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

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Resumo

Num mundo em que a economia está constantemente a crescer, tal como a procura nos mercados globais, os navios são uma das melhores soluções para transportar grandes quantidade de mercadorias para médias e longas distâncias com um custo eficiente. No entanto, este tipo de transportes cria uma grande pressão nos terminais marítimos, causada pela capacidade crescente dos navios e consequente aumento das exigências operacionais para os carregar e descarregar. O caso em estudo é o do terminal de contentores de Alcântara que pertence à Liscont. Neste estudo analisam-se diferentes abordagens existentes na literatura para resolver problemas associados a terminais de contentores, tais como: a alocação dos contentores a zonas de parqueamento em terminais; a distribuição de tarefas pelos recursos utilizados para movimentar os contentores; e a atribuição eficiente do local onde o navio irá atracar. Os métodos apresentados recorrem à programação inteira mista, com vista à obtenção de soluções eficientes para os problemas antes referidos. Três algoritmos são apresentados, dos quais, dois são implementados em GAMS. O terceiro algoritmo serve para reagir à imprevisibilidade da chegada dos contentores ao terminal. No fim é possível verificar uma melhoria substancial nos resultados, face aos dados históricos fornecidos pelo Terminal o que comprova a eficiência dos métodos usados.

Palavras-chave: Terminal de contentores, Alocação de Contentores, Distribuição de tarefas de recursos, Alocação de navios, Programação Inteira Mista

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 Mixed Integer Programming, to achieve an efficient solution for the objectives previously mentioned. Three algorithms are presented, of which, two of them are implemented in the software tool GAMS. The third algorithm is used 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**.**

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List of abbreviations and acronyms

APL – Administration of the Port of Lisbon
BAP – Berth Allocation Problem
CD – Crane of Destination
CO – Crane of Origin
FIFO – First-In, First-Out
GA – Genetic Algorithms
HSSA – Hybrid Sequence Stacking Algorithm
KPI – Key Performance Indicator
MPH – Movements per hour
P.P. – Percentage Point
QC – Quay Cranes
RTCG- Rubber Tyred Gantry Crane
SSAP – Storage Space Allocation Problem
TEU – Twenty-foot equivalent unit
UNCTAD – United Nations Conference on Trade and Development
XT- External Trucks
YC - Yard Cranes

1 Introduction

1.1 Problem background and motivation

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.

1.2 Objetives

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

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 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 not economic efficiency.

1.3 Work development stages

Figure 1 illustrates the stages which will be followed in this work.

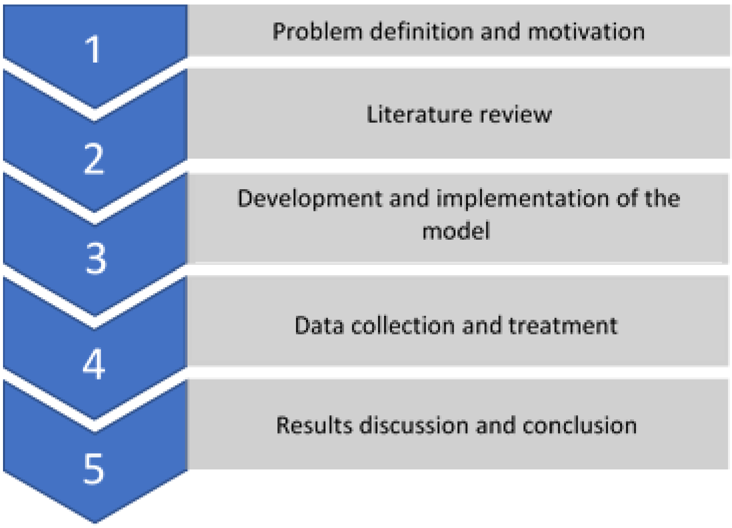


Figure 1. Schema of the work development stages

In the first stage, the problem will be contextualized in the present environment so that the situation of Liscont is understood in terms of its economic impact in Portugal. Additionally, all the operations and resources flows will be characterized. The objectives will then be explained, taking into the account the problem that will be addressed.

The second stage concerns about reviewing the literature to allow a presentation of the methods already utilized in similar problems.

The third phase will be concerned in the development of the selected approach. A full planning of the operations scheduling and task distribution will be developed, not despising the constraints of the terminal, whether on capacity or on safety rules. This will be laid under the validation of Liscont.

Regarding “Data collection and treatment”, information will be accessed and presented. The treatment of the data will be performed following the methodology selected for this case. During the work, some assumptions will be taken so that the problem is viewed in less complex form. These assumptions are important for the development of this work, since the methodologies selected has to fit them.

The results will be analyzed and discussed in the fifth and final stage. Feasibility analysis is critical to determine which solution are actually possible to engage and put in practice.

1.4 Project structure

The remainder of this document is structured as follows.

Chapter 2 presents Liscont and the group to which the company belongs. It includes a brief history of Liscont, a short economic analysis and a detailed explanation of the processes, infrastructures and resources within its Alcântara container terminal. Next, it describes the limitations found in the operations developed at the container terminal.

Chapter 3 contains a literature review which is used to identify the best approaches to address problems similar to those identified at the Liscont’s Alcântara container terminal.

Chapter 4 presents the algorithms that were selected in chapter 3. Each of the equations is explained, as well as how they affect the solving process.

In chapter 5 the methods are explained using practical examples: In addition, it is also describes how the methods should be applied.

Chapter 6 contains the final results obtained by the algorithms

Chapter 7 presents the conclusions of this study and its limitations. This chapter also includes some recommendations for future developments.

2 The Liscont's problem

This chapter describes the company on which the project is being developed. It will be presented the environment where Liscont is inserted. Given that, 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. Today, the group owns 20 marine ports and terminals: one in Peru, Malta, Norway and in Ecuador, two in Spain and Sweden, five in Turkey and seven in Portugal.

Further ahead the operations developed at the Liscont's Alcântara container terminal are explained, as well as the flow of resources and all the decision making involved in managing this complex set of activities on a daily basis.

2.1 The company: Liscont

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. Along the years, Liscont acquired some navigation lines and lost others, influencing the activity of the company, more precisely, on the quantity of containers to be handled. With the increase of operations, the terminal was obliged to expand its area. Investments on machinery to operate the containers were also required to keep the competitive efficiency.

2.1.1 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. Each time a container is mentioned, it is referred as a TEU or 20’. However, companies also use another type of container, the 40-foot Equivalent Unit (FEU or 40’), which basically, is considered the double of a TEU.

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

From Table 1 it is possible to conclude that Liscont is the facility with the highest percentage of movements, which represents 43.5% of the number of containers handled. Therefore, is the terminal that has most impact in Lisbon, thus, more revenues. In year 2016 the operations with containers in the Liscont’s terminal represented a profit of €16, 855,381. It must be mentioned that the profits in year 2016 decreased 16.7% in comparison with the year 2015 in which was of €20,224,045, which were attributed to stevedores strikes (Liscont, Annual Report and Accounts, 2016). Table 2 establishes a comparison between the activity of imports and exports in year 2016, which were operated at Liscont’s container terminal and the total verified in Portugal.

Table 2. Imports and exports of Portugal in 2016

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

Source: www.portodelisboa.pt and www.ine.pt

It is possible to conclude that Liscont is responsible for handling 2.05% of the exports and 0.73% of the imports in Portugal.

2.1.2 Infrastructures

As mentioned before, Liscont is located in Alcântara. The area utilized for the commercial activity is of 142,354 m^2. Figure 2 represents the organization and area of the container yard at the terminal of Alcântara.

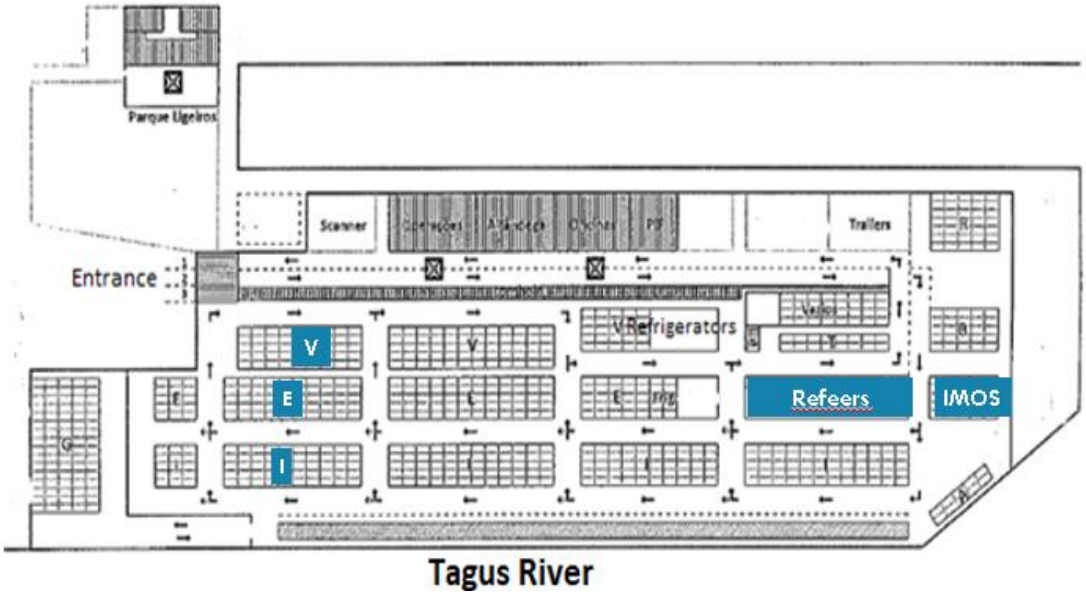


Figure 2. Liscont's terminal layout

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. In the past, the areas had different purposes (I for imports and E for exports) but Liscont decided to change them. In this change, the names of the zones were not changed, so that people who work in the operations would not get confused, since they were used to the old system.

These specific areas are also sub-divided in lanes, bays, stacks and tiers (see Figure 3). 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).

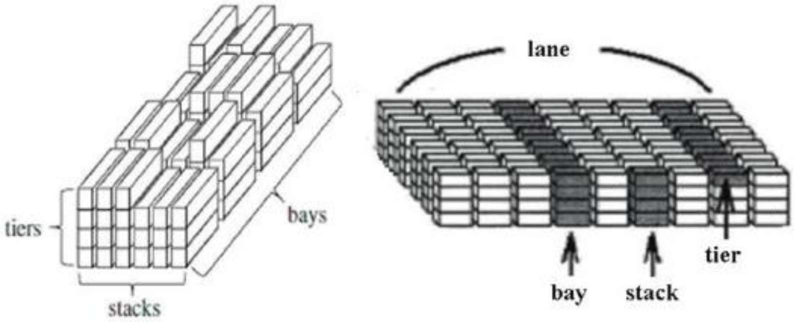


Figure 3. Representation of lanes (Source: Kim & Günter, 2006)

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. A QC is responsible for loading and unloading ships (Zhang et al., 2003).

Liscont has available 10 rubber tyred gantry cranes (RTGC), 10 container stackers, 19 trailers and 17 tractors, which guarantee the function in the yard. To ensure the activity in the quayside, there are available four quay cranes. Figure 4 presents the most important cranes.

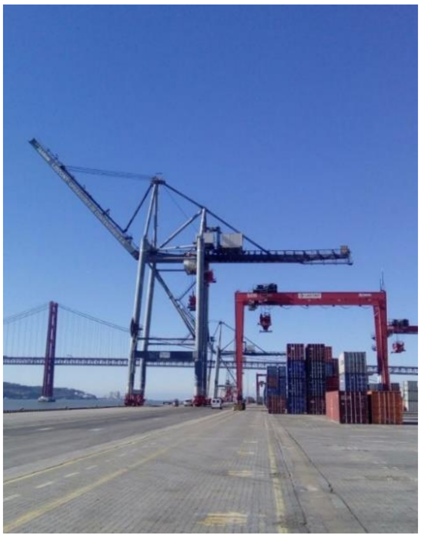


Figure 4. Quay Crane (at left) and RTGC (at right)

2.1.3 Process

This section is focused on the process of placing a container in the ship.

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).

In all of this process, there are main activities that need some decision making, which are critical to the efficiency of the operations: Berth and QC Allocation, Storage Space Assignment, Rubber Tyred Gantry Crane Deployment, Scheduling and Routing Vehicles and Appointment Time of XTs (Ozcan & Eliiyi, 2017):

- Berth and QC Allocation - responsible for the decision of where the ship is going to take berth, which QC are going to be used with the main focus on minimizing the time that the ship is taking berth;
- Storage Space Assignment - responsible for minimizing the number of unnecessary movements of the containers by assigning the correct positions to them;
- Rubber Tyred Gantry Crane Deployment - has the objective of minimizing the berth time of the ship and the waiting time of all the remaining resources (QC, trailers and stackers) by deciding how many RTGCs will be used in each lane;
- Scheduling and Routing Vehicles - by optimizing the scheduling and the routes of the vehicles used to move the containers it is expected that the transportation costs are reduced as well as the waiting times of the RTGCs and QCs;
- Appointment Time of XTs - responsible for the decision of when the XT arrive minimizing their waiting times and reduce the traffic congestion in the terminal.

The optimal organization of the yard, which is called as “Housekeeping” facilitates the decision-making process, thus the loading and the unloading of the ship will be more efficient. (Mili & SadraOui, 2015).

Figure 5 represents the “housekeeping” decision-making sequence on a daily basis.

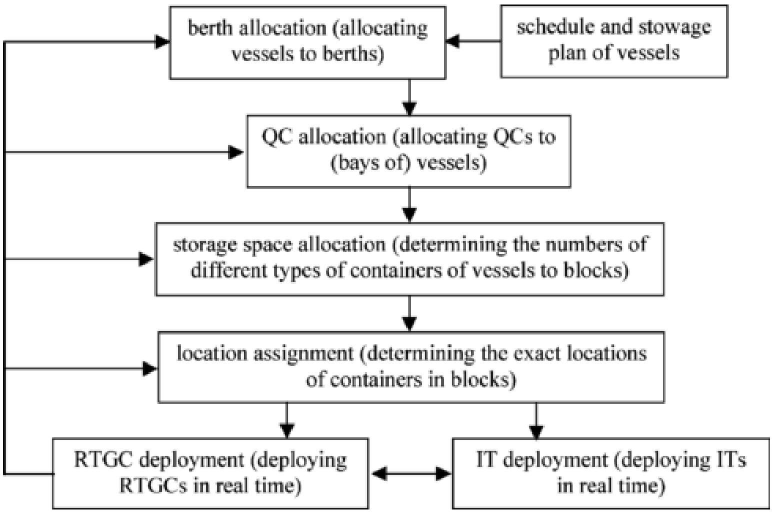


Figure 5. “Housekeeping” decision-making sequence (Source: Zhang et al., 2003)

2.1.4 Conditional Factors

The usual process of shipping a container is presented in section 2.1.3**Error! eference source not found.**. However, there are some conditional factors that need to be considered, which will be mentioned in the present section.

The first condition to be addressed is the *dwell time*, which is the time that a container remains in the yard between being discharged from the ship and being picked up by a XT, or between being unloaded from a XT and loaded onto the ship. Terminals do not tax the storage costs for a certain number of days to the clients so that they can arrange the customs and the clearance of the goods. Worldwide, the dwell time of the first case (import) is about five to seven days, and on the second case (export) is about three to five days. (Gardiner et al., 2014). Note that, terminals do not have control on the dwell time, however it is possible to influence it by changing the tariff of the storage costs if the dwell time is not respected.

Since long dwell times result in a higher occupancy of the container yard, the efficiency of the operations will be affected negatively.

The second condition to be considered is the *number of tiers* that the yard can operate. Despite Liscont can operate with tier 5 containers, this avoided because it may lead to inefficiencies, such as unnecessary movements and is preferable to spread the containers instead of stacking them. Also, the time that it takes to retrieve a tier 5 container is longer than to retrieve a tier 4 container, due to the time that the YC takes to reach the height of the container. Therefore, retrieving a tier 4 container takes more time, than to retrieve a tier 3 container.

The third condition is related with the *safety of the yard and operations*. It must be taken into account that dangerous goods need to be placed in a restricted zone to avoid larger accidents.

And finally, the *distribution of refrigerator containers*. The reason why this type of containers has its specific area is due to the fact of the requirement of power supply, which is concentrated in only one place in the yard.

2.1.5 Benchmarking

In this section the most relevant key performance indicators of this work will be explained. Data collected from Liscont will be compared with the average of the rest of the terminals in the world. The KPIs to be analyzed are concerned about the capacity of the container yard and its performance, and the performance on the quay cranes.

2.1.5.1 Yard capacity and performance

The yard capacity is one of the most important key performance indicators since it will influence all the operations. According to Gardiner et al. (2014), the yard is considered a buffer area where the containers are stored for a variable amount of time. The capacity can be measured in terms of the total number TEU slots in the yard. Despite the terminals have a certain theoretical capacity, it can never be used in its totality because it may lead to unnecessary movements of containers and the machinery have operational constraints that do not let them operate everywhere. The usage of the yard should be between 70% and 80% of this maximum theoretical capacity.

According to the United Nations Conference on Trade and Development (UNCTAD), the storage capacity of a terminal (C_y) is given by

$$\mathrm{Cy} = \#GS \times h \times r \tag{1}$$

in which: *#GS* is the number of ground slots (TEU positions); *h* is the average operational height of stacks; and *r* is the average number of turnovers per year (Martín Soberón, 2012).

By applying equation (1) we found that Liscont has a theoretical capacity of 567,641 TEUs whereas the average capacity of the terminals around the world is about 820,609 TEUs, which represents 45% more capacity than Liscont's terminal.

2.1.5.2 Performance of the Quay Cranes

As it was explained before, the Quay Cranes (QC) are the machinery responsible for loading and unloading the ship with the containers. To evaluate the performance of the QC it is used the measurement of quay crane moves per hour (MPH). This key performance indicator represents the number of cycles that the crane makes, and has impact on other KPI, the gross and net averages. Gross average is the average moves per hour the crane operates, the net average is the same but takes into the account the time that the crane has stops for maintenance or other reasons.

At a worldwide level, the average of gross movements per hour is between 20 to 30, and the net movements per hour go from 25 to 40. In year 2017, the averages of gross and net movements of LISCONT were 25.33 and 38.2, respectively. Thus, Liscont at this level has reasonable performances.

2.1.5.3 Unnecessary Movements

The key performance indicators presented previously are always bond to the organization of the yard. In other words, if the containers are perfectly distributed, the number of movements each container will have inside the yard would be only two (when they are dropped off by an XT and when they are picked up by a yard crane to be placed onto the ship). However, this is utopian, since the capacity of the yard is a hard constraint, and the container will always suffer re-organizational movements. These procedures are considered bottlenecks, because they may delay the activity of the QC, creating idle times, thus increasing the cost of the ship stay.

Liscont has an average of 2.25 movements per export container and an average of 2.3 movements per import container.

2.4 Chapter Conclusions

The core activity of container terminals is explained. Figure 6 represents the activity of exporting a container.

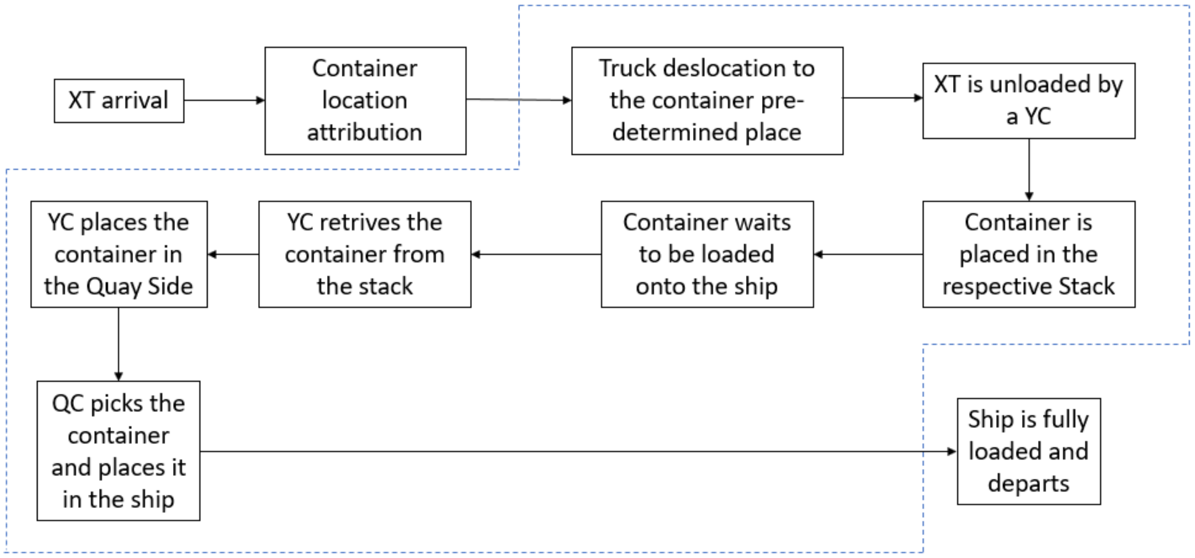


Figure 6. Chain activities in exporting a container

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.

In order to improve the efficiency of the operations, the most suited distribution of the container along the yard must be achieved by reducing the unnecessary movements that will, overall, increase the turnaround of ships.

3 Literature Review

3.1 Introduction

The present chapter reviews the existent literature related with the three main decisions, oriented to the reduction of unnecessary movements of containers inside a container terminal yard.

Usually in the literature, these decisions that are referred 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.

From receiving the container, to loading it onto the ships, the decision-making proposals in the process are based on optimization.

3.2 Yard Planning

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.

The method has the objective of deciding the number of containers that each bay should have. Assumes that the containers are one sized, since the method is not directly affected because, normally, different containers are assigned to different bays.

Lee & Kim (2010) also studied 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.

Alcalde et al. (2015), developed an analytical model based in a continuous operation in time, in order to predict the requirement of space for allocating the containers utilizing the potential of Monte Carlo simulation.

Ozcan & Eliiyi (2017) focused on the reduction of the vessels' berthing time, which causes large costs. Developed a reward-based algorithm for reducing the time that the ship takes berth by minimizing the "non-value-added handling" of the containers, having obtained successful results in this objective. The methodology considers four key indicators:

1) The distance from a container to the closest RTGC;
2) The workload of each RTGC;
3) The number of containers stacked in the bays;
4) The heights (tiers) of the containers.

The algorithm is expected to reduce the number of reshufflings needed, therefore reducing the berth time of ships in terms of operations.

Other literature available, which are going to be presented next, focus only on the organization of the yard, and not trying to integrate the distribution of the containers with the rest of the operations. The design of the yard is the principal objective.

Bazzazi et al. (2009) proposed a genetic algorithm to solve the SSAP. In their work, the different types of container are also a constraint, whether they are empty, full, refrigerators containers, or even dangerous goods. The objective is to determine how many containers should be allocated to each bay in the terminal. They assume that there are not enough resources to handle the workload in the yard and that is known where a certain type of containers must be allocated.

The objective function tries to balance the number of containers among the bays at each period of time to be considered.

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. (2014) created two methods to solve the container allocation problem, one considering the height of each stack and the other considers the configuration for a given stack. In their study, they proposed to solve the problem with dynamic programming.

The previous authors considered that the yard should have a static design. Whether it had a large number of containers or not, the yard should not change. But Tan et al. (2017), proposed a flexible yard template in their study. They had the objective of relieving the limitation on a static layout, creating a mathematical model for the space allocation. However, they concluded that the terminal benefits from a static layout, which reduces reshuffling and ships berth time, but if the objective of the terminal is to improve effectiveness in operating costs and space utilization, they recommend the utilization of a flexible terminal.

3.3 Berth allocation and crane deployment

The reason why both the berth allocation and the crane deployment decisions are going to be tackled together is because they influence each other. When deciding the berth location of ships, the QC must be deployed to them as well. And the deployment of the YC is also related with the QC due to operational times. By reducing the operational times, the best berth allocation can be determined.

To solve this combined problem, Song et al. (2012) developed a Bi-Level programming approach that provided an integrated solution for both concerns, using genetic algorithms to assess the best optimal solution.

In the berth allocation problem, the algorithm developed has the objective to minimize the waiting time and handling of the ships that will take berth. It is considered a dynamic scheduling, since the order of taking berth is determined after the vessels are on port. The algorithm is an alternative to the simple method of First-In, First-Out (FIFO), which may not be optimal.

In the second problem, which is the crane scheduling, the algorithm provides a technique to determine the sequence of loading and unloading containers from the vessel and has the objective to minimize the time spent in the operation. Includes a clustering of containers that have the same characteristics, which is considered a “block” (e.g. containers with the same destination port).

Summarizing, this approach assumes that the ships are already on port, each berth location can only be associated to one ship and does not consider the water draft (depth of the water). It also considers the possibility that some operation cannot be executed in parallel, and that, some ships must be unloaded before others, following an already defined schedule.

The approach of breaking down the problem in two is also adopted by Karam & Eltawil (2016). In their models, the arrival of ships is considered dynamic and assume that the arrival time of all vessels is known, and the water draft does not affect the location of the vessel. The formulation starts by creating a set of vessels, a set of time periods and a set of berthing positions. Then the objective function is formulated to minimize the sum of handling costs of containers. The quay crane problem will be in charge of assigning the quay cranes to the vessels and has the objective of minimizing the operation time for each vessel.

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.

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.

All the previous papers have focused on just one terminal, but 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.

However, some authors developed models that focus only on the yard crane deployment. Zhang et al. (2002) developed an algorithm in which they try to balance the workload of the RTGCs and the make span 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.

All of the reviewed approaches result in efficiency improvements in maritime terminals. However, some are too complex to apply to the Liscont’s terminal.

Some of the analyzed approaches consider 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.

Other approaches try to resolve issues related with transshipment (where, for example, a container is discharged from a ship, stored in the yard for a certain time, and after is loaded onto another different ship), which is a problem that does not affect Liscont.

The most promising approaches for improving the efficiency of operations at Liscont’s container terminal are:

- 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 next method.
- 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).

- 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 span.

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 considering 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 (see Figure 2), the ship that has the largest number of movements with refrigerator containers will be placed closer to this reserved area. The decision of where the ship is going to take berth will serve as an input on the first methodology that will be developed, the HSSA (Hybrid Sequence Stacking Algorithm).

Allocation of container in the yard

As already mentioned in this chapter, 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 7).

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 8.

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

Figure 7. Vertical Stacking

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

Figure 8. Horizontal Stacking

So, as the result of the combination of both strategies, the HSSA is created. Figure 9 shows the representation of the final layout that results from the combination of the two previous layouts presented in Figure 7 and Figure 8.

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 9. Hybrid Stacking

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.

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 span of the overall operation.

3.4 Chapter conclusions

This chapter presented a literature review on the methods developed by different authors trying to solve the problems addressed in this work. After analysis each one it was concluded that for the ship berth allocation, the decision would only be based on the number of refrigerator containers to be loaded on to the ship, considering the specific zone in the terminal for this type of containers.

For the allocation of the containers, the method to be used is the one developed by Chen & Lu (2012), which is divided into two-stages and has the objective to reduce the number of containers in the terminal that will be re-handled.

Finally, for the crane deployment, the method to be used will be the one developed by Zhang et al. (2002), which minimizes the number of movements that the cranes will do between blocks of containers so that the operations have a shorter duration.

4 Definition of the Mathematical Models

4.1 Introduction

This chapter fully explains the three methodologies selected which were only briefly presented in previous chapter 3.

The first one is based on the number of containers and their type and considers the water draft and the operational capabilities of a ship, allows define the location where the ship should take berth.

The second methodology analyzed, developed by Chen & Lu (2012) is concerned with the allocation of the containers, once they arrive to the terminal.

The final one, which was developed by Zhang et al. (2002) defines the crane deployment inside the container yard will.

4.2 Berth Allocation

The last decision to be made is concerned with where the ship is going to take berth on the quay side. As mentioned before, this is a simple process, because there are only two constraints to be dealt with, which are the water draft and the number of refrigerator containers that are going to be loaded onto the ship.

The first constraint to be considered is the water draft. If the water draft is not sufficient in one side of the quayside, the ship has to take berth on another location. Thus, this decision is made independently of the number of refrigerator containers to be loaded.

If the water draft is not a concern, the ship can take berth at any location on the quayside, therefore the number of refrigerator containers would be most important factor. If a ship has a high quantity of refrigerator containers to be loaded, then the best solution would be to place it near the areas that are specifically allocated for those containers. This decision has a high impact on the efficiency of the operations by reducing the travelling time of the yard cranes that are responsible for transporting the containers from the yard to the quayside.

This process has even more impact if it is followed by the HSSA method that was presented in section 4.2, since it uses as input the location of where the ships are taking berth.

4.3 Description of the procedure, phases and objectives

Determining the best space to place a container may bring operational benefits: it is expected to reduce the machines workload and to improve other key aspects, such as the average handling time required per container. Chen & Lu (2012) developed a two-stage approach to achieve such benefit.

The first stage allows to identify the bay that is more suited for a container, with the objective of reducing the time that the yard cranes will take to transport the containers from the yard to the quayside.

The second stage determines within the bay that was previously identified in stage 1, so that to minimize unnecessary movements of the containers.

4.3.1 Assumptions for both stages

As mentioned previously, this method uses some assumptions, to facilitate its usage and therefore eliminating complexity that is not needed.

In the first stage the following assumptions are made:

- The resources needed to handle the outbound containers, i.e. the containers brought by external trucks (XT), are always available.
- The berth locations of the ships are always known;
- Each bay will only take one container size; therefore, the module is not affected by the size difference between 40 TEU and 20 TEU.
- There is a clear division between the outbound containers and the inbound containers. In other words, the import and export containers are not mixed in the yard.
- And finally, containers with different destination ports are not mixed. This principle avoids extra handling of the containers.

In the second stage the following assumptions are made:

- The heavier containers are loaded onto the ship first, followed by the lightest. However, in practice, there may be some flexibility in that aspect since some lighter containers can be loaded first.

4.3.2 Modelization

This present section presents the algorithms applied in the two stages. The first stage uses a Mixed Integer Programming model, which is comprehensively described.

The second stage uses a simpler algorithm which can be followed by a decision tree and throughout several iterations of the process.

4.3.2.1 Phase 1 – Yard bay allocation for export containers

Based on the assumptions presented in section 4.3.1, the following parameters and indices have been established:

Indices: i index of yard bays, $1 \leq i \leq B$.

j index of ships.

k index of blocks, $1 \leq k \leq K$.

Sets: S_A the set of ships for which the space should be reserved during the planning horizon.

S_L the set of ships that will be loaded during the planning horizon.

$\underline{S_S}$ the set of ships for which the space was reserved during the previous planning horizon. Ships from S_A can also belong to S_S.

S the set of ships during the planning horizon ($S = S_S \cup S_L \cup S_A$).

B_j set of yard bays that have been reserved to store containers for ship j. It is also defined $\hat{B} = \{B_j | j \in S \backslash S_A\}$, which represents the yard bays that cannot be allocated to ships from S_A.

Parameters:

K total number of blocks to store the export containers in the yard.

B total number of bays to store the export containers in the yard.

C_i storage capacity of yard bay i.

b_i number of container block that yard bay i belongs to.

m_j maximum number of bays that containers for ship j can be stacked into.

D_j number of destinations of the voyage of ship j, $j \in S_A$.

V_i^0 number of containers in yard bay i at the beginning of the planning horizon, $1 \leq i \leq B$.

N_j expected number of export containers for ship j, that will arrive to the yard during the planning horizon, $j \in S_A$.

d_{ij} travel distance between yard bay i and the berth location of ship j.

γ allowable density for each yard bay.

The decision variables used in the model are the following:

x_{ij} number of containers that are destined for ship *j*, which will be stored in bay *i*.

δ_{ij} equals 1 if the containers for ship *j* are stacked in yard bay *i*; and 0, otherwise.

M_j total number of yard bays assign to ship *j*.

V_i total number of containers in yard bay *i*, at the end of the planning horizon.

W_k workload of block *k* during the planning horizon.

The allocation of the containers can be solved by the following optimization problem (see equations 2 to 15):

$$Min(w_1 \sum_{i=1}^{B} \sum_{j \in S_A} x_{ij} d_{ij} + w_2(maxW_k - minW_k)) \tag{2}$$

Subject to:

$$V_i = V_i^0 + \sum_{j \in S_A} x_{ij}, i = 1,2,\dots,B \text{ and } i \notin \hat{B} \tag{3}$$

$$V_i \leq \gamma C_i, i = 1,2,\dots,B \tag{4}$$

$$V_i = 0, i \in B_j, j \in S_L \tag{5}$$

$$\sum_{i=1}^{B} x_{ij} = N_j, j \in S_A \tag{6}$$

$$x_{ij} \leq N_j \delta_{ij}, i = 1,2,\dots,B, j \in S_A \tag{7}$$

$$\sum_{j \in S} \delta_{ij} \leq 1, i = 1,2,\dots,B \tag{8}$$

$$M_j = \sum_{i=1}^{B} \delta_{ij}, j \in S_A \tag{9}$$

$$M_j \geq D_j, j \in S_A \tag{10}$$

$$M_j \leq m_j, j \in S_A \tag{11}$$

$$\sum_{j \in S} M_j \leq B \tag{12}$$

$$W_k = \sum_{\substack{j \in S_A \\ b_i = k}} x_{ij}, k = 1,2, \dots, K \tag{13}$$

$$x_{ij}, V_i, M_j, W_k \geq 0, i = 1,2, \dots, B, j \in S_A, k = 1,2, \dots, K \tag{14}$$

$$\delta_{ij} \in \{0,1\}, i = 1,2, \dots, B, j \in S_A \tag{15}$$

Since this stage is concerned with the operations of loading the ship, the first term of the objective function (2) addresses the distance between the location of the container and the quayside. The total distance is calculated and minimized. The second term of the objective function (2) is concerned with the balance of the workload necessary for each bay. Since both terms may have different importance, the weights w_1 and w_2 were added to the equation.

The first constraint (3) defines the number of containers at each bay in the end of the planning horizon.

The following constraint (4) ensures that each bay will respect its density, by not exceeding a certain level.

Constraint (5) guarantees that the bays are empty for usage in the following planning horizon. Equation (6) ensures that the required space for ship *j* is available for the planning horizon.

In constraint (7) δ_{ij} is defined: it equals one if the containers for ship *j* are stored in bay *i* during the planning horizon; othwerwise, equals zero

Constraint (8) guarantees that containers for different ships are never mixed in the same bay.

Constraint (9) defines the number of bays to allocate containers for ship *j*.

Contraint (10) ensures that containers with different destination ports are not mixed in the same bay, even if they belong to the same ship.

The number of bays to be used for a ship has to be larger or equal to the number of destinations port of its itinerary. To avoid a larger covered area by the containers, which will bring less efficient operations, it was created the constraint (11), which ensures a maximum number of bays to be used to store containers for ship j.

Constraint (12) guarantees that the total amount of bays used in the planning horizon cannot exceed the number of bays available in the terminal.

The workload in each block is evaluated by the number of containers handled in the planning horizon, which is defined by constraint (13).

Finally constraint (14) ensures the non-negativity of the respective variables, and conntraint (15) defines sime variables as binary.

Before the model be implemented, its objective function (2) needs to be linearized. This is achieved by defining the following two new functions, P and Q, presented in equations (16) and (17) respectively:

$$P = \underset{\{k\}}{\max}\Big(\sum_{\substack{j \in S_A \\ b_i = k}} x_{ij}\Big) \tag{16}$$

$$Q = \underset{\{k\}}{\min}\Big(\sum_{\substack{j \in S_A \\ b_i = k}} x_{ij}\Big) \tag{17}$$

So, the objective function can be written as:

$$Min\left(w_1 \sum_{i=1}^{B} \sum_{j \in S_A} x_{ij} d_{ij} + w_2 (P - Q)\right) \tag{18}$$

The modified objective function (18) requires two additional constraints:

$$\sum_{\substack{j \in S_A \\ b_i = k}} x_{ij} \leq P, k = 1,2, \ldots, K \tag{19}$$

$$\sum_{\substack{j \in S_A \\ b_i = k}} x_{ij} \geq Q, k = 1,2, \ldots, K \tag{20}$$

4.3.2.2 Phase 2 –Hybrid Sequence Stacking Algorithm (HSSA)

In the second stage the problem is solved by using the Hybrid Sequence Stacking Algorithm, which was explained in the previous chapter.

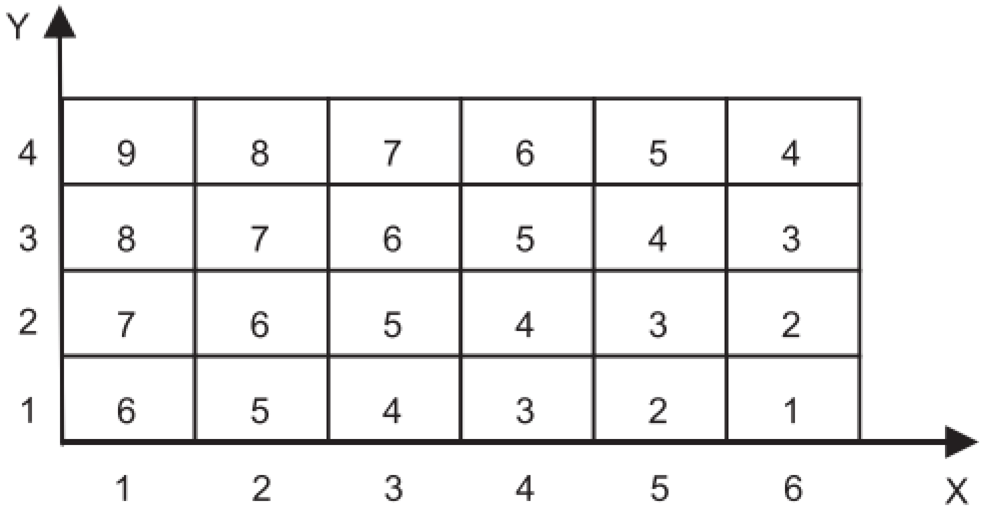
The following notation is used for this stage:

[W_{min}, W_{max}]	maximum and minimum weights of the containers.
W_c	weight of the container c.
L_c	the weight level of the container c.
l	weight level index.
S_l	the optimal slots in the bay for containers with weight index level l.
(x_l, y_l)	geometric center of the slots in set S_l.
(x_c, y_c)	best storage location for container c..
(x_c^s, y_c^s)	the available locations to store container c, which do not belong to set S_l.

L_c is limited as follows, and has as the input the weight of container c:

$$W_{min} + (L_c - 1)\frac{W_{max} - W_{min}}{8} \leq W_c \leq W_{min} + L_c\frac{W_{max} - W_{min}}{8} \qquad (21)$$

The notation previously presented required the definition of a set of coordinates to help navigate inside the pre-determined bay. Figure 10 depicts how the coordinates were established.



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

Figure 10. Coordinates of container bays for the HSSA

The figure suggests, the coordinates of the axis x evolve from left to right, and the coordinates of the axis y evolve from the bottom to the top. The numbers from 1 to 9 represent the weight level of each container, which is calculated using expression (21).

The HSSA follows a four-step process. The first step is the selection of the bay, which was pre-assigned in stage 1, that must not be full and only has containers with the same destination of the arriving container c. If any bay does not have these pre-established requirements, the arriving container c will be placed in an empty pre-assigned bay. In step 2 the weight level of the container (L_c) will be calculated, using as input its real weight (W_c). The third step will decide position to store the container inside the pre-selected bay, according to the following instructions:

(1) Get the set of optimal storage slots S_{L_c}, using as guide Figure , which is the optimal set for all weight levels.
(2) If there is an available slot in S_{L_c}; go to (3); If not, then go to step 4.
(3) Select a random available location $(x_{c,}\, y_c)$.
(4) Place the container *c* in $(x_{c,}\, y_c)$.
(5) Update the configuration of the bay.

The fourth step takes care of the situation when there is no available slot in S_{L_c}, and will find a new slot in the remaining available slots in the bay. For each (x_c^s, y_c^s) the rectilinear distance from the geometric center of S_{L_c} is given by expression (22):

$$d_s = \left|x_{L_c} - x_c^s\right| + \left|y_{L_c} - y_c^s\right| \qquad (22)$$

It will be then selected the slot with the minimum distance as the storage location (x_c, y_c). Then the container c is stacked, and the configuration of the bay is updated. In case that the expression (22) results in two different distances, it is pre-determined that the heavier container is always stacked in the left upper location, and the lighter container in the right lower location.

This process of using the HSSA is presented in the flow chart in figure 11:

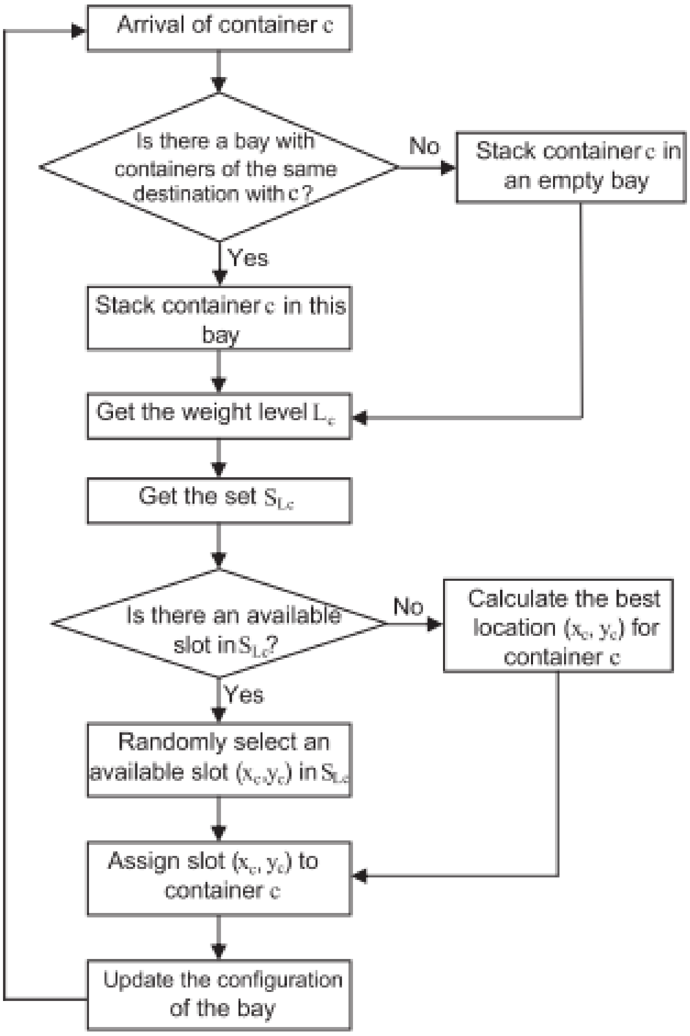


Figure 10. HSSA Process Diagram (Source: Chen and Lu, 2012)

4.4 Task Distribution for the yard cranes

4.4.1 Description of the procedure

The work developed by Zhang et al. (2002) allows to make the best crane (RTGC) deployment in the yard. The crane deployment is defined as the movement of a crane between an initial container block and a final container block. The algorithm to access the best distribution of the RTGCs is formulated as a mixed integer programming model, which has the objective of improving the operations of container handling by minimizing the sim of the workload left at the end of the planning periods.

A container yard operates in six different shifts over the day, which are mentioned in this method as planning periods. The planning periods have the duration of four hours, each. Therefore, a container yard works during the following shifts, which are general for all container terminals: [00:00-04:00], [04:00-08:00], [08:00.12:00], [12:00-16:00], [16:00-20:00], [20:00-24:00]. The deployment of the RTGCs is planned in advanced for each of the six planning periods, where is decided the number of moves a RTGC will make and, also the best route for each one of them.

The identification of the routes are very important because they have a great influence on the efficiency of the operations, because RTGCs are big and heavy machines that move very slowly. Therefore, if an RTGC has to change from a block to another, the route has to be well planned. Figure 11 represents the two types of movement a RTGC can make.

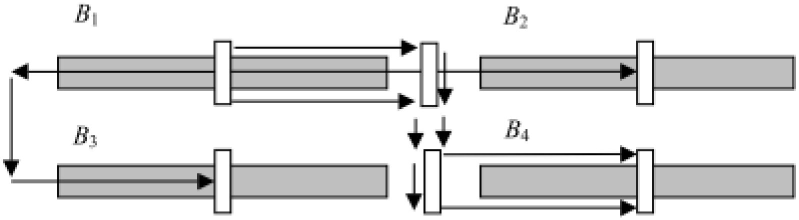


Figure 11. Possible routes for RTGC between blocks (Zhang et al., 2002)

It is preferred that the RTGC only make horizontal movements, for example from stack B_1 to stack B_2, because the wheels have no need to turn. A movement from stack B_1 to stack B_3 or B_4 will force the RTGC to make two 90º turns on the wheels, which takes much more time. Consequently, these turns cause the interruption of operations, create more traffic on the yard and may disturb operations that are taking place.

4.4.2 Assumptions

The model proposed by Zhang et al. (2002) works with the following assumptions:

- RTGC capacity is measured in crane minutes. The cranes have the capacity of 240 minutes in each planning horizon of four hours.
- For safety reasons, each block can hold, at most, two RTGCs.
- It is not allowed more than one RTGC to move between blocks in a period.
- To minimize the idle time and traffic in the yard, movements of RTGC between different zones are only allowed once a day, at midnight.
- Each RTGC can only be moved to another block one time, during each four-hour planning period.
- Any crane move starts and ends within the same planning period.

- If a task is not finished until the end of a period, it will be carried out on the following one.

4.4.3 Modelization

The present section presents the mixed integer programming model of Zhang et al. (2002), using the following notation:

Indices: *i* set of blocks in the container yard

t planning period

Parameters:

X_{ii0} number of cranes in block *i* at the beginning of the planning horizon.

C capacity of a crane within the planning horizon (C= 240 minutes).

N total number of blocks.

T total number of planning periods in a planning horizon (T= 6 periods).

B_{it} workload in block *i* within planning period *t*.

T_{ij} traveling time of a crane from block *i* to block *j*.

The following decision variables are also defined:

X_{ijt} number of cranes moving from block *i* to block *j* during planning horizon *t* (if *i* = *j*, then the cranes stay in the same block during period *t.*

Z_{ijt} workload fulfilled in block *i* by cranes that move from block *i* to block *j* during the planning period *t*.

Y_{ijt} workload fulfilled in block *j* by cranes that move from block *i* to block *j* during the planning period *t*.

W_{it} workload left in block *i* at the end of planning period *t*.

The mathematical model is then presented as an optimization problem (see equations 23 to 31):

$$Min \sum_{t=1}^{T}\sum_{i=1}^{N} W_{it} \tag{23}$$

Subject to:

$$\sum_{j=1}^{N} X_{ijt} = \sum_{j=1}^{N} X_{ji(t-1)}, \qquad i = 1,2,\dots,N, t = 1,2,\dots,T \tag{24}$$

$$\sum_{j=1}^{N} X_{ijt} + \sum_{\substack{j=1 \\ j\neq i}}^{N} X_{jit} \leq 2, \qquad i = 1,2,\dots,N, t = 1,2,\dots,T \tag{25}$$

$$W_{i(t-1)} + B_{it} - \left(\sum_{j=1}^{N} Z_{ijt} + \sum_{j=1}^{N} Y_{jit} \right) - W_{it} = 0, \qquad i = 1,2,\dots,N, t = 1,2,\dots,T \tag{26}$$

$$Z_{ijt} + Y_{ijt} \leq \left(C - t_{ij}\right) X_{ijt}, \qquad i = 1,2,\dots,N, j = 1,2,\dots,N, t = 1,2,\dots,T \tag{27}$$

$$W_{i0} = 0, \qquad i = 1,2,\dots,N \tag{28}$$

$$X_{ij0} = 0, \qquad i = 1,2,\dots,N, j = 1,2,\dots,N, i \neq j \tag{29}$$

$$W_{it} \geq 0, Z_{ijt} \geq 0, Y_{ijt} \geq 0, \qquad i = 1,2,\dots,N, j = 1,2,\dots,N, t = 1,2,\dots,T \tag{30}$$

$$X_{iit} \in \{0,1,2\}, X_{ijt} \in \{0,1\}, \qquad i = 1,2,\dots,N, j = 1,2,\dots,N, i \neq j, t = 1,2,\dots,T \tag{31}$$

In the objective function (23) it is considered the sum of the workload left at the end of all the planning periods, instead of only the sum of the workload left at the end of the last period. That is considered because, although the workload can be postponed to the next planning period, it has a limited due time.

Constraint (24) guarantees that the starting position of a crane in a planning period is equal to its last position in the previous planning period. Constraint (25) guarantees that, at most, two RTCGs can be used in a block, during the planning period.

Constraint (26) guarantees the balance between the workload that should be done and the one that can be done in each block. (that is for that purpose that were created the slack variables W_{it}).

Constraint (27) ensures that the workload capacity of each crane is not exceeded in each planning period.

Constraint (28) initializes the new planning horizon. All the delayed work from the previous planning period belongs to the first period of the new planning horizon.

The initial location of the cranes is defined by constraint (29) alongside with parameter x_{ii0}.

Constraints (30) and (31) ensure the non-negativity of the decision variables and that they are integer, respectively. The constraint (31) is also responsible to guarantee that at most, one RTGC is moved from one block to another in the same period, by making sure that the variable *Xiit* only takes the value 1 or 0.

4.5 Chapter conclusions

This chapter presented the mathematical formulation of the methods selected. All the variables are explained, as well as each constraint. All the assumptions assumed by their authors are also clarified.

The mathematical expression will be implemented in GAMS so that is possible to use the software to obtain results by using real data supplied by Liscont.

5 Application of the methods to Liscont's problem

5.1 Introduction

In this chapter real data from Liscont will be presented and organized in such a way that is possible to utilize it in the algorithms. The data used is the timeline for which the operations are planned and the number of containers that will be loaded for a given ship.

An example is shown so that it is easier to understand how the second stage of the bay allocation method is used.

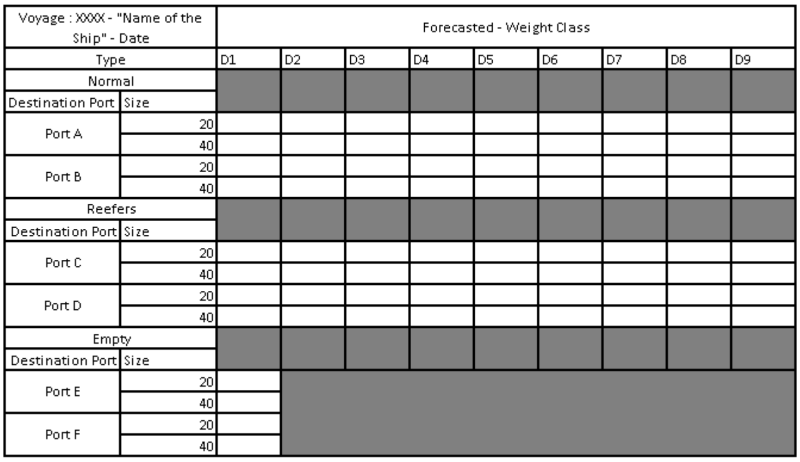
5.2 Timeline

The timeline proposed by Liscont is of two weeks. This time period was given for two reasons. First, because the average delivery time of containers before the day of the departure of the ships is about 12 days. Second, because it is sufficient time to plan ahead all the operations and ensure that when it is time to operate with a ship it all can go with lesser mistakes.

5.3 Containers to be distributed

As mentioned previously, there are three types of containers that will be addressed. The full export containers, the full refrigerator containers and the empty containers. Each type has its own specific zone to be stored, therefore, in terms of operations they need to be considered separately.

Figure 12 shows the template of the table that Liscont uses to organize all the data needed for the loading operations of ships.



Voyage : XXXX - "Name of the Ship" - Date		Forecasted - Weight Class								
Type		D1	D2	D3	D4	D5	D6	D7	D8	D9
Normal										
Destination Port	Size									
Port A	20									
	40									
Port B	20									
	40									
Reefers										
Destination Port	Size									
Port C	20									
	40									
Port D	20									
	40									
Empty										
Destination Port	Size									
Port E	20									
	40									
Port F	20									
	40									

Figure 12. Information of the containers to be loaded onto the ships

In the table in Figure 12 it is possible to find the number of the voyage of the ship. Data about the type of container is also available, and within the type of container we can categorize it as a normal container, refrigerator container (reefers) or empty containers. In the columns there is information about the weight class of the containers, which were defined by Liscont.

The categories presented for the weight classes follow this classification:

- Class D1: 0 to 1 ton.
- Class D2: 2 to 10 tons.
- Class D3: 11 to 15 tons.
- Class D4: 16 to 19 tons.
- Class D5: 20 to 23 tons.
- Class D6: 24 to 26 tons.
- Class D7, D8, D9: 27 to 99 tons.

The quantities of each type of containers that are going to be loaded onto the ship are a result forecast demand based on historical data. Since the terminal operates a large quantity of regular lines, forecasting is the better way to start planning ahead, because the quantities are constant.

With the number of refrigerator containers and the characteristics of the ship, it is possible to decide where the ship is going to take berth.

The table in Figure 12 is also the source of the majority of the inputs to be used in the algorithms that were explained before. There is information about the number of containers, of each type, the number of destinations of the itinerary of the ship and the weight classes.

Table 3 and 4 present the number of the ship and the number of containers to be loaded, using the template supplied by Liscont, but only for 20 TEU containers.

Ship 1	Forecasted - Weight Class									
Type	D1	D2	D3	D4	D5	D6	D7	D8	D9	
Normal										
Destination Port										SUM
AOLOB					4	2			15	21
AOMSZ									9	9
AOSOG		1	3	3	4	6			13	30
AOSOP		2	3	39	33	22			42	141
CGPNR					1					1
CIABJ					1					1
ESALG						4			5	9
Reefers										
Destination Port										SUM
AOSOG									7	7
AOSOP				1		4			18	23
CGPNR									1	1
ESALG			1						2	3

Table 3. Information about the first ship

Ship 2	Forecasted - Weight Class									
Type	D1	D2	D3	D4	D5	D6	D7	D8	D9	
Normal										
Destination Port										SUM
AOLOB					4	2			15	21
AOMSZ									9	9
AOSOG		1	3	3	4	6			13	30
AOSOP		2	3	39	33	22			42	141
CGPNR					1					1
CIABJ					1					1
ESALG						4			5	9
Reefers										
Destination Port										SUM
AOSOG									7	7
AOSOP				1		4			18	23
CGPNR									1	1
ESALG			1						2	3

Table 4. Information about the second ship

5.4 Addressing the problem

Using the data presented in section 5.3 it is now possible to apply the methods presented to address the Liscont's problem.

5.4.1 Berth allocation

Starting with the berth allocation of the ships, the decision is based on the amount of refrigerator containers that are presented in tables 3 and 4. Thus, the ship with a larger amount of this type of containers, will take berth on the locations that are closer to the specific zone for the refrigerator containers, so that the loading operation time is minimized, and therefore, reducing the work span of the machinery. In this case, both of them have the same amount, so they decision will have no implication in the future results.

5.4.2 Bay allocation and container distribution

5.4.2.1 Bay allocation Stage 1

The second problem which is the bay selection, uses as guidelines the result of the berth allocation of the ships, since the algorithm uses as input the number of bays and blocks that will be used for a certain ship.

Each bay has a maximum capacity of 25 containers. There are, in the container terminal, four blocks reserved for the full export containers. One block with three bays, two blocks with ten bays and one block with 12 bays. In sum, there are available four blocks and 35 bays for full export containers. Making it possible to store up to 875 containers.

For the refrigerator containers there are available two blocks, one with five bays and the other with twelve bays. Thus, two bays with 17 bays, capable to store 425 refrigerator containers.

And finally, for the empty containers, there are available three blocks. One block with nine bays, one block with 12 bays and another one with five bays. Making a total of three blocks, 26 bays and a capacity for 650 empty containers.

In order to use the algorithm presents, it was decided that for the first ship (in table 3) will be assigned 17 bays for the full export containers, and for the second ship (in table 4) the remaining 18 bays. For the refrigerator containers, the first ship will have available eight bays and the second ship will have nine. And for the empty containers, both ships will have available 12 bays.

This distribution indicates the maximum number of bays that might be used, not that they will be, in fact, used for each ship.

Figure13, Figure 14 and Figure 15 represent the previous distribution:

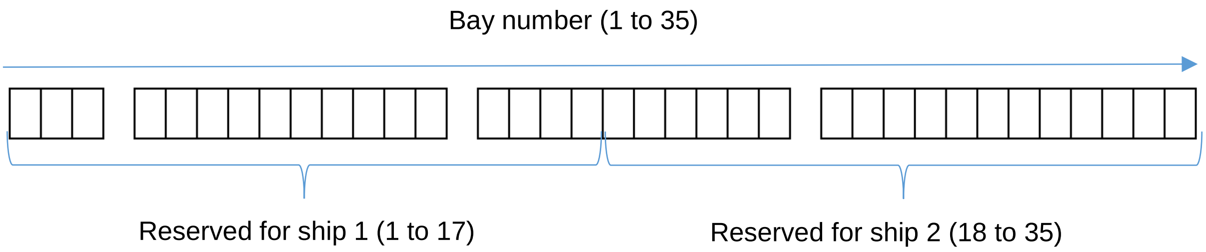


Figure 13. Bays allocated for export containers

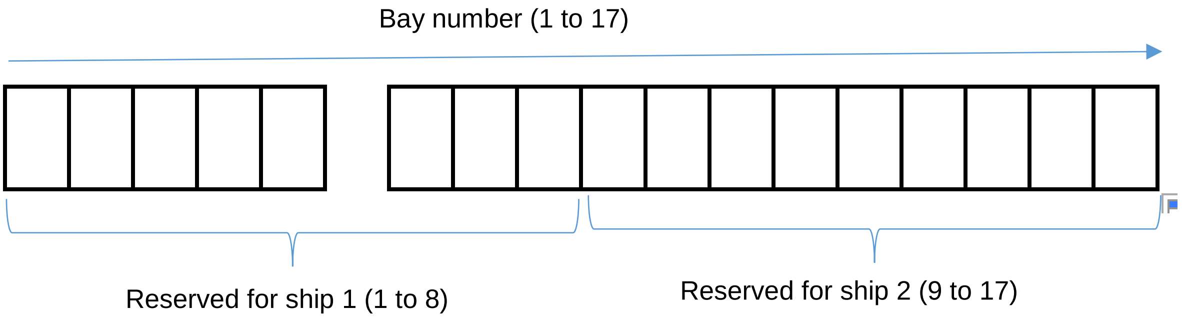


Figure 14. Bays for refrigerator containers

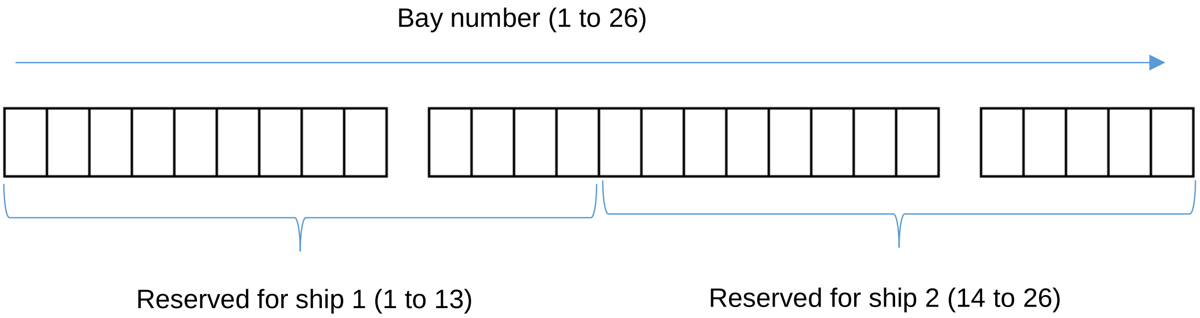


Figure 15. Bays for empty containers

Appendix 1 presents the algorithm implemented in GAMS.

5.4.3 Bay allocation Stage 2

After all the containers were appointed to a specific bay, it is important to decide the exact location in the bay. Making the right decision will improve the number of movements per container. The algorithm used follows the instruction given in Figure 10 (see section 4.1.3.1).

This process is considered to be more reactive than the previous stage, as the correct locations can only be attributed when the containers arrive. However, the method considers the unpredictability of the arrival of the containers, so it is possible to simulate how the organization of the terminal is going to be.

In order to simulate this stage, the containers that are forecasted to arrive have been put in a random sequence. The container arrives with the information about the ship where he is going to be loaded in, the destination port and the weight, which will correspond to a weight type, presented in section 4.3. This last information is all the data required to use the method.

5.4.3.1 Using the algorithm

An important guideline of this stage was presented in figure 10, which is the optimal distribution of the containers according to their weights, which was explained in section 4.1.3.2.

By chance, the Liscont terminal already utilizes the number of weights levels that the method uses (one to nine), so the step “Get the weight level Lc” will not be use, in this case. The steps before, the one just mentioned, will also not be used, since all the containers already have a pre-assigned bay. The only constraint is if the bay is already full. In that case, another pre-assigned bay will start to be used. In other words, if a ship has pre-assigned two bays for the same destination, the algorithm starts by utilizing the first bay at maximum before starting to use the other one.

When allocating containers, it is imperative that the template of Figure 10 is followed. However, in most cases it is not possible to follow it. For example, both slots for containers with weight level 2 are occupied. If a new container with weight level 2 arrives, there is no slot available for it. In these cases, it is necessary to calculate the center of mass of the possible slots for weight level 2 containers, which is marked in red in the following figure:

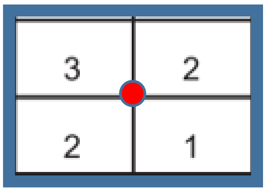


Figure 16. Center of mass of weight level 2 containers

The slot to be used is the one that is reserved for a container with a weight level 3, since it is the location that is nearest to the center of mass of the zone for the weight level 2 containers. On the other hand, if both slots are free, it is possible to choose either one, the bottom left slot, or the upper right slot. If the slot for the weight level 1 containers is free, the only slot for weight level 2 that is possible to use is the bottom left slot, since it is not possible to place a container in a slot if there are no containers under it.

To facilitate the understanding of the second stage, was created an illustrative example, in the following section.

5.4.3.2 Example

A ship is going to departure and has as an intermediate stop, Porto. It is forecasted that 28 containers will be loaded on to the ship, to be unloaded in Porto. The quantities and weight levels are presented in Table 5.

Table 5. Quantity of containers per weight level

Quantity	Weight Level
10	9
7	7
7	5
4	2

The container numeration will be the following:

- 1 to 10 to the containers that have weight class 9
- 11 to 17 to the containers that have a weight class 7
- 18 to 24 to the container that have a weight class 5
- 25 to 28 to the containers that have a weight class 2

To start distributing the containers, a sequence of arrivals was defined randomly in Table 6.

Table 6. Containers arrival sequence

Order of arrival	Container number	Weight Level
1	5	9
2	13	7
3	20	5
4	21	5
5	22	5
6	1	9
7	8	9
8	10	9
9	17	7
10	19	5
11	24	5
12	28	2
13	26	2
14	2	9
15	3	9
16	4	9
17	12	7
18	9	9
19	15	7
20	16	7
21	6	9
22	11	7
23	25	2
24	27	2
25	14	7
26	7	9
27	18	5
28	23	5

The first container that arrives has a weight class 9. Using the template, the container should be placed in the following slot, marked in red in Figure 17:

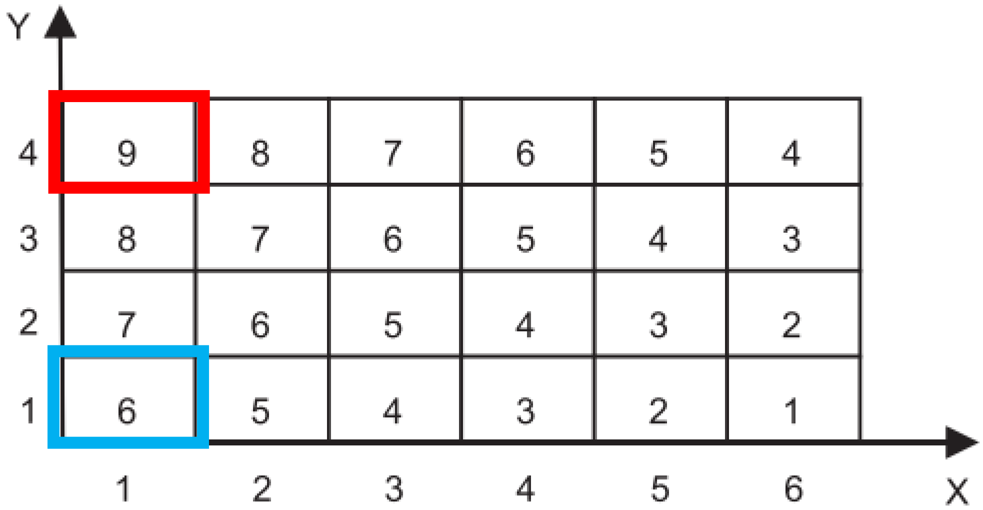


Figure 17. HSSA for container 1

However, since it is not possible to place a container in a slot, that has not any containers under it, we have to calculate the center of mass for the containers with a weight class 9 and chose the nearest possible location. Since the template only uses one slot for weight level 9 containers, the center of mass is the slot itself. So, the nearest possible location for the containers is the one marked in blue in Figure 17, despite being a slot for a weight level 6 container. Afterwards, the configuration of the bay has to be updated (see Figure 18).

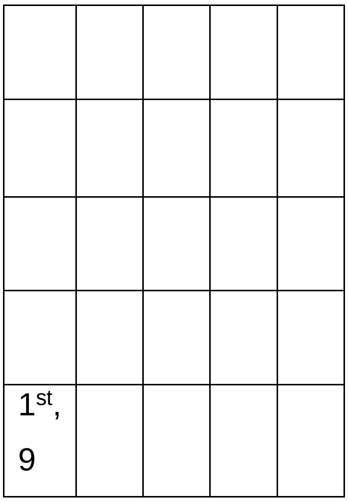
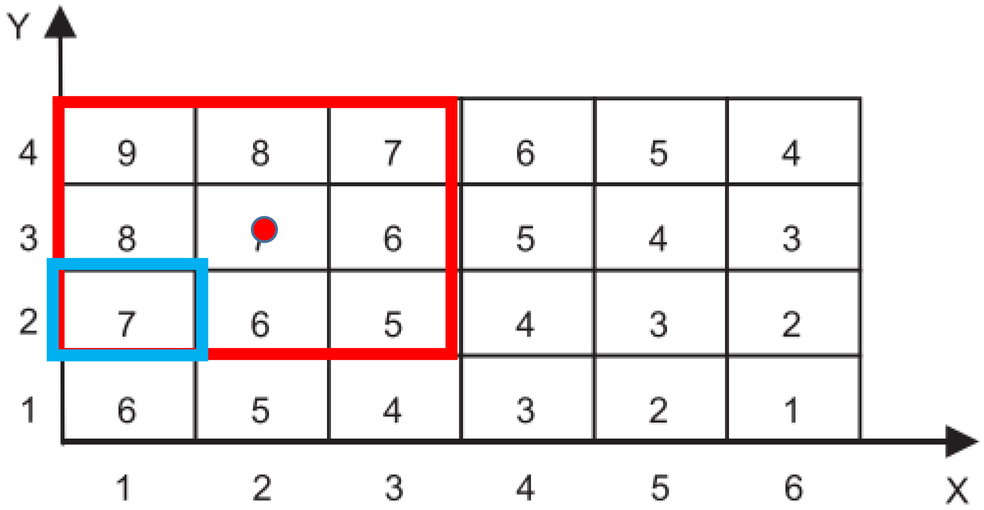


Figure 18. Layout after deciding the location of the first container

The second container to arrive has a weight level 7. The same situation occurs now. Figure 19 shows the center of gravity of slots for weight level 7 containers marked in red.



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

Figure 19. HSSA for container 2

Following the same logic of the previous containers, the slot to be chosen is the one marked in blue in Figure 19. Figure 20 presents the updated configuration of the bay.

2nd, 7				
1st, 9				

Figure 20. Layout after deciding the location of the second container

The logic repeats itself for all the containers, until the last one. The second bay will only be used after bay one is full.

For this example, the final configuration of the first bay is presented in Figure 21 and the second bay in Figure 22.

14th, 9	16th, 9	17th, 7	20th, 9	25th, 7
8th, 9	15th, 9	11th, 5	19th, 7	24th, 2
7th, 9	9th, 7	10th, 5	18th, 9	23rd, 2
2nd, 7	3rd, 5	5th, 5	13th, 2	22nd, 9
1st, 9	6th, 7	4th, 5	12th, 2	21st, 9

Figure 21. Final layout of the first bay

		28th, 5		
26th, 9		27th, 5		

Figure 22. Final layout of the second bay

5.4.4 Crane Deployment

The last method to be used is the crane deployment, in which the number of cranes that will be used in a block is determined and also the time that each crane spends in each block.

Appendix 2 shows the algorithm implemented in GAMS.

5.5 Conclusion

In this chapter the algorithms of the methods were translated into GAMS language. The values that are inserted in the algorithms were the ones used to obtain the results that are going to be presented in the next chapter. Since the second stage of the bay allocation method was not developed in GAMS, an example of the procedure was presented so that its comprehension is easier, therefore help in the comprehension of the final results.

6 Results

6.1 Introduction

All the results herein presented were obtained by running the GAMS algorithm on Neo-server.

6.2 Bay Allocation: Stage 1

The results of the bay selection in stage one for export containers are depicted in Table 7.

Table 7. Bays selected for ship one and two

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.

6.3 Bay Allocation: Stage 2

For Stage 2 was created a reactive tool, since the order of the containers in undetermined, which means that any order that is established will not be the reality. Planning ahead using the algorithm will only cause in unnecessary efforts since the final result is based in the order of the containers. All the export containers for ship one and two were allocated using the method. Each bay used is reserved for a specific destination port. In this case there are seven which are AOLOB, AOMSZ, CGPNR, CIABJ, EASLG, AOSOG and AOSOP. The final layouts for the bay with the destination AOLOB and AOMSZ are represented in Table 8; for CGPNR and CIABH are represented in Table 9; for ESAL is represented in Table 10; for AOSOG two bays are used and is represented in Table 11; and for AOSOP, six bays were used and are represented in Table 12.

Table 8. Final layout of bays for AOLOB and AOMSZ destinations for ship 1

AOLOB				
9	9	9	9	
9	9	9	9	
9	5	9	9	
6	5	9	9	
5	5	9	6	9

AOMSZ				
9	9			
9	9			
9	9			
9	9			
9	9			

Table 9. Final layouts of bays for CGPNR and CIABJ destinations for ship 1

CGPNR				
5				

CIABJ				
5				

Table 10. Final layout of the bay for EASLG destination for ship 1

ESALG				
9	9			
9	6			
9	6			
9	6			
9	6			

Table 11. Final layout of bays for AOSOG destination for ship 1

AOSOG (1st)				
9	9	6	5	9
9	9	6	4	6
9	9	5	4	6
9	6	4	3	5
5	6	3	2	3

AOSOG (2nd)				
9				
9				
9				
9				
9				

Table 12. Final layout of bays for AOSOP destination for ship 1

AOSOP 1st				
9	9	6	6	9
9	9	6	5	4
9	9	5	4	5
9	5	4	4	3
5	4	4	2	2

AOSOP 2nd				
9	9	6	6	6
9	9	6	5	5
9	6	6	5	4
9	6	5	3	5
9	4	4	3	4

AOSOP 3rd				
9	9	9	6	6
9	9	6	5	5
9	9	6	4	4
9	5	5	5	5
9	4	4	4	4

AOSOP 4th				
6	6	6	5	5
9	5	6	5	4
9	5	6	4	5
6	5	5	5	4
9	4	4	4	4

AOSOP 5th				
9	9	9	9	9
9	9	5	5	4
9	5	5	4	4
9	5	4	4	4
6	4	4	4	4

AOSOP 6th				
9	9			
9	9			
9	5	4		
9	5	4		
9	4	4	4	

For ship two, the final layout for the destination port for AOLOB and AOMSZ are represented in Table 13; for CGPNR is represented in Table 14; for AOSOG the final layout is depicted in Table 15; for destination ESAL, the layout is in Table 16 and for AOSOP the layout is in Table 16.

Table 13.Final layout of bays for AOLOB and AOMSZ destination for ship 2

AOLOB				
9	9	9	5	
9	9	9	5	
9	9	9	5	
9	6	9	9	
9	9	9	6	5

AOMSZ				
9	9			
9	9			
9	9			
9	9			
9	9			

Table 14.Final layout of bays for CGPNR destination for ship 2

CGPNR				
5				

Table 15. Final layout of bays for AOSOG destination for ship 2

AOSOG 1st				
9	9	9	9	3
9	6	9	4	2
9	9	6	4	4
9	9	5	5	5
9	9	6	3	3

AOSOG 2nd				
9				
9				
6				
6		5		

Table 16. Final layout of bays for ESALG destination for ship 2

ESALG				
9	9			
9	9			
9	6			
6	6			
9	6			

Table 17.Final layout of bays for AOSOP destination for ship 2

AOSOP 1st				
9	9	9	9	5
9	9	9	4	4
9	9	5	4	4
9	5	4	4	9
9	4	4	4	9

AOSOP 2nd				
9	6	5	6	5
9	6	5	5	4
9	5	5	4	5
9	5	4	4	4
9	4	4	4	4

AOSOP 3rd				
6	6	5	6	5
9	6	5	5	4
9	5	5	5	4
6	5	4	5	4
5	4	4	4	4

AOSOP 4th				
9	9	6	6	9
9	9	6	5	5
9	9	5	4	5
9	6	5	4	4
9	6	5	4	4

AOSOP 5th				
9	9	9	6	6
9	6	9	6	5
9	6	4	5	4
6	5	4	4	2
6	5	3	3	3

AOSOP 6th				
9				
9				
9	5	5		
9	9	4	4	
9	5	4	4	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 (32) represent this calculation:

$$MC = \frac{\mathrm{NrR\ x\ 3+NrNR\ x\ 2}}{\mathrm{C}} \quad (32)$$

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

6.4 Crane Deployment

Table 18 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 18. Crane movements for planning periods from 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.

The objective function (equation 23), which is the remaining workload for each block, had the final result of 0, meaning that no container was left to be loaded onto the ship in the end of the planning horizon.

In the algorithm, the workload that served as an input is just an example, since the terminal can choose to increase the workload for any planning period, which will change the final results.

6.5 Chapter conclusions

This chapter presented the results obtained using the data from Liscont and the algorithm implemented in GAMS, after using the second stage of the bay allocation method to a random sequence of the containers arrival.

The results present a reduction of 5% on the average number of movements per container, through the bay allocation method for the containers of ship 1. For the containers to be loaded onto ship 2 the average is 2.11, which corresponds to a reduction of 1% on the average number of movements per container. The results also show that the loading of the ship can be finished with no delays with the crane deployment method.

7 Conclusion, limitations of the work done and future developments

This document focused on the optimization of the operations of the Liscont's Terminal. The principal focus was to select the correct slot of each container when the terminal is exposed to high uncertainty of the arrivals of the containers.

In the first chapter it was presented the background of the problem studied, the objectives, and the work development stages that should be followed.

In chapter 2 Liscont is introduced. The process used by Liscont to load a container onto a ship is presented, as well as the infrastructures used. It was also explained the market in which Liscont is inserted, related with the Portuguese economy and KPIs were used to compare Liscont's operations performance with other terminals

Chapter 3 presents a literature review. Various methods are described in this chapter, which is concluded with a brief explanation of the selected methods to use. The first is useful to recommend the locations where the ships should take berth. The second method is divided in two-stages: The first stage identifies the bays that should be used to store containers for a certain ship, based on its berth location. In the second stage, the best locations for the containers are found. The last method focuses on the loading operations in order to minimize the time of operations, the number of movements of each yard crane with the guarantee that the planning horizon period is respected

Chapter 4 explains each method that was use. All the assumptions, for each method, are mentioned and the mathematical expressions are presented.

In chapter 5 all the data used to solve the problems are presented and re-organized so that it is possible to use it. In this chapter the algorithms are presented codified in GAMS language.

Chapter 6 presents the results of this study and how to interpret them.

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 nowadays 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 real data 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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APPENDICES

Appendix 1 – Algorithm for the bay allocation and container distribution implemented in GAMS

```
SETS
            i index of yard bays available /i1*i35/
            k index of blocks /k1*k4/
            j index of ships in the planning horizon /j1*j2/
             ;
PARAMETERS
Capacity(i) Storage capacity of yard bay i
                 /i1   25
                  i2   25
                  i3   25
                  i4   25
                  i5   25
                  i6   25
                  i7   25
                  i8   25
                  i9   25
                  i10  25
                  i11  25
                  i12  25
                  i13  25
                  i14  25
                  i15  25
                  i16  25
                  i17  25
                  i18  25
                  i19  25
                  i20  25
                  i21  25
```

i22 25
i23 25
i24 25
i25 25
i26 25
i27 25
i28 25
i29 25
i30 25
i31 25
i32 25
i33 25
i34 25
i35 25
/

YardBayOfContainerBlock(i) Number of the container block that bay i belongs to

/i1 1
i2 1
i3 1
i4 2
i5 2
i6 2
i7 2
i8 2
i9 2
i10 2
i11 2
i12 2
i13 2
i14 3
i15 3
i16 3

```
          i17      3
          i18      3
          i19      3
          i20      3
          i21      3
          i22      3
          i23      3
          i24      3
          i25      3
          i26      4
          i27      4
          i28      4
          i29      4
          i30      4
          i31      4
          i32      4
          i33      4
          i34      4
          i35      4
         /
D(j) Number of destinations of the voyage of ship j
         /j1   7
         j2   7/
V0(i) Number of containers in bay i at the beginning of the planning horizon
         /i1       0
         i2       0
         i3       0
         i4       0
         i5       0
         i6       0
         i7       0
         i8       0
         i9       0
```

```
i10     0
i11     0
i12     0
i13     0
i14     0
i15      0
i16      0
i17      0
i18      0
i19      0
i20      0
i21      0
i22      0
i23      0
i24      0
i25      0
i26      0
i27      0
i28      0
i29      0
i30      0
i31      0
i32      0
i33      0
i34      0
i35      0
/
 N(j) Number of containers for ship j that will arrive during the planning
horizon
/j1   197
j2   197/
 m(j) Maximum number of bays to allocate containers for ship j
/j1  17
```

```
j2  18/
 ;



 TABLE DistanceOfBayToShip(i,j) Distance from bay i to location of ship j in meters
         j1      j2
        i1      1       2
        i2      1       2
        i3      1       2
        i4      1       2
        i5      1       2
        i6      1       2
        i7      1       2
        i8      1       2
        i9      1       2
        i10     1       2
        i11     1       2
        i12     1       2
        i13     1       2
        i14     1       2
        i15     1       2
        i16     1       2
        i17     1       2
        i18     2       1
        i19     2       1
        i20     2       1
        i21     2       1
        i22     2       1
        i23     2       1
        i24     2       1
```

```
                         i25     2        1
                         i26     2        1
                         i27     2        1
                         i28     2        1
                         i29     2        1
                         i30     2        1
                         i31     2        1
                         i32     2        1
                         i33     2        1
                         i34     2        1
                    ;
SCALAR
 MaxOfContainerBlocks Total number of container blocks for storing the
containers
                          /4/
 MaximumNumberOfBays Maximum number of bays available for storing
containers
                         /35/
  Y Density factor for yard bays
                         /1/
   ;
VARIABLES
ContainersInBay(i,j) Number of containers that will go on ship j and that are
placed in bay i during the planning horizon
TraceContainer(i,j) Bynary variable that equal 1 if container for ship j are
stacked in bay i
BaysAssigned(j) Total amount of yard bays that were assigned to ship j
VEnd(i) The amount of container in bay b at the end of the planning horizon
Z objective functiion
 ;
BINARY VARIABLES
TraceContainer
 ;
```

```
INTEGER VARIABLES
ContainersInBay,BaysAssigned,VEnd
 ;
EQUATION
eq1(i)  Defines the total amount of containers in the yard bay at the end of the planning horizon
eq2(i) Ensures that the density of each bay will to be exceeded
eq3(j) Ensures that the sum of the containers that are placed in the bays is equal to the number of containers that will be loaded in ship j
eq4(i,j) Defines the binary variable
eq5(i) Ensures that containers for different ships are not mixed in the same bay
eq6(j) Specifies the number of bays to be used to store containers that will go for a certain ship
eq7(j) Ensures that the number of bays that will be used for a ship is greater or equal to the number of destinations of the ship
eq8(j) Specifies the maximum number of bays to be used to store containers for a certain ship
eq9(i,j) Container in Bay greater than 0
eq10(j) Bays assigned greater than 0
obj objective function
;
eq1(i).. SUM(j,ContainersInBay(i,j))+ V0(i) =E= VEND(i);
eq2(i).. VEND(i)=L=25;
eq3(j).. SUM(i, ContainersInBay(i,j))=E= N(j);
 eq4(i,j).. ContainersInBay(i,j)=L= N(j)*TraceContainer(i,j);
 eq5(i).. SUM(j,TraceContainer(i,j))=L=1;
 eq6(j).. BaysAssigned(j)=E= SUM(i,TraceContainer(i,j));
 eq7(j).. BaysAssigned(j)=G= D(j);
 eq8(j).. BaysAssigned(j)=L= m(j);
 eq9(i,j).. ContainersInBay(i,j)=G= 0 ;
```

```
    eq10(j).. BaysAssigned(j) =g= 0;
    obj.. z=E=SUM((i,j), ContainersInBay(i,j)*DistanceOfBayToShip(i,j));

   MODEL DissertacaoSelecaoDasBays /all/;
   DissertacaoSelecaoDasBays.optcr=0.0;
   SOLVE DissertacaoSelecaoDasBays using mip minimizing z;
   DISPLAY ContainersInBay.l
```

Appendix 2 – Algorithm for the yard crane deployment problem implemented in GAMS

```
SETS
      i Initial block where the crane is located /i1*i4/
      j Final block where the crane is located /j1*j4/
      t Planning period /t1*t6/

 TABLE B(i,t) workload in block i within the planning period t
          t1  t2   t3   t4   t5   t6
      i1  50  50  50  50  50  50
      i2  50  50  50  50  50  50
      i3  30  50  50  50  50  50
      i4  0      0    0    0    0    0

 TABLE time(i,j) traveling time of a crane from block i to block j
          j1   j2    j3   j4
      i1   0    2     3    4
      i2   2    0     2    3
      i3   3    2     0    2
      i4   4    3     2    0
SCALAR
      C capacity of one crane within the planning horizon
            /240/
```

VARIABLES

X(i,j,t) number of cranes moving from block i to block j during planing period t
X2(j,i,t) number of cranes moving from block j to block i during planing period t
Z(i,j,t) the workload fulfilled in block i by cranes that move form block i to block j during the planing period t
Y(i,j,t) the workload fulfilled in block j by cranes that move from block i to block j during the planing period t
W(i,t) the workload left in block i at the end of planing period t
Numberofcranes(i,t)
zfinal objective function

INTEGER VARIABLES

Z,Y,W,Numberofcranes

BINARY VARIABLES

X,X2

EQUATIONS

eq1(i,t) ensures that only two cranes can server a block in the planning period t

eq2(i,t) maintains the balance between the workload that should be finished and the workload that can be finished

eq3(i,j,t) ensures that the workload for a planning period is not exceeded
eq4(i,j,t) Z greater or equal to 0
eq5(i,j,t) Y greater or equal to 0
eq6(i,t) W greater or equal to 0
eq7(i,t) number of cranes per block in planning period t
eq8(i,t) number of crane movements in planning period 1
obj objective function

```
eq1(i,t)$(ord(t)>1).. SUM(j,X(i,j,t))+SUM(j$(not sameas(j,i)),X2(j,i,t))=L= 2;
eq2(i,t)$(ord(t)>1).. W(i,t-1)+B(i,t) - (SUM(j, Z(i,j,t))+ SUM(j,Y(i,j,t)))-W(i,t) =E= 0;
eq3(i,j,t)$(ord(t)>1).. Z(i,j,t) + Y(i,j,t) =L= (C-time(i,j))*X(i,j,t);
eq4(i,j,t).. Z(i,j,t)=G=0;
```

```
 eq5(i,j,t).. Y(i,j,t) =G=0;
 eq6(i,t).. W(i,t) =G= 0;
 eq7(i,t).. SUM(j,X(i,j,t))+SUM(j,X(i,j,t))=E=Numberofcranes(i,t);
 eq8(i,t)$(ord(t)=1).. SUM(j,X(i,j,t))+ SUM(j$(not sameas(j,i)), X2(j,i,t))=E= 8;

 obj.. zfinal =E=SUM((i,t),W(i,t));

MODEL DissertacaoCraneDeployment /all/;
DissertacaoCraneDeployment.optcr=0.0;
SOLVE DissertacaoCraneDeployment using mip minimizing zfinal;
DISPLAY X.l, X2.l, Z.l, Y.l, Numberofcranes.l
```