand, with bigger or smaller ships. In other

words, a typical Feedermax line, which arrives twice a week, may be replaced with Handysize line when demand increases. As an average, one can state that about twenty-seven ships arrive per week, about 61 % of the ship are of Feedermax class, 4 % are Feeder vessels, 23 % are Handysize, 11 % are Sub-Panamax and less than 1% are panama vessels. So, due to in-existence of references as a basis, the following ships were chosen, based on the logic of serving mainly larger ships, as shown in Table 1.

Table 1 – Container ships arriving at the new Terminal

Vessel Type	Monthly Average Arrival	Weekly Average Arrival
Feeder	0	0
Feedermax	13.5	3
Handy-size	13.5	3
Sub-Panamax	13.5	3
Panamax	0	0
Post-Panamax	4.5	1

Based on the logic presented in Table 1 and the values of quay length, which will be shown further ahead, a schedule was made, following the rule of fitting the maximum number of ships to the quay.

3.2 *Areas Required*

With the use of the equations, provided by (Rademaker 2007; Sharif Mohseni 2011; Thoresen 2003) one can arrive at the results shown in Table 2.

Table 2 – Areas required for the Terminal

Characteristic	Value
Total Area [Ha]	15
CFS Area [Ha]	0.6
Number of Ground Slots [-]	2762
Number of Blocks [-]	12
Empty Containers [%]	11
Reefer Containers [%]	4
Hazard Containers [%]	5
Length of Quay [m]	553

3.3 *Accessing the Terminal*

One of the primer parts of a design of a container terminal is the accessing. For this operation, two types of accesses are available: road and rail. Starting with the rail access, at present, there is a railway connecting the north side of the Fishing Docks with the existing South Terminal and to the Leixões Railway Track. Despite this access, it is impossible to deposit containers in the surrounding area of this railway track, due to the existence of a Bulk Terminal. Consequently, a new access, direct to the terminal, should be made. The most viable option off all would be to use the existing tunnel that runs under the Fishing Docks and enlarge it, so that two trucks and a train can pass through one single-track at the same exact instant, without damage to cargo and equipment. At present, the tunnel has about 8.5 m in width. The Iberian Track wide-span is of 1668 mm and a typical CP locomotive has a width of about 3 m. Consequently, it was decided that the new tunnel would be of about 10.5 m. This means that a single track runs on the eastern side of the tunnel and two road tracks at the western side. Only one track was chosen, due to the little current use of railway in Portugal. In fact, the INE states that only 2% of the total container movement is made by railway, which is obviously very little (Instituto Nacional de Estatística 2016). In the specific case of Port of Leixões, only 7000 TEU/year are moved by rail (RENFE 2016). If one assumed that a favourable development would be accomplished in upcoming years and, as such, the movement by rail should be of about 12%, which is already a practice in other European ports (iContainer 2016). Currently, there are already six weekly connections between the Port of Leixões and the Spanish Hinterland (RENFE 2016). In Portugal, each train carries about 48 TEU and to achieve the 12% mark (72,000 TEU/year), fifteen hundred connections should be made per year. This means that the train had to move ten times back and forth from the port to the hinterland. Ten times means two trains per day if we consider seven working days per week for rail workers. The line of Leixões is about 18.7 km long and according to (Alonso et al. 2010), the average speed of a goods train is of 70 km/h, but lower speeds will be studied, which is probably closer to reality. In respect to the road accesses, the internal access to the terminal is made by the tunnel. The internal roads of the port have access to the eastern highway, which runs in the North-South direction. At the terminal itself, the trucks enter the terminal by the East Entry and have a parking lot and CFS there. At the quay, there is also a 10 m wide road, in addition to the 7 m distance between blocks in the parking area, which allow the passage of two trucks at the same time.

3.4 *Equipment*

According to (Rademaker 2007), an STS Crane has a gross productivity of 70k-120k TEU movements per year. Based on the current gross productivity of the South Terminal, 85k TEU movements per year with four cranes, and applying the same productivity for the new terminal, one can obtain the same number of cranes. For each STS crane, (Rademaker 2007) states that five port tractors are needed, which makes a total of twenty tractors. Adding another four for the rail terminal, which are necessary, this makes a total of twenty-four yard trucks. (Rademaker 2007) also states that two to three RMGs are needed per quay crane, which makes a total of nine in the yard. Besides these equipment, some Reach Stackers are also needed for the Rail Terminal, which represents 12% of the total movements; instead of 5.5 per crane, as stated by (Rademaker 2007), only four will be needed for the Rail Terminal. The estimated value is an averaged one, according to (Thoresen

2003). The decision to choose four STS cranes was done to avoid track at the quay. For the park area, three RMGs were considered per row, due to their ability to perform high stacking heights, as well as little space usage, when performing their activities. The RMG is the most flexible solution (Thoresen 2003) available in the market for limited storage spaces. The distance amongst blocks imposed is due to the need for RMGs to move freely across the rows of blocks. If one considers that twelve containers are side-by-side (which gives a total of 25 m) and that the RMG still has to pass across these blocks, by checking the Liebherr catalogues (Liebherr 2016a), one can easily conclude that this solution is valid: RMG: 35 to 50 m x 27 m(L x B). In relation to the fork-lifts, which will be mainly used in the CFS area, where they will unload (in-/out-) bound trucks, but mainly the train, only three were deemed necessary, due to the fact that one reach stacker has an average 2 minute time to (un-)load a train (KALMAR 2016). The performances of the various equipment presented in this chapter will be further discussed in Chapter 5. A comparison with other terminals in the Iberian Peninsula is also presented in Table 3. The port of Vigo is a mainly reefer one, so the values of the new terminal are higher.

Table 3 – Rules of thumb for other terminals

Data	TCN	TCS	Liscont	Sotagus	Vigo Guixar	New Terminal
TEU/Area	4.17	2.19	2.92	2.74	1.39	4
TEU/Metre of Quay	694.44	648.15	555.56	606.47	328.08	1084.99
TEU/Gantry	125k	117k	117k	112.5k	62.5k	150k

4 MODELLING OF THE PROBLEM

When using a simulation software, such as ARENA, the formulation of the problem must be carefully delineated and variables, assumptions and other necessary data must be compilated, to guarantee quality of the results. The adaptability of the created model itself depends on how many assumptions are made, the reliability of the data available and how realistically the variables represent the true functioning of the container terminal.

In this context, flowcharts were chosen for the modelling of the new container terminal, due to their flexibility and adaptability to properly represent the functioning of a container terminal. The use of this type of approach is quite common in logistic processes, as well as in the "pre-simulation" of different components of CTs.

4.1 *External actors, entities and resources*

One of the most important steps of the modelling of a problem is to determine who the different actors, entities and resources are and in what way do they influence the diverse components of the entire system, which, in this case, is the container terminal. Different simulations with equal inputs may give different results, hence, several repetitions of the simulation must be made so that the obtained data becomes statistically relevant. For clarity and conciseness, any (in-/out-) bound entity will be referred as an external actor, whereas the other objects that flow inside the terminal will be denominated entities among which the different containers and merchandise flowing across the terminal are included, such as reefers, TEU, FEU and empty containers. The resources are the components that interconnect the several locations of the system. In a container terminal, the resources are the STS cranes, the yard trucks and the RMGs, among others, and they interconnect the ship with the quay (STS Crane), the quay with the container park (Yard truck) and the park with its specific position (RMG). To evaluate the performance of each of these components, different parameters have to be measured, so that the most desirable configuration is achieved. As such, the following parameters will be evaluated for the actors, resources and entities: Queuing Time; Waiting Time; Service Time; Saturation Levels; Number of entities in queues; Quay enlargement (quay only).

The initial data for this terminal is difficult to determine. Nonetheless, from the existing terminals and using the AIS system, data for typical waiting time, queuing time and service time for ships can be obtained and, therefore, the typical performance values of some of the resources, such as the STS Crane, can be evaluated. A generic model will be proposed before the modelling of the terminal itself in the ARENA environment.

4.2 *Generic model*

A generic model is first delineated, as presented in Figure 1 – Generic Flowchart. The model is divided into three sections: Seaborne operations, terminal and port operations and hinterland operations. These sections are submodels for the existing and interacting resources and actors in the different areas of the terminal and, as such, need proper flowcharts. The amount of each equipment type, as stated before is: four Ship-to-Shore (STS) gantry cranes Post-Panamax, nine Rail Mounted Gantry Crane (RMG), three Reach Stackers with spreader and twenty-four Yard Trucks. Each resource has a specific area of operation, in addition to a specific speed, transport capacity, performance, and so on, as well as a mean time to failure (MTTF) and a mean time to repair (MTTR).

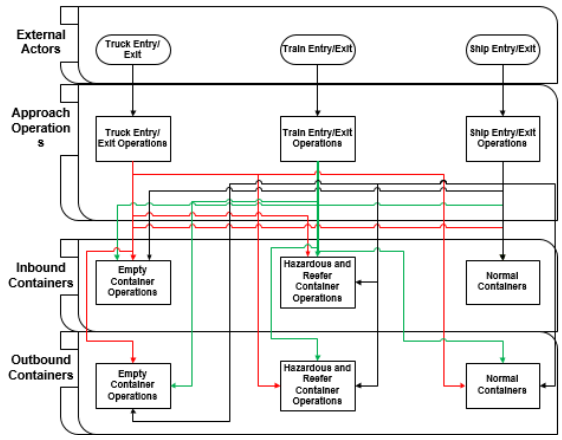

Figure 1 – Generic Flowchart

5 PRE-PROCESSING

At a preliminary stage, in order to have a proper representation of the actions and interactions of typical terminal operations, some considerations have to be made at the three major areas of interest at a container terminal: Berth and seaside operations; Yard and land operations and in- and outbound operations. These will imply the assumptions and preliminary calculations made, serving as input for the ARENA model.

5.1 *Statistics for data pre-processing*

Beginning with the data sample, some filtering had to be carried out, in order to remove the outliers and, consequently, represent the most common values present in the sample. To do so, based on the mean value and the standard deviation, one can determine the interquartile range, removing the outliers with the use of inter-quartile range.

5.2 *Pilot usage*

At present the Port of Leixões has four pilot boats and five pilots for every shift (8 hours), for a total number of 300 ships per month, which gives one pilot boat for every seventy-five ships per month. Adding another fifty-five ships per month, the logical approach would be to at least put one more pilot boat. The currently available pilot vessels are 4. Assuming an average speed of 16.25 knots (mean value of the boats), the pilot boat speed is 3 to 4 knots below the design speed, making it 12.25 knots. Based on the values available from the AIS system, it will be considered that the tugs will serve every type of ship, and that the arrival of other vessels will follow a distribution as shown further ahead, always considering the FIFO strategy. Furthermore, the required speed for the ship to enter the port is 5 knots ((APDL 2016)) and pilotage is mandatory when the ship enters the 2 nautical miles' radius of the entrance of the port (Entry Lighthouse).

5.3 *Other terminal ship arrivals and service times*

In order to model the pilot boat services, it was considered that ships would arrive and be served, according with a mean of the histogram distributions, using the FIFO strategy. Both arrival rates and service times, follow an exponential distribution, with a mean value of 2 and 19 hours, respectively, at 95% confidence value, having applied Chi-square and Kolmogorov-Smirnov tests.

5.4 *Atmospheric conditions*

The Atmospheric conditions also take place in the modelling of the Terminal. In particular, the tides and closure of the Port, due to bad weather were considered. The data for the tides was obtained from the Portuguese Hydrographic Institute, which state that the difference between high and low tide, was of about 3 metres. What port closure is concerned, data was provided from the Portuguese Ministry of Defence, which showed that this parameter is almost non-existing, as total port closure only happened once in the last 10 years, which makes this value of little relevance for this case.

5.5 *Quay crane performance and workability*

The quay cranes or STS cranes have a major influence in the performance of a container terminal, as they are responsible for loading and unloading the containers to and from the ship, respectively. Since there are no statistics for the cranes, an approach of the problem using speeds and distances of every component, provided by the manufacturers was made. Based on the values provided by Liebherr (Liebherr 2016b), one can calculate some average values for the STS cranes. The equations used are based on the moves presented in work made by (Rademaker 2007). Each part of the process will have an associated cycle time, a mean value and a standard deviation. Considering that a typical container is removed from the mid area of the ship and that the speeds are variable, one can achieve a time of about 2.1 minutes (average) for one cycle, with a given standard deviation. For this work, a normalized time is considered, which means that the most likely values will be in the mean range. When comparing these values with the ones provided by other authors, one concludes that the same line is being considered, as shown in Table 4.

Table 4 – Cycle times for STS Cranes

Performance	Saanen [75]	Silva and Soares [79]	Rademaker [66]	Cortés et al. [16]	Sharif Mohseni [78]	This study
Cycle Time [min]	1.5	1.5	1.81	2.73	2.18	2.1
Moves/hour	40	40	33	22	28	29

5.6 *Horizontal Vehicles*

Horizontal Vehicles are the ones moving the containers around the terminal, divided into three categories: Yard trucks, RMGs and reach stackers. For Yard trucks, (Saanen 2004), refers in his study that typical values for these are 7 km/h when loaded and 14 km/h for empty trucks and constant speeds, based on the design of Appendix X, the travel times are easily acquired. For the RMGs the same logic was applied as for the quay cranes, as the working principle of the RMGs and STS cranes is similar, which, recalling, was based on speeds and distances to mid points of the blocks and they have a mean value of 3.58 minutes.

5.7 *Failure, repair and maintenance*

Maintenance, repair and failure of equipment is an integral part of the life-cycle of every equipment. Consequently, this thesis will focus itself of the following equipment: Quay cranes, RMGs, yard trucks and reach stackers. For each of the items above, three main parameters have to be

considered: the lifetime of each equipment type, the mean time to failure (MTTF) and the mean time to repair (MTTR). For this study the failure rates and repair rates will be constant, as a simplification of the real problem. For this work., due to lack of more concrete data, the typical values from the literature were used, as presented by (Martínez 2013; Rademaker 2007; Silva and Soares 2007; World Cargo News 2006).

5.8 *Container Freight Station*

The Container Freight Station described in Chapter 3, will have an average dwell time of 7 days, meaning that as the containers flow into and out of the CFS, 7 days will pass. The Port of Leixões is not a major port in the East-West cargo flow, meaning that the seasonality of containers is probably very low. Consequently, by making an average of the container terminal throughput of various terminals with the CFS throughput, one can achieve a reasonable value for the CFS. The data obtained for this is shown in Table 5.14.

5.9 *Gate operations*

At present, the gate of the Port of Leixões possesses the following schedule, divided into three shifts:8h-12h; 13h-20h and 21h-24h. According to the Port Authority (APDL 2016), the average service time of trucks at the gate is of 11 minutes. In addition, according to dos (dos Santos Cardoso 2012), if the information flow is not previously made, the truck will have to wait an additional 5 minutes, making a total of 16 minutes. For the modelling of the gate, queuing theory will be used with an M/M/S model, which, according to (Saanen 2004), is a very good approximation and has been vastly used. Concerning the inter-arrival of trucks, (dos Santos Cardoso 2012) states that the variance goes from 1 to 10 days, transporting 1 FEU or 2 TEU. According to (Guan 2009), the optimum number of inter-arrivals for this case are 66-87 trucks/hour, meaning that over a year, 528,000 trucks had to go through the gate. This would imply that 91 trucks had to pass each hour. (Guan 2009) in his dissertation states that this value would be more in the range of 6 lanes.

5.10 *Inspection*

Finally, for import containers, inspections have to be taken out for proper validation of the container an, consequent removal from the Yard. Inspections is a crucial part of the working principal of the Port of Leixões, as the containers are stacked, in accordance with the fact of having been inspected or not. The work of (Hyun, Kap, and Kim 2006), who states that the exit process without survey follows a Triangular distribution, as shown in Equation 1.

$$T_{Inspection} = TRIA(4.54,5.9,28.2) \quad (1)$$

6 DATA ANALYSIS

This data analysis will focus on the different components of the new terminal namely: Entry and quay operations; yard operations and in- and outbound operations. In each of these topics several queues, times and utilization rates, as will be seen further ahead. Furthermore, as a parametric study, three different possibilities for arrival rates were considered, to check the flexibility of the terminal. This parametric variation will appear last in this chapter. In all scenarios, the call-size was considered to be constant, throughout the simulation, meaning that all ships will have the same call-size for each scenario created. In some simulations, high workloads will be checked, as well as, occupancy ratios, in order to better determine the actual maximum capacity of the terminal. Each simulation was carried out for 10 cycles of 1 year, so that a more even balanced and statistically representative results can be obtained.

6.1 *Entry and quay operations*

Beginning with the maritime connection, there are two main components to be evaluated: the queueing and waiting time. Queueing time is related to the time that a ship must wait for a terminal to be available, whereas a waiting time is the time a ship must wait for the tide to go up or a pilot boat to come. It is important to state that no or minimal dredging was considered. The actual ZH for the Port of Leixões is 11 metres, which with high-tide becomes 14 metres which is enough for the ships to enter, with minimal dredging, assuming that the ships are full. The maximum queueing time obtained for the terminal was of 0 hours, which is the ideal value, when comparing to values from the literature, presented by (Böse 2011; Saanen 2004; Sharif Mohseni 2011). It is important to state that in all these works, the waiting refers to the queueing time. Picking up at the other parameters analysed by (Böse 2011) and comparing them to the ones obtained by simulation, as a normal workload is always present in the terminal, the number of ships, that have to wait in a queue, which is of 0, is an ideal value and perfectly in line with the referenced values. The average queueing time obtained for this 10-cycle simulation was of 0 hours, which is perfect, considering that, as will be seen further ahead, when making parametric variations, these values tend to increase considerably.

Analysing the quay, the focus will be on the quay utilization and the number of quay metres seized. So, for this simulation, the time average is at about 100 metres, meaning that if the values of quay metres utilization level would be averaged along the time, in opposition, to instantaneous utilization values, the average would be 100 metres. But the main interest relies in the berth occupancy ratio, which implies a ratio of 35%, which is in line with the number of berths existing (Berths=2), according to (Thoresen 2003), as can be seen Table Table 5. When comparing with these values from the literature, which are desirable values, and with the desirable value of Chapter 3, one can state that the value is the ideal one.

Table 5 – Desirable BOR Values

	Saanen (2002a)	Ligteringen (2009), Thoresen (2010)	Thoresen (2010) 2 Berths
BOR	60-65%>	30-75%	35-50%

When analysing waiting times for pilot boats, the results observed throughout the simulation show that the maximum waiting time for a pilot boat was of 0 hours and, consequently, the average also 0, meaning that a pilot boat is always available for the terminal to perform well with an average utilization rate of 0.4.

When analysing the waiting times for tides to go up, the maximum value obtained was of 4.4 hours, whereas the average lies on the 1.41 hours. The queue length had a maximum value of 1 ship, being able to create a substantial queue, if the entrance of the port is not properly dredged.

The results for waiting and queueing times, in general, are very satisfactory, when comparing with the present results of the port of Leixões, which the author recalls was of 8.31 hours, as is stated in Chapter 3. When considering the busy times of quay cranes, the crane utilization rates to 50%, which is in line with what was expected, since the BOR has a moderate value. What concerns the maximum waiting times, the values are inside the expectable parameters, with a value of 0.285 hours. When comparing waiting times for cranes with values from the literature, (Günther and Kim 2006) state that the waiting time for Quay Cranes can reduce productivity up to 15%, meaning that 15% of the total service time is due to waiting time for quay cranes. Assuming 15%, this would give a service time of 1.9 hours, which is very unrealistic, hence validating the values of waiting time.

The average service times per ship can be observed in Table 7.3, being in line with the values considered in Chapter 5, where a cycle time of 1.93 minutes was considered and converting the values from the Table Table 6 from hours to minutes making a mean out of it, the results are of 2.02 minutes, which puts the values perfectly aligned.

Table 6 – Average Service Time per Container

Average Service Time per Container	Scenario 1
Feedermax Service Time [hours/per container]	0.053
Handy-size Service Time [hours/per container]	0.05
Sub-Panamax Service Time [hours/per container]	0.051
Post-Panamax Service Time [hours/per container]	0.049

6.2 *Yard Operations*

The yard operations are divided into three different components: the yard occupation, the transporters and the inspection utilization, as shown in the upcoming sections.

6.2.1 *Yard occupation*

Beginning with the import yard, the occupation level is very high, which was expected, when considering that the maximal throughput of the terminal is aimed. As a rule of thumb often used in the literature, the terminal capacity should not overcome 80%, which happens in this case. The average occupation ratio for import containers is around 92%, which makes sense due to the dwell time containers spend in port, which according to (Voβ, Stahlbock, and Steenken 2004) is of 3 to 5 days and according to (Saanen 2004) is 5 to 15 days, although these values can be higher, due to low utilization levels. The dwell for Import Containers had an average value of 5.3 days, which is in line with both above mentioned references, being clear that this is one of the bottlenecks of this terminal, which was expected, considering the low area for construction available.

When analysing the export yard, the export terminal utilization level is around 55%, which is more in line with the previously stated rule of thumb. This gives a global occupation level of the yard of about 73.5%, which is within the acceptable values.

Typical values of truck arrivals were imposed to be of 0 to 6 days before the day of departure, implying that per week the number of blocks will never pass much more than 50%, due to the reservation of lines for different companies and lesser dwell time. When analysing the export dwell time, which was of 3.96 days, it is evident that the values are lower than the ones of the import containers, due to the regular lines of ships, still being in line with (Voβ, Stahlbock, and Steenken 2004).

Finally, for empty, hazard and reefer yard occupation levels, the occupation ratios are lower than the other blocks existing at the terminal, which is an optimal value, with exception made for the empty block, due to the fact that it was considered that empty containers would not leave the terminal, except for CFS purpose, not being loaded to ships either, creating a considerable bottleneck and consequent problem.

The train terminal yard occupation levels, show similar patterns of occupation levels as the import and export yards, having an average ratio below 25%. The greater level of occupation of the import is due to the instant movement of a container after being cleared by inspection to the train terminal yard, where it will wait for a train to arrive. In opposition, containers for export are first unloaded and then directly moved to the export yard, where they will wait before being loaded onto a ship, creating a low time-averaged occupation of the export train yard is very low.

6.2.2 *Transporters*

This section will be divided into two main components: the yard cranes (RMGs) and the other yard equipment (Trucks, reach stackers and forklifts). Beginning with the yard cranes, when a ship arrives, a higher productivity is required from the crane, when comparing with other situations, where there is no ship. The results showe that no RMG has a constant use and their average utilization, with a few exceptions tend to be around 50%, validating the number of RMGs present in the terminal, where one is present per block.

When evaluating the other transporter units' performance, one will reach close to the same conclusions shown beforehand. It becomes clear that the number of yard trucks is more than enough to serve the terminal, after being increased to 30 units, due to long queueing times verified throughout the simulation process. The remaining number of transporter units is sufficient to serve the terminal, considering the number of trains arriving at the terminal, served by the reach stackers, and the number of forklifts present at the CFS.

6.2.3 *Inspection utilization*

To finalise this section, the degree of utilization of the inspection service present in the new terminal is more than enough, considering that occupation levels are around 60%.

6.3 *In- and outbound operations*

In this section, the analysis will focus on the gate performance, from an entry and exit perspective, as well as the train terminal performance, CFS performance and the service times of trains, CFS trucks and trucks.

6.3.1 *Gate performance*

The gate performance will be evaluated by analysing the queues existing at Entry and Exit level, for maximum and average values, which will then be compared with values from the literature, so that nexus is achieved. Starting with the entry gate, the gate workstation utilization levels and average waiting times had an average utilization rate of 51%, which means that no major queues can be created, and the average waiting time at the gate is close to none (0.01 hours), which is in line with what was expected, as presently the Port of Leixões does not suffer from a major bottleneck at the gate area, and with what was expected, as they are in line with the values presented by (Guan 2009), For the exit gate, the same logic applies. Both entry and exiting have little to no queues (the average waiting time at the exit gate is of 0.05 hours) and although gate utilization rates are a slightly higher for the exit gate, no major differences are verified, due to high and not evenly spaced arrives.

6.3.2 *Train terminal performance*

The train terminal performance concerns itself with the occupancy of the terminal, which has only one service station. Due to the low number of Trains arriving per week and the schedule based arrival of trains with little to no delays, the train terminal has little occupancy, as it has an occupancy ratio of 0.03% and no waiting nor queueing time. The speeds of access to the terminal, mentioned in Chapter 3 do not take major influence in the performance of the train terminal.

6.3.3 *CFS performance*

The CFS is the component responsible for the stuffing and stripping of part of the containers, that arrive to the terminal. The CFS working station has several stations to be worked on (10 in total), but only 5 are necessary for the CFS to work. Utilization ratios are at about 50% and that the waiting time is almost non-existent. When analysing average values of the simulation, one can conclude that, as there are no queues, the values are perfectly in line with the expected and acceptable performance needed.

6.3.4 *Turnaround times of trains, CFS trucks and trucks*

It is fundamental that turnaround times of trains and trucks stay as low as possible, in order to get a preferably high transporter utilization of the equipment of the terminal. Starting with the turnaround time of trucks it is recommended that values for the turnaround time are around 40 to 60 minutes, as shown in Figure 2 – Turnover time of Trucks, source: (Giuliano and O'Brien 2007), provided by (Giuliano and O'Brien 2007), who studied queueing issues in the Ports of Los Angeles and Long Beach. The values obtained of simulations are of 0.57 hours and the values are perfectly in line with the values obtained by

Transaction type	Turn time
Bobtail in/container out	40.2
Container in/bobtail out	37.9
Container in/container out	60.5

(Giuliano and O'Brien 2007).

In what concerns the CFS truck and train turnaround times, the CFS trucks have an average service time of 3 hours. Trains have a higher turnaround time. is clear that these values are directly proportional to the number of containers available in the yard and the number of slots available

Figure 2 – Turnover time of Trucks, source: (Giuliano and O'Brien 2007)

at the train.

6.4 *Parametric Variation*

Parametric variation showed that, for two additional Sceanrios: Scenario 2 will consider a smaller call-size, reducing from 20.65% containers to 20.65% TEU, which implies an increment in the number of ships and Scenario 3 with the same call-size as Scenario 2, but with bigger ships. As a general perspective, quay parameters for the additional scenarios had a major increase for both average and maximum queueing times, which is due to the high values of BOR. The time-averaged quay crane utilization suffered an increase, when comparing the results from the base scenario. Pilot boat utilization, which depends on all the ships that arrive at the port, have similar values, which is expected. The higher number of the base scenario is directly related to the fact that more ships entered the terminal and did not have to wait in queue. As stated before, since there is a significant queue present in both additional scenarios, the export Levels are obviously higher and higher dwell times are verified. In opposition, by the same logic, the values of the import yard are lower than expected, when comparing to the basic scenario. Also, since there are lesser ships and less containers, the degree of inspection use is lower, making the containers more quickly

available for the outbound trucks to pick them up and trains to move them out, which arrive daily. Hence the dwell time is significantly reduced. Hazard and reefer blocks suffer from the same issue as the import terminal, as not enough ships enter the port. The empty container yard, where containers arrive per ship and are only moved by the use of the CFS, is a major problem, requiring further insight and probably a hub outside the port for further storage. Concerning the use of the RMGs, it becomes clear that, in accordance with the blocks being used, the RMG usage will vary. In fact, since there is less movement at the quay, there is an obvious reduction of RMG utilization throughout the yard. What concerns the other transporters, reach stackers, forklifts and yard trucks, a clear reduction of yard truck utilization is verified, in line with the other parameters directly related to ship arrival, whereas reach stackers and forklifts have similar patterns in all three scenarios. Train turnaround times decreased in Scenarios 2 and 3, due to the lower number of containers in the yard, whereas turnaround times of trucks have slightly decreased in value, when compared to the other values of Scenario 1, due to the lesser number in containers at the terminal and consequent lesser queue waiting for an RMG. The train terminal occupation levels decrease, once again, in line with the number of ships which enter the terminal. Finally, the gate performance is directly proportional to the number of trucks arriving at the terminal, which increases for Scenarios 2 and 3. Still, as no bottleneck is created, no major issues from increasing the loads is created.

6.5 *Throughput capacity of the terminal*

Every simulation scenario should move 600,000 TEU or more. So, one must analyse how many containers were moved by the terminal. The values are presented in Table 7 – Total Throughput for three Scenarios. When analysing the throughput, it becomes clear that the first scenario is the one that presents the best values. It is, once again, inversely proportional to the number of vessels waiting in queue to enter the terminal, becoming clear that the more vessels there are in queue, the less the terminal moves. Clearly, the best results are presented by Scenario 1, making this the most favourable simulation, considering the other values.

Table 7 – Total Throughput for three Scenarios

Total Throughput	Scenario 1	Scenario 2	Scenario 3
Throughput [Containers]	647,301	398,690	463,109

7 CONCLUSION

The Port of Leixões, with all its history, as one of the first artificial ports in Portugal, is the key port in the Northern Region of Portugal. The present facilities are already at their maximum capacity and with the expectable even greater increase of freight transport, due to the European Corridors moving containers from the countryside to the coast, the need becomes even greater. With the 2020 Horizon program, the financial resources will be available to assist the development of a new terminal at Leixões. In recent news, some questions have been made if the new container terminal would be able to handle 600,000 TEU, which is the objective of the new terminal.

The present work aims at analysing the feasibility of a new container terminal at the Port of Leixões, placed at the current location of the Ro-Ro ramp and close to the Fishing Docks, with a capacity of 600,000 TEU. From the start on, it was clear that space was always going to be an issue in this area, due to the narrow quay and rather small yard, which would always imply nearly ideal working principles. Up until now, no integrated study of container terminal pre-dimensioning and simulation of the same had been published in the literature in Portugal, being this the literature gap, when considering previous studies.

As a basis, a pre-dimensioning was made, based on several works of the literature, which revealed to be quite accurate, as a general perspective. Since data from the existing terminals were not able to be received, the option of using the AIS system and empirical formulae to solve to problem proved to be quite accurate, as pre-dimensioning results, when compared to the simulation values, were very satisfactory. In what concerns the results, it revealed that, as a general perspective, the most appealing scenario is the first one, because it is the one that moves the biggest number of containers, as well as having modest values for utilization. But as it was proven in the previous Chapter, one of the biggest bottleneck is related to the quay which is limited to 553 metres, which, although never being passed, there are times where it is almost fully occupied (550 metres), for scenarios 2 and 3, making it clear that the main problem with this terminal is the short quay it possesses for the number of containers it wants to move (600k TEU) and the types of ships that the new terminal wants to receive (Post-Panamax 2nd generation). The second major problem present at the terminal is the import yard which has a major occupation level. Due to lack of space at the yard, the new terminal should adopt active policies, such as to oblige companies to pick-up their containers early on, so that the dwell time is reduced and, consequently, lower occupancy levels. In addition, the empty containers yard is clearly under-dimensioned, being this the major bottleneck of the new to be established terminal. A clear solution, such as an outside lying hub, or simple increase and re-arrangement of the terminal, is needed, to solve this issue, being the recommendation of the author to use a hub. For further work, the insertion of detail to the level of the pile of containers, which was not considered, due to the actual politics of the Port of Leixões, could allow for further studies of terminal performance. Other more detailed approaches, such as the modelling of all the processes at the CFS, as well as the inclusion of a special gate where trucks, who do not have clearance to enter can request their documents, if the data is available, should be studied. Other further studies would be to include, the whole port into a simulation model, to better model the gate system. Also, the modelling of the different depths of the port and

the occupancy of the manoeuvring basin could also be included in further studies. The model could also be used to test different additional strategies (stacking and others), as well as additional or other equipment, the addition of a hub terminal and consequent further analysis of throughput. As a final remark, the objectives set for this work were clearly achieved, having been demonstrated that, under certain conditions, the new terminal at the Port of Leixões is able to move the 600,000 TEU, reaching the 1,2 million TEU target.

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