OPTIMIZATION AND SIMULATION MODELS FOR EFFICIENT PORT CONTAINER TERMINAL MANAGEMENT

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ABSTRACT

OPTIMIZATION AND SIMULATION MODELS FOR EFFECTIVE PORT CONTAINER TERMINAL MANAGEMENT

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Port of Izmir is a crucial node in global maritime supply chain and thus efficient management of the port is a thing of utmost importance for the region and Turkish economy. Current facts reveal that the upgrading of the existing cargo terminal is of great importance and urgency in terms of meeting the ever-increasing demands of the national as well as international economies. This thesis proposes novel approaches that aim to improve the most important successive steps in port management activities.

Initially, a multi-period assignment problem that seeks to allocate vessels to berthing spaces and quay cranes is studied. A mathematical model that handles berth and crane allocations simultaneously for multiple terminals is developed. The method is able to model continuous quay allocation with fixed and mobile cranes. Furthermore, the vessel handling times are dynamic and dependent on the unfixed crane assignments that may be altered throughout the service time of the ship. The suggested optimization model minimizes the handling times of the vessels. Practical achievements are assessed by an implementation of the model to the Port of Izmir. Comparisons with the actual records show that noteworthy reductions in current vessel waiting times can be achieved.

Subsequently, a discrete-event simulation model for the real life detailed processes performed during the handling of import containers is developed. In particular, the model focuses on the storage assignment problem at the operational level in a container terminal with a multiple-berth structure. A novel approach by means of a hierarchical structure is adapted to partition the assignment problem into two sub-problems and solve each of them using separate decision rules. Suggested storage policies are evaluated in view of the overall performance of the container terminal. Different traffic densities are experimented to reflect the real-time environment. Simulation runs emphasis the bottleneck at the quay cranes. Results confirm that the quay crane efficiency may be improved by using appropriate storage policies. Strategies that adopted the integrated assignment method at the first level, where travel distances and gantry crane workloads are considered, performed best when coping with this crisis. At the second level of the hierarchy, with the use of segragated strategy, in which estimated container departure dates are considered, number of reshuffles is reduced. Implementation of the model to the existing terminal shows that noteworthy improvements in the current port performance indicators can be achieved.

The implementation of the project will lead to the efficient port management, better operational and financial performance for the Izmir Port and externalities such as increase in employment, development of qualified labor force and expansion of trade volume in the Aegean Region.

Keywords: port management; port logistics; modeling; simulation; transportation; container handling; optimization

ÖZET

EFEKTİF KONTEYNER TERMİNALİ YÖNETİMİNDE EN İYİLEME VE BENZETİM MODELLERİ

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Küresel tedarik zincirinin, kritik bir deniz ulaşım noktasında bulunan İzmir Limanının etkin olarak işletilmesi bölge ve Türkiye ekonomisi açısından ayrı bir önem taşımaktadır. Mevcut veriler ve yapılan gözlemler, liman işletim faaliyetlerinin önemli bir aşaması olan kargo terminallerinin daha etkin olarak kullanılmasının, giderek artan iç ve dış talebin karşılanmasında acil bir ihtiyaç olduğunu ortaya koymaktadır. Bu tez, kargo terminal işlemlerinin iyileştirilmesinde özgün yaklaşımlar geliştirmeyi amaçlamaktadır.

Öncelikle, çoklu zaman dilimlerinde, gelen gemilerin rıhtım ve kıyı vinçlerine atanması problemi çalışılmıştır. Birden fazla terminal için, rıhtım ve vinç atamalarını eş zamanlı olarak gerçekleştirebilen matematiksel bir model geliştirilmiştir. Çalışmada, sürekli rıhtım yapısı ile birlikte sabit ve gezer vinç özellikleri de modellenmiştir. Gemilerin elleçleme süreleri dinamik olup, servis süresince değiştirilebilen vinç atamalarına bağlı olarak belirlenmektedir. Önerilen model, gemilerin elleçleme sürelerini mimimize etmeyi amaçlamaktadır. Modelin pratikteki etkilerini değerlendirebilmek amacıyla İzmir Limanı için bir uygulama gerçekleştirilmiştir. Mevcut durum ile yapılan karşılaştırmalar gemi bekleme sürelerinde önemli kısalmalar elde edilebileceğini göstermektedir.

Ardından, İzmir Limanındaki kargo terminalinin bir "kesikli benzetim modeli" geliştirilmiş ve bu model ithalat kargo konteynerlerinin elleçlenmesi probleminin analizinde kullanılmıştır. Model, çoklu rıhtım yapısında, depolama alanı tahsis problemini operasyonel düzeyde ele almaktadır. Hiyerarşik bir çözüm yöntemi geliştirilerek her aşamada farklı karar verme kuralları uygulanmıştır. Önerilen depolama yöntemlerinin değerlendirilmesinde tüm konteyner terminalinin performansı dikkate alınmıştır. Gerçek zamanlı ortamın yansıtılabilmesi için farklı trafik yoğunlukları uygulamaya alınmıştır. Benzetim modeli uygulama sonuçları rıhtım vinçlerindeki darboğazı işaret etmektedir. Rıhtım vinci veriminin uygun depolama stratejileri kullanımıyla iyileştirilebileceği görülmektedir.

İlk aşamada, taşıma uzaklıklarını ve depolama alanı vinçlerinin iş yüklerini dikkate alan, entegre atama yöntemi, rıhtım vinci darboğazını en iyi şekilde kontrol edebilmektedir. Hiyerarşik yapının ikinci aşamasında ise, tahmini konteyner liman terk ediş zamanlarının dikkate alındığı, ayrılmış stratejinin kullanılması ile gereksiz konteyner yer değiştirmelerinin sayısının azaldığı gözlemlenmiştir. Modelin uygulanması, mevcut liman performans göstergelerinde önemli iyileştirmeler ortaya koymuştur.

Projenin İzmir Limanında uygulanması, etkin bir liman yönetimi, daha iyi faaliyet ve mali performans göstergeleri yanında bölgede istihdamın arttırılması, kalifiye işgücünün geliştirilmesi ve giderek Ege Bölgesinde ticaret hacminin artmasını sağlayabilecektir.

Anahtar Kelimeler: liman yönetimi, liman taşımacılığı, modelleme, benzetim, taşıma, konteyner elleçleme, en iyileme

To Mom and Dad

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INTRODUCTION

Owed to the increased global trade, international sea-freight container transportation has grown dramatically over the last two decades. Among other sea transportation modes, containerized sea-freight transportation has grown noticeably more, about 7-9% per year, while others have grown around 2% per year (Crainic and Kim 2007). Today, approximately 90% of non-bulk cargo worldwide moves by containers stacked on transport ships. Especially, between economically strong and stable countries containerization is up to 100% (Hulten 1997; Muller 1995). The trend towards containerization stimulates the competition between ports, especially between geographically close ones. The time a ship spends at the terminal is the main concern measured for the competitiveness of a port. To accomplish this objective, significant investments and improvements on container terminal infrastructure, storage spaces, logistics, management, and technical equipments are strictly required in order to take part in the container logistics sector. This increased pressure on managing these operations underscores the importance of research to be done in this field.

Port management entails a multifaceted system of interrelationships. In general, when a ship arrives at the port, it is docked on a berth and import containers are taken off the ship by the use of quay cranes. These containers are then transferred to the stacking area by transporters where a gantry crane takes the container off the vehicle and stores it in a stack.

After a certain period, the gantry crane picks the container up from its storage location and puts it on an external truck, which then exits the port through the gate. To load the export containers onto a ship, these processes are executed in reverse order.

The berth allocation problem (BAP), quay crane allocation problem (CAP) and container handling problems are the most important decision points faced by port managers. Without a doubt the outputs have an enormous impact on port efficiency and profitability, and hence these activities have received high priority from terminal managers. By ensuring each decision is attractive to target customers and profitable to the bottom line, the port benefits from improved profitability. However, no dominant solution has yet emerged for BAP, CAP and container handling problems, so this subject represents an opportunity for academia to contribute to enhancing port operations in practice.

The purpose of this thesis is to renovate the key port management decision making processes to be more analytic and data oriented. To realize this objective, a methodology based on mathematical models and simulation techniques is built. Efforts are concentrated on the operational parts on a container terminal, namely, berth allocation, quay crane allocation and import container storage space assignment aspects of port management. Firstly, a novel approach for the first two activities will be considered: the Berth Allocation Problem is solved simultaneously with the Crane Allocation Problem. Then a new hierarchical method for the full import container handling problem covering storage space assignment will be developed and realized within a simulation model.

It is projected that the developed methods, which respond to the most crucial port management problems, will enable the ports to benefit from faster vessel service times, increased container handling capacity and consequently elevated efficiency.

This thesis has four chapters in total. A brief outline of the contents is given below.

Introduction gives the framework of the study. Background of the work is summarized together with the unsettled problems in the field. Finally, the scope and the objectives of the thesis are clarified.

Chapter 1 is devoted to contemporary port management issues and summarizes quayside and yard side operations. A brief history of containerization is provided starting from its emerging urgency. Then, present situation throughout the world is represented with fact and figures. Next, a forecast of the containerization trend is laid out by several resources.

Chapter 2 presents a review of berth allocation, crane allocation and container handling problems. Technical background for these concepts, which constitutes a base for the proposed models, and literature relevant to these theories are examined in detail. Next, the methodology of the work is proposed. The SBCAM (simultaneous berth and quay crane allocation model) is formulated with a nonlinear mathematical model. The structures of CHSIM (container handling simulation) models are described. Each simulation model adopts a different method proposed for the storage space assignment problem including the present system.

Chapter 3 is devoted to the application of the models to an existing port. First, a detailed depiction of Port of Izmir is given. Port's container traffic compositions are studied with comparisons with competitors. Present problems are discussed along with the future growth expectations. Subsequently, the physical and technical infrastructure of the port is explained. The findings of the experiments regarding SBCAM and CHSIM models are presented. Performance comparisons between the present situation and the developed models are discussed.

Chapter 4 is the final section of the thesis. In this part, summary of the findings for the studies are discussed along with the contribution of the work.

CHAPTER 1

CONTEMPORARY PORT MANAGEMENT AND CONTAINERAZATION

In this first chapter, contemporary port management processes will be studied first. Operations at the quayside and the yard side will be explained. The evolution of containers with past, present and future containerization trends will be discussed next.

1.1 PORT MANAGEMENT PROCESS

Port management is a complex activity and in order to achieve the port's macro goals of maximizing throughput and revenue, a vast number of interconnected operations need to be addressed in the port. Murty et al. (2005) state these operations in nine phases as:

1. allocation of berths to arriving vessels,
2. allocation of quay cranes to docked vessels,
3. appointment times to external trucks,
4. routing of trucks,
5. dispatch policy at the terminal gatehouse and the dock,
6. storage space assignment,
7. gantry crane (yard crane) deployment,
8. truck allocation to quay cranes,
9. optimal truck hiring plans.

The complexity in port management stems from the fact that these activities are closely interrelated and decisions made in one stage affects the other.

A container terminal is a zone of the port where sea-freight dock on a berth and containers are loaded, unloaded and stored in a buffer area called yard. The unloading and loading actions at a typical container terminal are illustrated in Figure 1-1.

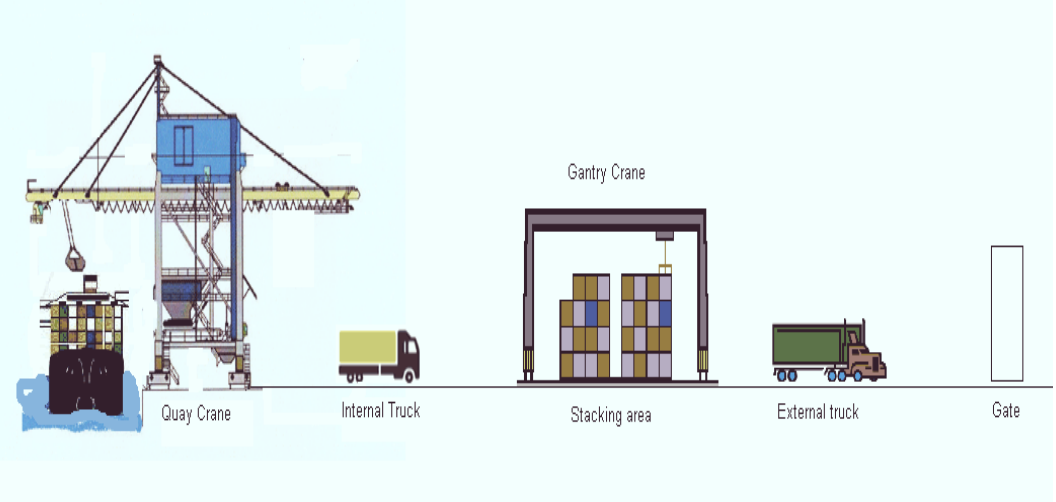


Figure 1-1: Container loading and unloading process

A terminal can be ideally divided into two areas; the quayside and the yard (Vacca et al. 2007). Berthing and crane allocation take place in the quayside part of a container terminal. The other seven phases stated by Murty et al. is typically related to the yard, which serves as a buffer for loading, unloading and transshipping containers.

To enhance clarity berth-crane allocation operations on the quay-side and container handling operations on the yard-side will be studied in two subsections.

1.1.1 Berth and crane allocation operations on the quay-side

When a ship arrives at the port, it will be docked on a berth and quay crane(s) will be dedicated to take the import containers off.

The first problem is the Berth Allocation Problem (BAP) where a ship must be assigned to a berthing position at determined time intervals. Berth management drives the port management process and the major objective for this process is to determine the optimal location and optimal berthing time for the vessels. The decision plays a critical role in minimizing the turnaround time, since the handling time of a vessel is not necessarily the same at every berthing position and schedule.

Following suitable berth allocation, proper allocation of quay crane(s) must be organized. Quay crane allocation to docked vessels determines the assignment sequence of quay cranes to a container ship in fulfilling pre-specified objectives and satisfying various constraints. These quay cranes will offload the containers from the vessel to the trucks. The servicing time of a vessel will be directly effected by the assignment sequence of these cranes.

A key issue to note is that these two main operations at the quay-side, berth allocation problem (BAP) and crane allocation problem (CAP) should be determined together to avoid suboptimal results. Berthing position of a vessel will directly affect the set of quay cranes that may be assigned. An optimal solution for the first problem may not guarantee the minimum servicing time of the vessels at the quayside. Therefore, although more complex, solving these two problems simultaneously will lead to results that are more acceptable.

1.1.2 Container handling operations on the yard-side

At the yard side, transporters will transfer the offloaded containers to the determined stacking areas. Generally, two different types of transportation vehicles are recognized for this purpose: straddle carriers and trucks.

In the former case, quay cranes will take off the containers from the vessels and place them on the buffer area within its reaching point. A straddle carrier, which combines the stacking and transportation functions into one, will lift a container from the ground and transfer it to its appropriate destination.

In the latter case, the quay crane picks up a container from the vessel and places it on top of a truck. A major challenge here is the synchronization of the quay crane and the internal truck. Since the quay crane picks up the container from the vessel and places it on top of the truck, the truck must be readily available at the reaching distance of the quay crane to accomplish the work.

In practice, at times, the two methods are used together. Furthermore, there are some mixed applications where a straddle carrier is used to pick up a container from the buffer area to place it on top of a truck. The truck then is used to transfer the container to the destination point.

Allocation of transporters to the quay cranes is another issue to be handled. Minimizing the travelling distance between the quay-crane and the stacking area may reduce the transfer time for vehicles with identical technical specifications

There are different types of containers. Two main categories are as import and export. In each group, there may be full and empty containers. Mostly, for each category there are separate storage locations within the container terminal.

Determining the stacking area in the dedicated storage location is referred to as the storage space assignment problem. Generally, the stacking area is separated into blocks. The position of a container inside a block is identified by row, column and tier. Figure 1-2 shows an illustration of a block in the storage yard.

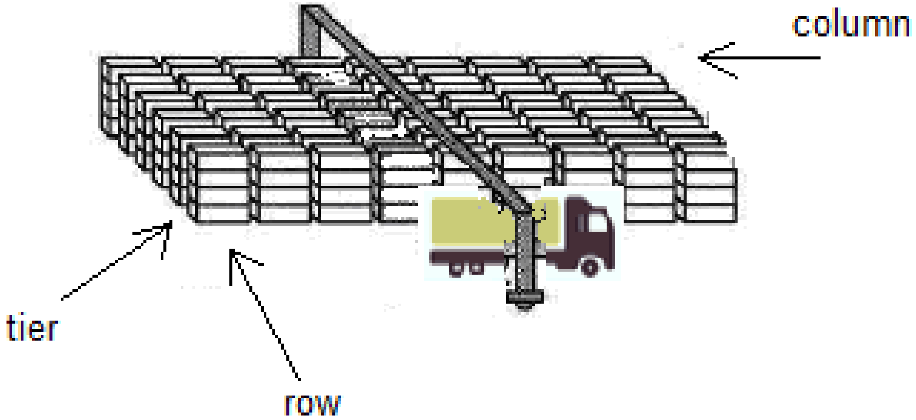


Figure 1-2 : A block in a container storage yard

The containers are assigned to a specific block, row, column and tier in a manner so as to reach predefined goals. Numerous different policies and rules may be implemented at this stage. Generally, the number of moves needed to place a container in the storage area and to remove it, is tried to be kept at a minimum level. Conflicting and interacting factors make the problem complex and sophisticated. Commonly, land space is a scarce resource and stacking containers on top of each other is unavoidable. However, this will increase the number of moves needed to reach some containers. Increased number of reshuffles versus greater stacking capacity are two conflicting issues to be handled. Storage space assignment problem deals with the assignment of these spaces in this yard with several objectives such as minimizing reshuffling volume and maximizing container storage capacity.

Yard (gantry) cranes serve each container block in the yard. These cranes are used to pickup containers from the trucks and place them in the determined yard positions. Gantry cranes may be dedicated to a block or may move among different blocks. Allocation of these cranes among blocks, routing and scheduling of operations in order to meet the predefined goals is determined by the gantry crane deployment problem. On departure time, gantry crane will pickup the container this time from its storage space and place it on an external truck.

Transportation between the yard and the gates is commonly carried out with trucks. Hiring, routing and determining the dispatch policies of these trucks are additional problems to be worked out.

The vast number of activities mentioned above is closely interrelated and judgments made at one phase have a great influence on the other phases. This makes port management a complex and a challenging issue that needs to be worked out expertly in order to take place in the highly competitive market. The trend toward containerization makes the problem even more significant.

1.2 CONTAINERIZATION

1.2.1 The need for containers

Actually, containers, huge metal boxes, were born out of a sense of urgency. Prior to its introduction in 1950s cargo handling was mainly labor-intensive. The crates were first unloaded onto pallets using cranes with slings. Next, manpower was used to organize them on the pallets, which were then moved by forklifts to the storage spaces. This process was slow and the cargoes were vulnerable to damage and theft. Therefore the invention of containerization is regarded by some as the most significant shipping innovation in the 20th century.

Compared to conventional bulk, the use of containers has several advantages, namely less product packaging, less damaging and higher productivity (Agerschou et al. 1983). The containers can be transferred between ship, rail and trucks very quickly. A 1998 study of post-containerization employment at United States ports found that container cargo could be moved nearly twenty times faster than pre-container break bulk. (Herod 1998). Furthermore, the introduction of reefers, temperature-controlled containers, allowed the worldwide transport of perishable goods.

The dimensions of containers have been standardized by the International Standards Organization, so that they fit all ships, cranes, and trucks. The sizes of containers in most frequent use have an exterior dimension of 20ft length x 7ft 9ins wide x 8ft 6 ins high or 40 ft, with same height and width (Figure 1-3).

The term ‘TEU’ (twenty-feet-equivalent-unit) is used to refer to one container with a length of twenty feet. A container of 40 feet is consequently expressed by 2 TEU.

1.2.1 Growth in containerization

As pointed out earlier, according to past statistical data, a great amount of non-bulk cargo worldwide is transported in containers. In 2008, the world total of containerized trade was estimated at 137 million TEUs (1.3 billion tons), an increase of 5.4 percent over the previous year (Clarkson Research Services 2009) (see Figure 1-4).

Figure 1-3: Dimensions of a 1 TEU container

Over the last two decades, global container trade (in tons) is estimated to have increased at an average annual rate of 10 per cent, while the share of containerized cargo in the world’s total dry cargo is estimated to have increased from 5.1 per cent in 1980 to 25.4 per cent in 2008.

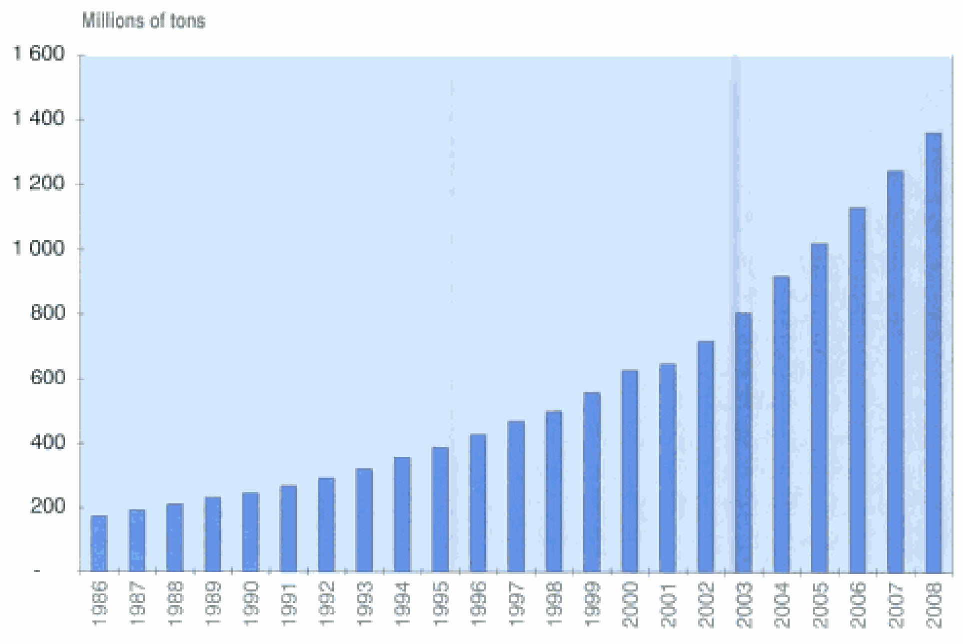


Figure 1-4. International containerized trade growth, 1986–2008 *(Million tons)*

Source: Clarkson Research Services, Shipping Review Database, Spring 2008, p. 101.

The significant structural change in international general cargo shipping brought by containers is still not completed. Past container turnover figures of the ports of the world show high growth rates. The slowdown in 2008 is due to the current economic global crisis. (see Figure 1-5). Based on forecasts by International Monetary Fund, the economic recovery is anticipated to re-emerge in 2010 and the container market conditions are expected to return to balance by 2013.

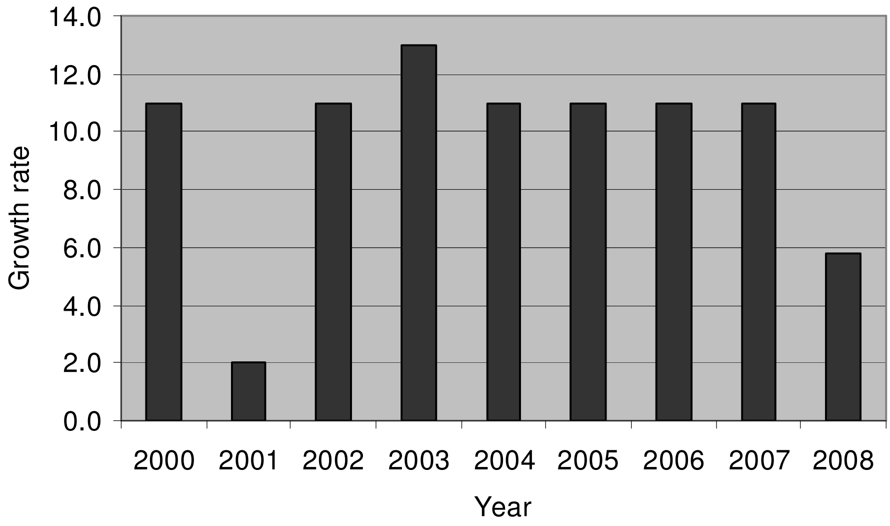


Figure 1-5. World container growth rate in TEU

A forecast done before the crisis, ending in 2020 indicated that container trade is expected to reach 219 million TEUs in 2012 and 287 million TEUs in 2016, and to exceed 371 million TEUs in 2020 (UNCTAD 2007). Due to current crisis, mid term container port forecasts are consequently lower than previously anticipated.

Although much will depend on the duration and the extent of the economic crisis, shippers and carriers still have to plan for future developments. Investments and improvements on container terminal infrastructure and technical equipments may be required for long-term future growth but these involve a great deal of capital investment. Under uncertain demand and economic conditions, to remain competitive, ports managers may opt for less capital-intensive investments.

CHAPTER 2

BERTH-CRANE ALLOCATION AND CONTAINER HANDLING PROBLEMS

In this chapter, quayside operations and container handling operations in a terminal will be examined in detail. The components of the associated problems are explained and the focus of the work is put forward. Appropriate literature is also provided in this chapter. The methodology of the work is proposed next. The SBCAM (simultaneous berth and quay crane allocation model) is formulated with a nonlinear mathematical model. The structures of CHSIM (container handling simulation) models are described in depth.

2.1. THEORETICAL BACKGROUND AND REVIEW OF THE LITERATURE

There are more than 2000 ports around the world, ranging from single berth locations handling a few hundred tons a year to multipurpose facilities handling up to 300 million tons a year (UNCTAD, 2004). Their operation and management policies vary to great extent according to their natural layout, capacity limitations and decision makers. As container terminals become more important, an ever increasing number of publications on the subject have appeared in the literature. We briefly summarize what is available in this chapter.

Berth allocation is an assignment and scheduling problem, where the incoming vessels are assigned to berthing positions at determined schedules. Figure 2-1 illustrates the problem in a two-dimensional space. The positioning problem of the vessels in the decision space without overlapping each other and while satisfying several constraints is NP-hard. Mathematical modeling, heuristics and simulation are the methods widely used for the solution of berth allocation problem.

In terms of quay treatment there are two approaches in the literature: the discrete approach and the continuous approach. In the discrete approach the quay is divided into predetermined length segments. There are finite set of berths, to which arriving vessels are assigned according to suitable lengths. Although discrete berth allocation problem is easier to solve, it causes ineffective space utilization. Using long berth segments will result in idle spaces while using short segments will likely result infeasible solutions. Continuous approach overcomes these problems by considering that ships can berth anywhere along the quay. The continuous approach has enormous flexibility for the berth allocation, achieving higher efficiency in berth usage and productivity. However, this advantage is offset by the difficulty in solving the problem due to its complexity (Imai et al. 2005). For this reason, most of the studies concentrate on the discrete case of the berth allocation problem rather than the continuous case.

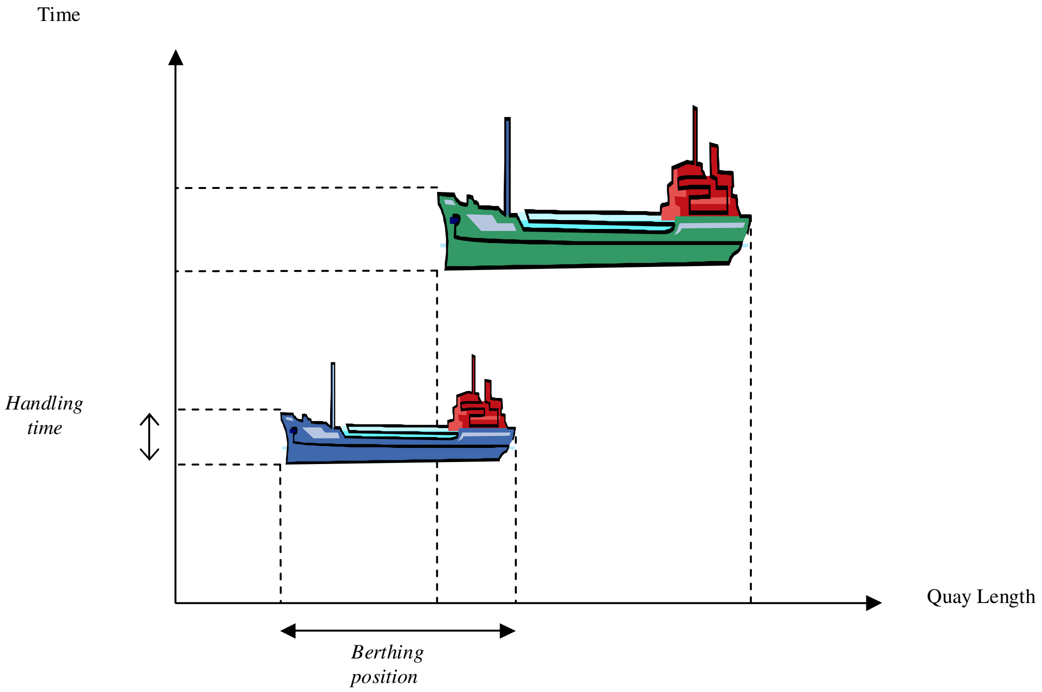


Figure 2-1: Berth allocation problem

In the studies of Lim (1997), Nishimura et al. (2001), Imai et al. (1997, 2001, 2003) a berth is allocated for each vessel adopting the typical discrete approach. Guan et al. (2004) expanded the discrete approach by allowing multiple mooring at one berth. Imai et al. (2007a) studied the discrete berth allocation problem for a terminal with indented berths, where an indented berth is characterized by its capability of handling from both sides if the ship size is large. Multiple small ships can be serviced by the same indented berth simultaneously. The problem is formulated as an integer linear problem and solved by genetic algorithms. Solutions are evaluated by comparing the indented terminal with a conventional terminal of the same size: tests on generated instances show that the total service time for all ships is longer in indented terminals, although mega-ships are served faster.

Cordeau et al. (2005) and Imai et al. (2005) have worked on the continuous mode of the berth allocation problem. Cordeau et al. presented a tabu search algorithm to solve the problem and tested the algorithm on realistic generated instances, derived by a statistical analysis of traffic and berth allocation data of the port of Gioia Tauro (Italy). Imai et al. (2005) developed a heuristic algorithm that incorporates with the existing berth allocation in the discrete quay location problem. This algorithm solves the problem in two stages: in the first stage the algorithm of the BAP identifies a solution given the number of partitioned berths, and in the second stage the other procedure relocates the ships that may overlap or be located sparsely in a scheduling space, which is defined by the discrete BAP algorithm.

Apart from the discrete and continuous classification, the berth allocation problem can also be categorized as static and dynamic. The static version treats only ships that have already arrived at the port before the scheduling begins, whilst the dynamic one takes into account ships that have already arrived as well as those that have not arrived at the time of planning and will arrive at some later moment during the planning horizon (Imai et al. 2005). The static version may be adequate for regimented terminals with highly developed information sharing possibilities. But for terminals with common last minute arrivals, although more complicated, dynamic approach is more suitable. Imai et al. (2001) have proposed the dynamic berth-allocation problem formulation, as opposed to a previous study by Imai et al. (1997), which considers the case where all ships are already in the port when the berths become available. To be able to solve the problem in polynomial time they presented a Lagrangian relaxation-based heuristic algorithm for the dynamic mode. Their computational results show that the dynamic berth-allocation problem is easy to solve as long as the instances are “close” to the static case, in the sense that most ships are already in the port when the berths become available.

The next operation after proper berth allocation in port management process is quay crane allocation. With appropriate crane assignments and scheduling, containers can be offloaded from the vessel fulfilling pre-specified objectives while satisfying several constraints such as quay restrictions, crane characteristics…etc. While this process is one of the key decision factors for optimum port management, compared to the berth allocation problem, little attention has been paid to it in the literature. A crane scheduling problem aiming to minimize the vessel waiting time, originally solved using heuristics by Daganzo (1989) was later solved with branch and bound technique in a subsequent study by Peterkofsky and Daganzo (1990). Kim and Park (2004) proposed a branch and bound method to minimize the ship's turnaround time and a heuristic search algorithm, called greedy randomized adaptive search procedure (GRASP), to overcome the computational difficulty of the branch and bound method. The performance of GRASP is compared with that of the branch and bound method. However, this study should be measured with a different perspective from the two previous studies, because their study focused on the crane scheduling problem for a single ship instead of multiple ships.

Treatment of berth and crane allocation in isolation from each other leads to suboptimal results. There are even fewer studies, which deal berth and crane allocation together. Park and Kim (2003) worked on both problems. A two-phase solution procedure is suggested. The first phase determines the berthing position and time of each vessel as well as the number of cranes assigned to each vessel at each time segment. Quay crane allocation is then constructed in the second phase based on the solution found from the first phase. A study that considers berth and quay crane allocation problems simultaneously is by Imai et al. (2007b). The authors develop a genetic algorithm for reaching near-optimal solutions for a discrete berth structure. However, their study did not consider the relationship between the handling time and the number of cranes. Their ship handling requires a specific number of cranes and it does not begin until that number of cranes is available leading to ineffective crane usage.

An overview of the selected research on berth and crane allocation problems in the literature is provided in Table 2-1.

As mentioned before, a terminal can be ideally divided into two areas, the quayside and the yard. Berthing and crane allocation activities explained above take place in the quayside part of the terminal. A detailed look at the activies that must be performed at the yard side is required for a complete analysis. The container yard is separated into blocks. The position of a container inside a block is identified by row, column and tier. Storage planning or stacking decision system deals with the problem of allocating these storage spaces to the arriving containers. Since it is very hard to maintain enough storage space in most port container terminals, this decision problem has become a field of increasing importance, playing an important role for the terminals' overall performance. The problem is complex and sophisticated, requring parallel considerations of a large number of interacting factors. As the ground space is a scarce resource, piling containers on top of each other is compulsory. This leaves some containers in an indirect access

Table 2-1: Summary of literature on berth and crane allocation

Paper	**Berth structure**	**Arrivals**	**Scope**	**Remarks**
Daganzo C (1989)	-	-	CA	heuristic algorithm
Peterkofsky RI, Daganzo CF (1990)	-	-	CA	branch and bound technique, attempts to minimize delay costs
Imai A., Nagaiwa K., Chan W.T. (1997)	D	S	BA	a heuristic that maximizes berth performance while minimizing dissatisfaction
Lim A.(1998)	C	S	BA	minimizes the total berth length used for a given set of vessels
Nishimura E., Imai A., Papadimitriou S. (2001)	D	DY	BA	up to two ships can share the berth, multi-water depth configuration.
Imai A., Nishimura E. , Papadimitriou S. (2001)	D	DY	BA	lagrangian relaxation-based heuristic algorithm
[Imai A., Nishimura E. , Papadimitriou S. (2003)	D	DY	BA	considered service priorities
Kim K.H., Moon K.C. (2003)	C	S	BA	simulated annealing algorithm
Park Y-M.,Kim K.H. (2003)	D	S	BA+CA	solved sequentially
Kim K.H., Park Y.-M. (2004)	-	-	CA	for a single ship instead of multiple ships
Guan Y., Cheung R.K. (2004)	D	S	BA	multiple mooring at one berth
Cordeau J.F., Laporte G., Legato P., Moccia, L. (2005)	C	S	BA	tabu search algorithm
Imai A., Sun X., Nishimura E., Papadimitriou S. (2005)	C	DY	BA	two stage heuristic algorithm
Imai A., Sun X., Nishimura E., Papadimitriou S., Hattori M. (2007a)	D	S	BA	indented berth structure
Imai A., Chen H., Nishimura E., Papadimitriou S. (2007b)	D	DY	BA+CA	fixed crane allocation for a vessel

D :discrete ; C: continous; S: static; DY: dynamic; BA: berth allocation; CA: crane allocation

location, entailing reshuffles to occur. Therefore, higher stacking may lead to incrased reshufflings. The maximum number of tiers also depends on the stacking equipment used, either straddle carriers or gantry cranes. A straddle carrier (Fig2 - 2) combines the stacking and transportation functions in one. Its flexibility over a gantry crane (Fig 2-3) is offset by its lower storage capacity: A straddle carrier has a shorter stacking height and requires extra space between every lane of containers to accommodate its legs (Murty et al. 2005).

Figure 2-2: Straddle carrier in Port of Izmir

Figure 2-3: Gantry crane in Port of Izmir

Other interrelated factors that have an effect on the performance of the storage and stacking system are the performance of the quay cranes, internal and external transportation equipment, layout of the container terminal and arrival patterns of vessels and trucks. The random and complex environment of the problem makes simulation modeling a suitable tool to work with.

Literature relevant to container handling may comprise studies on terminals that discuss the stacking of containers and simulation modeling.

The container activities in a terminal can be classified into import and export. These have different characteristics in terms of arrival and retrieval patterns. Export containers arrive at the terminal by trucks with uncontrollable entry times. They are stacked in the storage area until the relevant vessel arrives at the terminal. The destination vessel and departure time is comparatively known in advance. This allows the arrangement of the stacks according to pre-known data. Contrarily, import containers arrive at predictable times but leave in a random order. This makes the situation even harder for the stacking decision problem of the import containers. Due to its dynamic characteristics, less research has been done on space allocation for import containers.

Castilho and Daganzo (1993) have worked on import containers and developed general expressions for the expected number of moves required to retrieve a container from storage stacks under two fundamentally different approaches (segregating vs nonsegregating). While the nonsegregating strategy aims to reduce the difference in stack heights, the segregating strategy groups the containers according to the arrival times. They find that the appropriate strategy depends on the stack height and container dwell times. Kim and Kim (1999) worked on the similar problem. Their objective is the minimization of the expected total number of rehandles. The height of stacks and the amount of space allocation are the decision variables in their model. Different container arrival rates, constant, cyclic and dynamic, are analyzed using the same segrating strategy.

Zhang et al. (2003) decomposes the storage allocation problem for the import containers into two levels, formulated as a mathematical programming model. The first level determines the total number of containers that can be assigned to each storage block so as to balance the workloads among blocks in each period. The solution to the second level allocates the number of containers of each vessel to the blocks, in order to minimize the total distance travelled by the internal trucks.

Kim and Kim (2002) proposed a cost model for the determination of the space requirement and the number of transfer cranes in import container yards. Their model includes the cost of space, transfer cranes, and the external trucks with two different objectives: minimization of the costs of only the terminal operator and minimization of these costs combined with the costs of the customers.

On the export side, Taleb-Ibrahimi et al. (1993) analyzed the space-allocation problem with two storage strategies. They conclude that the strategy of having temporary storage areas virtually eliminate wasted space. Kim and Park (2003) worked on the storage space allocation problem for outbound containers using different transfer systems. Two heuristic algorithms are suggested based on the duration-of-stay of containers and the sub-gradient optimization technique, respectively. The first heuristic employs the least duration-of stay (DOS) rule in which a storage requirement with a shorter DOS in the container yard has a higher priority than that with a larger DOS in allocating spaces. They compared the two algorithms for direct and indirect transfer systems. The direct transfer system includes the onchassis system and the carrier direct system, and the indirect transfer system includes the straddle-carrier-relay and the transfercrane- relay systems.

It should be mentioned that none of the studies above considers the storage location of containers in the operational stage. They deal with the space requirement for planning or the amount of rehandling work of containers. The storage assignment problem is a one-step further stage than the space allocation problem, dealing with the decision of exact locations, denoted by a block, a column, a row, and a tier number. Following studies by Kozan and Preston (1999) and Preston and Kozan (2001) considered the exact locations of containers on the export side. Kozan and Preston (1999) used genetic algorithms to evaluate alternative plant layouts, storage policies and number of yard machines. They concluded that the storage policy, where export containers are stored in the closesest rows to the berth is better than random storage policy. Genetic algorithms was also used by Preston and Kozan (2001) to compare FCFS, LCFS and random container-handling schedules Their experiments showed that there is little difference in the average transfer time after using the different schedules. They stated that the type of schedule has no effect on the transfer time when using a good storage layout. The performance indicator used at both studies when comparing the storage policies compromises the unloading time of the container by a gantry crane and the transfer time from its location in the storage yard to the berthing place of the vessel. But, on the other hand, the quay crane operations are not taken into account.

Hirashima et al. (2006) also dealed with the exact locations of containers but their work was upon reaarranging containers that are already in a the stockyard. For this they proposed a Q-Learning algorithm. The learning process consists of two parts: rearrangement plan assuring explicit transfer of a container to the desired position, and removal plan for preparing the rearrange operation. In their solution, each container has several desired positions that are in the same group, and the learning algorithm is designed considering the feature.

As stated previously, container terminals deal with a complex system with many factors and entities interrelated to each other. To view subsystems showing stochastic behaviour, simulation tools may be used A summary of literature found on container simulation models is as follows:

Bruzzone and Signorile (1998) use genetic algorithms in their simulation model to determine the berth allocation and storage area allocation for container clusters of a vessel. Two genetic algorithms are used, one in ship scheduling and another in creating the cluster in the yard for the export containers. They use the simulation model to provide operational parameters, such as ship arrivals, to the genetic algorithms.

Merkuryev et al. (1998) used simulation to improve the documentation management system at Riga Harbour container terminal. The decision to install a new data processing system was taken following the model results. Another use of simulation at the strategic level is by Thiers and Janssens (1998). The decision to build a container quay on the river, outside the port of Antwerp, was investigated through the use of the model. Simulation experiments are run based both on current real-life measurements and on traffic forecasts. Ada (1984) focused on the port congestion problem at the port of Mersin. The ouputs of study is used to aid port managers in strategic decision making for the blockage problem. Vis (2006) compared the performance of two different types of handling equipment (gantry cranes and straddle carriers) at a container terminal according to the estimates of total time required to handle a fixed number of requests. Their results vary according to some criterion such as reshuffling requirements, block width and stack layout.

Lee et al. (2003) applied a supply chain modelling and its analysis framework to the supply chain in the port industry. With simulation they analysed and evaluated different strategies in view of partnership's strength and information sharing. Hartmann (2004) developed an approach for generating scenarios for port container terminals, which may be used as input for simulation models and as test data for algorithms to solve optimization problems. A scenario contains data on arrivals of ships, trains and trucks and information about containers being delivered or picked up. The generation of a scenario is controlled by means of various parameters specified by users.

Yun and Choi (1999) proposed a reduced model of the container terminal in Pusan and analysed the performance indicators of the port, such as yard tractor utilization, container yard occupancy rate, and average ship waiting time. Cortes et al. (2007) focused on the simulation of freight transportation at the Port of Seville beginning with the movement through the estuary of the river and finishing with the vessels arriving to the port dependencies. The storage and retrieval activities are modelled roughly, the incoming containers are simply stored on the surface of the dock that corresponds to each company and are kept there until lorries of a certain logistic company move them out of the port.

Sgouridis et al.(2003) designed a simulation model for a medium-sized terminal using an ''All-Straddle-Carrier'' system. The model was used to study the current state of a container terminal and possible future expansions to handle increased throughput. The model focuses on the unloading operations of containers from the import area stacking yard to the external gates. The quayside operations are limited to a single-berth structure.

Petering and Murty (2008) studied the effect of different block lengths and yard crane deployment systems, on the performance of quay cranes. According to their results, for a theoretical terminal, a yard crane deployment system that restricts yard crane movement among blocks yields a higher performance than a system that allows greater yard crane mobility. Multiple berth structure was built in their model but their implementation is on the export side of a container terminal where there are no external trucks or gates and hence their effect to the performance is not considered.

The CHSIM model used in this work handles the storage assignment problem at the operational level with a multiple-berth structure for the full import containers of a real terminal. The assessment of the effect of the storage policies proposed is done in view of numerous performance criteria of the container terminal. That is, time delays due to operations processed by quay cranes, internal trucks and the gantry crane movements along with their utilization rates are considered.

The SBCAM structure on berth and crane allocation described in this thesis is noteworthy in the following aspects: First, this study attempts to simultaneously determine the berthing and crane allocations. Second, the wharf is considered to be a continuous space rather than a collection of partitioned sections. Third, unlike in the study by Imai et al. (2007b), which assumed fixed handling time of the vessels, this study suggests an optimizing method that considers the handling time as a function of crane allocations in each time segment. Moreover, multiple continuous quay structure and collective mobile and quay-dedicated crane allocations are also considered in this study. Therefore, this thesis fills an important gap in the port management literature by providing a general model for a simultaneous allocation for a continuous berth structure and container handling.

2.2 THE SBCAM APPROACH

Berth allocation problem deals with the problem of assigning berth spaces to the incoming vessels. Quay crane allocation is the next activity concerning the determination of the assignment sequence of quay cranes to a container ship. Literature shows that these two problems are mostly studied separately. Although these two activities occur one after the other the solution to the first problem greatly affects the performance of the second activity. If the concern is improving the whole system as opposed to achieving partial progresses, then a more refined solution model should be built.

Therefore, to avoid suboptimal solutions, this research offers a solution that proficiently combines the two problems. The multiparty problem can be represented in three-dimensional space shown in Figure 2-4. The rectangles stand for the vessels. A vessel's projections on the dimensions are the vessel-length added to the safety margin, assigned crane identification numbers and handling time. The problem is the positioning of the vessels in the decision space without overlapping each other while minimizing the total handling time of the ships.

Looking at the spatial dimension we see the representation of three quays: Q1, Q2 and Q3. Each may have different lengths that falls in line with the real physical structure of a port. As long as the length and crane restrictions are not violated, multiple ships can be assigned to a quay. The quay is arranged according to a continuous location structure which means that no reserved spaces are considered. Vessels are allowed to overlap either in time or in quay dimensions but not both. To illustrate the overlapping rule we may have a look at vessel i (vi) and vessel j (vj). They both have the same lengths: $l_i = l_j$. They are berthed within the first quay (Q1) and their berthing positions are the same: $x_{ik} = x_{jk}$. In the crane axis, we have seven cranes that are either quay specific or portable. Quay specific cranes can move along the quay it is located, whereas the portable ones are furthermore capable of moving between quays. Consequently, a vessel berthed at a quay has the option to choose from the cranes dedicated to the specific quay plus the portable cranes.

A key point in this model is that handling time and number of cranes to be assigned to the ship are not known in advance. This feature of the model puts it a step ahead of the solution techniques found in the literature. Handling time is not taken as an assumption but rather it is calculated dynamically throughout the service time. It is dependent on the number of cranes allocated to a vessel which is again dynamic throughout the service time. Dynamic feature comes from the fact that cranes dedicated to a vessel can be changed throughout its service time. For instance a vessel can start to be served by only one crane and end up being served by three cranes. Therefore, the ships do not have to wait until a specified number of cranes are available. This prevents suboptimal solutions resulting from misleading crane unavailability assumption. In Figure 2-4, during the periods 4 to 6, vessel k (v_k) is served by only one crane (crane number 5). At time period 6, by

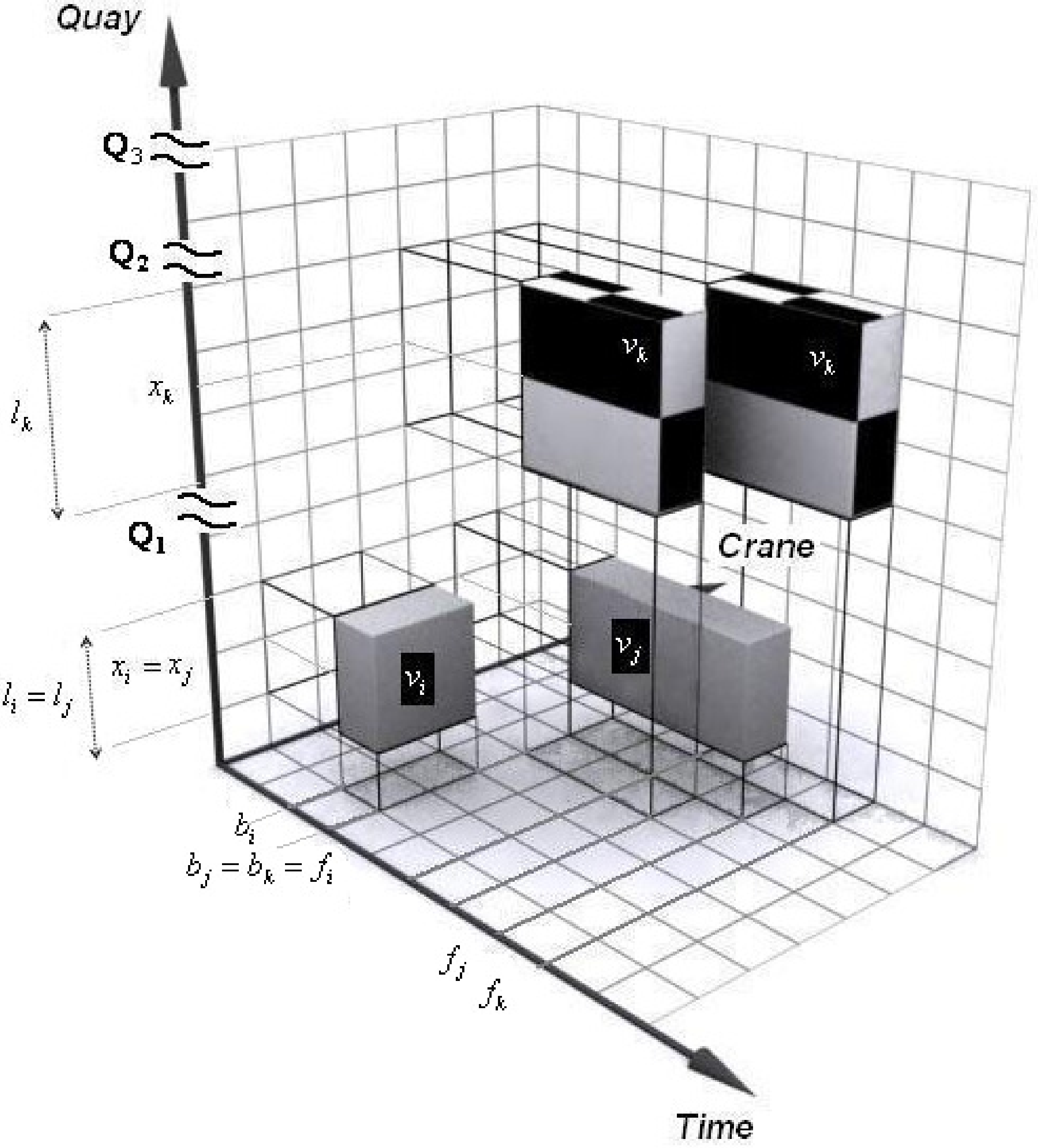


Figure 2-4: Berth-crane-time space

the addition of crane 7, number of cranes assigned to the ship is increased to two. The total handling time for v_k is $f_k - b_k = 5$.

Now, the dynamic simultaneous continuous berth and crane allocation model, which minimizes the total service time of vessels, will be presented. The assumptions of the model are as follows:

(1) Vessels are assigned to quays in a continuous allocation approach with respect to the vessel lengths.

(2) There are two types of cranes, quay dependent and mobile cranes. Quay dependent cranes can move along the dedicated quay line, mobile cranes are also capable of moving between quays. Mobile cranes can serve any vessel at any quay.

(3) A vessel can be assigned to a maximum number of four cranes at each time period. This restriction is for the prevention of potential physical conflicts that might arise from having too much cranes working close to each other.

(4) Crane allocation is dynamic throughout the handling period of a vessel. The number and type of cranes assigned is flexible and arranged according to the optimization rules.

(5) Vessel handling time is dependent on crane allocations, and the handling starts as the vessel is berthed.

The unit of lengths is meters. The indices, parameters and decision variables and the nonlinear programming model are defined below:

Indices:

$i = (1, \ldots, I)$ set of vessels,

$j = (1, \ldots, J)$ set of cranes,

$k = (1, \ldots, K)$ set of quays,

$t = (1, \ldots, T)$ time periods.

Input Parameters:

l_i: vessel length including the safety margin for the vessel

Q_k : length of quay k

a_i : arrival time of vessel I

NC_i : Number of containers initially on the vessel

R: Number of cranes that can be handled in a time period

$$C(j,k) = \begin{cases} 1, & \text{if crane } j \text{ can serve on quay } k \\ 0, & \text{otherwise} \end{cases}$$

M_1, M_2, M_3: large constants

m= a value between 0 and 1

<u>Decision Variables:</u>

x_{ik} : position of vessel i at quay k

$$y_{ijtk} = \begin{cases} 1, \text{ if crane } j \text{ is allocated to vessel } i \text{ at time } t \text{ on quay } k \\ 0, \text{otherwise} \end{cases}$$

$$z_{itk} = \begin{cases} 1, \text{ if vessel } i \text{ is assigned at time } t \text{ on quay } k \\ 0, \text{otherwise} \end{cases}$$

N_{it} : total number of containers on vessel i at time t

H_i : Handling time of vessel i

The Model:

$$\text{Min } H = \sum_i H_i$$

s.t.

$$x_{ik} + {l_i}/{2} \le Q_k \qquad \forall i,k \qquad \text{Eq. (2-1)}$$

$$\alpha_{i,i',k} \left| x_{ik} - x_{i'k} \right| \ge \alpha_{i,i',k} \left(\frac{l_i + l_{i'}}{2} \right) \qquad \forall i,i',i \ne i',k \qquad \text{Eq. (2-2)}$$

$$\beta_{i,i',t,k} \left(z_{itk} + z_{i'tk} \right) \le \beta_{i,i',t,k} \qquad \forall i,i',i \ne i',t,k \qquad \text{Eq. (2-3)}$$

$$\alpha_{i,i',k} + \beta_{i,i',t,k} = 1 \qquad \forall i,i',i \ne i',t,k \qquad \text{Eq. (2-4)}$$

$$\sum_{k} x_{ik} - {}^{l_i}\!/_{2} \geq 0 \qquad \forall i \qquad \text{Eq. (2-5)}$$

$$x_{ik} . x_{ik'} = 0 \qquad \forall i, k, k', k \neq k' \qquad \text{Eq. (2-6)}$$

$$1 - x_{ik} \leq M_3 * \lambda_{ik} \qquad \forall i, k \qquad \text{Eq. (2-7)}$$

$$\sum_{t} z_{itk} \leq M_3 * (1 - \lambda_{ik}) \qquad \forall i, k \qquad \text{Eq. (2-8)}$$

$$\sum_{k} z_{itk} \leq 1 \qquad \forall i, t \qquad \text{Eq. (2-9)}$$

$$\sum_{t} \sum_{k} z_{itk} \geq 1 \qquad \forall i \qquad \text{Eq. (2-10)}$$

$$\sum_{k} \sum_{i} y_{ijtk} \leq 1 \qquad \forall j, t \qquad \text{Eq. (2-11)}$$

$$\sum_{i} \sum_{j} \sum_{k} y_{ijtk} \leq J \qquad \forall t \qquad \text{Eq. (2-12)}$$

$$\sum_{t=1}^{a_i - 1} y_{ijtk} = 0 \qquad \forall i, j, k \qquad \text{Eq. (2-13)}$$

$$\sum_{k} \sum_{j} \sum_{t} y_{ijtk} = \frac{NC_i}{R} \qquad \forall i \qquad \text{Eq. (2-14)}$$

$$\sum_{i} \sum_{t} y_{ijtk} * C(j, k) = \sum_{i} \sum_{t} y_{ijtk} \qquad \forall j, k \qquad \text{Eq. (2-15)}$$

$$\sum_{j} \sum_{k} y_{ijtk} \leq 4 \qquad \forall i, t \qquad \text{Eq. (2-16)}$$

$$z_{itk} \le \theta_{itk} \qquad \forall i,t,k \qquad \text{Eq. (2-17)}$$

$$\sum_{j} y_{ijtk} \ge m\,\theta_{itk} \qquad \forall i,t,k \qquad \text{Eq. (2-18)}$$

$$\sum_{j} y_{ijtk} \le M_1 \theta_{itk} \qquad \forall i,t,k \qquad \text{Eq. (2-19)}$$

$$z_{itk} \ge m\theta_{itk} \qquad \forall i,t,k \qquad \text{Eq. (2-20)}$$

$$\sum_{k} z_{itk} . N_{i,t+1} \le M_2 \phi_{it} \qquad \forall i,t \qquad \text{Eq. (2-21)}$$

$$\sum_{k} z_{i,t+1,k} \ge m\,\phi_{it} \qquad \forall i,t \qquad \text{Eq. (2-22)}$$

$$N_{it} - R\left(\sum_{k}\sum_{j} y_{ijtk}\right) = N_{i,t+1} \qquad \forall i,t \qquad \text{Eq. (2-23)}$$

$$N_{i1} = NC_i \qquad \forall i \qquad \text{Eq. (2-24)}$$

$$H_i = \sum_{t}\sum_{k} z_{itk} \qquad \forall i \qquad \text{Eq. (2-25)}$$

$$y_{ijtk}, z_{itk}, \theta_{itk}, \phi_{it}, \alpha_{i,i',k}, \beta_{i,i',t,k}, \lambda_{ik} \in \{0,1\} \qquad \forall i,j,t,k \qquad \text{Eq. (2-26)}$$

$$x_{ik} \ge 0 \qquad \forall i,k \qquad \text{Eq. (2-27)}$$

Below are the detailed explanations to the constraints:

The objective function minimizes the total handling time for each vessel .

Equation (2-1) assures that the allocation of a vessel does not exceed the quay length. Here, x_{ik} indicates the middle point of a vessel in its berthing position. Therefore, it is adequate that the half length plus x_{ik} is equal to or smaller than quay length.

Constraint sets (2-2) to (2-8) state the overlapping restrictions and a position to every vessel. Vessels can overlap either in time or in length dimensions, but not both. $\alpha_{i,i',k}$ and $\beta_{i,i',t,k}$ are auxiliary variables. By Eq. (2-4) we force one of them to have the value of 0 and then the other one should have the value of 1. The difference between two vessel's berthing positions ($|x_{ik} - x_{i'k}|$) should be equal to or smaller than their half value of ship length summations. This impedes the vessels from being berthed at the same positions. Eq. (2-3) tells us that maximum one of the values of z_{itk} may equal to 1. Recall that, z_{itk} will be equal to 1 if vessel i is assigned to quay k at time t. From the enforcement of auxiliary variables in Eq. (2-4) only one of the equations, either Eq. (2-2) or Eq. (2-3) will hold. To demonstrate the condition, for instance, let z_{itk} and $z_{i'tk}$ both have the value 1, meaning that both vessels are on the same quay at the same time. Then, constraint (2-3) will be: $\beta_{i,i',t,k} * 2 \le \beta_{i,i',t,k}$. In this case $\beta_{i,i',t,k}$ can only be zero. If $\beta_{i,i',t,k}$ is zero then due to Eq. (2-4), $\alpha_{i,i',k}$ is 1. When 1 is put for the auxiliary variable in constraint 2-2, constraint $\left|x_{ik} - x_{i'k}\right| \geq \left(\frac{l_i + l_{i'}}{2}\right)$ must hold, which enforces the two vessels to position them in a non-overlapping mode on the same quay.

For the other way around, where there is an overlapping on berthing positions, meaning that the vessels share the same berthing positions on the same quay, this time $\alpha_{i,i',k}$ will have to be zero for constraint 2-2 to hold. As expected, $\beta_{i,i',t,k}$ will take the value 1. If $\beta_{i,i',t,k}$ is 1 equation (2-3) becomes: $\left(z_{itk} + z_{i'tk}\right) \leq 1$. According to this constraint the two vessels' z_{itk} values can not be 1 at the same time. Hence, even if there is an overlapping in berth dimension, the time periods for the vessels will not be the same, which is entirely appropriate.

Eq. (2-5) and Eq. (2-6) will guarantee the positioning of vessels. Eq. (2-5) will force every vessel to be placed in a quay. Eq. (2-6) will prevent the vessel to be berthed to more than one quay.

Constraint sets (2-6) through Eq. (2-10) define a relation between x_{ik} and $\sum_t z_{itk}$. x_{ik} should have a value bigger than zero when $\sum_t z_{itk}$ is bigger than zero. That is, if a vessel is assigned to quay k at any time period then the vessel's berthing position at that quay should exist. λ_{ik} is the auxiliary variable. M_3 is a big constant. As z_{itk} is a binary variable, maximum value of $\sum_t z_{itk}$ can be equal to the number of time periods considered in the model. Hence, it is adequate for M_3 to be bigger than the total time periods. Looking at Eq. (2-8), if the value of $\sum_t z_{itk}$ is larger than zero then λ_{ik} has to be 0. If λ_{ik} is 0, for Eq. (2-7) to hold, x_{ik} value should not be zero. On the other side, if the value of $\sum_t z_{itk}$ is equal to zero then it is expected to have x_{ik} equal to zero too. If we give $\sum_t z_{itk}$ value zero then from Eq. (2-8) alone, λ_{ik} may be 0 or 1. Looking back again to Eq. (2-7), if λ_{ik} is 0, if forces x_{ik} value to be other than zero, which is contrary to the expectations. In fact, λ_{ik} can not take the value 0 from Eq. (2-8), when Eq. (2-6) holds: From Eq. (2-10) it is assured that all arriving vessels are served. So if $\sum_t z_{itk}$ is zero for a specific quay then there should be a quay where $\sum_t z_{itk}$ is not zero. At that quay x_{ik} will not be zero. (Due to equations 2-7 and 2-8). When x_{ik} is not zero for a specific quay, owing to Eq. (2-6). the other values at the rest of the quays for the variable will be zero. And when x_{ik} is forced to 0 , then λ_{ik} will be forced to be 1. (Eq. (2-7))

Constraint (2-9) implies that a vessel can be assigned to at most one quay.

Constraint (2-11) does not allow any crane to be allocated to more than one vessel at multiple quays at the same time period. Recall that, y_{ijtk} equals to 1 if crane j is allocated to vessel i at time t on quay k.

Equation (2-12) guarantees that the total number of cranes allocated in a time period can not go above the maximum number of cranes in the system. Here J stands for the maximum number of cranes in the system.

Constraint (2-13) does not allow any crane assignment before the arrival of vessels. According to the equation, values of y_{ijtk} will be zero until the arrival time (a_i) of the vessel.

Constraint (2-14) assigns just enough number of cranes to load/unload a vessel. If NC_i is the total number of containers in the vessel and R is the crane unloading rate then $\frac{NC_i}{R}$ will give the total number of crane assignments that should be made for emptying the vessel.

Constraint (2-15) is a covering type constraint, which defines the crane-berth pairs. The value of y_{ijtk} is organized according to the cranes and their dedicated berths.

Constraint (2-16) assures that four cranes at most can be assigned to a vessel at each time period.

Equations (2-17) to (2-20) define another relationship which is between the quay and crane allocations. If there is a quay assignment (z_{itk})for a vessel in a time period, there must be a crane assignment ($\sum_j y_{ijtk}$) also, and vice versa. θ_{itk} is a binary auxiliary variable. If z_{itk}>0 or in other words equal to 1 then from constraint (2-17), θ_{itk} should be 1. Due to constraint (2-18), value of $\sum_j y_{ijtk}$ should be more than zero. If z_{itk}=0 from constraint (2-20) value of θ_{itk} must be zero. Due to, this time, constraint (2-19), value of $\sum_j y_{ijtk}$ should be equal to zero. Considering the other way around that is the situation where $\sum_j y_{ijtk}$ is zero, from Equation (2-18) it can be seen that θ_{itk} should be zero. If so, then from Equation (2-18) z_{itk} should also be zero. If this time $\sum_j y_{ijtk}$ is not zero, from Equation (2-19) it can be seen that θ_{itk} should be 1. If so, then from Equation (2-20) z_{itk} should be 1.

Constraint couple (2-21) and (2-24) guarantees that there is no interruption in time periods till the service completion for each vessel. In Eq. (2-23), the number of containers to be handled in each vessel (N_{it}) is decreased by the total containers handled at each period ($R\left(\sum_k \sum_j y_{ijtk}\right)$). $N_{i,t+1}$ is the number of containers left for the following time period. Constraint (2-21) states that if the multiplication of $\sum_k z_{itk}$ and $N_{i,t+1}$ does not equal to 0, which means the vessel has taken service at time t and there is still more containers left then ϕ_{it} should be 1 too. From Eq. (2-22) it follows that the value of $\sum_k z_{itk}$ at the next time period which is denoted as $\sum_{k} z_{i,t+1,k}$, will be 1 too. Eq. (2-24) equates number of containers to be handled at the first time period to the total number of containers on the vessel.

Eq. (2-25) calculates the handling time of each vessel. This is equal to the sum of z_{itk} values. A vessels z_{itk} value at a time period t will equal to 1 if a crane or more than one crane is assigned to it. The value of z_{itk} for the following time periods will maintain its value as to be 1 until the loading/unloading operations are completed and the vessel is ready for departure. Consequently, addition of these z_{itk} values will be the handling time of a vessel.

2.3. THE CHSIM MODEL

Container terminals are extremely complex systems, dealing with a vast number of interrelated factors and variables. In particular, in the presence of non-deterministic variables, it is difficult to utilize analytical approaches for analysis. A pragmatic approach providing a comprehensive view of the interrelated factors is possible with the simulation technique. By experimenting with a model representing the real world, it is possible to effectively analyze and evaluate design and management alternatives.

With these facts, a discrete event simulation model of full containers import area yard-side operations inside a container terminal is formulated using Arena 11.0.

Main features and assumptions of the model are as follows:

(1) The model accommodates the handling of full import containers. Other types of processes that are irrelevant with full import container handling are ignored.

(2) The storage area for full import containers is divided into blocks. A gantry crane is dedicated to each block. Gantry crane transfers among blocks are prohibited.

(3) The terminal operates according to the arrival of containers on the vessels to the quays. The arrival pattern of vessels and number of containers on the vessels follow probability distributions that are user-defined.

(4) The performance of the same type of machines and vehicles are identical. Quay crane handling times and container departure dates follow probability distributions. Yard truck velocities, each discrete move of gantry cranes is defined in detail and distinct speeds are user-defined parameters.

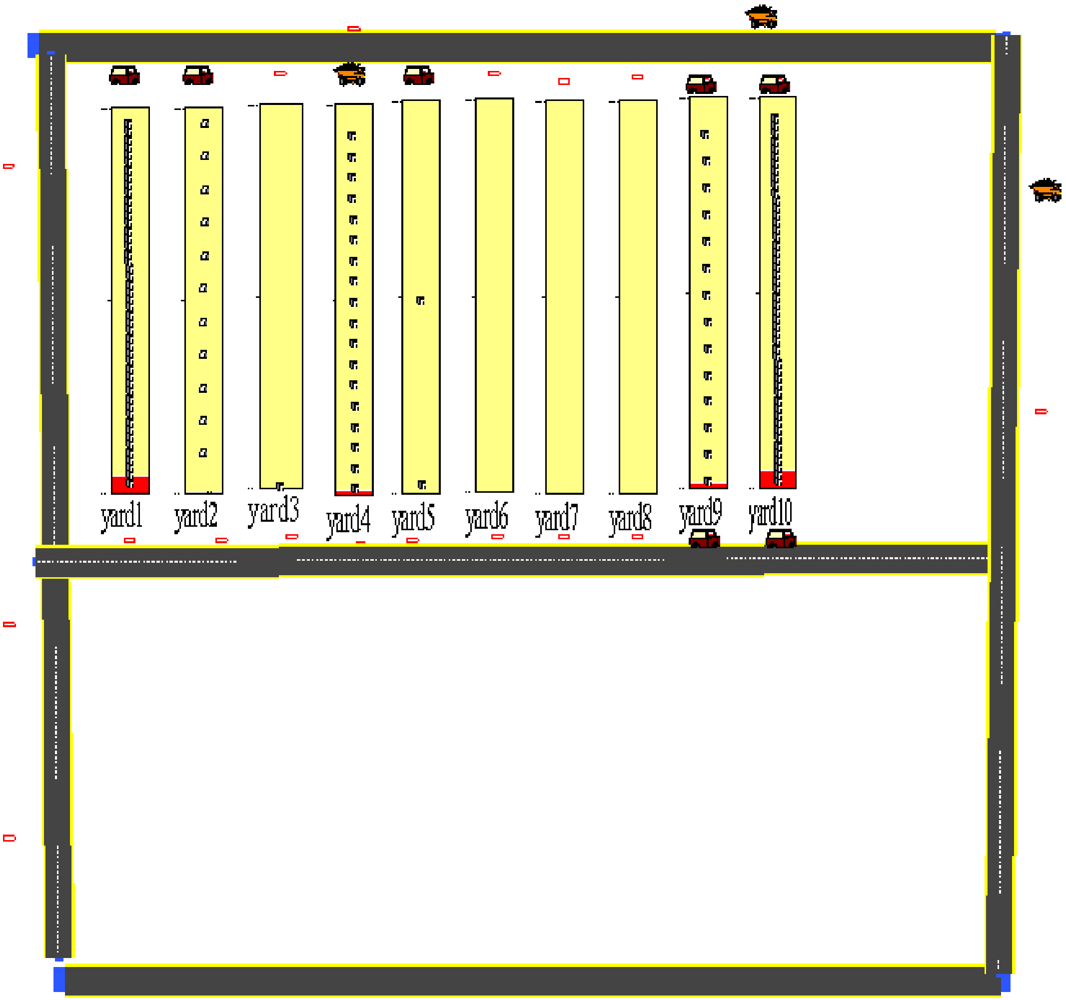
As vessels arrive to the port, they are berthed and quay crane assignments are performed. Berth and quay crane allocation is realized by the SBCAM approach explained in the previous section. Once the vessels are berthed on docks yard-side operations will begin. Containers will be transferred by the cranes and the yard trucks to the blocks assigned by the storage assignment policy. Gantry cranes will pick-up the containers from the yard trucks to store in dedicated rooms.

Containers will be kept in those spaces until their departure time arrives. At departure, gantry cranes will retrieve the container from its place and put it on the external truck. The truck will then move to the gate for departure. Figure 2-5 shows the layout of the animation screen of the simulation model, performing the summarized yard-operations above.

The logic model covers the following main operations: transfer of containers on yard trucks to storage yard, storage place assignment, stacking, external truck arrival, container pickup and departure. For each storage place assignnment policy some differences between the logic modules is needed. As mentioned earlier, on the yard side where transporters are allocated to containers for transfer, there may be two different approaches. The first approach is the use of straddle carriers, where containers are temporarily stored in the quay crane station area, waiting to be lifted up by straddle carriers. The second approach is the use of trucks and quay cranes concurrently which requires a more complex modelling structure.

As the studied port uses the latter approach, the second logic module where trucks are used for transferring purposes will be studied. (see Figure 2-6). The berthing of vessels at the docks initiates the simulation. The arrival pattern may be specified according to a schedule or past statistical distribution data such as the one of SBCAM output. As the containers are generated, they are assigned with some attributes such as identification number and departure time within the assign module. The "Decide" module will route the containers to the quay crane stations according to specified rules. Here, they will try to seize the crane when available.

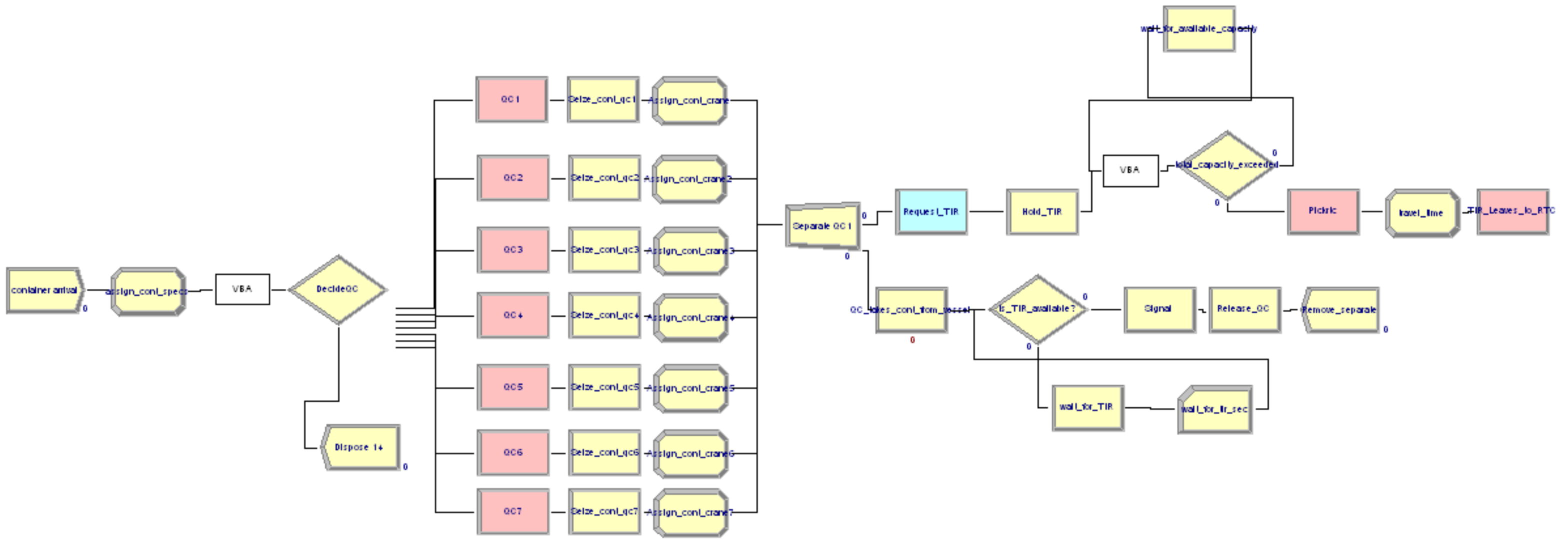
Figure 2-5: Snapshot of the simulation animation.



Previously, it was mentioned that the use of trucks requires the synchronization of the quay-cranes and the internal trucks. Since the quay crane picks up the container from the vessel and places it on top of the truck, the truck must be readily available at the reaching distance of the quay crane to accomplish the work. Compared to the first approach, the main difference here is the fact that crane allocation can not be done in isolation, beforehand. Crane allocation and truck allocation must be performed jointly.

As soon as a quay crane is seized, the container is duplicated to allow the quay crane to perform two tasks simultaneously: truck requesting and unloading operations. Otherwise, the quay crane would have to wait for the unloading operations to end before demanding a yard truck. The transfer time of the truck from its parking place to the quay crane would add up to the quay crane cycle time, causing a decrease in the performance. At the same time as the unloading operations start, a yard tractor is requested with the “request” module. Of the available trucks, the one that has the closest distance to the crane station is preferred. The quay crane and the yard truck must be coordinated. The quay crane has to wait for the truck to put down the container and the truck can not move before the quay crane finishes its job. Synchronization is ensured by the use of “Hold” and “Signal” modules. The yard truck will stay at the “Hold” module until it receives a signal from the gantry crane.

Figure 2-6: Yard truck allocation modules



On the duplicated part, the quay crane unloads the container from the vessel and the “Decide” module checks to see if the yard truck is available. If not, it will wait for some time and do the check again. If original side, before moving on to any block, a total capacity check is performed. If total capacity of all the full container storage yard area is exceeded, truck waits in its present quay crane station until there is available capacity. When capacity is obtainable, the vehicle is ready to head for the storage yard.

The storage place of the container is determined according to the storage policy implemented. Several policies are adopted in this study. These are explained in detail in Section 2.3.1. The yard truck moves to the specified block in the storage yard. Blocks may have two entrance and exit points. The entrance point that is closest to the yard truck is preferred for entering the block. The container then demands for the gantry crane dedicated to the block.

After seizing the gantry crane, a duplicate of the entity is created via the “Separate” module to allow for parallel processing. The original will be used for storing and retrieval operations and the copy will be used for managing the yard truck. On the copy side, the “Free” module releases the transporter and makes it available for others use. The copy is then expelled by the “Dispose” module.

On the side of the original copy, the gantry crane places the container to its storage place. The storage place of the container and the total time spent for storing the container is calculated through numerous computations in the visual basic application object. These calculations are explained in detail in Section 2.3.2.1. The gantry crane will be released by the “release” module after the “store” element, where the container is placed in the determined block, row, column and tier. With the “hold” module the container will be kept in the storage yard until its departure time. At the departure time the gantry crane dedicated to the block the container is stored will be seized again. Next, the container is picked up from its storage location and put down on to an external truck waiting to transfer the container to its final destination. The cycle time of the gantry crane and the transfer time of the external truck to the gate depends on the position of the container. Shuffles may be necessary to reach the container. Detailed calculations of the cycle time for the unloading operations are given in the Sections 2.3.2.2 and 2.3.2.3. Prior to the unloading process module, these computations will be realized within the VBA module.

Following the unloading operation, the gantry crane is released by the “release” module, the container is unstored with the “unstore” object and the model is ended with the disposal of the container from the system. Figure 2-7 illustrates the storage and retrieval operations of the container explained above.

2.3.1 Storage policies

The storage policy determines how the exact locations for the containers in the storage yard will be assigned. For the problem in our study a block number, a column number, a row number and a tier number for each container is specified.

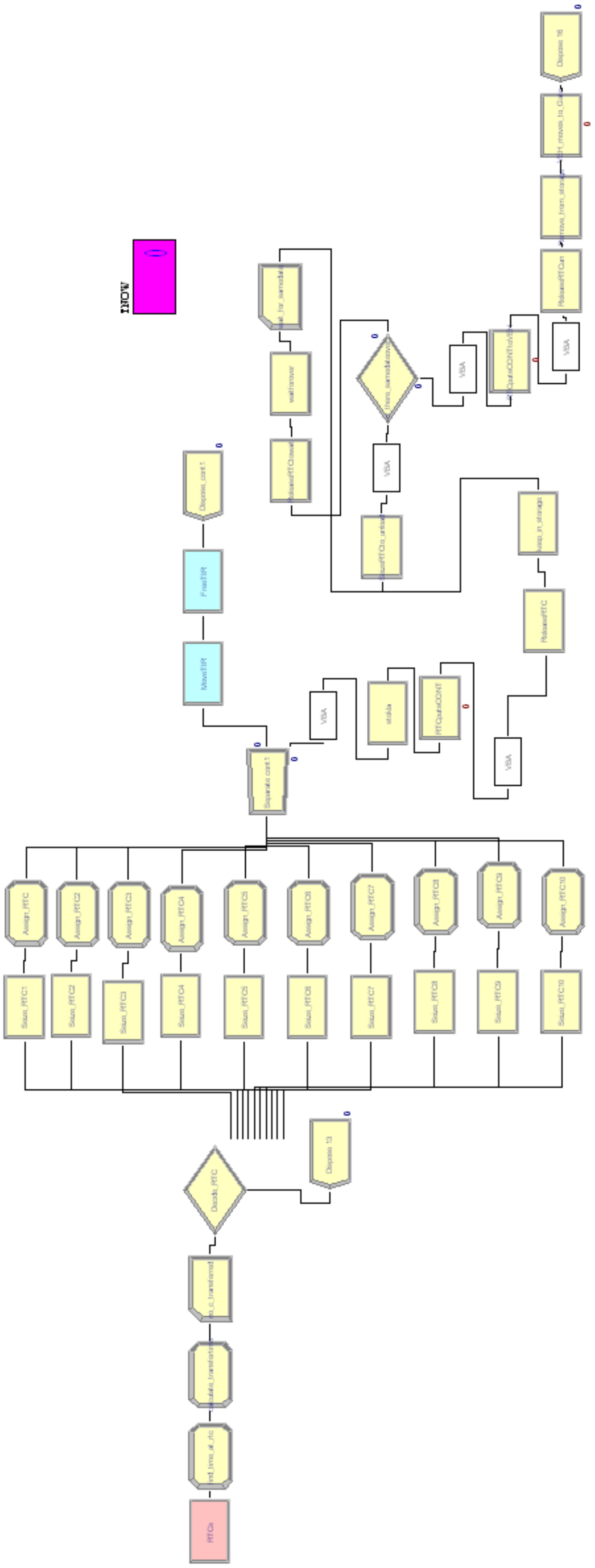


Figure 2-7 Gantry crane allocation, storage, retrieval and departure modules

A novel approach by means of a hierarchical structure with an integrated policy implementation is put into practice. A hierarchical approach is adopted to break the whole problem into two sub-problems and solve each of them using separate decision rules. At the first level, the block number is specified. The second level determines the column, row and the tier number.

Parameters considered at the first level are workloads of gantry cranes, number of transporters travelling to the gantry cranes and the distance travelled by transporters.

With workloads of a vessel dispersing in different blocks, the yard cranes in the blocks serve as parallel servers processing jobs for the vessel, and the deberthing time of the vessel is the maximal processing time of these parallel servers (Zhang et al. 2003). Balancing the workload of parallel servers generally works well to minimize the completion times of vessels. Similar results on the gantry crane deployment problem confirm that balancing workloads of blocks reduces delay in container handling (Zhang et al. 2002).

When dealing with the workloads of the gantry cranes, the number of transporters headed for the crane should also be considered. This would give a more accurate result for the forthcoming occupations of the cranes.

The minimization of the transportation distance from the quay crane to the stacking area is a further aspect considered. Picking a closer stacking area could shorten the transfer time by a meaningful ratio.

The strategies above are integrated into one policy to effectively coordinate the performance of transporters and gantry cranes. This policy will be named as the “integrated policy”.

Random storage policy is a commonly acknowledged strategy in the field of stacking logistics. In a book by Joy and Barry (2006) it has been stated that random stocking leads to the potential utilization of the whole facility because space does not have to be reserved for certain part families. They declare that random stocking systems can increase facility utilization and decrease labor costs.

At the second level of the hierarchical structure, when determining the row, column and the tier attributes of a container, two storage policies are suggested. A segregation strategy based on container departure dates is the first policy. A known method is to pile containers with the same departure dates together in their reserved slots in the storage yard. It is expected that less reshuffling will occur when the containers with the same tier and row attribute will be retrieved at similar time periods. Obviously, this strategy is based on the assumption that pickup dates for the containers are known in advance. Another drawback with this method is that reserving spaces causes inefficient usage of storage place. To eliminate wasted space and to note the fact that departure dates may not be absolutely available in advance, a more relaxed strategy is suggested. Storage spaces are partitioned according to thirty hour time slices. That is, a rough estimate of departure dates will be adequate for piling. In addition, in case the partioned area of the storage spaces are full, containers are allowed to be stored in any other empty space.

The other storage policy is the random storage policy where the row, column and tier attributes are picked randomly within a block. Table 2-2 summarizes the policies used in each strategy in the simulation model.

Table 2-2: Policies used at each level at a strategy

Strategy number	Level 1	Level 2
st1	Random	Random
st2	Integrated	Random
st3	Random	Segregated
st4	Integrated	Segregated

Level1: block selection

Level2: column, row and tier selection

2.3.2 Calculating service times

Total handling times consist of full and empty travelling times of transporters and gantry cranes, reshuffling times and external truck transfer times. In this study, rather than using estimated results, exact calculation methods are realized.

2.3.2.1. Stacking

To stack an import container to its storage location numerous steps are tracked. First, the transporter carrying the container enters the block from any of the two entrance points and drives through the lane dedicated to the tractors until it reaches the row of the container storage place. Equation (2-30) shows the time required for this move. In this formulation row' equals the row of the container if the transporter uses the bottom entrance point. If the upper entrance point is used row' will be calculated as follows:

$$row' = block\_length - row \qquad \text{Eq. (2-29)}$$

$$\frac{row' * container\_length}{yard\_truck\_speed} \qquad \text{Eq. (2-30)}$$

Next the gantry crane will drive to the row from its last parking place .

$$\frac{| row - ganrty\_crane\_park |}{Driving\ speed\ empty} \qquad \text{Eq. (2-31)}$$

Now the transporter will be under the gantry cranes. Gantry crane moves down to pick up the container:

$$\frac{gantry\_crane\_heigth - yard\_truck\_heigth}{hoisting\_speed\_empty} \qquad \text{Eq. (2-32)}$$

Gantry crane picks up the container and moves up:

$$\frac{gantry\_crane\_heigth - yard\_truck\_heigth}{hoisting\_speed\_full} \quad \text{Eq. (2-33)}$$

Gantry crane moves the container to the specified column:

$$\frac{Lane\_width + (column * container\_width)}{trolley\_speed} \quad \text{Eq. (2-34)}$$

Gantry crane puts the container down:

$$\frac{gantry\_crane\_heigth - (tier * container\_heigth)}{hoisting\_speed\_full} \quad \text{Eq. (2-35)}$$

Container is now in its storage place. Gantry crane will now go to its parking place. First, the empty gantry crane will move up.

$$\frac{gantry\_crane\_heigth - (tier * container\_heigth)}{hoisting\_speed\_empty} \quad \text{Eq. (2-36)}$$

And last, it goes to the end of the column to wait for other requests:

$$\frac{Lane\_width + (column * container\_width)}{trolley\_speed} \quad \text{Eq. (2-37)}$$

2.3.2.2 Retrieval

To retrieve a container from its storage location several operations must be realized. First, the external truck will enter the block from the bottom entrance gate, and drive to the row of the container to be retrieved:

$$\frac{row * container\_length}{external\_truck\_speed} \qquad \text{Eq. (2-38)}$$

The gantry crane will also drive to the same row from its last parking place:

$$\frac{|\, row - ganrty\_crane\_park \,|}{Driving \ speed \ empty} \qquad \text{Eq. (2-39)}$$

Gantry crane will move sideways to the column of the container:

$$\frac{Lane\_width + (column * container\_width)}{trolley\_speed} \qquad \text{Eq. (2-40)}$$

Gantry crane will move down to pick up the container:

$$\frac{gantry\_crane\_heigth - (tier * container\_heigth)}{hoisting\_speed\_empty} \qquad \text{Eq. (2-41)}$$

It will now carry the container to the tractor. First it needs to lift the container up:

$$\frac{gantry\_crane\_heigth - (tier * container\_heigth)}{hoisting\_speed\_full} \qquad \text{Eq. (2-42)}$$

Now it will move right to the vehicle lane:

$$\frac{Lane\_width + (column * container\_width)}{trolley\_speed} \qquad \text{Eq. (2-43)}$$

Next, the gantry crane will descend to place the container to the truck awaiting under it:

$$\frac{gantry\_crane\_heigth - external\_truck\_heigth}{hoisting\_speed\_full} \qquad \text{Eq. (2-44)}$$

As the next step, the empty crane will move up and wait at its parking place:

$$\frac{gantry\_crane\_heigth - external\_truck\_heigth}{hoisting\_speed\_empty} \qquad \text{Eq. (2-45)}$$

Lastly, the external truck will head for the gate with the container:

$$\frac{Dis\tan ce\ (block10,\ gate)}{external\ truck\ speed} + \frac{Dis\tan ce\_between\_stacks * (dist(block10 - block\_container))}{external\_truck\_speed}$$

Eq. (2-46)

2.3.2.3. Reshuffling

If there are containers above the container to be retrieved, reshuffling moves will be necessary. Time needed for such moves are calculated as follows. First the gantry crane will reach for the container that will be moved:

$$\frac{gantry\_crane\_heigth-(container\_heigth*tier)}{hoisting\_speed\_full} \qquad \text{Eq. (2-47)}$$

In Eq. 2-46 “tier” is the tier of the container to be reshuffled. Next, the picked up container will be placed on the next column. For that, the gantry crane will move sideways:

$$\frac{container\_width}{trolley\_speed} \qquad \text{Eq. (2-48)}$$

Then, it will move down to drop the container. “m” stands for the number of containers in the column that is used as a temporary storage location for the container to be reshuffled.

$$\frac{gantry\_crane\_heigth-(m*container\_heigth)}{hoisting\_speed\_full} \qquad \text{Eq. (2-49)}$$

The empty gantry crane will now move up:

$$\frac{gantry\_crane\_heigth-(m*container\_heigth)}{hoisting\_speed\_empty} \qquad \text{Eq. (2-50)}$$

The operations stated above are repeated until there is no container left above the container to be retrieved. Next, the container in the temporary storage area should be put back to its original column and row. The tier attribute of the container will be altered.

The gantry crane will descend to pick up the container.:

$$\frac{gantry\_crane\_heigth-(m*container\_heigth)}{hoisting\_speed\_empty} \qquad \text{Eq. (2-51)}$$

The container will be lifted up:

$$\frac{gantry\_crane\_heigth-(m*container\_heigth)}{hoisting\_speed\_full} \qquad \text{Eq. (2-52)}$$

Then it will be moved sideways to its original column:

$$\frac{container\_width}{trolley\_speed} \qquad \text{Eq. (2-53)}$$

Finally, it will be placed to its original row and column with the altered tier:

$$\frac{gantry\_crane\_heigth-(container\_heigth*tier)}{hoisting\_speed\_full} \qquad \text{Eq. (2-54)}$$

2.4 THE INTEGRATION OF BERT-CRANE ALLOCATION AND CONTAINER HANDLING OPERATIONS

The aim of this study is to reestablish the major decision making policies in a container terminal to decrease vessel service times and increase import container handling capacity. Formerly the processes on the terminal are split as quayside operations and container handling operations on the yard side. Despite such categorization, upgrading on both groups are compulsory for achieving such improvement and enhancements.

With the SBCAM approach, an optimal berth-crane allocation plan that will minimize the total servicing time for the arrived vessels is investigated. However, without a smooth flow of container traffic within the yard, the results from the first part may not be meaningful. Quay crane stations may be overflowed with containers waiting to be moved to its storage yards. As stated initially, all activities are closely interrelated and decisions made in one stage affects the other. With this in mind, the CHSIM model is developed. The focus is on the discovery of appropriate storage policies that will improve the performance of the import container handling process. Use of a simulation technique in this part enables the model to be evaluated under different traffic scenarios and container arrival patterns.

Port managers may use the two models, for more accurate and rational decisions. The simultaneous berth and crane allocation model may be used as an analytical decision making tool at the operational level. The weekly arrival plans may be used as an input to the model. The output, berth and crane assignments may be used for daily operations.

On the other hand, the container handling simulation model may be used as a support tool for tactical and strategic level decisions. The output traffic data of the SBCAM approach may be used as an input to the CHSIM model to give insights to the dynamics of the import area functions, determine storage policies for settled terminal configurations and assess equipment utilizations.

CHAPTER 3

APPLICATION OF SBCAM AND CHSIM MODELS IN THE PORT OF IZMIR

In this chapter, a comprehensive depiction of the Port of Izmir with its container traffic data, significance and physical characteristics will be given first. Next, the application and the findings of the experiments regarding SBCAM and CHSIM models will be presented separately. Integration of the results will be discussed in the last section of this chapter.

3.1. PORT OF IZMIR

In 1970s, due to the Lebanon civil conflict, and the war between Iraq and Iran, Middle East lost its position as the transit transportation center. Looking for optional routes, container liners headed for the ports of Syria, Jordon, and Turkey. As the conjecture was favorable for Turkey, container liners chose to take benefit from the potential of the nation. Hence, beginning from the second half of 1970s, Turkey substantially increased its share in the container transportation market.

Containers have begun to be used first in Iskenderun, Mersin and Izmir ports. Today, Port of Izmir is the most important container terminal in Turkey. 826.645 TEUs in 2009 were handled (See Table 3-1). Approximately half of this container traffic is inbound, with 172,996 TEU full and 156,618 TEU empty containers for unloading (Turkish State Railways 2009).

With an 11-15 % increase in traffic each year, the port has been continually growing due to its geographical advantages and closeness to international sea lanes. Facing the Aegean Sea, the port is situated at a pivotal point of sea trade between Europe, Black sea countries and North America, and thus plays a substantial role as the core of agriculture and industrial trade in the Mediterranean region. Further, the Port of Izmir has a vital function in terms of Turkish exports due to its vast agricultural and industrial hinterland. According to

Table 3-1: Annual container traffic

		CONTAINER TRAFFIC									
		(LOADING)				(UNLOADING)					
PORTS	YEARS	20		40		20		40		TOTAL UNIT	TEU
		FULL	EMPTY	FULL	EMPTY	FULL	EMPTY	FULL	EMPTY		
IZMIR	2002	114,177	4,962	85,855	3,476	32,997	74,469	40,497	43,475	399,908	573,211
	2003	130,341	4,625	104,417	4,728	38,577	92,790	51,983	56,103	483,564	700,795
	2004	147,126	12,099	112,933	8,901	53,966	104,640	66,816	54,716	561,197	804,563
	2005	152,624	3,358	111,466	8,605	49,861	104,216	66,759	50,329	547,218	784,377
	2006	154,538	6,168	124,258	7,625	58,614	99,156	73,742	59,100	583,201	847,926
	2007	172,999	6,322	123,322	10,638	65,177	112,137	73,427	63,404	627,426	898,217
	2008	184,020	4,008	119,075	11,287	63,030	125,158	68,854	55,129	630,561	884,906
	2009	173,845	4,328	109,829	9,280	42,084	122,724	65,456	57,267	584,813	826,645
Total	2002	185,373	22,642	163,809	25,469	103,642	98,620	123,983	63,014	786,552	1,162,827
	2003	221,177	23,407	191,156	38,413	116,180	127,670	156,633	77,608	952,244	1,416,054
	2004	243,279	34,763	213,117	57,155	143,471	140,007	205,401	71,915	1,109,108	1,656,696
	2005	264,416	30,208	215,432	67,166	157,274	142,671	215,070	65,970	1,158,207	1,721,845
	2006	281,717	48,656	230,645	72,224	186,957	148,287	236,871	73,653	1,279,010	1,892,403
	2007	225,413	49,107	183,183	56,405	156,342	126,309	175,630	70,264	1,042,653	1,528,135
	2008	208,129	40,520	152,480	35,314	128,649	127,403	119,286	61,394	873,175	1,241,649
	2009	188,010	23,367	125,542	23,150	76,329	126,075	90,701	60,972	714,146	1,014,511

the data supplied by Turkish Statistical Institute, 80% of the total exports, 91% of the total imports and 88% as a whole is transported via sea.

Currently, the container traffic of the Port of Izmir has exceeded its capacity of 800.000 TEU. Together with the other ports total capacity of the country is about 3.5 million TEUs. In 2007, more than 3.6 million TEUs were handled, alerting the inadequate capacity problem in Turkey. In Europe, annual capacity is projected by assuming 1 TEU for each 10 citizen. Then, with a 70 million population, a capacity of at least 7 million TEUs should be achieved. (Arkas L. 2005)

Four Mediterranean ports are positioned in the world top 50 ranking list of the top world ports in terms of total TEUs handled in 2006. Facing the Strait of Gibraltar, the leading port the Mediterranean Sea is the Algeciras Port with 3.257.000 TEUs. The other three in the list are Gioia Tauro in Italy and Valencia along with Barcelona in Spain. Piraeus in Greece with 1.403.408 TEU, Haifa in Syria with 1.078.000 TEU and Marseilles in France with 941.400 TEUs are other important ports of the Mediterranean Sea. The records imply potential container traffic anticipated for a port.

Figure 3-1: Satellite image of major ports in Europe and Mediterranean

The satellite image in Figure 3-1 locates the major ports in Europe and the Mediterranean Sea. About 10 per cent of global seaborne trade passes through the Suez Canal. Approximately 60% of this route is from the south to the East Mediterranean (AREMTS 2007). In this background, by means of its geographical advantage and closeness to international sea lanes, the potential of the Port of Izmir is remarkable. However, insufficient capacity problem is observed in the port mainly due to technical and managerial problems. Hence, the waiting times of the vessels (before they start getting service from the port) are considerably high. Table 3-2 displays container waiting times between June 2007 and March 2008 adapted from Izmir Chamber of Maritime Statistics. The records emphasize the severity of the problem. Half of the incoming ships have waited more than a day to get service from the harbor. 20% of them have waited between 3 and 23 hours. Related to these long waiting times of the vessels, Port of Izmir has started to lose its importance compared to past decades. Due to inadequate service, vessels are forced to use the Port of Piraeus in Greece, which causes about 200 million dollars loss in revenues each year (Milliyet, 2006). Besides this opportunity cost, the congestion problem puts burden exporters by forcing them to pay a congestion fee varying between $25 and $125 per container according to the container size and the destination port. Since 2004, approximately an extra $350 million have peen paid as congestion fee by the exporters to the ship-owners. Moreover, the roughly daily waiting cost for each vessel varying between $50.000

Table 3-2 Monthly vessel waiting times

Year	Month	0-3 hours	%	3-6 hours	%	6-8 hours	%	9-11 hours	%	11-14 hours	%	15-17 hours	%	18-20 hours	%	21-23 hours	%	1-2 days	%	2-3 days	%	>3 days	%	Total
2007	June	74	56%	14	11%	8	6%	4	3%	3	2%	2	2%	1	1%	0	0%	22	17%	1	1%	3	2%	132
	July	63	47%	12	9%	8	6%	2	1%	3	2%	2	1%	3	2%	0	0%	36	27%	5	4%	1	1%	135
	August	51	38%	11	8%	5	4%	6	4%	7	5%	1	1%	0	0%	1	1%	49	36%	2	1%	3	2%	136
	September	52	44%	14	12%	9	8%	6	5%	5	4%	0	0%	3	3%	0	0%	25	21%	1	1%	2	2%	117
	October	13	11%	0	0%	1	1%	1	1%	0	0%	2	2%	0	0%	0	0%	46	38%	45	37%	14	11%	122
	November	24	20%	4	3%	2	2%	3	2%	3	2%	5	4%	3	2%	1	1%	52	43%	19	16%	6	5%	122
	December	38	28%	11	8%	7	5%	7	5%	2	1%	4	3%	1	1%	0	0%	62	45%	5	4%	0	0%	137
2008	January	66	52%	7	6%	8	6%	5	4%	3	2%	0	0%	0	0%	0	0%	29	23%	6	5%	3	2%	127
	February	23	20%	2	2%	8	7%	7	6%	5	4%	0	0%	3	3%	1	1%	48	41%	19	16%	0	0%	116
	March	12	9%	4	3%	5	4%	6	5%	8	6%	1	1%	2	2%	0	0%	52	41%	35	28%	2	2%	127
		416	**32%**	**79**	**6%**	**61**	**5%**	**47**	**4%**	**39**	**3%**	**17**	**1%**	**16**	**1%**	**3**	**0%**	**421**	**33%**	**138**	**11%**	**34**	**3%**	**1271**

and $100.000 according to the ship size may further be added to the costs incurred by the congestion problem (Denizhaber, 2008).

Apart from the operational problems dictated above there is also the depth problem. Inadequacy of water depth disables the port from accommodating third generation container vessels. It is estimated that dredging the port deeper to accept the larger ships would cost approximately US$53 million dollars (Akarsu et al. 2002).

City of Izmir is situated in the western coast by the Aegean Sea. With its favorable climate, fertile soils, rich mineral resources and suitable geographical assets Izmir has always been an important port city. The restructuring of the port in the city will ensure its continuing importance into the 21st century.

The port of the city has a vast agricultural and industrial hinterland. It is the port for the Aegean Region's industry and agriculture playing a vital function in the country's exports. According to the data supplied by Turkish Statistical Institute, 90% of the region’s exports and a third of the total country exports is transported via the Port of Izmir. It has superb road connections to its natural and extended hinterland, and appears to be a logical hub port choice. The duration to the airport is 25 minutes and to several important industrial zones is between 10 to 30 minutes. The port is also connected with the state railway network.

Figure 3-2: Port of Izmir

Port of Izmir is operated by General Directorate of Turkish State Railways since 1989. With an area of 902.000 m2, it is the third largest port of Turkey and has the best natural harbor. (see Figure 2-2) There are 24 berths with a total quay length of 3.319 m and a water depth of 10-13 m. This port renders services to passenger ships and cargo and container ships with dry and liquid cargo. Table 3-3 displays berth lengths, depths and cargo types and Figure 3-3 illustrates the terminal and the berth assignments.

Table 3-3: Berth lengths, depths and cargo types

Berth No	**Cargo Handled**	**Length(m)**	**Depth(m)**
1	Passenger	140	8
2	Passenger	190	8.5
3	Dry Bulk, Ro-Ro	150	10.5
4	General Cargo	120	10.5
5	General Cargo	150	10.5
6	General Cargo	75	10.5
7	General Cargo	130	10
8	General Cargo	120	9.5
9	General Cargo	122	9.5
10	General Cargo	126	6.8
11	General Cargo	97	7.5
12	General Cargo	125	8
13	Container	150	13
14	Container	144	13
15	Container	144	13
16	Container	162	13
17	Container, Ro-Ro	150	13
18	Container, Ro-Ro	150	10
19	Container, Ro-Ro	150	10
20	General Cargo	130	10
21	General Cargo	150	10
22	General Cargo	120	10
23	Dry Bulk	220	10
24	Dry Bulk	205	10

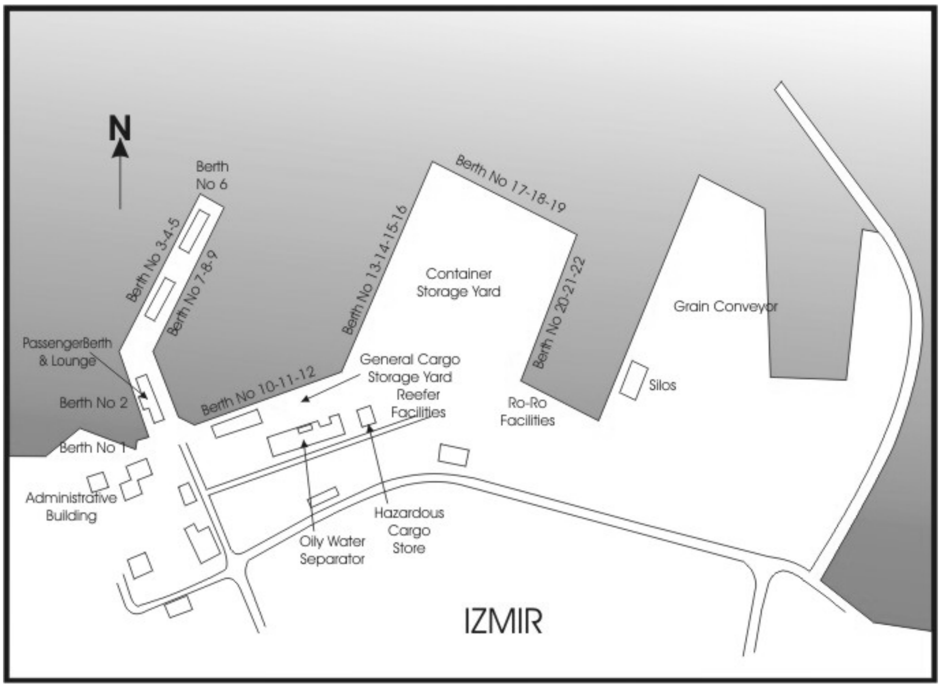


Figure 3-3: Terminal and the berth assignments.

Two reinforced concrete grain silos belonging to Turkish Grain Board (TMO) of having a total 76.000 tons capacity are available for bulk cargo and there is a conveyor system connection with the quay.

The berths and the yard behind are equipped with the following handling facilities:

Table 3-4: Handling and stacking equipment

Equipment	**Quantity**	**Capacity(tons)**
Rubber tired Transtainers	19	35
Empty container forklifts	14	8
	2	12
	4	10
Reach stackers	16	40
	3	42
	1	25
Tug masters	34	50
Container quayside cranes	5	50
Container mobile quayside cranes	2	100
Mobile cranes	9	10
	1	25
	2	6
Floating crane	1	90
Shore cranes	2	3
	3	5
	1	10
	1	15
Standard masted forklifts	4	5
	1	3
Small masted forklifts	10	3
	6	2
	3	2

Vessel loading and unloading at the berths are carried out by seven quay cranes (Fig 3-4).

Fig 3-4: A quay crane at the Port of Izmir

Container operations at the quays are handled by 10 gantry cranes of 40 tons capacity. The operations at the container yard are carried out by 19 rubber tired transtainers and 21 reach stackers of 40 tons capacity, together with 28 containers forklifts of up to 42 tons capacity. Reefer facilities for refrigerated containers are also available (Figure 3-5).

Storage facilities of the port consist of 215.940 sqm. open and 26.978 sqm. covered areas including a hazardous cargo warehouse.

Figure 3-5: Reefer facilities

The container terminal alone has 7 berths that have an alongside depth of 13 m. The total length of the berths is 1.050 m. Due to the geographical layout, these berths reside in three separate quays (Figure 3-6). More than one ship is allowed to berth at the quays according to length and crane restrictions. Seven quay cranes (c1, c2, c3, c4, c5, m6, m7) are deployed for loading/unloading containers to/from the vessels. On average a crane can unload 23 containers per hour.

Figure 3-6: Container terminal layout

There are ten blocks dedicated to full import containers in the storage yard area. The dimensions of the block are 245 meters length and 25 meters width. In each block there are 5 columns and 36 rows which results in 1800 cells in the yard. Each cell can be stacked with up to four containers. Therefore, the capacity of the yard is approximately 7200 TEUs.

In the storage area, a gantry crane is assigned to each block. Technical specifications of the gantry cranes are given in Table 3-5.

Table 3-5: Technical specifications of a gantry crane

Trolley speed	1.17 m/s
Driving speed empty	2.17 m/s
Driving speed full	0.5 m/s
Hoisting speed empty	0.67 m/s
Hoisting speed full	0.33 m/s

34 yard trucks serve the quay and gantry cranes with a speed of 6 m/s when empty and 4m/s when full. There is an adjacent lane to each storage block, for the trucks use. Every block has two entrance and exit points. For example, in Figure 3-6, for block 1 these points are denoted as “rtc1d” and “rtc2d”. The trucks may use either of the two according to the applied storage policy. The white lines, in Fig. 3-6, represent a road in the yard, which are bidirectional. Table 3-6, demonstrates the travel distances in meters, where infeasible paths are denoted by an x. With seven

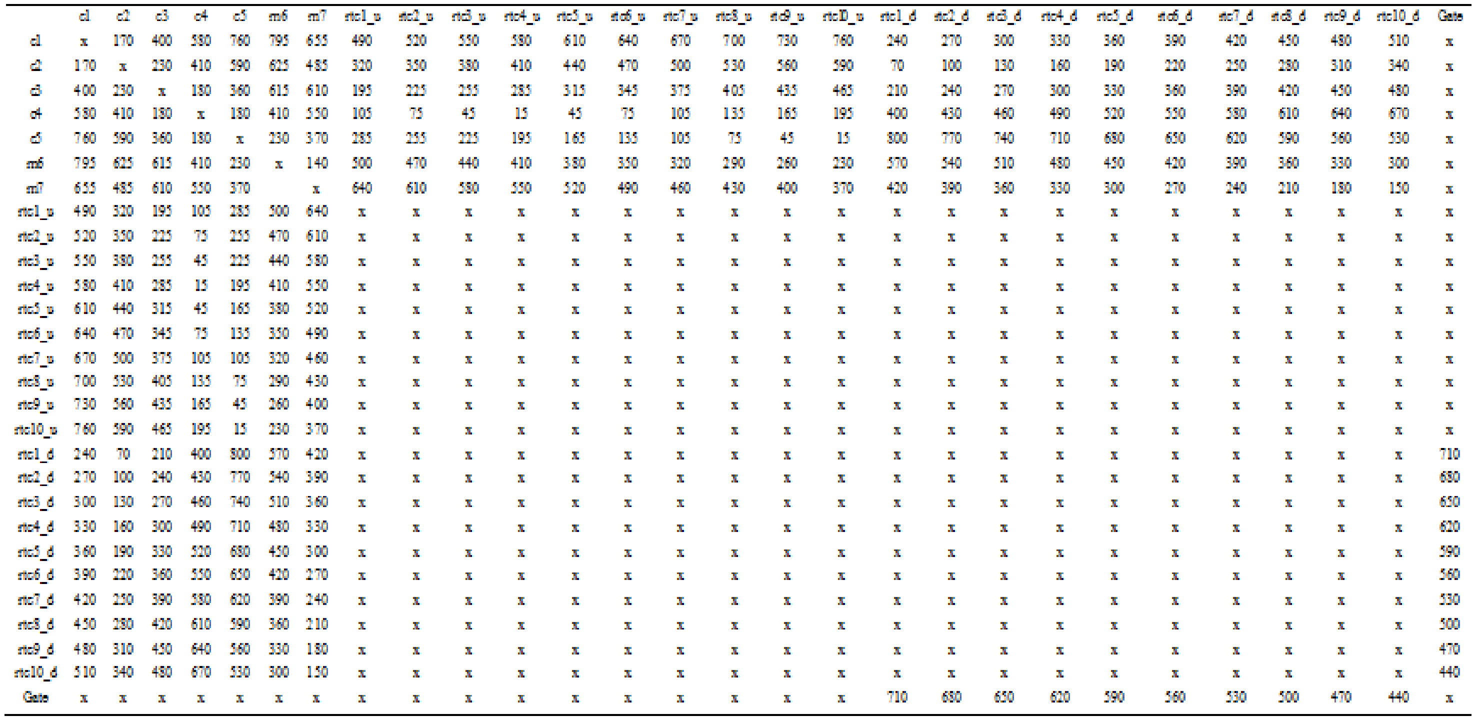
quay cranes and twenty block entrance points transfer distances vary between 15 meters to 800 meters.

It appears that the upgrading of the existing cargo terminal is of great importance and urgency in terms of meeting the ever-increasing demands of the national as well as international economies. The implementation of the project will lead to the creation of employment, development of qualified labor force and expansion of trade volume in the Aegean Region.

3.2. SBCAM EXPERIMENTS AND ANALYSIS

The SBCAM model presented previously is implemented at the container terminal of the Port of Izmir. Through the model, the allocation of berths and cranes to the incoming vessels is optimized simultaneously. Recall that, the port is the busiest container port of the country with unacceptably long waiting times (Table 3-2). On average, half of the incoming ships wait more than a day before starting to get service from the harbor. The berthing time at the quays while being serviced is added to the waiting time of the vessels. Consequently, this study will try to decrease the total time a ship spends at the port, starting from the arrival of the vessel to the port.

Table 3-6 Distances in the terminal



	c1	c2	c3	c4	c5	m6	m7	rtc1_u	rtc2_u	rtc3_u	rtc4_u	rtc5_u	rtc6_u	rtc7_u	rtc8_u	rtc9_u	rtc10_u	rtc1_d	rtc2_d	rtc3_d	rtc4_d	rtc5_d	rtc6_d	rtc7_d	rtc8_d	rtc9_d	rtc10_d	Gate
c1	x	170	400	580	760	795	655	490	520	550	580	610	640	670	700	730	760	240	270	300	330	360	390	420	450	480	510	x
c2	170	x	230	410	590	625	485	320	350	380	410	440	470	500	530	560	590	70	100	130	160	190	220	250	280	310	340	x
c3	400	230	x	180	360	615	610	195	225	255	285	315	345	375	405	435	465	210	240	270	300	330	360	390	420	450	480	x
c4	580	410	180	x	180	410	550	105	75	45	15	45	75	105	135	165	195	400	430	460	490	520	550	580	610	640	670	x
c5	760	590	360	180	x	230	370	285	255	225	195	165	135	105	75	45	15	800	770	740	710	680	650	620	590	560	530	x
m6	795	625	615	410	230	x	140	500	470	440	410	380	350	320	290	260	230	570	540	510	480	450	420	390	360	330	300	x
m7	655	485	610	550	370		x	640	610	580	550	520	490	460	430	400	370	420	390	360	330	300	270	240	210	180	150	x
rtc1_u	490	320	195	105	285	500	640	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc2_u	520	350	225	75	255	470	610	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc3_u	550	380	255	45	225	440	580	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc4_u	580	410	285	15	195	410	550	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc5_u	610	440	315	45	165	380	520	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc6_u	640	470	345	75	135	350	490	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc7_u	670	500	375	105	105	320	460	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc8_u	700	530	405	135	75	290	430	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc9_u	730	560	435	165	45	260	400	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc10_u	760	590	465	195	15	230	370	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
rtc1_d	240	70	210	400	800	570	420	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	710
rtc2_d	270	100	240	430	770	540	390	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	680
rtc3_d	300	130	270	460	740	510	360	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	650
rtc4_d	330	160	300	490	710	480	330	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	620
rtc5_d	360	190	330	520	680	450	300	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	590
rtc6_d	390	220	360	550	650	420	270	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	560
rtc7_d	420	250	390	580	620	390	240	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	530
rtc8_d	450	280	420	610	590	360	210	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	500
rtc9_d	480	310	450	640	560	330	180	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	470
rtc10_d	510	340	480	670	530	300	150	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	440
Gate	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	710	680	650	620	590	560	530	500	470	440	x

In Figure 3-3, the layout of the whole port is illustrated. The berths dedicated to the container terminal are numbered from 13 to 22. Figure 3-7 focuses on the container terminal. As anticipated from the partitioning of the quays into 10 berths, the current berth structure is discrete. As stated in the previous sections, this structure generally leads to the inefficient utilization of the quay area. To overcome this drawback, despite the complexity downside, the partitioning of the quays will be eliminated in the solution.

Looking at Figure 3-7, one can notice the unusual layout of the terminal. This rectangular shape brings another challenge in modeling since it does not allow linearization. The cranes numbered through c1 to c5 and m6 to m7 depict the quay cranes, the last two of which are mobile. While quay dependent cranes can only be used along the quay they are positioned, the mobile cranes can serve all the quays, which again add to the complexity of the model.

The model is coded in GAMS 22.5 with BARON solver. The computational experimentation is conducted on a 1.7 GHz, 512 MB RAM computer.

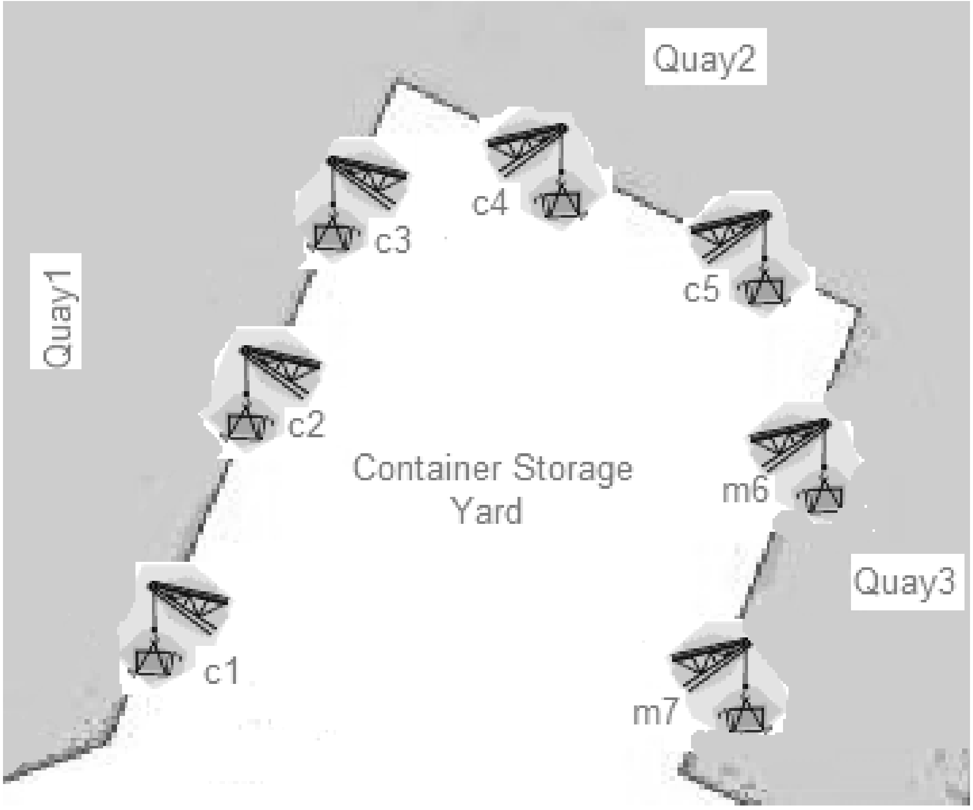


Figure 3-7. The Container Storage Yard and the Quays used in the model.

For the input data, a weekly schedule of the Port of Izmir is considered. The period considered in performance evaluations of the model is through March 1st to March 7th 2008. However, it has been observed that on the first day of March there are still vessels waiting in queue arrived on previous days. Moreover, at the end of the experimentation period there may be unhandled vessels. In that case, their service will be postponed to the days after 7th of March. Vessels arriving on those days must also be taken account for realistic evaluation. Therefore, to consider these circumstances, data compromising a period of 9 days is required. Table 3-7 shows the arrival data of the terminal for 9 days.

For each incoming vessel, the table includes information as to the name of the vessel, number of containers (NC) to be loaded or unloaded, the length of the vessel, and the arrival day and time to the Izmir Bay. The lengths of the three quays and crane performances are other inputs to the model. Quay 1 has a length of 600 m, quay 2 is 450 m. and quay 3 is 280 meters long. On average a crane can unload 23 containers per hour.

To avoid the expansion of the model size, a 24-hour day is represented by 8 equal time intervals. All the times in Table 3-7 are converted accordingly. Table 3-8 illustrates the time scale used for modeling the problem for the whole days. On the left side of the timing intervals, the vessels arrived at the corresponding time period are shown. For instance "MSCAdriana" has arrived at day 29-Feb-2008 at 20:30. This will correspond to the seventh time period. Another vessel Neptun' s arrival is on the next day morning at 7:00 am. According to the time scale, the vessel has arrived at the third time period of the next day. Three vessels have arrived together on that time period.

Table 3-7: Vessel schedule covering 9 days

Vessel Name	NC	Length (m)	Arrival day	Arrival time
Marcommander	490	151	29.Feb.08	13:45
Maersk Newark	210	211	29.Feb.08	14:45
MSCAdriana	630	216	29.Feb.08	20:30
Neptun	280	118	01.Mar.08	07:00
MRSTrapani	420	161	01.Mar.08	08:15
HMSLaurence	840	165	01.Mar.08	08:45
Windward	420	170	01.Mar.08	13:45
KpErgun	210	149	01.Mar.08	16:00
VentoDiBora	350	155	01.Mar.08	22:30
OrkunK	350	149	02.Mar.08	05:45
WandaA	420	122	02.Mar.08	08:00
Catania	70	107	02.Mar.08	14:10
MaerskBrisbane	420	240	03.Mar.08	04:45
GrandWiew	770	225	03.Mar.08	10:50
YMOcean	490	210	03.Mar.08	11:10
MSCEugenia	2170	275	03.Mar.08	19:30
Rousse	420	157	03.Mar.08	21:00
EurusStockholm	490	192	03.Mar.08	16:10
IremKalkavan	210	149	04.Mar.08	05:45
Liguria	350	157	04.Mar.08	19:15
MSC Damla	560	258	04.Mar.08	21:30
MSC Elena	560	202	04.Mar.08	21:50
Adele-C	140	107	05.Mar.08	03:30
Contaz Ankara	280	156	05.Mar.08	08:00

Table 3-7(continued): Vessel schedule covering 9 days

Vessel Name	NC	Length (m)	Arrival day	Arrival time
Aleko Konstantinov	140	160	05.Mar.08	08:30
Santa Monica	560	182	05.Mar.08	21:30
Serap-K	210	149	05.Mar.08	22:00
İtal Verde	350	151	06.Mar.08	07:40
Erkut-A	70	122	06.Mar.08	10:45
MSC Sarah	910	295	06.Mar.08	19:30
Merkür	350	159	07.Mar.08	06:00
Britain Star	350	157	07.Mar.08	07:15
King Byron	350	178	07.Mar.08	10:10
MSC Caitlin	350	215	07.Mar.08	11:15
Glenmoon	350	130	07.Mar.08	22:30
Tomriz-A	420	168	07.Mar.08	23:00
Alkın Kalkavan	700	149	07.Mar.08	22:45
Besire Kalkavan	280	149	08.Mar.08	08:00
Bella-I	560	240	08.Mar.08	12:15
Nessebar	140	150	08.Mar.08	16:30
MSC Adele	1400	188	08.Mar.08	19:43

Table 3-8. Time scale used for modeling the problem.

					t
			29 Feb		
			00:00	03:00	1
			03:00	06:00	2
			06:00	09:00	3
			09:00	12:00	4
	Maersk Newark	Marcommander	12:00	15:00	5
			15:00	18:00	6
		MSC Adriana	18:00	21:00	7
			21:00	24:00:00	8
			01.Mar		
			00:00	03:00	1
			03:00	06:00	2
HMS Laurence	Maersk Trapani	Neptün	06:00	09:00	3
			09:00	12:00	4
		Windward	12:00	15:00	5
		KpErgun	15:00	18:00	6
			18:00	21:00	7
		VentoDiBora	21:00	24:00:00	8
			02.Mar		
			00:00	03:00	1
		OrkunK	03:00	06:00	2
		WandaA	06:00	09:00	3
			09:00	12:00	4
		Catania	12:00	15:00	5
			15:00	18:00	6
			18:00	21:00	7
			21:00	24:00:00	8

Table 3-8 (continued). Time scale used for modeling the problem.

				t
		03.Mar		
		00:00	03:00	1
	MaerskBrisbane	03:00	06:00	2
		06:00	09:00	3
YMOcean	GrandWiew	09:00	12:00	4
		12:00	15:00	5
	Eurus Stockholm	15:00	18:00	6
Rousse	MSCEugenia	18:00	21:00	7
		21:00	24:00:00	8
		04.Mar		
		00:00	03:00	1
	IremKalkavan	03:00	06:00	2
		06:00	09:00	3
		09:00	12:00	4
		12:00	15:00	5
		15:00	18:00	6
	Liguria	18:00	21:00	7
MSC Damla	MSC Elena	21:00	24:00:00	8
		05.Mar		
		00:00	03:00	1
	Adele-C	03:00	06:00	2
Aleko Konstantinov	Contaz Ankara	06:00	09:00	3
		09:00	12:00	4
		12:00	15:00	5
		15:00	18:00	6
		18:00	21:00	7
Serap-K	Santa Monica 560	21:00	24:00:00	8

Table 3-8 (continued). Time scale used for modeling the problem.

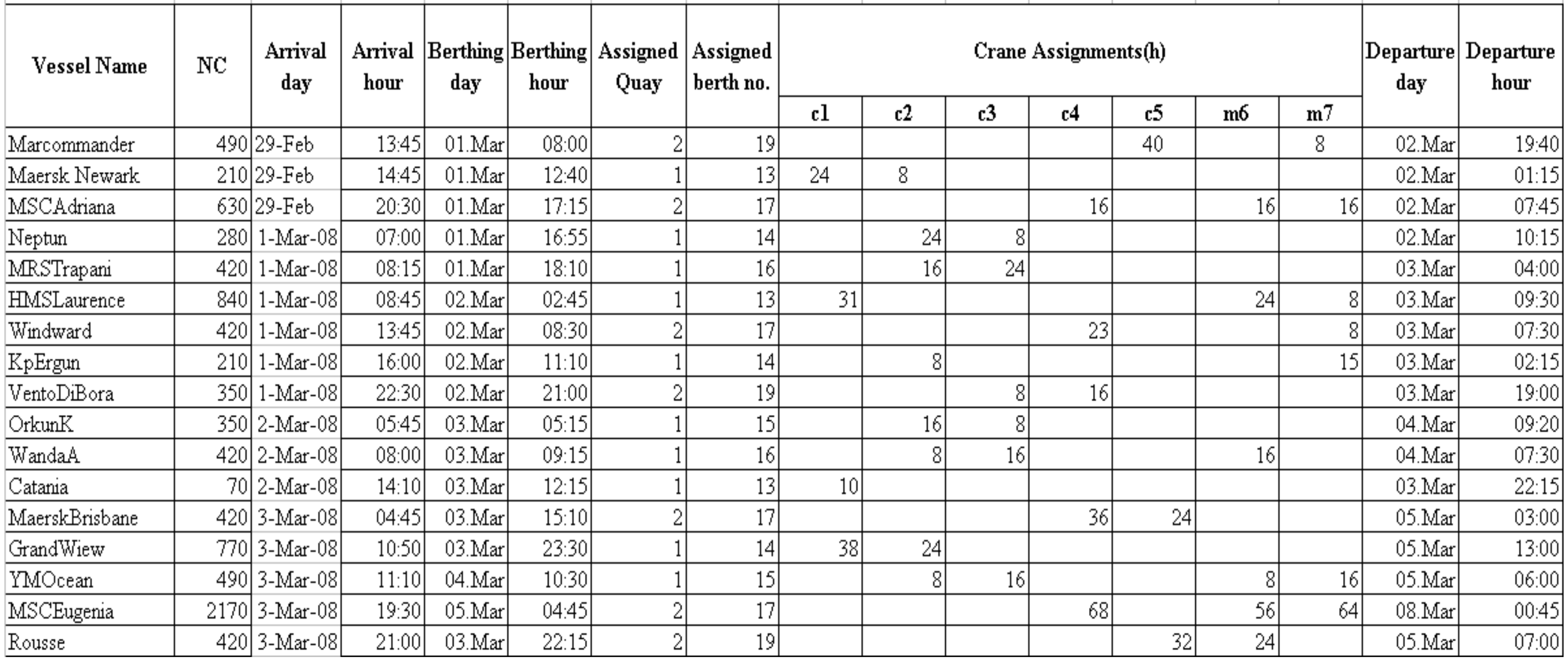
					t
			06.Mar		
			00:00	03:00	1
			03:00	06:00	2
		İtal Verde	06:00	09:00	3
		Erkut-A	09:00	12:00	4
			12:00	15:00	5
			15:00	18:00	6
		MSC Sarah	18:00	21:00	7
			21:00	24:00:00	8
			07.Mar		
			00:00	03:00	1
		Merkür	03:00	06:00	2
		Britain Star	06:00	09:00	3
	MSC Caitlin	King Byron	09:00	12:00	4
			12:00	15:00	5
			15:00	18:00	6
			18:00	21:00	7
Glenmoon	Alkın Kalkavan	Tomriz-A	21:00	24:00:00	8
			08.Mar		
			00:00	03:00	1
			03:00	06:00	2
		Besire Kalkavan	06:00	09:00	3
			09:00	12:00	4
		Bella-I	12:00	15:00	5
		Nessebar	15:00	18:00	6
		MSC Adele	18:00	21:00	7
			21:00	24:00:00	8

First, the real performance statistics of the port at the considered week will be represented. Then, the proposed model's performance figures will be presented and the two results will be compared.

Table 3-9 contains the actual weekly records. The table shows the number of containers (NC), arrival day/ hour, berthing day/ hour, assigned quay number and berth number, crane assignments and crane working hours and departure day/ hour for each vessel. For instance the vessel "MSC Adriana" with 630 containers on it, have arrived on 29th of February on 20:30. It has waited till the next day first of March to be berthed. At 17:15, the vessel is berthed at the berthing position 17 on Quay 2. Cranes c4, m6 and m7 have been dedicated to the vessel for 16 hours each. The loading and unloading processes have been completed on the next day 2nd of March at 7:45 and the vessel has departed.

For the actual data, performance indicators such as average waiting time, the duration berthed and total time in the system are presented in Table 3-10. Note that, vessels arriving before 1st of March and after 7th of March are not included in the performance evaluations. The waiting time is defined as the time a vessel spends in the bay before being berthed; i.e. the berthing time minus the arrival time. Duration berthed is the time vessel spends at the port. Total time in the system is the difference between the departure time and the arrival time of a vessel..

Table 3-9 Actual weekly records



Vessel Name	NC	Arrival day	Arrival hour	Berthing day	Berthing hour	Assigned Quay	Assigned berth no.	Crane Assignments(h)							Departure day	Departure hour
								c1	c2	c3	c4	c5	m6	m7		
Marcommander	490	29-Feb	13:45	01.Mar	08:00	2	19					40		8	02.Mar	19:40
Maersk Newark	210	29-Feb	14:45	01.Mar	12:40	1	13	24	8						02.Mar	01:15
MSCAdriana	630	29-Feb	20:30	01.Mar	17:15	2	17				16		16	16	02.Mar	07:45
Neptun	280	1-Mar-08	07:00	01.Mar	16:55	1	14		24	8					02.Mar	10:15
MRSTrapani	420	1-Mar-08	08:15	01.Mar	18:10	1	16		16	24					03.Mar	04:00
HMSLaurence	840	1-Mar-08	08:45	02.Mar	02:45	1	13	31					24	8	03.Mar	09:30
Windward	420	1-Mar-08	13:45	02.Mar	08:30	2	17				23			8	03.Mar	07:30
KpErgun	210	1-Mar-08	16:00	02.Mar	11:10	1	14		8					15	03.Mar	02:15
VentoDiBora	350	1-Mar-08	22:30	02.Mar	21:00	2	19			8	16				03.Mar	19:00
OrkunK	350	2-Mar-08	05:45	03.Mar	05:15	1	15		16	8					04.Mar	09:20
WandaA	420	2-Mar-08	08:00	03.Mar	09:15	1	16		8	16			16		04.Mar	07:30
Catania	70	2-Mar-08	14:10	03.Mar	12:15	1	13	10							03.Mar	22:15
MaerskBrisbane	420	3-Mar-08	04:45	03.Mar	15:10	2	17				36	24			05.Mar	03:00
GrandWiew	770	3-Mar-08	10:50	03.Mar	23:30	1	14	38	24						05.Mar	13:00
YMOcean	490	3-Mar-08	11:10	04.Mar	10:30	1	15		8	16			8	16	05.Mar	06:00
MSCEugenia	2170	3-Mar-08	19:30	05.Mar	04:45	2	17				68		56	64	08.Mar	00:45
Rousse	420	3-Mar-08	21:00	03.Mar	22:15	2	19					32	24		05.Mar	07:00

Table 3-9 (continued): Actual weekly records

Vessel Name	NC	Arrival day	Arrival hour	Berthing day	Berthing hour	Assigned Quay	Assigned berth no.	Crane Assignments(h)							Departure day	Departure hour
								c1	c2	c3	c4	c5	m6	m7		
EurusStockholm	490	3-Mar-08	16:10	03.Mar	16:10	3	20						16	24	04.Mar	16:45
IremKalkavan	210	4-Mar-08	05:45	05.Mar	06:55	1	16			15					05.Mar	22:15
Liguria	350	4-Mar-08	19:15	05.Mar	13:45	1	15		22						06.Mar	11:40
MSC Damla	560	4-Mar-08	21:30	07.Mar	12:10	1	14	24	16				24	16	08.Mar	17:15
MSC Elena	560	4-Mar-08	21:50	05.Mar	15:30	1	13	48	24						07.Mar	10:30
Adele-C	140	5-Mar-08	03:30	05.Mar	08:15	2	19					11			05.Mar	19:00
Contaz Ankara	280	5-Mar-08	08:00	05.Mar	20:50	2	19					23			06.Mar	19:30
Aleko Konstantinov	140	5-Mar-08	08:30	06.Mar	14:45	1	15	8	14	8					07.Mar	03:30
Santa Monica	560	5-Mar-08	21:30	07.Mar	08:35	1	15		24	26					08.Mar	10:00
Serap-K	210	5-Mar-08	22:00	05.Mar	23:30	1	16		8	22					06.Mar	20:40
İtal Verde	350	6-Mar-08	07:40	06.Mar	20:40	2	19				8	8			07.Mar	23:30
Erkut-A	70	6-Mar-08	10:45	06.Mar	21:40	1	16			10					07.Mar	07:30
MSC Sarah	910	6-Mar-08	19:30	08.Mar	18:30	1	13	32	24				8	24	10.Mar	02:30
Merkür	350	7-Mar-08	06:00	08.Mar	00:45	2	19				8	22			08.Mar	22:30
Britain Star	350	7-Mar-08	07:15	08.Mar	11:00	2	19		8	13					09.Mar	00:10
King Byron	350	7-Mar-08	10:10	08.Mar	18:00	2	17				13				09.Mar	07:20
MSC Caitlin	350	7-Mar-08	11:15	08.Mar	02:30	2	17				15		8	8	08.Mar	17:00
Glenmoon	350	7-Mar-08	22:30	08.Mar	23:40	2	19					23			09.Mar	23:00
Tomriz-A	420	7-Mar-08	23:00	09.Mar	07:15	3	20						24	16	10.Mar	07:50
Alkın Kalkavan	700	7-Mar-08	22:45	09.Mar	01:00	1	16			45					10.Mar	22:30
Besire Kalkavan	280	8-Mar-08	08:00	09.Mar	08:20	1	17				16				10.Mar	00:30
Bella-I	560	8-Mar-08	12:15	10.Mar	00:00	2	19				8	39			11.Mar	14:30
Nessebar	140	8-Mar-08	16:30	10.Mar	03:30	1	15		12						10.Mar	15:50
MSC Adele	560	8-Mar-08	19:43	10.Mar	01:20	1	17				15		8	8	10.Mar	16:00

For instance, “Neptun” has waited for 10 hours before being berthed Another 17 hours have passed during the loading and unloading operations, the total time in system to be equal to 27 hours. The average waiting time of the vessels for a week has been realized as 20.09 hours, whereas the duration berthed is 25.03 hours. It can be noticed that the waiting times are again very long, parallel to the yearly average statistic data given in Table 3-2.

Now, the outputs of the proposed solution model will be exhibited. In Table 3-11, the model outcomes are presented together with the objective function values and CPU times. Vessel name, arrival times, number of containers and length are input parameters, whereas assigned quay number, quay position, berthing time, departure time, crane assignments are outputs corresponding to the decision variables. The column arrival day gives the actual arrival date of the vessel. Adjacent column presents the real arrival hour. The column named as “arrival (model)” shows the arrival period input into the model. The real arrival hour and the model arrival hours might be different is the vessel’s handling can not be started on its arrival day. For instance, “VentoDiBora” has actually arrived on day 01.03.2008 at time interval 8, but it can only be given service on the next day. Therefore, its arrival in the model input is depicted as the first time interval on the next day. The vessels that are postponed to the next day are shown in italic letters in the table.

Table 3-10: Performance indicators for the actual weekly records

Vessel Name	**Waiting time (h)**	**Duration Berthed (h)**	**Total Time in System (h)**
Neptun	10	17	27
MRSTrapani	10	34	44
HMSLaurence	18	31	49
Windward	19	23	42
KpErgun	19	15	34
VentoDiBora	23	22	45
OrkunK	24	28	52
WandaA	25	22	47
Catania	22	10	32
MaerskBrisbane	10	36	46
GrandWiew	13	38	51
YMOcean	23	20	43
MSCEugenia	33	68	101
Rousse	1	33	34
EurusStockholm	0	25	25
IremKalkavan	25	15	40
Liguria	19	22	41
MSC Damla	63	29	92
MSC Elena	18	43	61
Adele-C	5	11	16
Contaz Ankara	13	23	36

Table 3-10 (continued): Performance indicators for the actual weekly records

Vessel Name	**Waiting time (h)**	**Duration Berthed (h)**	**Total Time in System (h)**
Aleko Konstantinov	30	14	44
Santa Monica	34	26	60
Serap-K	2	22	24
İtal Verde	13	27	40
Erkut-A	11	10	21
MSC Sarah	47	32	79
Merkür	19	22	41
Britain Star	28	13	41
King Byron	32	13	45
MSC Caitlin	15	15	30
Glenmoon	25	23	48
Tomriz-A	8	24	32
Alkın Kalkavan	26	45	71
Average	**20.09**	**25.03**	**45.12**

The next column "N(t)" shows the number of containers to be handled on the day. For instance, "VentoDiBora" has 350 containers to be handled on the 2nd of March. It has a length of 155 meters and is berthed at the 77.5th meter of the first quay. The quay position corresponds to the middle point of the vessel. The berthing time interval is the same as its arrival time. Recall that, each time interval corresponds to a period of 3 hours, which means that the vessel has not waited at all, or has waited for maximum 3 hours. As for the crane assignments, at time 1, cranes c1, c2 and c3 have worked together on the vessel. At the second time interval c3 has left working but c1 and c2 continues to work. No crane assignments are realized at the next time periods, this indicates that the unloading and loading operations have been completed and the vessel has departed at time period 2.

Toward testing out the overlapping restrictions, on the first day, it can be seen that there are 8 vessels on total. Of these 8, four of them are positioned on the first quay, three of them on the second quay and one on the third quay. For the vessels, sharing the same quays and the same positions along the quay, there should be no overlapping in time periods, and vice versa. "Marcommander", and "Maersk Newark" are both given service on time 1. However, their berthing positions are different. The first is berthed on quay 1 at the 77.5th meter and the latter is berthed on the second quay at the 105.5th meter.

It can also be observed that a crane is not assigned to more than one vessel at the same time period. For instance at day 1, time interval 6, mobile crane m7 is dedicated to "Windward". On the other hand, "KpErgun" is berthed at quay3 and needs the mobile cranes to get service. But, the vessel can acquire crane m7 only after "Windward", frees it. Accurately, crane m7 is freed by "Windward" and it starts to give service to "KpErgun" just then at time 7.

If a vessel's handling can not be finished at the same day, the remaining containers can be handled on the following day. In this case, the vessel with the left over containers is input into the model on the next day. The vessel is treated together with the next days vessels again with the aim of minimizing the total handling time of all the vessels. For example, "MSC Sarah" takes service on both 6th and 7th of March. 560 containers are handled on the first and the remaining 350 containers are left for the next day. The vessel leaves the port at the second time interval on 7th of March.

Table 3-12 presents the performance measure values calculated in a similar fashion as to that of Table 3-10. Yet again, vessels arriving before 1st of March and after 7th of March are not included.

Table 3-11 : Proposed model outputs

Day	Obj. Func	CPU	Vessel Name	Arrival day	Arrival (real)	Arrival (model)	N(t)	Length (m)	Quay no	Quay Position	Crane Assignments t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8
01.03.2008	17	13:00	*Marcommander*	*29.Şub.08*	*5*	*1*	*490*	*151*	*1*	*77.5*	*c1,c2,m7*	*c1,c3,m7*						
			Maersk Newark	*29.Şub.08*	*5*	*1*	*210*	*211*	*2*	*105.5*	*c4,c5,m6*							
			MSC Adriana	*29.Şub.08*	*7*	*1*	*630*	*216*	*2*	*108*			*c4,c5,m7*	*c4,c5,m6*	*c4,c5,m7*			
			Neptun	01.Mar.08		3	280	118	1	156.7								c1,c3,m6,m7
			MRSTrapani	01.Mar.08		3	420	161	1	80.5						c1,c2,c3	c1,c2,c3	
			HMSLaurence	01.Mar.08		3	840	165	1	82.5			c1,c2,c3,m6	c1,c2,c3,m7	c1,c2,c3,m6			
			Windward	01.Mar.08		5	420	170	2	260						c4,c5,m7	c4,c5	c4
			KpErgun	01.Mar.08		6	210	149	3	74.5						m6	m6,m7	
02.03.2008	7	00:42	*VentoDiBora*	*01.Mar.08*	*8*	*1*	*350*	*155*	*1*	*77.5*	*c1,c2,c3*	*c1,c2*						
			OrkunK	02.Mar.08		2	350	149	2	74.5		c4,c5,m6,m7	c4					
			WandaA	02.Mar.08		3	420	122	1	71.2			c1,c3,m6,m7	c2,c3				
			Catania	02.Mar.08		5	70	107	1	72.9					c1			
03.03.2008	11	05:24	MaerskBrisbane	03.Mar.08		2	420	240	1	129.3		c2,c3,m6	c1,c2,c3					
			GrandWiew	03.Mar.08		4	770	225	1	184.8				c1,c2,c3,m7	c1,c2,c3	c1,c2,c3,m6		
			YMOcean	03.Mar.08		4	490	210	2	105				c4,c5,m6	c4,c5,m6,m7			
			EurusStockholm	03.Mar.08		6	490	192	1	173.6							c1,c2,c3,m6	c1,c3,m7
			Rousse	03.Mar.08		7	420	157	2	83.4							c4,c5,m7	c4,c5,m6
04.03.2008	12	00:09	*MSCEugenia*	*03.Mar.08*	*7*	*1*	*2170*	*275*	*1*	*137.5*	*c1,c2,c3,m6*	*c1,c2,c3,m6*	*c1,c2,c3,m6*	*c1,c2,c3,m6*	*c1,c2,c3,m7*	*c1,c2,c3*	*c1,c2,c3,m7*	*c1,c2,c3,m7*
			IremKalkavan	04.Mar.08		2	210	149	3	74.5					m6	m6,m7		
			Liguria	04.Mar.08		7	350	157	2	78.5							c4,c5	c4,c5,m6

Table 3-11(continued) : Proposed model outputs

Day	Obj. Func	CPU	Vessel Name	Arrival day	Arrival (real)	Arrival (model)	N(t)	Length (m)	Quay no	Quay Position	Crane Assignments t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8
05.03.2008	9	04:04	*MSC Damla*	*04.Mar.08*	*8*	*1*	*560*	*258*	*1*	*160.9*	*c1,c2,c3,m6*	*c1,c2,c3,m6*						
			MSC Elena	*04.Mar.08*	*8*	*1*	*560*	*202*	*2*	*101*	*c4,c5,m7*	*c4,c5,m7*	*c4,c5*					
			Adele-C	05.Mar.08		2	140	107	1	129.4					c1,c2			
			Contaz Ankara	05.Mar.08		3	280	156	1	78			c1,c3,m6,m7					
			Aleko Konstantino	05.Mar.08		3	140	160	1	128				c1,c3				
			Serap-K	05.Mar.08		8	210	149	1	127.5								c2,c3,m7
06.03.2008	7	00:33	*Santa Monica*	*05.Mar.08*	*8*	*1*	*560*	*182*	*1*	*143.3*	*c1,c2,c3,m7*	*c1,c2,c3,m76*						
			İtal Verde	06.Mar.08		3	350	151	1	125.4			c1,c2,c3,m7	c2				
			Erkut-A	06.Mar.08		4	70	122	1	129.7					c1			
			MSC Sarah	06.Mar.08		7	560	295	1	147.5							c1,c2,c3,m6	c1,c2,c3,m7
07.03.2008	12	10:22	*MSC Sarah*	*06.Mar.08*	*7*	*1*	*350*	*295*	*1*	*148.3*	*c1,c2,c3,m6*	*c2*						
			Merkür	07.Mar.08		2	350	159	2	79.5		c4,c5,m6	c4,m7					
			Britain Star	07.Mar.08		3	350	157	1	181.5			c1,c2,c3,m6	c1				
			King Byron	07.Mar.08		4	350	178	1	89					c1,c2,c3	c2,c3		
			MSC Caitlin	07.Mar.08		4	350	215	3	172.5				m6	m6,m7	m6,m7		
			Glenmoon	07.Mar.08		8	280	130	1	148.7								c1,c2,c3,m7
08.03.2008	13	42:36:00	*Glenmoon*	*07.Mar.08*	*8*	*1*	*70*	*130*	*3*	*65*		*m7*						
			Tomriz-A	*07.Mar.08*	*8*	*1*	*420*	*168*	*2*	*84*	*c4,c5,m6,m7*	*c4,c5*						
			Alkın Kalkavan	*07.Mar.08*	*8*	*1*	*700*	*149*	*1*	*74.5*	*c1,c2,c3*	*c1,c2,c3,m6*	*c1,c2,c3*					
			Besire Kalkavan	08.Mar.08		3	280	149	3	191			m6,m7	m6,m7				
			Bella-I	08.Mar.08		5	560	240	1	107.5					c1,c2,c3,m6	c1,c2,c3,m6		
			Nessebar	08.Mar.08		6	140	150	1	74.6							c1,c2	
			MSC Adele	08.Mar.08		7	560	188	2	94							c4,c5,m6,m7	c4,c5,m6,m7

"Neptun" has arrived on 1st of March at time interval 3, and has been berthed at the same day on time interval 8. It has a waiting time between 15 and 18 hours. This column is the difference of berthing time interval and arrival time interval which is 5 for this case. As each time period compromises duration of 3 hours, then it can be said that this vessel has been waited for minimum 15 hours and maximum 18 hours. Duration berthed is calculated in the same fashion, this time calculating the difference between departures and berthing time intervals. It is found as minimum 0 hours and maximum 3 hours for the vessel discussed. Total time in system is simply the summation of the former two values.

The average waiting time of all the vessels throughout the week has been realized as 4.03 hours, whereas the duration berthed is 4.69 hours. Average total time in system is calculated as 8.8 hours.

In Table 3-13, the comparison of the actual data outcomes and the model outputs are presented. For "HMSLaurence" the waiting time of the vessel until being berthed is reduced by 16.5 hours on average, calculated by taking the average of minimum and maximum values in column "waiting time" in Table 3-12 first and then subtracting this value from the waiting time column in Table 3-10. This reduction in waiting hours corresponds to a 91.7% average improvement in the waiting time. The berthing duration for the vessel is reduced by 23.5 hours, with a 75.8% improvement.

Table 3-12: Performance indicators for the model outputs

Vessel Name	Arrival day	Arrival (real)	Berthing day	Berthing time int.	Departure day	Departure time int.	H(I)	Waiting time (h)		Duration Berthed(h)		Total Time(h)	
								min	max	min	max	min	max
Neptun	01.Mar.08	3	01.Mar.08	8	01.Mar.08	8	1	15	18	0	3	15	21
MRSTrapani	01.Mar.08	3	01.Mar.08	6	01.Mar.08	7	2	9	12	3	6	12	18
HMSLaurence	01.Mar.08	3	01.Mar.08	3	01.Mar.08	5	3	0	3	6	9	6	12
Windward	01.Mar.08	5	01.Mar.08	6	01.Mar.08	8	3	3	6	6	9	9	15
KpErgun	01.Mar.08	6	01.Mar.08	6	01.Mar.08	7	2	0	3	3	6	3	9
VentoDiBora	*01.Mar.08*	*8*	02.Mar.08	*1*	02.Mar.08	*2*	*2*	*3*	6	3	6	6	12
OrkunK	02.Mar.08	2	02.Mar.08	2	02.Mar.08	3	2	0	3	3	6	3	9
WandaA	02.Mar.08	3	02.Mar.08	3	02.Mar.08	4	2	0	3	3	6	3	9
Catania	02.Mar.08	5	02.Mar.08	5	02.Mar.08	5	1	0	3	0	3	0	6
MaerskBrisbane	03.Mar.08	2	03.Mar.08	2	03.Mar.08	3	2	0	3	3	6	3	9
GrandWiew	03.Mar.08	4	03.Mar.08	4	03.Mar.08	6	3	0	3	6	9	6	12
YMOcean	03.Mar.08	4	03.Mar.08	4	03.Mar.08	5	2	0	3	3	6	3	9
EurusStockholm	03.Mar.08	6	03.Mar.08	7	03.Mar.08	8	2	3	6	3	6	6	12
Rousse	03.Mar.08	7	03.Mar.08	7	03.Mar.08	8	2	0	3	3	6	3	9
MSCEugenia	*03.Mar.08*	*7*	04.Mar.08	*1*	04.Mar.08	*8*	*8*	*6*	9	21	24	27	33
IremKalkavan	04.Mar.08	2	04.Mar.08	5	04.Mar.08	6	2	9	12	3	6	12	18
Liguria	04.Mar.08	7	04.Mar.08	7	04.Mar.08	8	2	0	3	3	6	3	9
MSC Damla	*04.Mar.08*	*8*	05.Mar.08	*1*	05.Mar.08	*2*	*2*	*3*	6	3	6	6	12

Table 3-12(continued): Performance indicators for the model outputs

Vessel Name	Arrival day	Arrival (real)	Berthing day	Berthing time int.	Departure day	Departure time int.	H(I)	Waiting time (h)		Duration Berthed(h)		Total Time(h)	
								min	max	min	max	min	max
MSC Elena	*04.Mar.08*	*8*	05.Mar.08	*1*	05.Mar.08	*3*	*3*	*3*	6	6	9	9	15
Adele-C	05.Mar.08	2	05.Mar.08	5	05.Mar.08	5	1	9	12	0	3	9	15
Contaz Ankara	05.Mar.08	3	05.Mar.08	3	05.Mar.08	3	1	0	3	0	3	0	6
Aleko Konstantino	05.Mar.08	3	05.Mar.08	4	05.Mar.08	4	1	3	6	0	3	3	9
Serap-K	05.Mar.08	8	05.Mar.08	8	05.Mar.08	8	1	0	3	0	3	0	6
Santa Monica	*05.Mar.08*	*8*	06.Mar.08	*1*	06.Mar.08	*2*	*2*	*3*	6	3	6	6	12
İtal Verde	06.Mar.08	3	06.Mar.08	3	06.Mar.08	3	2	0	3	0	3	0	6
Erkut-A	06.Mar.08	4	06.Mar.08	5	06.Mar.08	5	1	3	6	0	3	3	9
MSC Sarah	*06.Mar.08*	*7*	06.Mar.08	*7*	07.Mar.08	*2*	*4*	*0*	3	12	15	12	18
Merkür	07.Mar.08	2	07.Mar.08	2	07.Mar.08	3	2	0	3	3	6	3	9
Britain Star	07.Mar.08	3	07.Mar.08	3	07.Mar.08	4	2	0	3	3	6	3	9
King Byron	07.Mar.08	4	07.Mar.08	5	07.Mar.08	6	2	3	6	3	6	6	12
MSC Caitlin	07.Mar.08	4	07.Mar.08	4	07.Mar.08	6	3	0	3	6	9	6	12
Glenmoon	*07.Mar.08*	*8*	07.Mar.08	8	08.Mar.08	*2*	*2*	*3*	6	6	9	9	15
Tomriz-A	*07.Mar.08*	*8*	08.Mar.08	*1*	08.Mar.08	*2*	*2*	*3*	6	3	6	6	12
Alkın Kalkavan	*07.Mar.08*	*8*	08.Mar.08	*1*	08.Mar.08	*3*	*3*	*3*	6	6	9	9	15
								2.47	**5.58**	**3.2**	**6.17**	**5.8**	**11.8**

The total time the vessel spends at the port is reduced by 40 hours which is an improvement by 81.6% on average. These values are calculated in a similar manner with the waiting time. The average weekly improvement for the port is realized as 91.96% in waiting time, 69.9% in berthing duration, and 76% in total time spent.

The consequences of using the simultaneous berth and crane allocation model may also be evaluated by examining container-handling outputs within a time-period. According to real data, between March 1st to March 7th , 12.500 containers are handled on total by all the cranes. Outputs of the SBCAM put forward the total capacity as 14.140, which imply 1640 more containers to be handled.

From the numerical results, one can conclude that the optimal simultaneous assignment of berths and cranes brings out obvious reductions in all main performance measures. Average waiting time for a vessel is reduced from 20 hours to 4 hours. The duration berthed or the average processing time is reduced from 25 hours to approximately 5 hours. Average total flow time is reduced from 45 hours to 9 hours. A container handling capacity increase by 10% is put forward by the model.

Table 3-13 Comparison of results

	Reduction in Waiting time		Reduction in berthing time		Reduction in total time in system	
Vessel Name	**(h)**	**%**	**(h)**	**%**	**(h)**	**%**
Neptun	-6.5	0.0%	15.5	91.2%	9	33.3%
MRSTrapani	-0.5	0.0%	29.5	86.8%	29	65.9%
HMSLaurence	16.5	91.7%	23.5	75.8%	40	81.6%
Windward	14.5	76.3%	15.5	67.4%	30	71.4%
KpErgun	17.5	92.1%	10.5	70.0%	28	82.4%
VentoDiBora	18.5	80.4%	17.5	79.5%	36	80.0%
OrkunK	22.5	93.8%	23.5	83.9%	46	88.5%
WandaA	23.5	94.0%	17.5	79.5%	41	87.2%
Catania	20.5	93.2%	8.5	85.0%	29	90.6%
MaerskBrisbane	8.5	85.0%	31.5	87.5%	40	87.0%
GrandWiew	11.5	88.5%	30.5	80.3%	42	82.4%
YMOcean	21.5	93.5%	15.5	77.5%	37	86.0%
MSCEugenia	28.5	86.4%	63.5	93.4%	92	91.1%
Rousse	-0.5	0.0%	28.5	86.4%	28	82.4%
EurusStockholm	-7.5	0.0%	2.5	10.0%	-5	0.0%
IremKalkavan	14.5	58.0%	10.5	70.0%	25	62.5%
Liguria	17.5	92.1%	17.5	79.5%	35	85.4%

Table 3-13 (continued): Comparison of results

	Reduction in Waiting time		Reduction in berthing time		Reduction in total time in system	
Vessel Name	**(h)**	**%**	**(h)**	**%**	**(h)**	**%**
MSC Damla	58.5	92.9%	24.5	84.5%	83	90.2%
MSC Elena	13.5	75.0%	35.5	82.6%	49	80.3%
Adele-C	-5.5	0.0%	9.5	86.4%	4	25.0%
Contaz Ankara	11.5	88.5%	21.5	93.5%	33	91.7%
Aleko Konstantinov	25.5	85.0%	12.5	89.3%	38	86.4%
Santa Monica	32.5	95.6%	24.5	94.2%	57	95.0%
Serap-K	-2.5	0.0%	17.5	79.5%	15	62.5%
İtal Verde	11.5	88.5%	25.5	94.4%	37	92.5%
Erkut-A	6.5	59.1%	8.5	85.0%	15	71.4%
MSC Sarah	45.5	96.8%	18.5	57.8%	64	81.0%
Merkür	17.5	92.1%	17.5	79.5%	35	85.4%
Britain Star	26.5	94.6%	8.5	65.4%	35	85.4%
King Byron	27.5	85.9%	8.5	65.4%	36	80.0%
MSC Caitlin	13.5	90.0%	7.5	50.0%	21	70.0%
Glenmoon	20.5	82.0%	15.5	67.4%	36	75.0%
Tomriz-A	3.5	43.8%	19.5	81.3%	23	71.9%
Alkın Kalkavan	21.5	82.7%	37.5	83.3%	59	83.1%
Average	**16.12**	**69.9%**	**19.82**	**77.7%**	**35.94**	**76.0%**

3.3. THE CHSIM MODEL EXPERIMENTS AND ANALYSIS

3.3.1 Simulation environment and setup

The container handling simulation program was coded in Microsoft Visual Basic 6.0, embedded in Rockwell Software Arena 11.0. 2.81GHz Pentium desktop on a Windows XP environment with 2038MB of RAM is used in the experimental runs.

The plant layout and equipment configurations for the port of Izmir are considered. Typical parameters such as quay crane, gantry crane performances, yard and external truck velocities, distances are estimated by on-site measurements, observations and interviews with the operators.

According to the real container traffic data in 2008 (200,738 TEUs for inbound full containers) and a storage yard capacity of 7200 TEUs , on average, the storage area will be filled and emptied within 13 days. For acquiring a steady-state representation of the world, although the simulation runs collapses 30 days the performance evaluations are based on the last 15 days. The first 15 days are used as an initial preheating model running time in order to fill up the stacking area to a realistic capacity.

Two different container terminal configurations are practiced for storage policy evaluations. The first configuration's parameters are taken from real data distributions. The second configuration uses the SBCAM output data distributions.

Similar model logic is applied for the two experiments. The logic where yard trucks are used for transferring purposes will be experimented. Presently, Port of Izmir uses this approach for full import container handling. As stated previously, this type of transportation requires the quay cranes and the yard trucks to work in synchronization.

Real data configuration

To obtain the vessel arrival distribution at the berths, real records between the 1st and the 7th of March 2008, which comprises the data set of SBCAM experiments, are examined. To do this, inter arrival times of consecutive berthing times are computed in minutes. This set of interarrival times is processed by the Input Analyzer tool by Rockwell for a probability distribution function fitness test. Applicable distribution functions (beta, erlang, gamma , exponential …etc) are tested and among them the function resulting in the smallest square error is selected. The distribution function for berthing interarrivals is found as 15 + Expo (309) with a square error of 0.019 minutes.

The same method is applied for full import container arrivals per berthed vessel. This time an exponential distribution of 0.999 + Expo(107) with a square error of 0.007 is calculated.

SBCAM data configuration

The second terminal configuration parameters are obtained from SBCAM output data distributions. To compute the distributions for the vessels' docking to quays, berthing data output of the SBCAM tool is inspected. First, as each time period compromises duration of three hours ,the berthing times shown in Table 3-12 are converted to regular minute base, by the use of a random generator . Then, differences between consecutive berthing times are calculated for the fitness test. The distribution function of berthing times is found as -0.001 + Expo (289) with a square error of 0.020 minutes. This increased density of traffic compared to the real data configuration was anticipated as the SBCAM technique docks more vessels within equivalent time durations.

The distribution for full import container arrivals per berthed vessel is found to be an exponential distribution as 0.999 + Expo(109) with a square error of 0.007.

After being berthed by either of the two terminal configurations, for every container, a departure date is assigned by the model. In practice, this departure date is mostly uncontrollable and not known in advance. This is the main reason why stacking decisions for the import containers are harder compared to export containers. According to the operations director, container duration of stay at the storage yard before being picked up by external trucks varies randomly between 1 and 15 days. The segregation strategy used in this experiment is designed considering these facts. Storage spaces are partitioned loosely, in thirty hour time slices so that a rough estimate of departure dates will be adequate for piling.

Containers with given attributes will be assigned to quay cranes according to past statistical probability distributions. These distributions are calculated through hourly crane assignments in the investigated period. At this point, each container will wait in queue and try to seize its dedicated quay crane when available. When seized, the quay crane will pickup the container from the vessel to place on an available truck. Onsite time studies are used to calculate the time required for this process. Minor differences are observed between different quay cranes and processing time is found to be normally distributed with a mean of 180 seconds.

In the previous chapter, the synchronization of the yard trucks and the quay cranes was explained in detail. The quay crane will request for a yard truck and will wait in “hold” state until its arrival. There are 34 yard trucks in the system, with a speed of 6 m/s when empty and 4m/s when full. Of the available trucks, the truck that has the closest distance to the quay crane station will be chosen. These distances are measured using satellite images (see Table 3-6).

Once the truck is loaded with a container, total capacity check is performed. Full import container storage yard has 10 blocks, each served by a gantry crane. Every block consists of 5 columns, 36 rows and 4 tiers. If total capacity is not exceeded storage assignment operations will begin.

Four different strategies for storage, summarized in Table 2-2, are taken into consideration. The first strategy, st1, uses random strategy for block selecting and column, row and tier assignment. Next strategy, st2, uses the integrated strategy where workloads of gantry cranes, number of yard trucks travelling to the gantry cranes and the distance travelled by yard trucks are evaluated for block selection. Exact location within the block is selected randomly. Third strategy, st3, picks one of the ten blocks randomly similar to st1, but for column, row and tier selection it uses the segregated strategy. Containers with similar departure dates are piled together in their slots. The last strategy, st4, combines the integrated strategy and the segregated strategy. Currently, the port does not use a structured or a predefined strategy, decision making is judgmental.

According to the decision taken by the used strategy, the yard truck will move to the specified block in the storage yard. Every block has two entrance and exit points. (see Figure 3-6). The yard truck will prefer the entrance point that is in the closest distance. The container will then demand for the gantry crane dedicated to the block.

The total time spent during storing, transfer, reshuffling and unloading of the containers is calculated through numerous computations explained in the subsections of 2.3.2. Technical specifications of gantry cranes given in Table 3-5 are used as input parameters.

The comparison among different strategies is done in view of numerous performance criteria. The variables considered for assessment are the following:

- Container waiting time in hours to seize a quay crane to be unloaded from the vessel (seqcu)
- Quay crane waiting time in hours for a yard truck to arrive per container (qcwtyt)
- The waiting time in hours for a container to seize the gantry crane for being stored (segcl)
- Number of reshuffles required per container retrieval (resh)
- Quay crane, yard truck and gantry crane utilizations (qcutil,ytutil,gcutil)

It should be mentioned that due to irrelevant operations with the full-import area operations not simulated here, in the assessment of the different storage policies, for some outputs, the relative magnitude of the results rather than the face values should be considered. Typical examples will be discussed in later sections.

3.3.2 Experimental results and discussion

Tables 3-15 show the performance measures respectively under two different data configurations. First, real data and then the SBCAM output data configuration is represented. The rows correspond to the different storage policies

Table 3-15: Experimental results for terminal configurations

	Level 1	Level 2	St. id	(1) seqcu	(2) qcwtyt	(3) segcl	(4) resh	(5) qcutil	(6) ytutil	(7) gcutil
Real_data	*Random*	*Random*	**st1**	0.610	0.011	0.238	0.556	0.184	0.204	0.451
	Integrated	*Random*	**st2**	0.527	0.006	0.185	0.566	0.152	0.175	0.460
	Random	*Segregated*	**st3**	0.604	0.010	0.242	0.513	0.176	0.189	0.442
	Integrated	*Segregated*	**st4**	0.531	0.006	0.199	0.534	0.166	0.182	0.477
SBCAM	*Random*	*Random*	**st1**	0.678	0.012	0.267	0.621	0.206	0.230	0.510
	Integrated	*Random*	**st2**	0.590	0.006	0.200	0.634	0.175	0.197	0.515
	Random	*Segregated*	**st3**	0.679	0.011	0.249	0.584	0.196	0.220	0.494
	Integrated	*Segregated*	**st4**	0.602	0.007	0.205	0.598	0.185	0.204	0.526

applied. The columns show the different performance indicators. Ten independent simulation runs of 30 days each were performed and the last 15 days are considered to obtain each piece of data. The averages of these ten simulations results were calculated to achieve the final numbers.

At the first glance, a common fact is observed for the terminals and the strategies. That is, the main bottleneck spot in the terminals occurs to be at the quay cranes. The time a container waits to seize a quay crane to be unloaded from the berthed vessel (seqcu) encompasses a long duration. This waiting time rapidly increases as the terminal traffic gets more demanding.

Recall that the quay cranes and the yard trucks must be working in synchronization. When a container seizes the quay crane, a truck must be ready waiting to be loaded. The waiting time of quay cranes for truck arrivals per container is shown in the second column (qcwtyt). This waiting time will effect quay crane allocation time as the quay crane will not be released for other containers use, before the arrival of the truck. For higher waiting times of qcwtyt, higher seqcu is expected.

Column number three (segcl) shows the waiting time in hours for a container to seize the gantry crane for being stored in the storage yard. After being loaded, the yard truck will move to the specified block and wait for the gantry crane to be available for picking up the container. Until then, the truck will be conserved. In the same manner, for higher waiting times of segcl, higher qcwtyt and consequently higher seqcu is expected.

Looking at the first three criteria in Table 3-15, wee see lower values for the strategies st2 and st4. This superiority probably originates from the fact that these two strategies both consider the workloads of gantry cranes, number of yard tractors travelling to the gantry cranes and distance travelled by yard trucks when deciding for a block. For the strategies that select the blocks randomly (st1 and st2) without computing the workloads of gantry cranes, the truck waits longer if the crane is busy at that time (segcl). This will in turn cause the quay crane to wait longer for available truck (qcwtyt). This fact is common for both traffic scenarios. Figure 3-8 demonstrates the dynamics for the waiting time at the quay crane queue for the SBCAM traffic load. The plot diagrams of strategies st1 and st4, where the latter uses the integrated strategy, illustrates the decrease in the waiting queue.

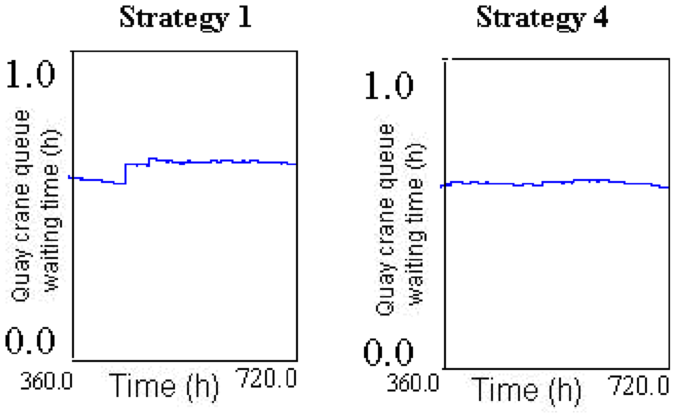


Figure 3-8: Quay crane queue waiting time dynamics

Experiments show that, in the storage yard it takes more time to unload containers compared to storing them. This stems from the fact that reshufflings occur during the unloading process. Column (4) in Table 3-15 shows the number of reshuffles required per container retrieval for different strategies. Comparing two storage policies st2 and st4, the latter using a segregated policy, eliminates more containers from being reshuffled. The difference in total number of reshuffles between the two strategies is approximately 220 for 15 days. Each reshuffling move takes about 390 seconds. This lowers the total monthly workload of the ten gantry cranes by approximately 50 hours.

An additional essential parameter for the assessment of a terminal is the equipment utilization factor. A utilization factor of less than 20% is considered poor, whereas more than 80% is a very intensive one (Thomas and Roach 1999). For our case, some resources, such as yard trucks and quay cranes are also used for tasks other than full container import area operations. Full import area containers make up for the 25% of all the containers. Therefore, utilization values will be evaluated allowing for these circumstances. For our purposes, a good value would range between 5 and 20% for quay cranes and yard trucks.

Columns (5), (6) and (7) show quay crane, yard truck and gantry crane utilizations accordingly. With values between 44 and 52%, current gantry crane capacity seems tolerable. Some critical issues are to be discussed for quay cranes and yard trucks. Their values are spread around the upper limits. Strategies that use the integrated strategy for block selection seem to cope better with this crisis. In fact, under the traffic load of the SBCAM approach, the utilization rates rise above the upper limits for random selection policies. Therefore, it is compulsory to use the integrated policies for the system to proceed smoothly.

3.4 INTEGRATION OF THE SBCAM AND CHSIM RESULTS

The use of the two SBCAM and CHSIM model's results by the port managers will enhance the port operations by a great extent. With this in mind, we have used the SBCAM outputs as an input for the CHSIM model. The container handling strategy that is most capable of dealing with the suggested scheduling is put forward by the simulation outputs. The aim is to ensure a smooth flow of containers back and forth between the dock, yard and the gate.

The use of simultaneous berth and crane allocation model will aid in shortening the waiting and the berthing times for the vessels. For the test data, average waiting time of a ship before being serviced is reduced from 20 to 4 hours. Berthing time is lowered to 5 hours from 25 hours. It should be noted that in practice there might be various interruptions such as machine breakdowns or employee absences that are not represented in the model.

The container handling simulation model results reveal that container handling capacity may be improved by using appropriate strategies. As the major bottleneck is at the quay cranes, the strategy that copes best with this problem should be preferred. Indeed, one of the most important performance indicators of a port is the quay crane productivity, which makes it a common dilemma for all the world ports. For the vessel operators, less waiting time for an available quay crane would mean less time spent at the port and more time at the sea. Such an improvement could mean significant gains for both the terminal and vessel operators. From the experimental results, we may conclude that using integrated strategy at the first level is undeniably superior to using the random storage policy. This superiority is apparent in both the terminal configurations.

At the second level, segregated strategy reduces the number of reshuffles compared to the random policy. Its effect should not be overlooked, as the traffic intensity gets more demanding, the gap between strategies for all the outcomes increases noticeably.

A critical issue to note is that under the increased traffic load offered by the SBCAM output data, due to the bottleneck at the quay cranes, the use of the integrated policy at the first level is essential. With future expectations of busier terminal traffic, these results should be examined carefully.

CHAPTER 4

CONTRIBUTIONS OF THE DEVELOPED SBCAM AND CHSIM MODELS ON PORT MANAGEMENT

This final chapter is dedicated to the discussion of contributions of this thesis. Contributions both to theory and to practice will be exhibited first for the SBCAM study. Discussions for the CHSIM model will be presented next.

This thesis focused on the operational problems at seaport container terminals. The objective of this thesis was to renovate the port management decision making procedures to be more analytic and data oriented. It was projected that the developed methods will enable the ports to benefit from faster vessel service times, increased container handling capacity and consequently elevated added value and port services.

4.1. CONTRIBUTIONS OF THE SBCAM

In the simultaneous berth and crane allocation model, berth allocation and crane allocation activities are explored. This research makes several contributions to theory. Instead of solving the two allocation problems separately, a simultaneous technique is developed. For efficient use of scarce space resources, a continuous berthing structure is adopted rather than partitioning the quay into sections. Furthermore, the model is formulated with multiple quays or terminals. Handling times of the vessels are taken as decision variables rather than input parameters and departure times are determined accordingly. Cranes with mobile and static features are further aspects considered in this study.

Numerical experimentations are provided to improve berth and crane utilizations at the Port of Izmir. Contribution to the practice is measured by comparing the results with the actual performance figures observed in the port for a specific time period.

Contribution of the proposed model is noticeable in terms of performance measures such as waiting times and operation times. Efficiency of the berthing and container handling operations has been increased markedly as a result of continuous and simultaneous berth and crane allocation approach.

The model proposes an average capacity increase of 10% for the total number of serviced containers. Average waiting time for a vessel is reduced from 20 hours to 4 hours. The duration berthed or the average processing time is reduced from 25 hours to 5 hours. Average total flow time is reduced from 45 hours to 9 hours. This reveals the fact that in the current practice, the vessels are not continuously served but they face inexplicable crane service interruptions. With approximate daily waiting costs varying between \$50.000 and \$100.000 for each vessel, savings from the implementation of the model could be remarkable, compared with the cost of minor changes on berths for continuous allocation.

Indeed, the mathematical model may support the port managers in preparing efficient berth allocation schedules but an issue to note is that the results should be evaluated together with the probable uncontrollable factors such as machine breakdowns, operator absences and some environmental factors. The SBCAM may be considered as an analytical support tool for the decision making process of the port management

4.2. CONTRIBUTIONS OF THE CHSIM MODEL

The container handling simulation model is used to examine the container handling activities. The main component of the container handling problem is denoted as storage space assignment. The focus of the study was on the discovery of a new storage policy that will improve the performance of the full import container terminal. With that purpose, a discrete-event simulation model of a terminal that goes into details on the storage assignment problem at the operational level is constructed. A theoretical contribution, that can be applied to other terminals, was made by developing a hierarchical approach with a multi-level structure for the storage assignment problem. The first level determines the specific block the container will be stored. The second level assigns the exact location for the container within the block. The row, column and the tier number is determined. In this structure, four different storage policies are proposed: At the first level, random storage policy or integrated storage policy in which workloads of gantry cranes, number of yard trucks travelling to the gantry cranes and the distance travelled by yard trucks are measured together may be applied. At the second level, random assignment policy or segregated assignment policy, which exercises, containers' estimated departure dates, may be implemented.

Contribution to the practice is measured by the developed discrete-event simulation model of the Port of Izmir. Comparisons are made under two different traffic intensities, computed from past real traffic data and SBCAM output data accordingly. Assessments for the different strategies are made with a broad outlook of the terminal performance data.

Results from the experiments emphasis the bottleneck at the quay cranes. Strategies that adopted the integrated assignment method at the first level performed best when coping with this crisis. On average with the use of integrated storage policy, monthly container handling capacity may be increased by 10% on average. Reshufflings are considered as unproductive moves. Using the segragated strategy at the second level of the hierarchical model , reduces the number of reshuffles. The total time gain by eliminating these rearrangements is approximately 50 hours according to different strategies and trafic densities.

Furthermore, the simulation model results may guide the container terminal operators through various the decision-making processes. For instance, by looking at the utilization values, we may conclude that future investments on container terminal infrastructure may be considered. Increasing the number of quay cranes may relax the traffic density within the terminal.

CONCLUSIONS AND FUTURE WORK

Aegean region of Turkey has always played an important role in the national economy. A safe, efficient and cost effective transport is a critical factor for the region's development. In this respect, transportation via sea is the most preferred method in the global trade. Transport by water is significantly less costly than other alternatives: It is estimated to be 14 times less costly than air-transport, 7 times less costly than land-transport and 3.5 times less costly than railway-transport. Analogous to the global statistics, according to the national data supplied by Turkish Statistical Institute, 80% of the total exports, 91% of the total imports and 88% of total foreign trade in Turkey is transported via sea.

Consequently, ports are crucial nodes in global maritime supply chains and thus efficient port management is a thing of utmost importance for national economies. The benefits of sea-freight transportation, draws attention towards the Port of Izmir. Today, the port is the most important container terminal in Turkey.

Furthermore, annual revenues around $90 million and profit around $55 million, position the port as the nationwide leader in terms of profitability. In fact, over 70% of total profit is being realized by the Port of Izmir (Turkish State Railways 2007).

Currently, the container traffic of the Port of Izmir has exceeded its capacity of 800.000 TEU. The port's present handling capacity is exhausted by the needs of the surrounding cities of the Aegean Region as well as the area extending deep into Anatolia, its natural hinterland. The waiting times of the vessels before they start getting service from the port are considerably high. Nearly, half of the incoming ships waits more than a day to get service from the harbor. This problem is common for most of the terminals around the world.

The emerging needs of Izmir Port management under privatization attempts provided another motivation for our study. The existing decision making process at the Port of Izmir is judgmental, and the facilities cannot be utilized efficiently. Reestablishment of container terminal infrastructure or renewing equipments involve a great deal of capital investment and long time to organize. This thesis has shown, through a mathematical and a simulation model, how an existing terminal can operate at higher efficiencies using the same equipment and labor force. We can simply calculate the magnitude of economic impact of the models by taking into account the daily cost of waiting vessels in Izmir Port which is estimated as $300,000 (Dunya Gazetesi, 2007). The economic impact of congestion faced by the Port of Izmir is enormous It is possible to expand impact estimations of Izmir Port efficiency by including the externalities and indirect contributions to the foreign trade and employment for the region. The implementation of the project will lead to the creation of employment, development of qualified labor force and expansion of trade volume in the Aegean Region. Improving utilization of limited resources such as container terminal by enhanced port management models will increase revenue and reduce operation costs, resulting a better financial performance of the Izmir Port.

Based on the detailed analysis of the experiments and particular conclusions drawn from these findings, it should be stated that the research has successfully served to develop a common means of improving port management operations. The suggested simultaneous berth and crane allocation model, the hierarchical storage assignment policy and the simulation model will guide the container terminal operators through various the decision-making processes.

Further research on efficient port management is a thing of utmost importance. This research could be expanded on several ways.

The application of the two models to similar ports around the worlds is achievable. Comparisons of performance measures will give an opportunity to generalize the results and assess the strength of the outcomes of this research.

Further development of the two models is another opportunity for future works. Both models may form a basis and additional features may be added to reflect different real world conditions. For instance, the container handling model could be expanded to involve export containers and the outer connections of the port. The truck waiting queue outside the port entrance and exterior gate traffic appears to be a problem that needs attention. However, especially in the case of the mathematical model, expansion of the model should be done cautiously as increased complexity might be a challenge to manage in this circumstance.

Finally, particularly the simulation model may be used for other assessments such as strategic and tactical decision problems. Effects of different terminal layout plans may be simulated. Prior to any investments on container terminal infrastructure proposed plans could be tested on the simulation environment. With this purpose, developing the simulation model to be more user-friendly and interactive may be a further research topic.

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