Container and Berth Allocation, and Yard Crane Deployment at the Liscont's Container Terminal

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Abstract

In a world where the economy is constantly increasing as well as the demand in the global markets, shipping as turned to be one of the most viable solution being able to carry large quantities for medium and large distances with efficient cost. However, this type of transportation creates a lot of pressure on the maritime terminals due to the increasing capacity of ships and consequently the exigency level of the operations of loading and unloading the ships. The case in study is the container terminal of Alcântara, that belongs to Liscont. In this study different approaches will be analysed in the existent literature, regarding the problems associated with container terminals, such as: the allocation of containers in the terminal yard; the deployment of yard cranes to move the containers; and the selection of the position of where the ship should take berth in the quay side of the terminal. The methods presented are based on operational research, more specifically, Mixed Integer Programming, to achieve an efficient solution for the objectives previously mentioned. Three algorithms will be presented, of which, two of them will be developed using the software GAMS. The one remaining is used has a tool to react to the unpredictability of the arrival of the containers to the terminal. In the end it is possible to verify a substantial increase of the expected efficiency in the operations.

Keywords: Container Terminals, Container Allocation, Yard Crane Deployment, Berth Allocation, Mixed Integer Programming, Operational Research

1 Introduction

Nowadays with the exponential growth of the economy and the vast globalization of the commerce, countries increasing importance of having commercial activity with other countries, which are spread all over the world. In order to satisfy the demand, it is critical to select the best mean of transportation of goods. According to Steenken et al. (2005), the maritime transportation is seen as a solution with numerous advantages. Similar to air transportation, large distances can be reached, but the maritime transportation allows companies to ship larger quantities, therefore economies of scale are possible, reducing internal costs.

Generally, the goods that are transported by maritime transports are carried inside containers, which represents a determinant advantage - standardization (Güven & Eliiyi, 2014). Standardization allows companies to reduce the amount of packaging and reduces the probability of damaging the goods. For these reasons, containerized cargo has seen an increase of utilization over the last years.

With the increasing demand, the competitiveness of the maritime transport has also rise. Thus, the ship-owners are driven to mainly reduce the operation costs and increase the capacity of their ships, so that all the demand is satisfied. Such requirements put a massive pressure on container terminals (Froyland et al., 2008). These terminals not only have to guarantee fast-paced operations to reduce the costs of the ship (berthing costs, maintenance costs and ship's crew cost, but also must constantly adapt to the rising increase of the ships' capacities.

Despite the high pressure by the ship-owners to improve the operations with the ship, containerized shipping volumes have increased 6.1 p.p in 2014 and 2.9 p.p in 2015, due to container terminals developments, only possible because of the efforts of engineering and operational research (Zukhruf et al., 2017).
This work focuses the operations at the Liscont's container terminal in the Port of Lisbon, where is important to minimize the time that the ships are taking berth by improving the efficiency of the activities to load it, that is, to reduce the number of movements of the containers and reduce idle machines times.

1.1 Objectives

Within a container terminal, the operations usually have bottlenecks and inefficiencies regarding three types of decision-making:

1) Allocation of containers inside the terminal;
2) Yard crane deployment;
3) Allocation of ships berths

The three points mentioned above have the same purposes: the reduction of movements that the containers will suffer, the reduction of the make span and workload of the operations.
This work has the objective of proposing a new method to reach higher levels of efficiency on the export activity, by reducing waiting times of the external truck that bring the containers to the yard and and unnecessary movements of containers, taking into the account the position of where the vessel is going to take berth and the resources available. Note that the objective of this work is to reach optimal operational settings and not economic efficiency.

1.2 Liscont, YILPORT and the Port of Lisbon

LISCONT was created in 21 November of 1983, but it started operating only in 1984, at the Alcântara container terminal, in the Port of Lisbon. The sole purpose of this company is loading and unloading container ships, storing and transporting the containers inside the terminal. It is a concession holder of the Administration of the Port of Lisbon (APL), who is responsible for the area used for the activity of the terminal. Liscont has to communicate the activities and the investments it makes to APL.
Liscont was acquired by the international group YILPORT in 2016. YILPORT was founded in 2004 with the objective to create the first terminal service in Turkey, which was constructed in the city of Gebze. The company has grown worldwide and currently occupies the 15th place in the worlds ranking of Container Terminals Operators, being expected to be within the top 10 operators in 2025.

1.3 Market

In Lisbon there are three main facilities that operate with ships and shipping containers: the container terminal of Santa Apolónia; the Multipurpose Terminal of Lisbon, that operates containers and other types of cargo; and the container terminal of Alcântara (Liscont). Table 1 presents the annual growth movements of containers (imports and exports) between 2013 and 2016, in number and in TEUs. TEU is the standard measure for containers, which means 20-foot Equivalent Unit.

Table 1. Number of containers and TEUs operated between 2013 and 2016 in the Port of Lisbon

	Number of Containers	TEUs
Container Terminal of Santa Apolónia	444,887	662,562
Container Terminal of Alcântara	559,353	825,847
Multipurpose Terminal of Lisboa	209,861	320,702
Others	69,243	114,949
Total	1,283,344	1,924,060

Source: www.portodelisboa.pt

Liscont is the facility with the highest percentage of movements, which represents 43.5% of the number of containers handled.
Liscont's profited €16, 855,381 which represents a decrease of 16.7% in comparison with the year 2015 in which was of €20,224,045. This downfall was justified by the stevedores strikes (Liscont, Annual Report and Accounts, 2016).
Liscont is responsible for handling 2.05% of the exports and 0.73% of the imports in Portugal, which is possible to conclude from Table 2.

Table 2. Imports and exports of Portugal in 2016

	Imports (tons)	Exports (tons)
Liscont	1,077,356	308,099
Portugal	52,444,087	41,845,414

1.4 Infrastructures

The area utilized for the commercial activity is of 142,354 m2. The terminal is divided in three different areas. Area I, where the containers that are going to be exported are placed; area E, where the import containers are stored and where the full refrigerator containers have a special location; and area V, where the empty containers are stored whether for exports or from imports including the empty refrigerator containers. However, there are special areas reserved for dangerous and hazardous goods, which is the area A. These specific areas are also sub-divided in lanes, bays, stacks and tiers (see Figure 1). In the Liscont terminal, area V, E and I are composed by different lanes. Each lane has different bays, that are subdivided in stacks and each stack can have a height of five containers (Güven & Eliiyi, 2014).

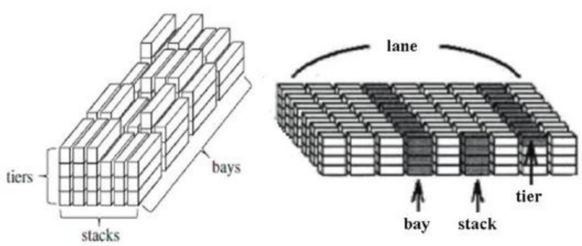

Figure 1. Representation of lanes (Source: Kim & Günter, 2006)

Specialized equipment is used to move the containers inside the terminal. The technology used can be divided in two types, yard cranes (YC) and quay cranes (QC). The YC are the machinery responsible for moving the containers inside the yard, whether it is an import container, which is brought from the quayside (where the ship takes berth) to the yard, or an export container that will be moved from the yard to the quay side.

1.5 The process

The container is brought by the clients using trucks (hereafter named as external trucks, XT) that enter the terminal. Each truck will wait at the terminal gate until its driver receives the information about the location that is attributed to the container. Once this location is known, the truck will move there, to be unloaded by a certain YC onto the stack, and afterwards the truck will leave the terminal. The container will be kept in the yard, until its ship arrives.

When the ship is at bay, the discharge and charge plan are completed, in which the order of the containers to be unloaded and loaded is established. These plans will influence the movements of the containers. Whenever a container is going to be loaded, a YC retrieves and places it on the quay side. It will then be picked up by a QC and placed onto the ship (Ozcan & Eliiyi, 2017).

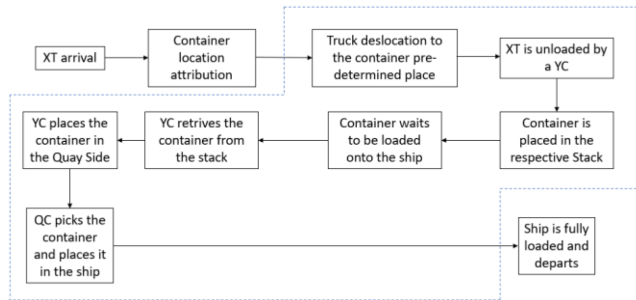

Figure 2. Chain activities in exporting a container

Figure 2 represents the chain activities to export a container. The dashed blue line represents the activities that take place inside the container yard. In this type of systems, the bottlenecks are in the yard operations and not in the quay side, since the velocity of loading the containers are fast paced due to experience of the workers and technology developments.

3 Literature review

The existent literature related with the three main decisions, oriented to the reduction of unnecessary movements of containers inside a container terminal yard. These decisions refered are usually mentioned as:

- Storage Space Allocation Problem (SSAP), when the problem is related with the yard planning;
- Berth Allocation Problem (BAP) when the problem is related with the berth allocation of ships;
- Yard crane deployment when the problem is related with the allocation of the yard cranes to the respective container lanes.

The concept of the Storage Space Allocation Problem (SSAP) in the storage yards of terminals was developed by Zhang et al. (2002), who solved this problem using a rolling-horizon approach. For each planning horizon, the problem is decomposed into two parts, each one being formulated as a mathematical programming model. In this method, the allocation of containers has a fixed temporal horizon. Within this time horizon it is possible to plan the operation, in real-time, based on the most recent information received. This pattern repeats itself over time. So, in the first stage of the algorithm the time horizon is calculated, and within this time horizon, operations are managed almost in real-time, using information that is acquired along the time horizon. Lee & Kim (2010) foccused their studies on the configuration of the stacks, and they developed two methods to optimize their size. One considering the performance of the YC and the other considering the storage requirements for the containers. They had the objective to determine the optimal number of bays in each lane. Chen & Lu (2012) developed a two-staged algorithm to decide the best storage location for outbound containers. In the first stage, an algorithm is created to decide the correct bay in which the container should be placed, using as decision variable the destination port of the container. In the second stage, a second algorithm is formulated, to decide the exact position for the container in the, already decided, bay using the weight of the containers as variable. Results show a large reduction on reshuffling operations, which is the main goal of this project.

Zhang et al. (2002) developed an algorithm in which they try to balance the workload of the RTGCs and the make spam of the operations in defined time periods. The problem was modulated as a mixed integer programming model, which is solved through a Lagrangean relaxation, adding so specific constraints. Results showed robustness of this method, since it does not depend on the number of lanes existent in the container yard. Genetic algorithms also have a spotlight in these types of cases. Correcher & Valdes (2017) developed a GA to assign a number of cranes and location for ships to take berth, in the terminal. The algorithm is based on a Biased Random-Key genetic algorithm. Starts by considering a population with a number of individuals. The number of individuals depends on the number of ships. Each individual has two lists: (1) keys-to-vessels and (2) number of cranes to vessels. Then the algorithm is developed to achieve a feasible berth plan taking in consideration the lists above mentioned. Agra & Oliveira (2018) also proposed a mathematical model to decide the berth and QC allocations utilizing big-M constraints and the branch-and-cut method.

The authors start by separating these two problems, as did Song et al. (2012). The problem is then divided in the Berth Allocation problem and Quay Crane assignment and scheduling.

The formulation of the first problem the quay side of the terminal is divided in sections and the time horizon in periods. Then the mathematical formulation is developed. In the second problem, the mathematical formulation is achieved by taking into account the cargo volume in the ships and the rate of each crane in each period of time. Then the objective function is defined to minimize the time of service completion. Budipriyanto et al. (2017) made an interesting contribution in which they propose the collaboration of different terminals in order to increase performance of ports when it comes to uncertainty. Using a discrete event simulation, they concluded that the collaboration brings welfares to the whole system and minimizes inefficiencies concerned with the turnaround time of vessels, waiting times and the handling of containers inside the yard and in the quay side. It is important to note that only the system benefits from such collaboration, and not the terminals in particular.

Some of the analyzed approaches take into account the variability and uncertainty of the arrival of vessels, and large number of ships, which in the case of Liscont, is not verified, because all the vessels that take berth in Alcântara are considered regular lines and are not that many. In other words, all the ships have a clear pattern for their arrival frequency, which can be weekly, biweekly or monthly. Therefore, approaches that assume uncertainty on the arrival are unnecessary for the case analyzed in this work. The most promising approaches for improving the efficiency of operations at Liscont's container terminal are:

- Presented by Chen & Lu (2012), regarding the allocation of the containers in the yard, to facilitate the loading operations, and most importantly, to reduce the number of unnecessary movements of the containers (i.e. reshuffling). The approach to be applied is known as HSSA (Hybrid Sequence Stacking Algorithm).

- The simplest berth allocation strategy will be applied, due to the reduced complexity of the terminal and the few restrictions that exists there. The decision of the berth allocation will serve as an input on the HSSA.

- Presented by Zhang et al. (2002) in their paper titled as "Dynamic crane deployment in container storage yards, for the yard crane deployment. It uses as input the expected workload on each lane, which is assessed after the allocation of the containers is defined. This last algorithm is focused, not on the reshuffling issue, but on deciding where each yard crane will operate, in order to reduce operational times and make spam.

2.1 Allocation of container in the yard

The algorithm of Chen & Lu (2012) has two stages. In the first one, the most correct lane and bay will be decided using an algorithm developed by the authors, that takes mainly, into account, the ship that the container is going to be placed on, and the destination port. Once the bay is decided, the best location for the container, inside the bay, is determined. In this stage the decision variable is the weight of the container. The algorithm, to decide the exact place of the container, inside a bay is called “Hybrid Sequence Stacking Algorithm” (HSSA), which combines the vertical and horizontal stacking strategies. To explain this stacking strategies, the weight of the containers will be categorized from 1 to 9, being 1 the lightest and 9 the heaviest. In the vertical stacking strategy, containers with similar weights are stacked on top of each other (see an example in Figure 3). In the horizontal stacking, containers with similar weights are stacked in the same height tier, along the bay, as represented in the example in Figure 4.

5	4	3	2	1
5	4	3	2	1
5	4	3	2	1
5	4	3	2	1

Figure 3. Vertical Stacking

4	4	4	4	4
3	3	3	3	3
2	2	2	2	2
1	1	1	1	1

Figure 4. Horizontal Stacking

So, as the result of the combination of both strategies, the HSSA is created. Figure 5 shows the representation of the final layout.

9	8	7	6	5	4
8	7	6	5	4	3
7	6	5	4	3	2
6	5	4	3	2	1

Figure 5. HSSA

This approach was chosen due to the fact that it responds better to the uncertainty of the arrival of the containers than the other reviewed methods.

2.2 Berth Allocation

The process of deciding the approach for the berth allocation of ships was not simple. All the cases reviewed had more restrictions than the case studied in this work, therefore, they bring unnecessary complexities. In the case of Liscont, the decision process is much simpler due to the small amount of ships and space available for them to take berth. The decision of the berth location can be done with only two constraints. One of them is very important, which is the water draft, already mentioned before. The water draft varies along the quay side of the terminal, and some ships may not be able to take berth in the areas where the draft is smaller. So, the position of the ship is restricted by it. In the case of having two ships that can take berth in every place of the quay side, the decision is made taking into account the number of refrigerator containers to be loaded onto the ships or unloaded them. Since the refrigerator containers have a specific zone allocated to them, the ship that has the largest number of movements with refrigerator containers will be placed closer to this reserved area.

2.3 Yard Crane Deployment

The last approach to be used is the one developed by Zhang et al. (2002) in their paper titled as “Dynamic crane deployment in container storage yards”. In this algorithm, an efficient RTGCs distribution, along the existent lanes in the container yard is assessed. It considers different planning periods to make the management of the machinery. In addition, it takes into account some import safety rules, because we are dealing with very heavy machinery that can cause severe injuries or even death to the workers of the terminal, or damages to the cargo, ships or vehicles in the terminal. The objective of this methodology is to balance the workload of the RTGCs in every lane possible and reduce the make spam of the overall operation.

The three methods can be used in sequence. The decision of the berth allocation of the ships is used as an input for the method used to allocate the containers in the yard. The amount of containers in each blocks is a souce of information to use and adapt it as an input fot the method used for the crane deployment.

3 Results and Discussion

3.1 Bay Allocation: Stage 1

The results of the bay selection in stage one for export containers are depicted in Table 3.

Table 3. Bays selected for ship 1 and 2

Bays/Ships	j1	j2
i2	25	
i3	25	
i4	25	
i5	25	
i6	25	
i7	25	
i8	25	
i14	22	
i19		25
i20		25
i21		25
i22		25
i23		25
i28		22
i30		25
i35		25

Bays with number 2,3,4,5,6,7,8 and 14 are used to store all the containers that will be loaded on to ship number one. Bays number 19,20,21,22,23,28,30 and 35 are used to store the containers for ship number two. The computational time to obtain these results was of 0,002 seconds.

3.2 Bay Allocation: Stage 2

Analyzing the allocations presented, it is possible to conclude that the average number of movements per container for ship one is 2.02. For ship two, the result is 2.11. This result was obtained by the sum of the total number of movements each container will suffer, which will be then divided by the total number of containers. If a container is not positioned in the best location it will have to have re-handled in some time in the future, therefore the container will be moved three times. If the container is in the best location it will not be re-handled, therefore the container will only be moved two times. Equation (1) represents this calculation:

$$MC = \frac{\text{NrR x 3+NrNR x 2}}{\text{C}} \quad (1)$$

In which:
NrR represents the number of containers that will suffer re-handling
NrNR represents the number of containers that will not suffer re-handling
C represents the total number of containers
MC represents the number of movements per container

3.3 Crane Deployment

Table 4 presents the results obtained when applying the algorithm to the export containers of ship one, using the results of the second stage of the bay selection method as inputs. The first column refers to the movement of a crane between the Crane of Origin (CO) and the Crane of Destination (CD).

Table 4. Crane movements for planning periods 1 to 6

BO/BD	t1	t2	t3	t4	t5	t6
i1.j1	1					
i1.j2	1				1	
i1,j3	1	1				
i1.j4	1		1	1		1
i2.j1	1					
i2.j2	1					
i2.j3			1		1	
i2.j4		1		1		
i3.j1						1
i3.j2				1	1	
i3.j3						
i3.j4						
i4.j1						
i4.j2					1	1
i4.j3		1	1			
i4.j4						

Initially, blocks one had two cranes, block two had two cranes, block three had one crane and block four had one crane. From planning period to planning period cranes move from a block to another. For example, if the line correspondent to "*i2.j3*" has a the value one, it means that a crane moved from block two to block three.

4 Conclusions

The methods implemented to improve the operations in the Liscont's container terminal of Alcântara presented good results. In the method presented for the crane deployment, all the containers are loaded onto the ship in the planning horizon and minimized the number of movements of each crane.

The most significant result was obtained in the second stage of the bay selection method. It was obtained an average of 2.02 movements per container whereas Liscont has an average of 2.13 movements per container. Therefore, this method obtained a reduction of 5% in the average number of movements per container.

A limitation for the bay selection method is that the terminal is assumed to be empty in the beginning of the planning horizon, as well as the assumption that no other containers for future ships would arrive meanwhile. For the crane deployment no unpredictable events with the machinery are considered, therefore no contingency or preventive measures are contemplated in this work.

In future developments, these methods should be applied in Liscont's terminal so that the real values can be compared with the theoretical values. Another future development would be to create an algorithm that could decide by itself the correct slot to allocate the containers in order to avoid human mistakes.

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