MODELING AND SIMULATION ON THE YARD TRAILERS DEPLOYMENT IN THE MARITIME CONTAINER TERMINAL

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Evangelos I. Kaisar, Department of Civil, Environmental and Geomatics Engineering, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the College of Engineering and Computer Science and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

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In recent years, there has been an exponential increase in container volume shipment within intermodal transportation systems. Container terminals as part of the global port system represent important hubs within this intermodal transportation system. Thus, the need to improve the operational efficiency is the most important issue for container terminals from an economic standpoint. Moreover, intermodal transportation systems, ports and inland transport facilities should all be integrated into one coordinated plan. More specifically, a method to schedule different types of handling equipment in an integrated way within a container terminal is a popular topic for researchers. However, not many researchers have addresses this topic in relationship to the simulation aspect which will test feasible solutions under real container terminal environment parameters.

In order to increase the efficiency of operations, the development of mathematical models and algorithms is critical in finding the best feasible solution. The objective of this study is to evaluate the feasible solution to find the proper number of Yard Trailers (YTs) with the minimal cost for the container terminals. This study uses the Dynamic YTs operation's method as a background for modeling. A mathematical model with various constraints related to the integrated operations among the different types of handling equipment is formulated. This model takes into consideration both serving time of quay cranes and yard cranes, and cost reduction strategies by decreasing use of YTs with the specific objective of minimum total cost including utilization of YTs and vessel berthing. In addition, a heuristic algorithm combined with Monte Carlo Method and Brute-Force Search are employed. The early Stage Technique of Monte Carlo method is proposed to generate vast random

numbers to replicate simulation for real cases. The Brute-Force Search is used for identifying all potential cases specific to the conditions of this study.

Some preliminary numerical test results suggest that this method is good for use in conjunction with simulation of container terminal operation. The expected outcome of this research is a solution to obtain the proper number of YTs for transporting containers with a minimum cost; thus, improving the operational efficiency in a container terminal.

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1. INTRODUCTION

Today, we see a renewed focus on the intermodal freight transportation. The term of intermodalism, especially for the freight transportation, can be simply defined as a single-bill-shipment uses multimodal transportation mode. The intermodalism originated in maritime transportation, which is a very huge part of the global transportation network, with the development of the container almost five decades ago. Moreover, today's globalization of trade and the subsequent breakdown of trade barriers have spurred tremendous growth in marine container traffic. Ports, which serve as hubs of container transshipment, play critical roles in the marine transportation network.

Technological improvements in recent years have made it essential to plan the transportation system of a developing country as a whole, in order to achieve a balance between the capacities of the various ports. In maritime transport, it is sometimes possible, particularly for bulk and unitized cargo, such as a container, to include the shipping. Thus, ports and inland transport facilities work best when they are included into one coordinated plan for intermodal conveyance. In other cases, the ship traffic is not under the control of the planner, and it is only possible to coordinate the port facilities with those of inland transport and distribution (Port development: A handbook for planners in developing countries, 1985). Considering the containers' transportation within the port, only planning the vessel transportation without considering the connection with terminal facilities may lead to serious faults in communication. Because the container freight traffic is rapidly growing, efficiency in container handling operations, which includes the utilization of resources in the port, is so important for the demand of high quality services from container terminals. Methodological advances regarding container terminal operations have considerably improved through much research. However, in the past research, most focus on a single type of equipment without considering the sequence of the different equipment in the systems. Also, the connectivity of handling operations between quaysides and yards in container terminals is the most critical issue, which may cause delay problems to arise with significant impact on the whole container handling processes, so the efficient solutions for this problem are critical for systems to have efficient and productive performance.

1.1 The Port and Container Terminal

A port is a site next to a body of water containing one or several harbors where marine transportation modes can dock and transport people or shipments to or from land. Seaport locations are chosen to optimize access between land and water in regards to business purposes and refuge from hazardous weather. Deep water ports are less common, but can serve a larger variety of vessels. Since ports have been very influential historically, they frequently dominate the local economy and vary widely.

As the concept of intermodal transportation has become more efficient, economical, and practical, a port is treated as an importation element in the global transportation market by serving as a multi-modal interface, which often links the sea and land transportation.

Ports often have cargo-handling equipment for use in loading and unloading vessels, and some ports feature canals, which allow vessels further movement inland. Access to the intermodal transportation, such as railways and land transportation, is critical to a port so that passengers and cargo can also move further inland beyond the port area.

Because the international demand for containers is rising, container terminals have become an important mode in the global transportation network and have become a vital role within the intermodal transportation system. A nautical container terminal is normally a component of a larger port; it is a facility where containers are transferred among different transportation modes for continued distribution. The big marine container terminals are similar to key harbors because they transfer containers within a global transportation network. "Maritime container terminals provide many functions, such as transship, transfer, or storage. As the demand for international trade and global logistic services continues to increase substantial investments and improvements in both physical capacity and operational efficiencies are necessary to enhance terminal productivity" (Eric Ting " Container Terminal Operation and Cargo Handling").

Cargo passes through a container terminal usually in three different ways: it may be imported, exported, or transshipped: moved from one vessel to another. containers terminals can be designed in base of the concern of handling, storage, and possibly loading or unloading of cargo into or out of containers, and where containers can be picked up, dropped off, stored, maintained, unloaded or loaded from one mode of transportation to another , that is, vessel, truck, rail, even plane. Being categorized by their ownerships, container terminals can be generally classified into five part: public terminals, carrier-leased dedicated terminals, terminal-operator built and operation terminals, carrier built and operation terminals, and joint venture of carriers and terminal operators, these different type of terminals are explained in following by Eric Ting;

- Public terminals

Shipping lines can share the facilities and operations of public terminals with each other. They are charged at tariff rates. The first come, first serve principle is usually used, and there is no priority in berth usage except by paying the priority fee. Container handling and other charges are calculated at common tariff rates or paid at quantity discount rates based on the container volume if it is over the fixed quantity agreed upon in contracts. The terminal in Singapore (PSA before 1997) is categorized into this class.

- Carrier-leased dedicated terminals

Emphasizing on their exclusive use, carriers make the long-term lease contracts with the port authorities. Carriers pay rents and facility charges and have priority and right for berth usage. Carriers can purchase or set up container handling facilities at their own account to compensate for rents and facility charges. Kaohsiung, Keelung (some parts of the port), Kobe, Yokohama, and Tokyo are categorized into this operation pattern.

- Terminal-operator built and operation terminals

A terminal operator builds an operation terminal or invests in the construction and handling facilities. Hong Kong (HIT, MTL, CHT), Tianjin (CSXOT), and Singapore (PSA after 1997) are categorized into this category.

- Carrier built and operation terminals

Carriers will build container terminals or invest directly in the construction. The handling facilities and the operations of the container terminal are managed by the carriers. Except with the usage of their own fleet, the carriers are authorized to provide other shipping lines with berthing and container handling services. Taipei Port (invested by Yang Ming Line, Evergreen, Wan-Hai),Qingdao (Zhunguang, Kuaikuei, Tiasing), and Malaysia (PTP) are categorized into such operation patterns.

- Joint venture of carriers and terminal operators

Both shipping lines and terminal operators establish a company to joint venture together, by making a joint investment in building or leasing of the container terminals or investing directly in the construction and handling facilities. Shanghai (Yangshan terminals and Zhunghai terminals) and Shenzhen belong to this group.

Container terminals vary in location, size, operation methods, management, kinds of equipment, arrangement and other aspects, which means that there are many factors affecting container terminal design and decision making in the early stages. As Hwarng (1998) mentioned, the interrelationship between various activities in container terminals usually leads to a terminal operation problem that is dynamic in nature and with stochastic behavior.

In the container terminal, the yard area, as a large component of it, provides many functions within the system. These functions include the container unloading/loading operations for storage, transshipment operations, or turnaround. Hence, any type of container flow will be served in the yard. Figure 1 shows the regular container terminal allocation. Introduced by Eric Ting in his study, the container yard usually includes several types:

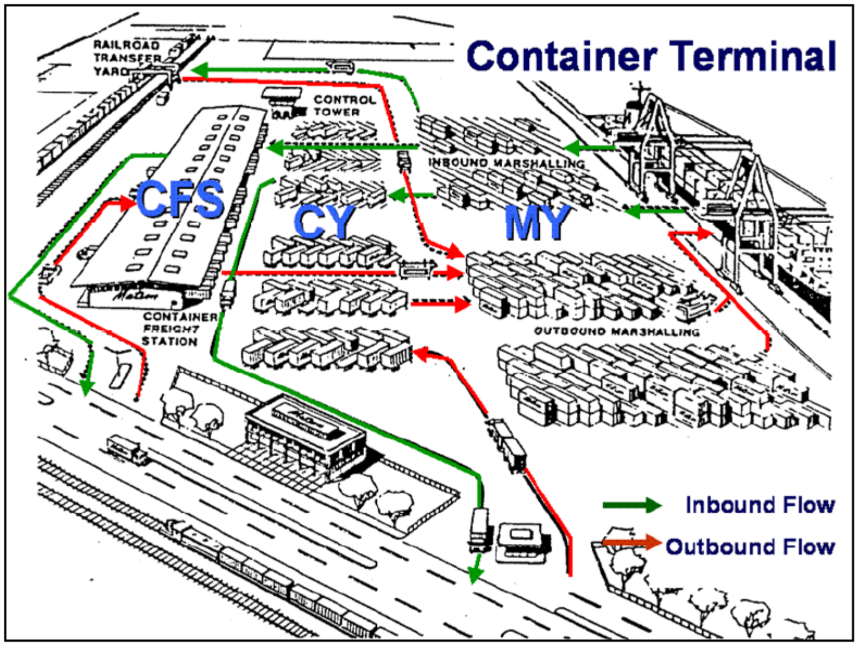

Figure 1: A Typical Yard Allocation (Eric Ting)

(1) Marshalling Yard (MY), which is located close to the berth, used to improve the efficiency of loading/unloading operations for vessels. The export containers are stacked according to certain rules or plans in this yard before loading to the vessel. And for the import containers, they are also stacked in this yard as a temporary method. They are usually served randomly.

(2) Back yard, which is not contained in every terminal, is utilized for turnaround, storage of containers, especially for heavy and empty containers. It is always treated as the connection area between the whole terminal and the land, served for the containers' distribution.

(3) Empty containers yard, especially for the collection, store, and turnaround of empty containers in case of shortage area of the first two types of years. Both back yard and empty containers yard can be called into Container Yard (CY)

In the whole terminal, there is another area: Container Freight Station (CFS). It usually contains one or more sheds, warehouses or uncovered storage areas where cargoes are loaded into or unloaded from containers and may be temporarily stored in the sheds or warehouses.

Currently, in most studies, the marshalling yard is called yard, which is close to the berth. As shown in figure 2: “a typical yard consists of several blocks, and each block consists of 20±30 yard-bays. Each yard-bay contains several (usually 6) rows. Each ground slot, denoted as a rectangle in the diagram, can store 5-7 containers. When an outside truck delivers an outbound container to a yard, a transfer crane picks it up and stacks it in a yard-bay” (Kap Hwan Kim, et al. 1999).

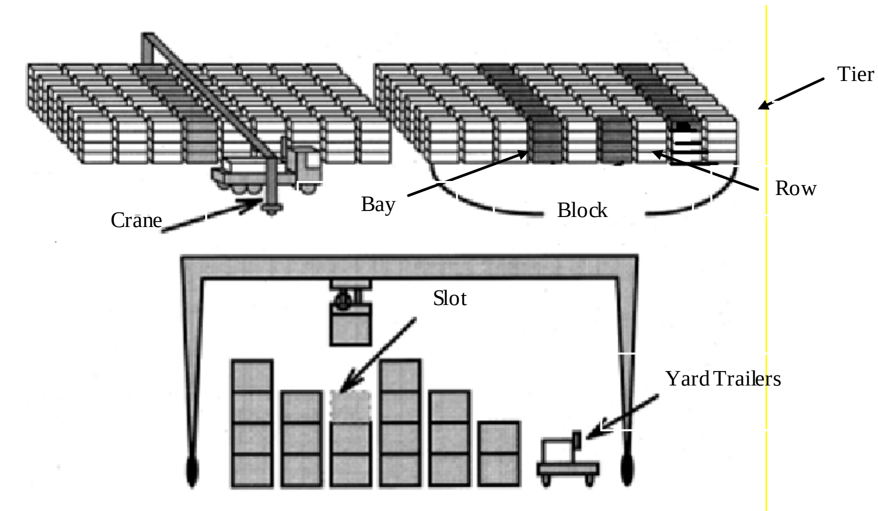

Figure 2: A Typical Container Allocation in a Yard

1.2 Cargo Transportation---Containerization

According to the International Organization for Standardization (ISO), containerization is a network of intermodal cargo transportation using typical intermodal containers. These can be transported by vessels, airplanes, railway trains, and ground vehicles. Containerization brings an important improvement to the field of logistics, which has revolutionized freight transportation in the last century. The transportation of cargo containers originated at the beginning of the 19th century. These containers can be transferred among different methods of transportation, such as railroads, vessels, or trucks. The containers used in the past were much smaller than the containers being used today. In the 1920s, the Milwaukee Railway and the Chicago North Shore companies began using different vehicles, such as plane cars, to transport cargo. Shortly after, Seatrain Lines started carrying railroad boxcars onto ships to transport cargoes between Cuba and New York. In the 1950s, these plane cars were furnished with new decks. In 1951, containers were transported for the first time by vessels between Alaska and Seattle. The first container ship was constructed in Canada in 1955. In its first voyage, it handled 600 containers between Skagway, Alaska and North Vancouver. This method of transportation gradually achieved intermodalism. In 1956, Malcolm McLean developed the standard containers which are used today. They could be moved by cranes onto a vessel or a truck, making transfer operations more efficient.

Currently, there are two standard containers sizes: the twenty-foot equivalent unit (TEU = 20' length x 8' width x 8.5' height) and the forty-foot equivalent unit (FEU = 40' x 8' x 8.5'). Instead of using the Dead Weight Tonnage (DWT) to define capacity units for all container ships, TEU and FEU are widely used today.

Vessel designs and harbor capacities have been developed to meet current container needs. Therefore, containerization and intermodalism have completely revolutionized the transportation of cargo. Today's global fleets are made up of 3,375 containerships with 7.2 million TEUs. According to Chris Koch, president of the World Shipping Council, containerization has made global business transportation smooth and more efficient. In effect, the development of containers allowed the shipping industry to grow significantly (P. Jaime Tetrault, 2010).

Expansion in container trade is mostly driven by economic growth, and today's focus of intermodalism has been on containerization. By the end of October 2008, there are 4627 container vessels with a total capacity approximately to 12.2 million TEUs [AXS-Alphaliner, 2008]. Therefore, containerization has become more important as the integral part of logistics. It has revolutionized the cargo shipping. According to the CBS data from Netherland, from 2002-2007, only the container trade to Netherland is increasing every year showed in figure 3. And based on the prediction, in the next coming years, the container trade will be continually rising shown in figure 4. Today, nearly 90% of global trade volume is shipped in containers. One fourth of world's total containers start from China.

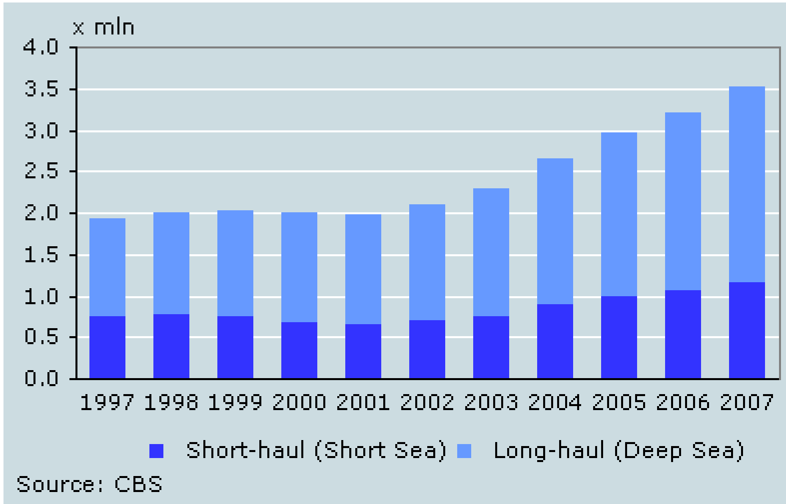

Figure 3: Container Volume (Peter Smeetes, 2009)

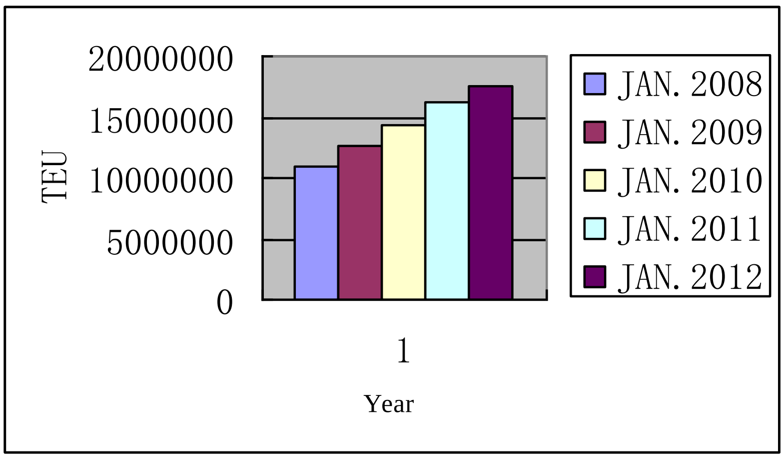

Figure 4: Container Projections 2008-2012 (AXS-Alphaliner, 2008)

As containerization become the broad tendency in cargo transportation, the benefits of it can be described as followed:

- Goods in lots which are too small for the traditional bulk transport can be moved using containers.
- Containerization can provides the high-value and delicate cargo to be safety from human and natural factors
- As containers are moved intact, the time and labor cost can be saved which would otherwise have spent on unloading and loading goods.
- It has better quality in handling of good than it in bulk transport systems.

- Containerships provide regular service to overseas ports, thus it minimizes the waiting time.
- Compare to the bulk systems, containerization could not only reduces the transit time, but also reduce the inventory costs and increases reliability.

However, as the development of handling and information technologies in current container terminals, automated cargo handling systems are increasingly being arranged to increase the overall efficiency. These systems are consisted with equipments that cooperate and communicate with one another to reach the various material handling tasks. As this important point, it is essential to develop a mathematical method to formulate this problem in order to achieve satisfactory overall performance. (Ioannou et al., 2000; Meersmans, 2002).

1.3 Container Terminal Operations Description

The efficiency of container terminals rely on a great extent on the effectiveness of operations: Container assignment; Resource allocation; Logistics and transportation. And quay crane scheduling, berth planning optimization, human resources management, Storage and load planning, sequencing delivery and receiving operations for storage space cranes, YTs operations are more specific jobs in the yards. (Dirk Steenken, et al. 2004)

The container terminals can be defined as an open system of material flow. (Xi Guo, et al., 2009) the Terminal operations can be also roughly categorized into three types by areas: gate-, yard-, and quay-side. Gate side works for the containers from land transportation to be loaded to the vessels to transfer to the maritime transportation mode; and yard side, as mentioned in the previous part, is the area served transferring containers among various transportation modes, also sometimes can be a temporary storage place. And quay side is the berth that served for the multiple quay cranes loading and unloading the containers to the vessels.

For most container terminals, between the yard-quay sides, there are mainly three types of equipments that being used in loading and unloading, are Quay Cranes (QCs), Yard Trailers (YTs), and Yard Cranes (YCs). when vessels are berthed alongside in the port container terminal, each of them is served by multiple QCs which are supported by a lot of YCs and YTs in the yard. The containers from unloading vessel are first unloaded by a QC which puts them onto a YT which is waiting under it on the ground, and then they are transported by the YT to the YC stayed in the yards to load them into the temporary storage points, this procedure express the import containers flow, the export containers flow usually is the reverse way. A typical container flow is shown in figure 5. At some later time, a YC retrieves the container from the yard and places it onto an XT (external truck) or train, which then takes the container to its final mainland destination to achieve door to door services (Matthew E.H. Petering, 2009).

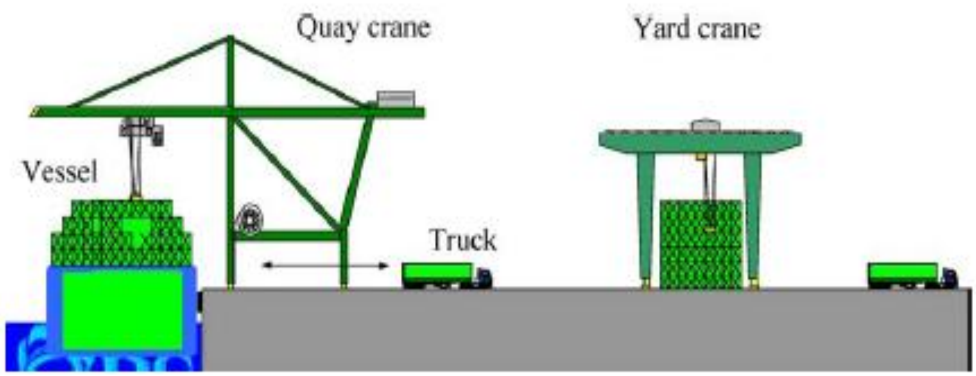

Figure 5: Typical Flow Containers in Terminal Operations (W.c.Ng, K.L.Mak, 2003)

In usual terminals, the storage yard is divided into several tens of blocks with a number of rows in parallel to the berth. Depending on the terminal layout design, each yard block may have more than 30 slots of containers placed end to end with each other. Containers to be further loaded onto another vessel or to be transferred inland later will be stored in the yard temporarily. When multiple vessels are served for loading and unloading, YTs will arrive at different slot locations in a yard block for storing and retrieving containers. The YTs could also arrive to unload at some slot locations for import containers or to pick up an export containers. As a result, YCs need to be fixed between different slot locations in serving YTs jobs with a combination of different types of operations. Both the YC and the YT must be at the same slot position for loading or unloading of containers in the yard.

One of the most important performance targets of terminal operation is to minimize the total container transferring time. Therefore the main objective of the operations system is to serve the cranes and YTs jobs as efficient as possible, which allow vehicles, reduce their delay at the yard side in order to continuously feed the vessels. (Henry Y.K. Lau, et al. 2008)

1.4 Research Objective

The major goal of this study is to simulate an integrated handling system and to find an efficient solution algorithm for Yard Trailer (YT) arrangement. In order to achieve the purpose of this study, the following objectives will be pursued:

- Development of a mathematical model for Yard Trailers arrangement, which is considered under the conditions of both loading and unloading synchronously. This model will be used for finding the exact solution.
- Development of an algorithm to reach a general simulation for searching for the best number of YTs in specific cases. The basic stage technique of Monte Carlo method will be used to generate the random number to simulate, and the Brute-Force method will be used to find the best solution.
- For the final best feasible solution, the proper number of YTs in regards to minimal cost will be presented.

1.5 Thesis Organization

The rest of this thesis is organized as follows: Chapter 2 presents a survey of research work closely related to this thesis's field. Charter 3 addresses the problem statement with discussing the important issues of handling system in the container terminal and the developed model, discussion follows based on constraints. Chapter 4 provides and simulation algorithms and the results of test studies in order to examine the model performance. Charter 5 summarizes the contributions and limitations of the work in this thesis, and indicates some possible future researches.

2. LITERATURE REVIEW

Issues related to container terminal have gained attention recently due to the increased importance of marine transportation systems. There are several aspects in this field. In following, a brief review of existing studies related to this topic is provided in different parts, which are container terminal, handling operations in the container terminal, optimization algorithms which were popular employed in researches. .

2.1 Container Terminal

Modern container terminals are not passive points of interface between sea and land transport, the container terminals have been treated as a logistics centre acting for intermodal interchange. The importance of container terminals to the economic and social dimensions of a community, nation, or region is significant. Better performances of container terminals, could contribute in increasing trade and development of national economies (W. Winklemans and E. Van de Voorde, 2002).

Container terminals can be described as open systems of material flow with two external interfaces. These interfaces are the quayside with loading and unloading of vessels, and the landside where containers are loaded and unloaded on/off trucks and trains. Usually, container terminals are described very specifically with respect to their equipment and stacking facilities.

In many container terminals, zones are normally formed by grouping adjacent yard blocks together so as to simplify the yard crane movement. In figure 6, there are two zones in the yard, zones 1 and 2, formed by grouping blocks 1 and 2, and blocks 3 and 4 together respectively (W.C. Ng., 2005).

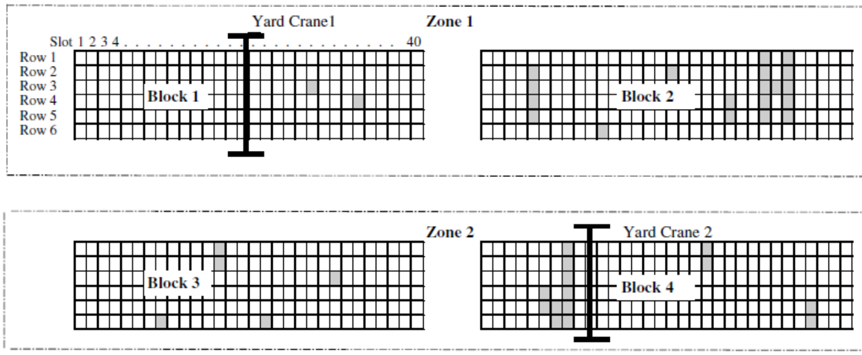

Figure 6: Typical Container Yard Layout of a Container Terminal (W.C. Ng., 2005)

The yard stacks, vessels, trains, and trucks belong to the category 'stock'. Stocks are statically defined by their ability to store containers while from a dynamic point of view. a stowage (or loading) sequence is necessary to instruct that how and where containers would to be stored. There is no principal difference between these different types of stocks but only a difference in capacity and complexity. (Dirk Steenken, et al., 2004).

2.2 Container Terminal Handling Operations

There are many different handling operations in the container terminals. Researchers have been explored many studies in different parts which can be separated into different aspects depends on the serving procedure. The related research is summarized into the next several groups.

2.2.1 Container Loading /Unloading Process

The container-loading problem has been explored for many years by researchers. Avriel and Penn (1993) developed a simplified mathematical model for the stowage-planning problem based on 0-1 binary linear programming. It tried to minimize shifting operations without considering stability constraints. Avriel et al. (1998) continued to study this problem as a two-dimensional stacking problem, and a heuristic algorithm was developed with the objective of minimizing the number of shifting operations. However, it assumed that there is only one large cargo bay in a vessel without considering constraints related to batch covers and the stability of the vessel.

Kaisar (1999) studied the containership operation. In his study, a vessel visits a series of ports, it was totally empty at the first port the vessel by assumption, and then a mathematical model presented by considering varies factors, such as longitudinal moment, trim. This model deal with containers with same dimensions, different weights, and assumes the container first assigns containers to available positions, if it is not satisfied, then re-assigned. Mix Integer Programming (MIP) with the objective of minimizing the extra container handling was developed in this study. And he continued this problem in his PhD dissertation (2006), he addressed the vessel turnaround time at container terminals is an important measure of a port's efficiency and attractiveness. The speed and quality of load planning affect the length of turnaround time considerably, and the stability of the vessel and a variety of other stochastic processes should be considered. A MIP model was also formulated for the stowage-planning model to minimize extra shifting. And a heuristic algorithm was developed to solve this problem.

The key contributions of this dissertation are as follows.

(1) A mathematical model is developed by considering real life constraints and considering loading/unloading along the entire voyage.

(2) A second mathematical model is formulated to obtain a lower bound on the value of the objective function of the exact solution.

(3) A heuristic algorithm is developed that is guide by practical considerations that account for the structure of the stowage-planning problem.

(4) All proposed mathematical models and heuristic are validated with experimental results. In all cases, these results demonstrate the stability, flexibility and efficiency of the model, and establish its potential as a versatile and practical method for large scale container loading.

2.2.2 Quay Crane Scheduling

Concerning cranes, different types are used at container terminals. The Quay Cranes (QCs) which are worked for loading and unloading vessels play a major role. Two types of QCs can be distinguished: single-trolley cranes and dual-trolley cranes. They move the containers from the vessel to the shore either putting them on the quay or on a vehicle (and vice versa for the loading cycle). There is a picture of QCs provided by Dick in 2004, shown in figure 7

Figure 7: Quay Crane: Dual-Trolley Cranes (Dirk Steenken, et al., 2004)

Various studies on the scheduling of QCs were done by different researches. Daganzo (1989) studied the static and dynamic QC scheduling problems for multiple container vessels. He firstly assumed that container vessels were divided into holds, and only one QC could work on a hold at a time. QCs could be moved freely and quickly among holds, and container vessels could not depart until all their holds had been handled. The objective was to serve all these container vessels, while minimizing their aggregate cost of delay. And then exact and approximate solution methods for QC scheduling were presented. Later, a branch and bound algorithm was developed for further study on the same problem by Peterkofsky and Daganzo in 1990. However, both of these two papers overlooked that the QCs could unrealistically cross over each other.

Lim et al. (2004) continued to consider this problem by adding non-interference constraints. They assumed that containers from a given area on a container vessel, and there was a profit value when a job was assigned to a QC. The objective was to find a crane-to-job matching which maximized the total profit. A probabilistic Tabu Search algorithm and a squeaky wheel optimization heuristic were proposed for solving the problem. However, it is difficult to define a profit value associated with a crane-to-job assignment in practice, and hence this research cannot be applied in port container terminals easily.

Kim and Park (2004) discussed the QC scheduling problem with non-interference constraints (QCSNIP). Only single container vessel was considered. Firstly, they defined a task as an unloading or loading operation for a collection of adjacent slots on one single container vessel. The objective was to minimize the weighted sum of the makespan of the container vessel and the total completion time of all QCs. And then they proposed a branch and bound algorithm and a heuristic algorithm called 'greedy randomized adaptive search procedure (GRASP)' for the solution of the QC scheduling problem. But the computational complexity of this problem was not discussed in this study.

Lee et al continued to analysis this problem in 2008. Firstly they developed a MIP model with the objective of minimizing the makespan of handing one single container vessel, which was the latest completion time among all holds according to configuration of container vessels. Secondly, they discussed the computational complexity of the QCSCIP and proved it was NP-hard problem by 4 steps. Thirdly, they proposed an approximation algorithm to obtain near optimal solution, and then evaluated by twenty experiments, the results showed the proposed algorithm was effective and efficient in solving the QCs scheduling.

2.2.3 Yard Trailer Scheduling

Nishimura et al. (2005) considered dynamic YTs scheduling problem in his model. A heuristic was developed and a wide variety of computational experiments were conducted. The results of the experiments demonstrated that the dynamic routing reduced travel distance and generated substantial savings in the trailer fleet size and overall cost (15% reduction). The contribution of this study is the development of a new routing plan achieving container handling cost savings for a terminal. However, the loading and unloading operations of QCs are not considered, and thus it cannot realize the operation coordination between different QCs.

Truck scheduling and storage allocation, as two separate sub-problems in port operations, have been deeply studied in past decades. However, from the operational point of view, they are highly interdependent. Storage allocation for import containers has to balance the travel time and queuing time of each container in yard. Cao, et al. (2008) proposed an integer programming model handling these two problems as a whole. The objective of this model was to reduce congestion and waiting time of container trucks in the terminal so as to decrease the makespan of discharging containers. As the complexity of the problem, a genetic algorithm and a greedy heuristic algorithm were developed to attain near optimal solutions. It showed that the heuristic algorithm can achieve the optimal solution for small-scale problems. The solutions of small-and large-scale problems obtained from the heuristic algorithm are better than those from the genetic algorithm. Der-Horng Lee, et al. (2008) continued to propose a novel approach that integrates these two problems into a whole. The objective was to minimize the weighted sum of total delay and the total travel time of yard trucks. Due to the intractability of the proposed problem, a hybrid insertion algorithm is designed for effective problem solutions. Computational experiments are conducted to examine the key factors of the problem and the performance of the proposed heuristic algorithm.

2.2.4 Yard Crane Deployment

The Yard Cranes (YCs) operations were commonly organized into 3 levels by many researchers.

(1) Before the start of operations, the number of YCs to be deployed for the shift is decided with reference to the number of QCs that will serve the vessels, the number of YTs expected for import/export containers and the amount of container re-shuffling work within the yard.

(2) YCs are distributed to different rows of the yards.

(3) YCs deployment aims to determine the order in which the vehicle (the loading or unloading jobs) is served by the multiple cranes which are sharing the workload in the row of yard blocks.

Kim and Kim (1999) proposed the problem of routing single YC for loading operations of a vessel as Mixed Integer Programming (MIP) model, and in 2003, they continued this problems but solved by presented Genetic Algorithm (GA) as shown by numerical experiments. However, the contribution from them just focused on the vessel loading operations in not useful for large terminals with many berths.

Zyngiridis, et al. (2005) proposed linear integer programs for one or two equal sized Automated Stacking Cranes routes scheduling in a single block working with straddle carriers. The objective was to minimize the total travel distance of cranes while giving priority to export. The big contribution of this work was considering the straddle carriers. The difference between them from normal vehicles was that straddle carriers can pick up and place down the containers by themselves while normal vehicles need cranes in carrying out these operations.

Lee, et al. (2007) presented the problem of loading operations with two YCs serving one QC. A simulated annealing algorithm was addressed with the objective which is minimizing the total loading time at the stack area.

There are some but not abundant works which focused on the inter-block level YC deployment. Rubber Tired Gantry Cranes (RTGCs) are the most frequently used equipment in yards for container handling. The efficiency of yard operations highly depends on the productivity of these RTGCs. Zhang, et al. (2002) addressed the RTGC deployment to find times and routes for RTGC movements. Firstly, given the forecasted workload of each block in each period of a day, the objectives were to find the times and routes of cranes movement among blocks and minimize the total delayed workload in the yard. The problem is formulated as a mixed integer programming (MIP) model and solved by Lagrangean relaxation. To improve the performance of this approach, the authors developed this Lagrangean relaxation model by adding additional constraints and modify the solution procedure accordingly. Computational experiments showed that the modified Lagrangean relaxation method worked well and could reach good solutions in a short time. Cheung, et al. (2002) also used MIP model for the problem about allocating YCs among yard blocks to schedule inter-block movements. But they did not show simulation to test performances.

W.C.Ng, K.L.Mak (2005) addressed the problems of scheduling YCs to perform a given set of loading/unloading jobs with different ready times within movement zone. Firstly, they formulated this problem as a MIP model with the objective that minimizing the sum of job waiting times. Secondly, they noted that for this case, YCs deployment was a problem of non-reemptive scheduling with different job ready times on a single machine to minimize total completion time and the scheduling problem is an NP-complete problem, a branch and bound algorithm was proposed to solve it optimally, and in order make it be more efficient, there was an efficient and effective heuristic used for searching the lower and upper bound. Finally, the small size number randomly generated problems were solved by CPLEX, the larger size number randomly generated test problems were solved by the branch and bound algorithm. The computation results have shown that the algorithm works well for most of the test problems.

XiGuo, et al, (2008) considered the problem of partitioning h blocks in the same row in the container storage yard into k non-overlapping zones, there was two assumptions in the YC dispatching problem: Each vehicle job handles one container only and real time information on the location of each vehicle with becoming to the row of yard blocks for the storage/retrieval job is available. The objective of partitioning h blocks in the container storage yard into k non-overlapping zones was to minimize the average job waiting time for reducing the QC waiting time for vehicles so as to reduce vessel turnaround time. The problems solved by partition algorithm and simulated by real time data. Computation test results showed that choosing the best performing partition plan based on the optimized service sequence will be able to produce the smallest vehicle waiting time, which will help maintain the continuous feeding of the QCs by the vehicles and thus reduce the vessel turnaround time. The authors also recommended that developing techniques such as dynamic programming to remove repeated computation in the workload partition process is one is useful for future work.

2.2.5 Integration of the Operation Scheduling

The operation efficiency of container terminals depends on the coordination of different sub-processes, in order to improve the operation quality in the container terminals overall, the integrated handling system which combines those different necessary equipments. However, the optimization models mentioned above just focus on a single equipment operation optimization cannot optimize the cooperation activities.

Kozan and Preston (1999) first descript the layout of a multimodal container terminal by drawing a map, in figure 8, and they developed established a MIP model to optimize both of the loading and unloading. In this model, two areas were involved: storage strategy of the containers in the yard and loading and unloading orders. The objective of the model was to minimize the stay time of a vessel in a berth, and the vessels berthing time were employed as a constraint. The storage points were described by matrix based on Cartesian coordinates. Then, a genetic algorithm was used to obtain near-optimal solutions in reasonable time. the authors also recommended that The possibilities of using other heuristic techniques, like simulated annealing, neural networks, or Tabu search, should be examined in future research, to see if these techniques could work better than the GA and thus improve the solutions that can be found to schedule the order of container transfers.

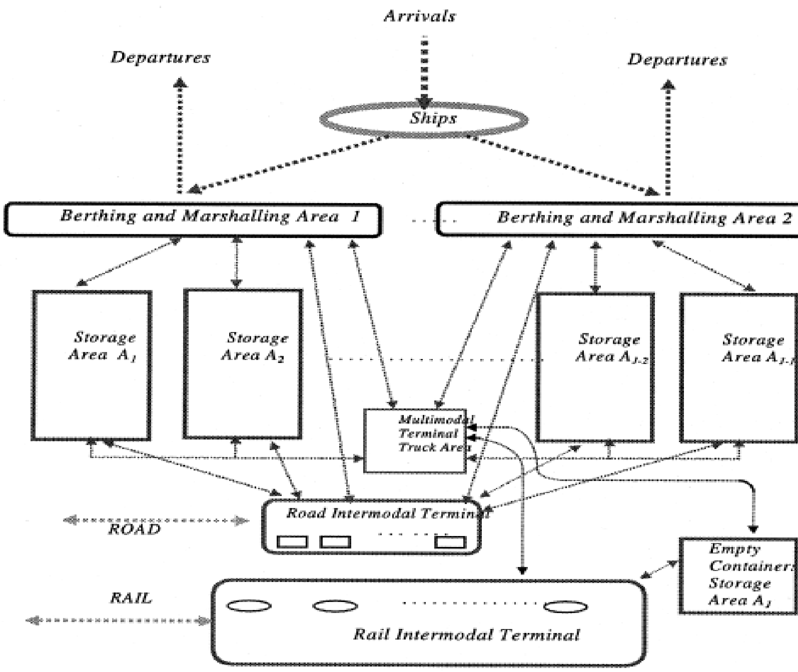

Figure 8: A Layout of a Multimodal Container Terminal （Kozen and Preston, 1999）

Patrick, Albert (2001) considered the problem of integrated scheduling of various types of handling equipment at a container terminal, where in order to minimize the makespan of the schedule. The model in this study was focused on the loading of a single container corresponds to three jobs, which are carried out by different types of equipment: the automated stacking crane (ASC), the automated guide vehicle (AGV) and the QC. The objective of this model is to minimize the time at which the last QC finished loading. A Branch & Bound algorithm was presented that uses various combinatorial lower bounds. Computational experiments show that this algorithm is able to produce optimal or near optimal schedules for instances of practical size in a reasonable time. The authors also develop a Beam Search heuristic that can be used to tackle very large problem instances. The experiments show that for such instances the heuristic obtains close to optimal solutions in a reasonable time.

Bish (2003) addressed the problems to integrate several sub-processes which contained a storage location for each unloaded container, dispatching vehicles to containers and a schedule for loading and unloading operations on the cranes so as to minimize the maximum time it takes to serve a given set of vessels. He proposed a heuristic algorithm based on formulating the problem as a transshipment problem schedule unloading and unloading simultaneously. The effectiveness of the heuristic was analyzed from both worst-case and computational points of view.

Chen et al. (2007) developed an integrated model to schedule the equipment in the container terminal to optimize both loading and unloading process. The problem was formulated as a Hybrid Flow Shop Scheduling problem with precedence and blocking constraints (HFSS-B). A Tabu Search algorithm is proposed to solve this problem.

Lau, Zhao (2008) constructed an operation model for optimizing the AGV, working orders of QCs and YTs simultaneously. Firstly, a mixed-integer programming model was designed which considered various constraints related to the integrated operations between different types of handling equipment. Secondly, a heuristic method was proposed called multi-layer genetic algorithm (MLGA) to obtain the near- optimal solution of the integrated scheduling problem, and then an improved heuristic algorithm, called genetic algorithm plus maximum matching (GAPM) was developed for reducing the computation complexity of the MLGA method. Thirdly, the authors compared the performance of GAPM and MLGA, which indicated GAPM is more suitable for solving real-world problems, which usually involved large problem sizes.

Zeng, et al (2009) developed two scheduling model based on the "multi-crane oriented" method to optimize the loading and unloading operation simultaneously. Firstly, they constructed a model for an inter-ship-based sharing method which means that yard trailers (YTs) can be shared by QCs of different vessels, this model contained both of QCs scheduling and YTs routing, with minimize the completion time of unloading and loading container respectively, a two-phase Tabu Search algorithm was designed for this problem, which could improve the solution significantly and reach convergence in relatively efficient time in this cases. Secondly, a model for a ship-based sharing method which YTs can only be shared by QCs of the same vessel was developed by authors with the objective of minimizing the total unloading time. Q-learning algorithm was used to solve this problem for efficiently. Finally, the authors summarized through numerical results that the inter-ship based method can decrease YTs empty travel, improve the YTs utilization, and thus improve the operation efficiency of container terminals, while Ship-based sharing method can reduce the disequilibrium of different working lines, and thus can improve the loading or unlading efficiency.

Zhang Haiqing, et al, (2008) presented the new deployment about the horizontal transport and equipment in the container port such as container truck and find the mathematic model which took into consideration serving time of QC and YC, the efficiency of QC and so on. The model was this research is based on reducing waiting time in the container truck. They addressed a formula to evaluate the minimal using YTs numbers, which is showed as following:

$$Tr_{\min} = \frac{\min(\sum_{k=1}^{K} QC(k) + \sum_{j=1}^{J} YC(j) + \sum S_e + \sum S_o + \sum_{k_1=1}^{K}\sum_{k_2=1}^{K} TQ(k_1, k_2) + \sum_{j1=1}^{J}\sum_{j2=1}^{J} TY(j_1, j_2))}{\max\{QC(k), YC(j)\}}$$

Where: $QC(k)$ =unit serve time of QC

$YC(j)$ =unit serve time of YC

$TQ(k_1, k_2)$ =the time of YT travel from QC k_1 to QC k_2

$TY(j_1, j_2)$ =the time of YT travel from YC j_1 to YC j_2

This formula was base on the assumption that the utilization of QCs is 100%, and the waiting times of YTs are almost zero. Through the emulation, the author found that when the number of the container was constant, the new deployment advanced the old deployment in decreasing the container truck and the idle rate of the container truck.

2.3 Optimization Algorithms

In the most past research, the mathematical model and optimization algorithms are developed to look for the optimal solutions depends on some issues, such as what the type and the size of the problem. According to these characteristics, there are some optimal algorithm and methods are very popular for the researchers to conduct the studies.

2.3.1 Genetic Algorithm

Through computer simulation, genetic algorithms are applied to an optimization problem in order to find a better solution. This computer simulation is based on a group of abstract representations of individual solutions. In 1975, genetic algorithms were first created by J. Holland. Usually, solutions are represented in binaries of 0s and 1s, but other encodings are also possible. The evolution normally begins from a group of randomly generated individuals and occurs over generations. In each generation, the fitness of every individual in the group is evaluated; several individuals are selected from the current group depending on their fitness in order to draw a new population. This recombined and mutated population is then used in the next step of the algorithm. Normally, the search stops when either a maximum number of generations have been generated or an acceptable fitness level has been obtained for the group. If the search has stopped due to a maximum number of generations, an acceptable solution may or may not have been reached. Goldberg (1985) suggested that there are significant advantages if the chromosome can be structured.

2.3.2 Tabu-Search

Tabu search is a strategy for solving combinatorial optimization problems whose applications range from graph theory and matroid settings to general pure and mixed integer programming problems. It is an adaptive procedure with the ability to make use of many other methods, such as linear programming and specialized heuristics, which it can direct to overcome the limitations of local optimality. (Fred Glover, 1989). Fred Glover also describes clearly Tabu Search methods for solving mixed integer programming problems in Tabu Search- Part II. He also provided a flowchart of the Tabu-Search in 2001 which is shown in figure 9 and figure 10:

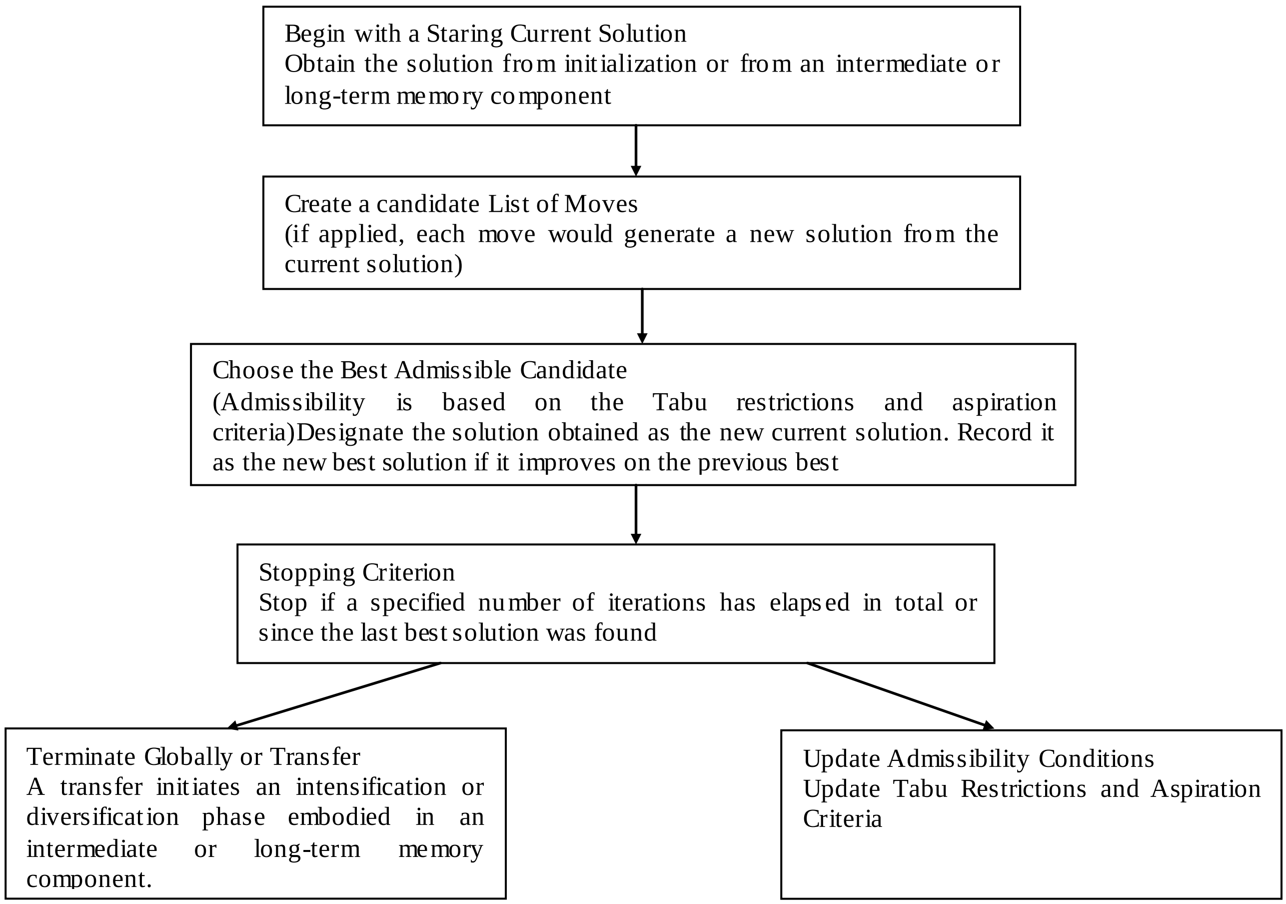

Figure 9: Tabu Search Short-term Memory Component (Fred Glover, 2001)

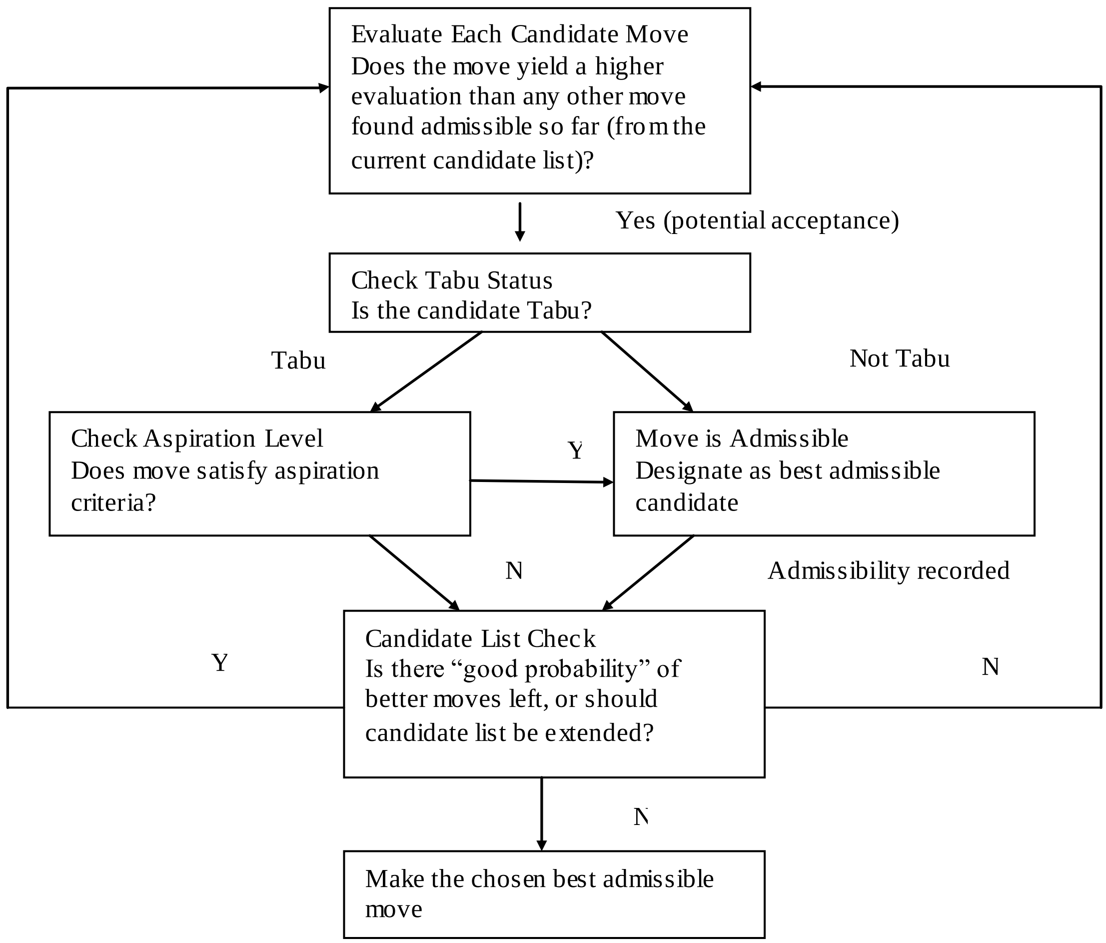

Figure 10: Selecting the Best Admissible Candidate (Fred Glover, 2001)

2.3.3 Monte Carlo Methods

The Monte Carlo simulation technique has been explored since 1940s, where it had applications in research into nuclear fusion. Monte Carlo methods (or Monte Carlo experiments) are a class of computational algorithms that depend on repeated random sampling to compute their results. It provides approximate solutions to a variety of mathematical problems by performing statistical sampling experiments. They can be loosely defined as statistical simulation methods, where statistical simulation is defined in quite general terms to be any method that utilizes sequences of random numbers to perform the simulation. Because of their reliance on repeated computation of random or pseudo-random numbers, these methods are most suited to calculation by a computer and tend to be used when it is unfeasible or impossible to compute an exact result with a deterministic algorithm. It is also useful for modeling phenomena with significant uncertainty in inputs.(Jonathan Pengelly,2002)

The technique of Monte Carlo Method means using random numbers in scientific computing. More precisely, it means using random numbers as a tool to find out the out coming which t is not random. For example, we can generate $X_1,...X_n$, n is independent random variables with the same distribution, then we can use those result to make the approximation of what we really want as:

$$A \approx \hat{A}_n = \frac{1}{n}\sum_{k=1}^{n} X_k$$

The strong law of large numbers in statistics states that $\hat{A}_n \to A$ as $n \to \infty$. The X_k and $\hat{A}_n$ are random and (depending on the seed) could be different or the same each time we run the program. Still, based on the strong law of large number, we can tell the target number A , is not random.

The Monte Carlo Simulation is based on the computer-generated random numbers, actually are not really random, as computers are deterministic. But, given a number to start with--generally called a random number seed--a number of mathematical operations can be performed on the seed and to generate unrelated (pseudo-random) numbers, then the set of random numbers can be used to simulate the distribution, to generate a simulated sample population, and the number we picked to start the performance is generally call the random number seed, which is here related to the result we get from the random experiments The way to do this is that the random variable generator is set to return a random number between 0 and 1.

The output of random number generators is tested with rigorous statistical tests to make sure that the output numbers are random in relation to each another. One caveat: Every time you use the same random number seed, you will always get the identical random numbers. Thus, for multiple trials, different random number seeds must be used. Commercial programs, like Mathematica l, pull a random number seed from somewhere within the system--perhaps the time on the clock--so the seed is unlikely to be the same for two different experiments (Joy Woller, 1996).

Here, there is a need to emphasize the difference between Monte Carlo and simulation. Simulation means producing random variables with a certain distribution just to look at them, for example, we might have a model of a random process that produces clouds. We could simulate the model to generate cloud pictures, either out of scientific interest or for computer graphics. As soon as we start asking quantitative questions about, say, the average size of a cloud or the probability that it will rain, we move from pure simulation to Monte Carlo.

2.3.4 Brute-Force Search

In computer science, Brute-Force Search, also named exhaustive search**,** known as generate and test, is a trivial but very general problem-solving technique that consists of systematically enumerating all possible candidates for the solution and checking whether each candidate satisfies the problem's statement.

Brute-Force Search is convenient to implement, and will always find a solution if it exists by checking every solution in the search space until the best global solution has been found. However, its cost is proportional to the number of candidate solutions, which, in many practical problems, tends to grow very quickly as the size of the problem increases. Therefore, Brute-Force Search is typically used when the problem size is limited, but very efficiency for small size problem to find the best solution. The method is defined as the following procedures: is an approximate solution satisfactory or must it be provably optimal? Heuristics are often used to restrict the search to parts of the state space, thereby sacrificing accuracy for speed. If a solution must be proven optimal, exhaustive search is used.(Ralph udo gasser,1995).

The general steps for the algorithm are:

Step 1: Align pattern at beginning of test

Step 2: Moving from left to right, compare each character of pattern to the corresponding character in test until all characters are found to match (successful search) or a mismatch is detected

Step 3 while pattern is not found and the test is not yet exhausted, realign pattern one position to the right and repeat Step 2.

Moreover, a Brute Force solution to a problem involving search for an element with a special property, usually among combinatorial objects such as permutations, combinations, or subset of a set, the method is:

- Generate a list of all potential solutions to the problem in a systematic manner
- Evaluate potential solutions one by one, disqualifying the infeasible ones.
- When search ends, announce the solutions found. (The Design & Analysis of Algorithms, 2nd

edition, 2007)

Many large problems, for instance integer factorization, traveling salesperson or molecular modeling, can be formulated as search problems. Therefore many researchers focus on problem-independent search algorithms. Naturally, not all search problems yield to the same algorithms. For those large size search problems, Branch and Bound Algorithm are popular as another search algorithm in heuristics.

2.3.5 Branch and Bound Algorithm

Solving *NP*-hard discrete optimization problems to optimality is often an immense job requiring very efficient algorithms, and the Branch and Bound Algorithm (B&B) is one of the main tools in construction of these. A B&B algorithm searches the complete space of solutions for a given problem to find out the best solution. However, explicit enumeration is normally an impossible mission due to the exponentially increasing number of potential solutions. The use of bounds for the function to be optimized combined with the value of the current best solution enables the algorithm to search parts of the solution space only implicitly (Jens Clausen, 1999).

For example, it can be assumed that the goal is to find the minimum value of a function f(x), where the domain of the function is some set S of admissible or candidate solutions (the search space or feasible region). Note that it is the same to find the maximum value of f(x) by finding the minimum of g(x) = − f(x).

We need two tools in the branch and bound procedure. The first one is a splitting procedure: given a set S of candidates, returns two or more smaller sets $S_1, S_2, ...$ which are smaller and the union covers S.. Note that the minimum of f(x) over S is $\min\{v_1, v_2, ...\}$, where each v_i is the minimum of f(x) within Si. This step is branching, as its recursive application defines a search tree whose nodes are the subsets of S. Another tool is a procedure that to find out the upper and lower bounds for the minimum value of f(x) within every given subset S. This step is called bounding.

3. METHODOLOGY AND MODEL DEVELOPMENT

3.1 Preliminary

For most container terminals, there are mainly three types of equipment involved in the operations of the containers, which are Quay Cranes (QCs) worked in the berth, Yard Cranes (YCs) worked in the yard, and Yard Trailers (YTs) worked to transfer containers between berths and yards. Because of the complexity of the scheduling of the YTs in the container terminal, how to dispatch and assign these YTs reasonably is the most important. The rules of dispatching this equipment are various. Generally, traditional operation and dynamic operation are widely used based on the container volume in the container terminal within different periods.

3.1.1 Traditional Operation

As the traditional method (static operation), the port dispatchers deploy the mechanical equipment according to the storage plan of vessels, the number of containers, and the yard slots allocation when the vessel is mooring in the berth. This means that when the vessel arrives, it should be determined whether it needs to be loaded or unloaded first. Then port dispatchers will deploy corresponding Quay Cranes (QCs) depending on the container volume. Based on the number of the QCs, each crane is equipped with 3-4 Yard Trailers (YTs), which means that the assigned YTs are fixed to only a specific QC, and each YT operates a clockwise direction along the transport route. The QCs are working until the vessel leaves the berth. In the process of loading and unloading, QCs, YTs, and YCs are formed into a fixed-line, shown in figure 11 (Liu, 2009).The advantage of this method is that it is easy to operate. However, it cannot meet the requirements in the case that there is a large volume of containers that need to be unloaded and loaded; it always causes gap time, which decreases the productivity. The disequilibrium of different working lines (QCs) may occur. For instance, some QCs may face a shortage of YTs, which probably decrease the entire operation’s efficiency. The disequilibrium of different working lines (QCs) may occur. For instance, some QCs may face a shortage of YTs, which may decrease the whole operation's efficiency.

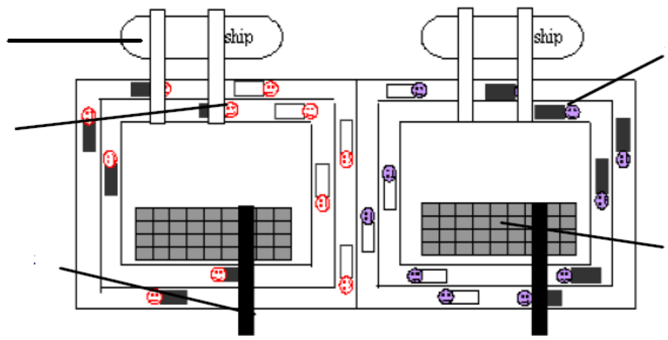

Figure 11: Traditional Operations of the Container Terminal (Liu, 2009)

3.1.2 Dynamic Operation

The traditional operations method cannot cope with large increases in container volume through container terminals. For this reason, dynamic operation scheduling methods have been developed and are widely used in many busy container terminals. There are 2 types of dynamic operations presented by Zeng, et.al. (2009), explained in the following paragraphs.

The first type is the "single-crane oriented" scheduling method. Under this method, the YTs can be shared by different QCs, but only for the same vessel. In figure 12, unloading operations of ship 1 can be divided into three QCs (QC1, QC2, and QC3); YTs are assigned to be shared by QC1, QC2, and QC3, but only for ship 1. Using this method, the imbalance of different working lines, which would occur through the traditional operation method, can be reduced. Thus, the operation efficiency can be improved. However, the YTs' travel distance cannot be decreased because there are many empty travels that would cause the resource to be wasted.

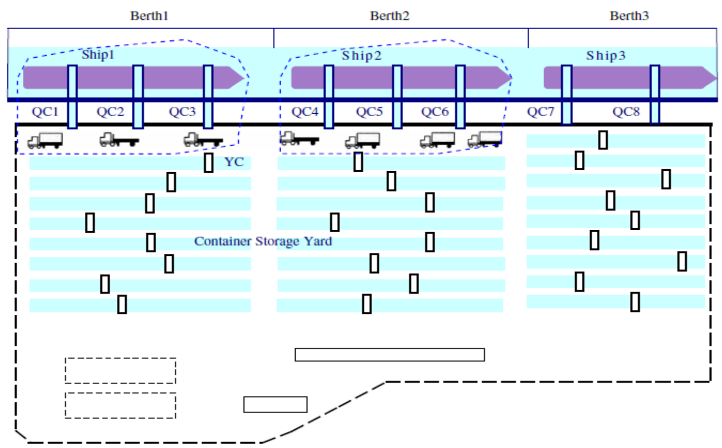

Figure 12: Traditional Method for Yard Trailer Operations (Zeng, et. al, 2009)

Another type of the dynamic method is called the "multi-crane oriented" scheduling method. The operation of this method is shown in figure 13, where D indicates the storage point of an unloading container, and L denotes the storage point of a loading container. When a YT reaches a storage point in the yard after receiving a container from the QC, instead of going back to the QC directly, it continues to go to the next storage point to pick up another container which needs to be loaded. Finally, it transports this container to the QC for loading. This method can reduce the number of YTs needed without increasing the overall dwelling time of the vessel in the terminal and decrease unproductive empty travel, also make the YTs' utilization efficient(Zeng, 2009).

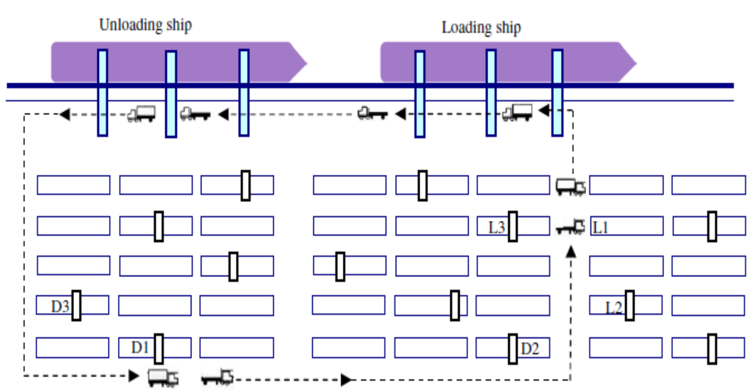

Figure 13: Dynamic Operations—YTs Share for Different Ships (Zeng, et. al., 2009)

In this study, the operations based on the "multi-crane oriented" scheduling method will be simulated. The model focuses on the deployment of the YTs as well as considers the serving time of QCs and YCs.

3.2 The Basic Idea of Modeling

According to practical experience, the mooring cost of the vessels is usually higher than the cost of using the YTs. Therefore in this study, the first principle is that the mooring time of the unloading vessel should be as short as possible. For this purpose, it is necessary to ensure that there are enough YTs for the unloading operations to run smoothly without gap time.

The time duration for one YT to finish a cycle of unloading and loading is random, and it depends equally on the distance of the path the YT travels as well as on the unloading and loading position the YT chooses. The intent of this study is to find all the different paths and to strategically pick the longest one amongst them as the decision basis. Then the distance that a random YT travels in its cycle will be no longer than this; thus, the additional YTs will spend no more time than this for any other travels. A natural result is that if the total number of the YTs is enough for this maximal time duration situation, then it will be enough for any other, so this strategy serves the first principle loyally --- reducing the mooring cost of the vessels.

However, it somewhat requires a considerably large number of YTs, which will cause queuing at those operating terminals and increase the cost of vehicles (YTs). So, under the first principle, the second principle is to find an appropriate total number of YTs that can quantitatively minimize the total cost --- both the vessels mooring cost and the YTs working cost.

3.3 Problem Assumptions and Analysis

Different from the most literatures of the past, this study, based on Zhang's paper in 2008, tries to use the minimal waiting time of unloading vessel as the basis for estimation, and then calculates the number of YTs which are necessary for it, in order to make the operations system run. It turns a series of individual operations for YTs, which include loading, unloading and ground operations, into one integrated deployment schedule, in which YTs can be used in all these tasks.

This study will help YTs to achieve the fully utilization. YTs work on the way between QCs and YCs and other empty YTs can be added dynamically to the operating line at anytime. It can reduce YTs' waiting time and fully use cranes, in order to reach the minimal number of YTs in use in order to make them achieve efficiency. Additionally, the costs of mooring the unloading vessel in the berth are considered as well as the costs of the YTs. They will be acted as elements of the objective function.

As the studied problem is concerning an integrated handling system of the container terminal, the combination of operations is shown in the figure 14. Before the development of the model, assumptions would be supposed:

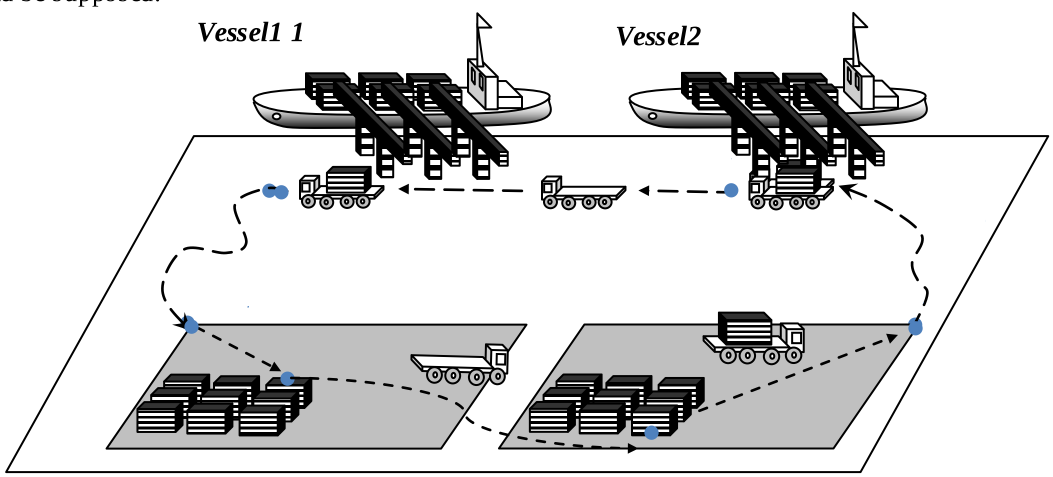

Figure 14: One Circle of YT Travel Route

(1) Suppose there are two vessels, Vessel1 and Vessel 2 for unloading and loading respectively; the operations of the two vessels are scheduled simultaneously:

- The ideal model is developed supposing the container volume of both the unloading and loading vessels are balanced, in order to make the YTs can be used in a full circle;
- These containers are operated from only one side of the vessels;
- The unit time of QC operations are constant;

Because there is a cost for being moored along the berth of unloading vessels, the gap time of two unloading operations needs to be decreased as much as possible, trying to best make the operations of unloading continuous. So, to be most efficient, at the point S there should be at least one YT every unit time of QC operation. (Assume every operation just can deal with one container).

(2) There are two storage yards in this model.

- Left yard, called S_1, is for loading containers which are from the unloading vessel (vessel 1 in the figure) to be stored temporally. The rule is that the containers can be stored at any empty slot temporarily, so in this model, the point in this area will be selected randomly;
- The other storage yard, S_2, is the area where the containers are picked to be loaded to the loading vessel (vessel 2 in the figure), according the description of the yard in the introduction of this study: always are stacked based on certain rules or plans in this yard before loading to the vessel, in this study, the details of the rule will not be developed. To consider this issue, the loading containers will be separated into several groups, and we give some weight value to define the different groups of containers, some of which are defined with the larger number, are first served. In the following model, there are 4 groups of containers which are valued with 4,3,2,1 and will be operated as the certain rule: 4-3-2-1;
- Four containers can be stored in one point.
- The unit times of YC operations in the yards are constant, and assume the YCs are enough that when YT reaches the points, the YC is ready to connect the job.

(3) This study focuses on the finding the proper number of YTs, so the main object is the YT. For whole operations of the YT.

- The job of each YT worked for both unloading a container and loading a container can be described as a circle: it starts from point S at the unloading vessel, then it picks up a container from a QC worked from the unloading vessel to store it in the area S_1, and then goes to area S_2 to pick up another container to load it to the loading vessel. This operations assignment of YTs can reduce the empty ride, which is more efficient.
- As the points in the yards are random, the travel distances of the circles are random, and the travel time of every circle is also random.
- The travel distance of an YT for one circle is shown in the figure 14. The whole distance of one circle (for each YT) can be separated into 6 sections, which are d_1, d_2, d_3, d_4, d_5, d_6. d_1, d_2, d_3 are constant because the position of vessels and yards are fixed, and d_4, d_5, d_6 are variables as the storage points are unknown. It can be expressed through coordinates, however, within the path

$(A\text{-}P_a\text{-}P_b\text{-}B)$, it is not a straight line connecting every 2 points in the yards, the real distance between these 2 points are also not the straight line Euclid distance. 1-norm $d = \|r\|_1$ will be expressed as the real distance.

(4) Because of the randomness of the total time of YTs, the number of the YTs which need to be replenished is also random, which leads to the cost for yard trailers in use is the extraneous variable. We assume that the cost for the use of yard trailer is expressed as a increasing function, $VC(k)$, while the cost for mooring the berth of unloading vessel is expressed as an decreasing function, with k is the number of YTs, because the more YTs that are used, the more cost from this part. However, the more YTs available for use, the less time needed for operations, so mooring the berth cost will be less. However, as the variable $MC(k)$ approaches a certain value it will become constant from the point of the proper number of YTs available, because an increase in the number of YTs available past this point will cause no reduction in total operations time. Also, after combination of these two kinds of cost, there is a balance point (H), shown in the figure 15.

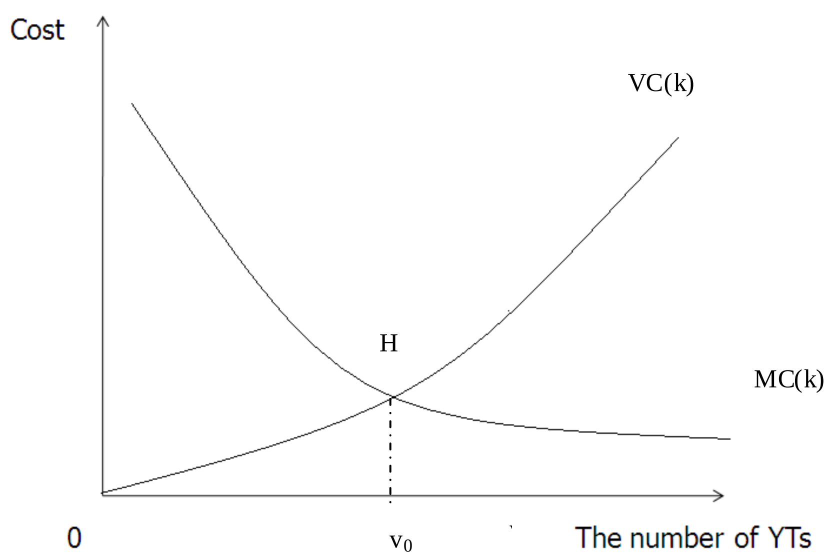

Figure 15: The Relationship between the Cost Function and the Number of YTs

3.4 Modeling

Based on these assumptions, this problem will be developed as a mathematical model with constraints and objective function, as well as some issues that can be also described as math formulas, which are used to replicate and define the simulation.

3.4.1 Notations and Variables

Firstly, the data sets, variables and parameters used in the formulation are defined before development of the mathematical model.

Data

R :	Total number of distance sections, $r \in R$
N^-:	Total number of containers for unloading,
N^+:	Total number of containers for loading, $c, c' \in N^+$
A :	Store point sets in the storage area for loading containers from unloading vessel (which is left area in the figure 14), $a \in A$
B :	Store points set in the storage are of picking up containers for loading vessel (which is right area in the figure 14), $b \in B$
I :	Total number of YTs
L :	Total cycles done by all YTs

Indices:

r :	Index for different section travel distance, $r = 1,\dots,R$.
a :	Index for the points in the area S1 which is for storage, $a = 1,\dots,A$.
b :	Index for the points in the area S2 Which is for picking up, $b = 1,\dots,B$.
c :	Index for the containers which are need to be loaded, $c = 1,\dots,N^+$
i :	Index for different YTs, $i = 1,\dots,I$.
l :	Index for different cycles done by each YT, $l = 1,\dots,L$.

Variables:

k :	The number of YTs in use
P_a :	The random position in the yard S_1 for storage which is available $P_a = (x_a, y_a) \in S_1$
P_b:	The random position in the yard for loading to the vessel which is available $P_b = (x_b, y_b) \in S_2$

$MC(k)$: The cost for mooring in the berth of unloading vessel with k YTs.

$VC(k)$: The cost for YTs fee with k YTs.

d_r: The travel distance of r^{th} section, $r \geq 4$

d_{il}: The distance of the p^{th} cycle of the i^{th} YT

o_{il}: The value of the loading containers

t_{il}: The working time of the p^{th} cycle of the i^{th} YT

$\chi_a(x_a, y_a) = \begin{cases} 1, & \text{If the point } P_a \text{ has been already occupied} \\ 0, & \text{Otherwise} \end{cases}$

$\chi_b(x_b, y_b) = \begin{cases} 1, & \text{If the point } P_b \text{ has the containers needed to be loaded} \\ 0, & \text{Otherwise} \end{cases}$

Parameters:

Qut_0: The time of unit operation of unloading with a QC (min)

Qlt_0: The time of unit operation of loading with a QC (min)

d_1: The distance between unloading vessel and yard S1for storage.($S \rightarrow A$)(mile)

d_2: The distance between yard for loading and loading vessel($B \rightarrow D$)(mile)

d_3: The distance between the two vessels($D \rightarrow S$) (mile)

Yut_0: The time of unit operations for YC in the yard for storage (min)

Ylt_0: The time of unit operations for YC in the yard for loading to the vessel (min)

v: The speed of the trucks (meter/min)

MC_0: The unit cost of mooring in the berth of unloading vessel (\$/min)

VC_0: The unit cost of YTs fee (\$/min*per)

m_1, m_2, n_1, n_2: The length and width of the two storage areas(S_1,S_2)

3.4.2 Mathematical Analysis and Objective Function

(1) According to the first principle, that the mooring time of the unloading vessel should be as short as possible, enough numbers of YTs needs to be assigned at the unloading point to make the system operation run without any delay. So, from this point, there should be at least one YT every unit time of

QC operation. $k = \max_{il} t_{il} / Qut_o$ is used to calculate the number of YTs needed, and the maximum value of time of all circles is accomplished by selecting the longest circle distance that would occur in each simulation.

(2) As mentioned in the problem assumption and analysis, two cost elements are considered in the objective function: mooring in the berth of unloading vessel cost and cost of using YTs.

Therefore, the objective function of this integrated handling system model just based on the YTs scheduling could be expressed as:

$$Z = MC(k) + VC(k)$$

Based on the analysis before, the objective of this problem is to minimize the total cost for this integrated operation, which is denoted by

$$\min_{k \geq 1} Z$$

To define those cost functions specifically,

$$MC(k) = \sum_{l=1}^{L} MC_0 \max_{i,l} t_{i,l}$$

$$VC(k) = \sum_{i=1}^{k} \sum_{l=1}^{L} VC_0 * t_{il}$$

and,

$$\max_{il} t_{il} = \max_{il} \frac{d_{il}}{v} + Qlt_0 + Vlt_o + Vut_0$$

3.4.3 Constraints

(1) Distance constraints

For the total distance of one YT, which is also a whole track of one travel route the i^{th} YT, the equation [1] represents the way to calculate it:

$$\mathrm{d}_{\mathrm{il}} = \sum_{r=1}^{R} d_r , \forall r \in R \qquad [1]$$

(2) Yards constraints

The equations [2] and [5] show that what the ranges of coordinates are within, in order to define the size of yards.

$$0 \le x_a \le m_1 \qquad [2]$$

$$0 \le x_b \le m_2 \qquad [3]$$

$$0 \le y_a \le n_1 \qquad [4]$$

$$0 \le y_b \le m_2 \qquad [5]$$

(3) Container and loading sequence constraints

To simplify the model, also in order to make YTs efficient, we match each inbound container to each outbound container, means the volume of both unloading and loading are balance, the equation [6] restrict it:

$$N^+ = N^- \qquad [6]$$

As stated before, there should be a rule for the loading sequence of containers to vessels from the yard. To consider this point and to also to help the model to be developed easier, we define containers into the four groups with different values, and the sequence of picking up containers to be loaded based on said values. Some of the containers with the larger number will be loaded first. As in the equation [7], the value of the container $c+1$, which is the next loading container immediately follows container c, will be loaded in the loading vessel and cannot be exceed by the value of the last container of which is just loaded. It should be under the certain rule in which the smaller value of containers cannot skip the containers with larger value.

$$o_c - o_{c+1} \ge 0 \qquad [7]$$

3.5 Some Discussion

The following issues need to be discussed:

(1) When k increases, $MC(k)$ decreases because making the operations system keep running, especially at the unloading point, is the main purpose. however, $MC(k)$, this value will approaching a certain value with the increase of the number of YTs, because when the YTs are enough to be served for total containers, the operations time will be certain.

(2) When k increases, $VC(k)$ increases. The queuing is pretty likely to happen because our strategy is to choose k based on the longest path always. But in real situation every YT will arrive at the unloading terminal for a shorter time, and stocking queuing happens. Straight forward to calculate the cost of queuing in this case is very complicated, so this study tries to look for the relationship between the costs and k through the numerical simulation method.

(3) Cost calculation firstly depends on two main parameters: unit vessel cost MC_0 and unit vehicle cost VC_0, the ratio between them directly determines how much vehicle costs we should sacrifice for vessel cost. And, there are another several parameters affect the travel time of each circle and the queuing condition, unloading, such as the load of Vessel 1, which can be simply represented as total unloading number of containers divided by the number of QCs, as well as the unit operations time of every kind of cranes.

4. SIMULATION AND RESULT ANALYSIS

4.1 Simulation Idea and Algorithm

The purpose of this model is to look through the simulation for the best number of YTs with the lowest cost, so the object of the simulation is YT. The total time of one cycle of the YT's travel route includes the traveling time of all six sections and the YCs' unit operations in those two yards, as well as one loading operation of the QC, which is formulated in the following equation:

$$t_{il} = \frac{d_{il}}{v} + Yut_0 + Ylt_0 + Qlt_0$$

Here, the equation overlooks the unloading operation time of the QC from the unloading vessel because the cost of mooring in the berth in the objective function focuses on this unloading vessel. The operations of YTs are optimized for this vessel.

Furthermore, according to the total time per cycle, the number of YTs, which needs to be used to meet the volume requirement without any waiting time of QCs for this current condition, can be calculated with the following. The value calculated through this equation can reach zero gap time each cycle to make the operations connective:

$$k_{il} = t_{il} / Qut_0, \forall l \in L, i \in I$$

Because the time of each cycle of YTs varies from reaching different storage points, there should be a maximum value $\max_{i,l} t_{il}$ among all possible outcomes. The unloading operations will never stop if in $\max_{i,l} t_{il}$ YTs are equipped because during the cycle of any YT, there are always enough other YTs to unload containers from Vessel 1.

Therefore, due to the length of the yards and the technical limitations, the entire system is simulated for selected values of k in various given circumstances. Also, based on the simulation results, the value of

k in certain circumstances is approximately concluded, and the rough relationship between k and the most important given parameters will be considered.

In this study, two methods are employed to achieve the simulation of the operations. The Monte Carlo method is a computational method to approach the optimal solutions by probability statistics. First, in this model, the simple technique of this method is proposed to generate pseudo random numbers for the points in the storage yard to represent the real storage position for the containers in the simulation. The yards will be expressed as matrixes, and each storage point will be denoted as 0 or 1 to define the condition of every specific slot. Because the number of containers which always are provided before starting the operations in the real cases, so the operations need to be served can be known before, the range of YTs usage is defined to restrict the number of YTs in order to avoid worthless. That means there is a range of how many YTs determined with each volume of containers workload. So, in this study, the different cases with different number YTs will be simulated as experiments, so based on those cases provided at the beginning, Brute-force Method will be combined into algorithm to list all the situations results, and compare them. It will be conducted as the major circle of this simulation. Particularly, the steps of the developed algorithm for this specific problem are expressed in the following, and the logic flowing chart is shown in figure 16.

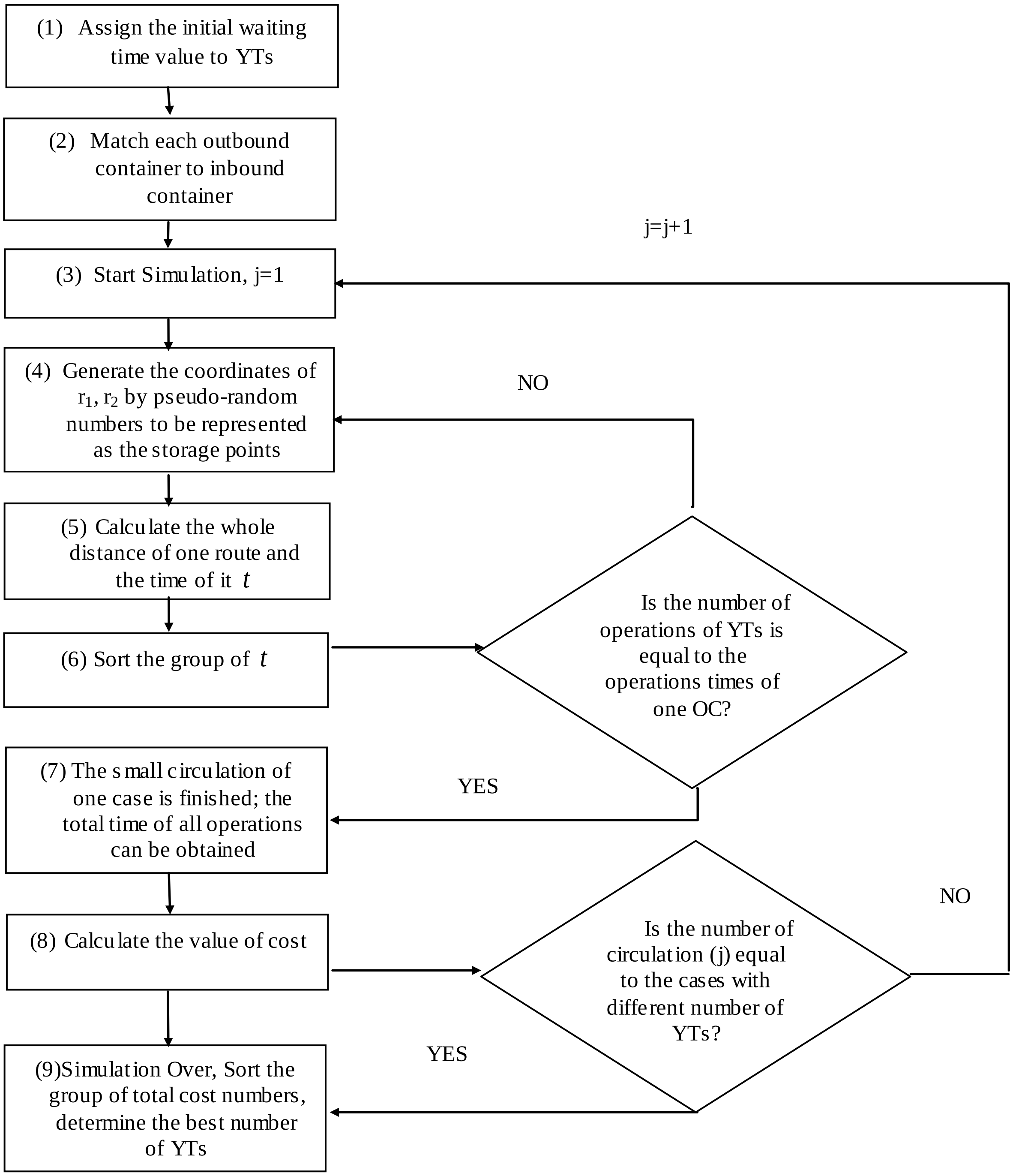

Figure 16: Flow Chart of the Algorithm

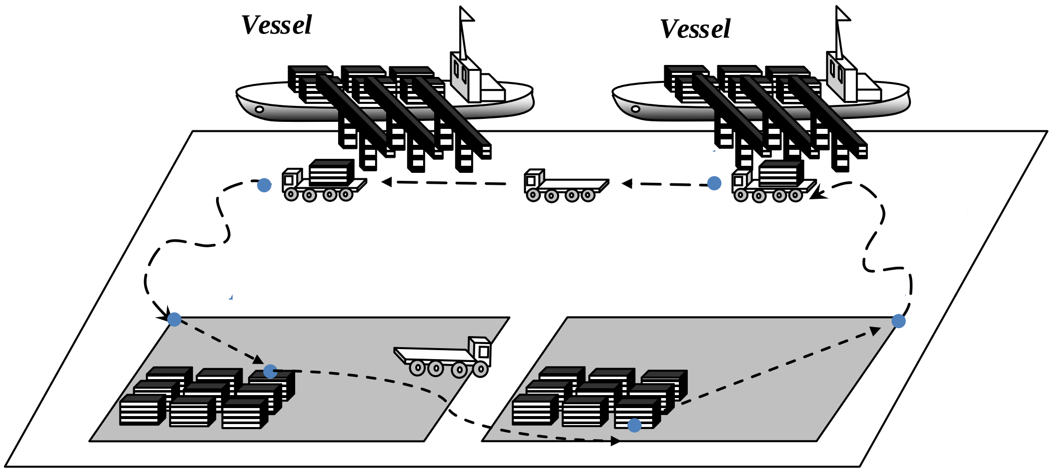

Figure 17: One Circle of YTs Travel Route

Based on it, the specific steps and the calculation methods for them are introduced in following:

Begin:

(1) First, begin to assign the value to the time for YTs which are waiting for unloading, initial the value of t is calculated by $t_i^{(0)} = (i-1)Qut_0$, $(i = 1,2,3,...,k)$, the superscript shows the number of the specific circle, start the first circulation j, , which j=1. Each different value of j represent different cases to be simulated, where, $i \in I = [1,k]$, $l \in L = [0, N^-/q/k = nk]$, $j \in J = [k_{lower}, k_{upper}]$;

(2) The whole route of a YT is S→ A →P_a → P_b → B→ D →S, shown in figure 17, which is a circle curve, the P_a , P_b are given randomly by pseudo random numbers, a distance from storage locations to the berth space is calculated based on the coordinates matrixes. The total distance for each circle is calculated in following, where x_1,x_2,y_1,y_2 represent the coordinates of the entry point A and the exit point B of the yards, x_a,x_b,y_a,y_b represent the coordinates of those storage points of P_a, P_b. And the time of being back to the start point can be get based on the specific formulas:

$$d_{il} = d1 + d2 + d3 + \left|x_1 - x_a^{(il)}\right| + \left|y_1 - y_a^{(il)}\right| + \left|x_a^{(il)} - x_b^{(il)}\right| + \left|y_a^{(il)} - y_b^{(il)}\right| + \left|x_b^{(il)} - x_2\right| + \left|y_b^{(il)} - y_2\right|$$

$$t_{il}^{(j)} = t_{il}^{(0-1)} + Qut_0 + d_{il}/v + Yut_0 + Ylt_0 + Qlt_0, \ (l = 1,2,3,...,nk).$$

(3) Based on the number of operations of the QCs (q) worked for the unloading vessel and the number of YTs decided before the simulation as the input data, the operations of each YT (nk) should be equal to the number of unloading containers (N^-) divided by q*k, and the number of QCs (q) worked for them.

Sort $\left\{t_{il}^{(j)}\right\}_{i=1}^{k}$, which is the set of t value of YT after one loop, where then obtain a new waiting time $\left\{t_{il}^{(j')}\right\}_{i=1}^{k}$。Compare the time value of every YT, If $t_{(i+1)l}^{(j')} - t_{il}^{(j')} < Qut_{o}$, it means that the YTs are enough for 0 delay, meanwhile, $t_{(i+1)l}^{(j')} = t_{il}^{(j')} + Qut_{o}$, $t_{i+1}^{(*)} = t_{i}^{(*)} + Qut_{o}$. If $t_{(i+1)l}^{(j')} - t_{il}^{(j')} > Qut_{o}$, it means that the backing YT cannot connect with last truck with no gap, the trucks is not enough to obtain 0 delay, so there is the cost for delay in this case. In this case, $t_{(i+1)l}^{(j')} = t_{(i+1)l}^{(j')}$. As a result, the total time for the case of k YTs after one circle, also can be represented as the initial time of the next circle, can be obtained, that is $t_{i(l+1)}^{(j)} = t_{il}^{(j')}$, $(l = 1,2,3,..., nk, i = 1,2,3,...k)$.

(4) If the number of YTs operations is less than the operations times of one QC, repeat 1-3 steps. If not, go to step 5.

(5) After the circulation done, the total time of each YT t_i multiple the unit fee, to get the utilization cost of k YT in one Quay Crane, it is $VC(k)$. In all YTs, the biggest value among the set of t_i is the total operations time of unloading operations for the unloading vessel, also can be treated as the mooring time in the berth of unloading vessel, so there is a cost for it, it is $MC(k)$.

(6) Consider the number of Quay Cranes (q), total YTs are $q*k$, cost for utilization is $q*VC(k)$, cost for delay is still $MC(k)$, total is $q*VC(k)+MC(k)$。

(7) Simulate different cases with different number of using YTs, if the number of circulations cannot cover all cases provided based on the number of YTs for use, go back to the first step, with j=j+1,otherwise, stop the all circulation.

(8) Listing all of the results from those circulations, the best feasible number of YTs with the minimal total cost can be obtained from comparison.

(9) Repeat 1-8 steps by multiple times, the statistical result can be approached.

End

4.2. Computation

According to the reality, the value of all parameters can be set up, and collecting the probabilities of all cases through computer simulation, then, the best value with minimal cost can be obtained in the certain condition.

4.2.1. Test Design and Results

Some tests for models will be conducted. Take a typical container as an example: there are two vessels in the berths at a certain moment, and they need to be unloaded and loaded simultaneously. The total number of containers that are needed to be unloaded from the unloading vessel is 2400. To balance the transportation of YTs, the loading containers volume is also 2400.The containers considered in this model are Twenty-foot Equivalent Units (TEU: 20ft*8ft*8.5ft). Moreover, the distance between the unloading vessel and the yard S_1 is 1 km, the distance between the other yard S_2 and the loading vessel is 1km, and the distance between these two vessels is 1km. The unit time of the QCs are 2 minutes per container, both for unloading and loading operations, and the unit time of unloading operations of the YCs is 1.5 minutes per container. However, the unit time of loading operations of the YCs is 1 minute per containers. The velocity of YTs is 20 kilometers/hour. The unit cost for using YTs is assumed as $0.2 per minute, and the unit cost for mooring in the berth of the unloading vessel is $30 per minute by assumptions.

The slot condition is generated randomly by matrixes through MATLAB. These specific two yards in the model, are represented by the coordinate matrixes in two dimensions, in order to calculate the distances. We consider four layers is allowed in the yards which means there are 4 containers can be store at every specific storage point. In programming, another two matrix composed by 0-4 with the same size of coordinate matrixes are generated, each coordinate can match a number between 1 to 4 to express how many container are already in this point. For the yard where the loading containers are stored, to consider the loading sequence of these containers to the vessel, we separate them in to four groups, with different number to represent the situation of the containers in each groups: 4,3,2,1: the containers graded with 4 should be loaded first, then 3,2,1. The containers with the smaller numbers cannot be loaded in the front, if there are still some containers with the numbers larger left. In real world, the loading rules designed based on several matters, such as the weight, destination and so on. As this model doesn't include the consideration of loading details, so we just simplify the loading sequence with grading numbers to define it.

To continue to generate the simulation, we assume there are six sections to compose the whole travel distance of a circle of an YT, the distances of the sections occur in the yards, would be calculated based on the coordinates. Because the distance calculation is a plane calculation, so we just need the x, y coordinates of each point. We assume that the capacity of yard S1 in the model is 100*75*4(length*width*height), total can be stored 30000 units, while S_2 is 100*125*4, total is 60000 units. Thus, there are two 0-1 matrixes are generated through MATLAB, one is 100* 75, while the other is 100*125, the space of each point are defined as the size of containers, the horizontal space is 20ft, the longitudinal space is 8 ft.

Before simulation, based the assumptions we talked about before, the details of the constants which are given as the input data, are shown in the following table.

Table 1 Input Data

Constants	***value***	***Constants***	***value***
N^-	2400	n_1	125
N^+	2400	n_2	75
n	4	(x_b, y_b)	$((m_1+m_2)*dx,0)$
d_1	1km	Qut_0	2min/container
d_2	1km	Qlt_0	2.5min/container
d_3	1km	Yut_0	1.5min/container
d_x	20 ft	Ylt_0	1min/container
d_y	8 ft	v^*	20km/hour
(x_a, y_a)	(0,0)	VC_0	0.2$/min
m_1	100	MC_0	30$/min
m_2	100	$[k_{lower}, k_{upper}]$	[1,20]

Because the storage points in the yards are generated randomly in this model, so the travel distance are variable from different simulations. To make the results and models valid, 10000 simulations are repeated to conduct to get the statistical results. After 10000 simulations runs through MATLAB, the results with these specific inputs are shown in the table. The figures show each cost function trend.

Table 2: Mean Value of 10000 Simulations Runs

The number of YTs	*MC(k)*	*VC(k)*	*Z*
1	437038.8	2918.466	448712.7
2	218410.7	2921.146	230095.3
3	145482.6	2922.37	157172
4	109054.2	2924.138	120750.7
5	87220.99	2926.298	98926.18
6	72685.27	2928.869	84400.74
7	62384.37	2925.714	74087.22
8	54559.96	2935.171	66300.65
9	48573.79	2933.968	60309.66
10	43733.27	2943.24	55506.23
11	39359.52	2914.201	51016.32
12	36076.3	2917.424	47746
13	35940	3151.2	48544.8
14	35940	3396.4	49525.6
15	35940	3642	50508
16	35940	3888	51492
17	35940	4134.4	52477.6
18	35940	4381.2	53464.8
19	35940	4628.4	54453.6
20	35940	4876	55444

The cost of YTs in use for each QC are increasing, especially after testing 12 YTs; the cost of mooring in the berth of unloading vessel has a typical characteristic: in the cases with 1-12 YTs, the value are decreasing, as more YTs are using, less serving time. However, from the case of 12 YTs, this cost function is convergent, which are shown in the following figures.

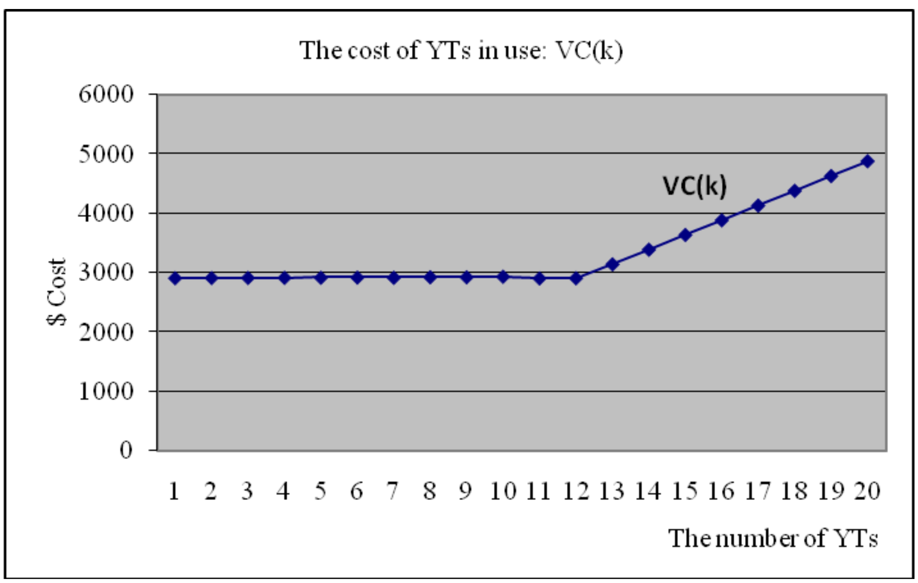

Figure 18: Scenario 1 Results: the Cost of YTs in Use for Each QC: VC(k)

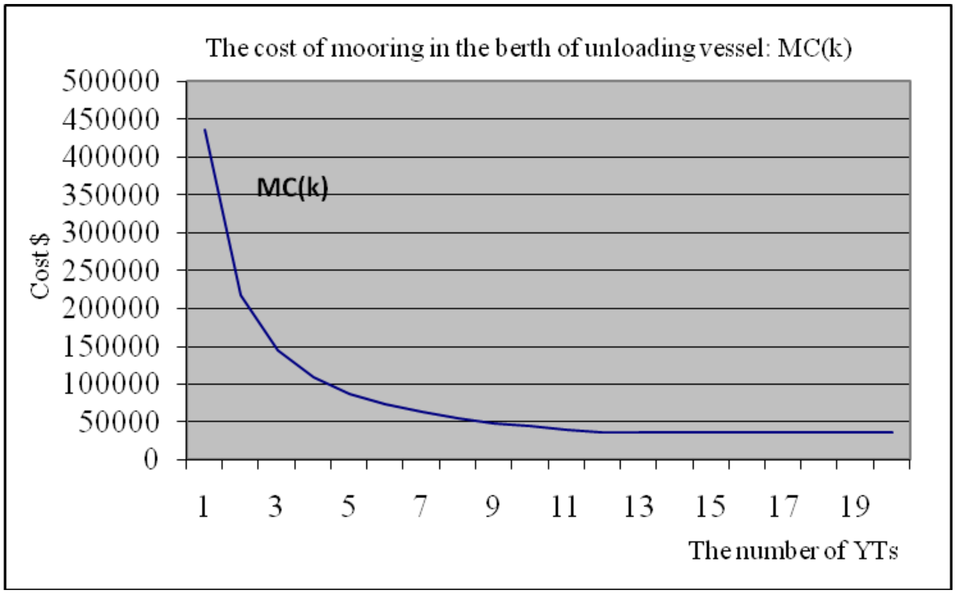

Figure 19: Scenario 1 Results: the Cost of Mooring in the Berth of Unloading Vessel: MC(k)

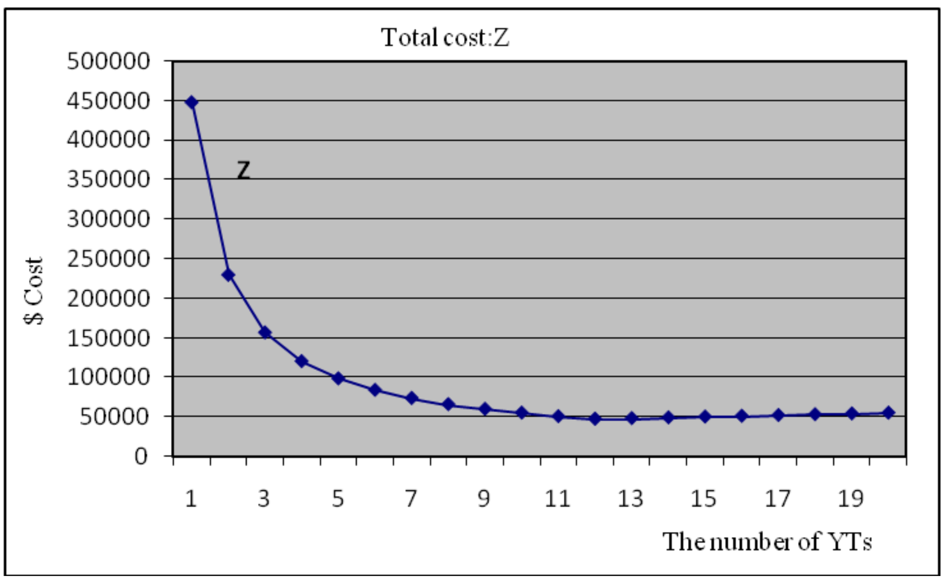

Figure 20: Scenario 1 Results: the Total Cost: Z

From those result obtained, start from testing the 12 YTs' performance, the cost of mooring in the berth of unloading vessel are constant, it means that the 12 YTs are enough for this volume of operations, the increase from the YTs available part will cause no reduction in the whole operations time past this best number of YTs point. Also, there is no linear relationship between the costs of YTs in use and YTs' quantity. This cost based on not only the number of YTs, but also the working time of those YTs. So, from the point of 12 YTs, the cost of YTs in use for each QC increases significantly, as there is no reduction in YTs' working time. Therefore, in case of 12 YTs those are for usage, the minimal cost can be reached in this condition. So, totally there are 4 QCs served for unloading vessel, totally 36 YTs are needed, and the total cost is 2906.4*4+35940=47565.6.

To test how the container storage configuration affect the results, 10 simulations results are selected randomly to be compared among them. The total cost function curves are shown in the following. From those results, we can see the different kinds of cost are variable in the tests of 1-11 YTs, and the 12 YTs are still the proper number of YTs in usage, the total cost are same from 12 YTs to 20 YTs, this characteristic is same as we explained before that 12 YTs can be served for all of the operations with no gap, and from that point, the total time of mooring in the berth of unloading vessel are constant, the spare YTs cannot provide any benefit in reduction time, so only produce the costs of YTs in use, which are become a constant here. The figure 21 shows that before the best number of YTs is reached, there are very small differences in cost between 10 simulations. After this point, cost is the same. So, the configuration of the containers has negligible effect on the cost.

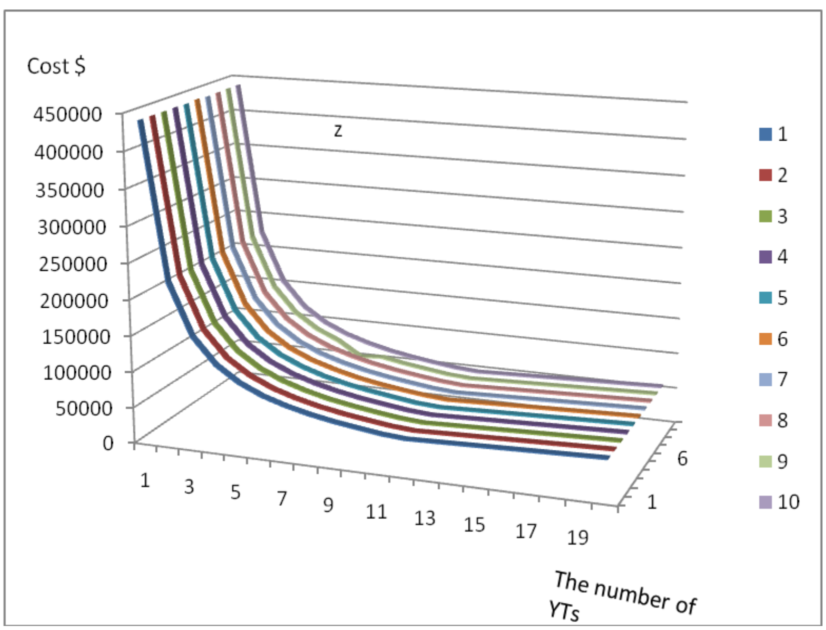

Figure 21: Ten Random Simulation Results

4.2.2. Other Numerical Tests and Analysis

Furthermore, numerical tests will be conducted to examine the validity of the simulation performance. According to the description in part 3.4, these tests are in order to find the relationship between some main parameters and the number of YTs. Cost calculation first depends on two main parameters: unit vessel cost MC_0 and unit vehicle cost VC_0. The ratio between them directly determines how much vehicle cost we should sacrifice for vessel cost. And, there are another several parameters that affect the travel time of each circle. The queuing condition, the load of Vessel 1 unloading, can be simply represented as the total unloading of the number of containers divided by the number of QCs, as well as the unit operation's time of every kind of cranes.

(1) Change in the ratio of the unit cost of unloading vessel moor and the unit cost of vehicle.

The unit cost of mooring of vessels and the unit cost of YTs vary depending on many factors, such as the port situation, the size and owner of the terminals, and the volume of the operations, if there are some leases between the port authority and the vessel companies. However, according to the actual situation, there should be a range that these two cost values can fluctuate within. MC_0 can fluctuate within [5, 30], while VC_0 can be different within [0.2,1]. Based on them, combining these two values randomly, 10 tests are conducted, and the results are shown in the following table:

Table 3: The Results with Different Unit Cost

VC_0-MC_0	***The number of YTs***	***MC(k)***	***VC(k)***	***Z***
0.7-23	12	27661	10211.5	68507
0.3-15	12	18038.4	4376.20	35543.20
0.6-15	12	18039.8	8753.41	53053.44
1-5	12	6013.05	14587.67	64363.72
0.8-9	13	17970	9453.60	55784.40

We can see the best number of YTs in use is also approximately 12. Therefore, the best number of YTs in use is not sensitive to the cost change within those ranges.

(2) Change the ratio of the unloading volume and the number of QCs

In this part, based on most of the input data from the previous test design part, with the same unit operation time of QCs, the same velocity of YTs, and the same size and definition of both yards, only the inbound container quantity and the number of QCs served for them are changed. Usually, the work load for the QC is within 200-600 containers for each vessel, and each vessel is usually assigned 2-6 QCs. According to this practice, the tests with the different groups will be simulated multiple times to get the statistic results, which are shown in the following table:

Table 4: The Results from Different Inbound Volume and Number of QCs

Inbound containers/ QCs for unloading	***best number of YTs***	***MC(k)***	***VC(k)***	***Z***	***maxt***
718/2	12	21627	1761.38	25149.76	716
978/3	12	21627	1602.5	26434.5	650
1214/4	12	23940	2111.2	26051.2	606
1342/4	12	20247.5	1651.34	26852.86	670
1611/5	12	19394.1	1582.81	27308.15	642
2448/5	12	29924.1	2425.3	42050.6	978
1554/3	13	31020	2724.8	39194.4	1034
1171/2	12	35238.7	2850.34	40939.38	1170
2898/5	12	34870.2	2820.91	48974.75	1158
2400/4	12	359400	2906.4	47565.6	1198

(3) Change the ratio of the unit time of the QC for unloading and loading

Keep any other parameters the same. Only the unit time for the unloading and loading of the QC is changed reasonably. Because of the limitation of the QC's technique, there will not be a significant difference in the unit time of the QC both for unloading and loading. So, four groups with different input values of the unit time are tested. The statistic results are shown in the following table:

Table 5: The Results with Different Unit Time of QCs

Qut_0/Qlt_0	***The number of YTs***	***MC(k)***	***VC(k)***	***Z***
1.5-3	12	35940	2906.4	47565.6
2-3	12	36545.2	2955.36	48366.64
1.5-3	16	27064.5	2916	38728.5
1.5-2.5	16	26955	2916	38619

4.3. Summary

From the conducted numerical tests within the same size yard, the container storage configuration has no previously effect on the best number of YTs. Changing the unit cost (with in a valid range) has no affect the best number of YTs; Changing the load on QCs (with in a valid range) also has no affect the best number of YTs, it will affect the total working time and the costs; Changing the unit operation time of the QC for unloading (with in a valid range) has a marginal impact on the best number of YTs because this parameter is the fraction’s denominator of the YTs calculation equation, affect the results directly. The best number of YTs also depends on the unit time of the cranes and the velocity of the YTs, which are the components of that equation. Moreover, even the unit costs will not change the number of YTs a lot; they will dominate the relationship and the trend of those cost functions.

5. CONCLUSION

This study simulates the operations procedures using dynamic YTs operation's method. It seeks to produce a simulation method to understand how this method works and find and evaluate the best feasible solution that considers both minimal cost and increased efficiency of operations for the proper number of Yard Trailers (YTs) at the container terminal. Currently, there has been an exponential increase in container volume shipment within intermodal transportation systems. Container terminals as part of the global port system represent important hubs within this intermodal transportation system. Thus, the need to improve the operational efficiency is the most important issue for container terminals from an economic standpoint and that is why, during recent years, much emphasis has been placed on optimization and simulation of operations planning and sequence in a container terminal.

5.1 Major Contributions of the Study

A mathematical model is developed to formulate an integrated handling system and to find an efficient solution algorithm for Yard Trailer deployment, considering both loading and unloading serving time. This model is used for finding the exact solution.

The model is tailored for certain conditions and is based on several assumptions to define it. Various constraints related to the integrated operations among the different types of handling equipment are formulated. This model takes into consideration both serving time of quay cranes and yard cranes and cost reduction strategies. By decreasing the use of YTs, this model considers the specific objective of minimum total cost, including utilization of YTs and vessel berthing time.

An algorithm is developed to reach a general simulation for searching for the best feasible number of YTs in specific cases. From the Monte Carlo Method, the early stage technique is utilized to generate vast random numbers, in order to replicate simulation for real cases. The brute-force search is used for identifying all potential cases specific to the conditions of this study.

Some preliminary numerical test results suggest that this method is good for use in conjunction with the simulation of container terminal operation, and the simulation make the operations procedure of the dynamic operations methods are understandable. The expected outcome of this research is to find a solution to obtain the optimum number of YTs for transporting containers with a minimum cost; thus improving the operational efficiency in a container terminal.

5.2 Limitations of the Study

This study investigated the mathematical model and a simulation algorithm. In the study, there are limitations relating to the quantity of available data. Also, it assumes several issues in regards to modeling, algoirhm. Limitations associated with each of these factors are discussed next.

Data Collection: Data related to input is critical for the study. While the input data in this study is based on assumptions: some are cited from past research, and some are from estimation. This may cause differences from the real world and eventually cause errors in the results.

Model development: the simulation in this study is based on several assumptions to simplify modeling, and these assumptions of operations and yard conditions make the model and the simulations a little bit different from reality.

Simulation algorithm: The algorithm employed in this study is very good for small sized problems and uses a classical search. Also, a test range specific to the amount of YTs is given in order to reduce the possible simulation times. Therefore, this range may not always guarantee global optimum solutions. Moreover, this study is just based on the simulation, the optimization is not developed, only best feasible solution can be reached, which may not be the optimal results.

5.3 Recommendations for Future Work

The recommendations for future work include the following:

- Input data could be investigated from the real cases in order to make the simulation model the real world.

- Assumptions should be reduced: the loading operations and unloading operations always are different; the yard operations have their specific rules in different cases. Usually, there is a certain arrangement method to generate corresponding positions for containers between vessels to yards. Moreover, cost functions should be considered further under different conditions because they are various according to terminal ownership. To deeply integrate different equipment, the cranes' scheduling should be included.
- This study does not employ the specific algorithm focus on the optimization; the best feasible solutions are reached by direct viewing results from the emulation. The core of this study is a process control problem, and highly depends on the random marks of the yard. To be further studied of the YTs deployment problems, the optimization of unloading and loading scheduling in the yards are strongly recommended to be joined to the model.

APPENDIX

1. The ten randomly different simulations results

The number of YTs	***VC(k)***	***MC(k)***	***Z***
1	2858.3	428050	439483.2
2	2858.3	213700	225133.2
3	2869.4	142820	154297.6
4	2858.8	106630	118065.2
5	2865	85370	96830
6	2870.2	71260	82740.8
7	2869.8	61170	72649.2
8	2869.8	53360	64839.2
9	2877.3	47600	59109.2
10	2877.6	42760	54270.4
11	2858.7	38610	50044.8
12	2906.4	35940	47565.6
13	3151.2	35940	48544.8
14	3396.4	35940	49525.6
15	3642	35940	50508
16	3888	35940	51492
17	4134.4	35940	52477.6
18	4381.2	35940	53464.8
19	4628.4	35940	54453.6
20	4876	35940	55444

The number of YTs	*VC(k)*	*MC(k)*	*Z*
1	2861.1	428450	431311.1
2	2865.6	214240	217105.6
3	2861.9	142510	145371.9
4	2860.5	106670	109530.5
5	2867.8	85520	88387.8
6	2866.9	71170	74036.9
7	2864.9	61050	63914.9
8	2874.8	53430	56304.8
9	2872.9	47520	50392.9
10	2880.5	42800	45680.5
11	2859	38610	41469
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

The number of YTs	*VC(k)*	*MC(k)*	*Z*
1	2861.9	428600	431461.9
2	2859.7	213820	216679.7
3	2863.9	142540	145403.9
4	2864.2	106820	109684.2
5	2865.3	85400	88265.3
6	2864.2	71090	73954.2
7	2866.1	61130	63996.1
8	2873.3	53450	56323.3
9	2867.8	47480	50347.8
10	2886.4	42870	45756.4
11	2854.7	38560	41414.7
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

The number of YTs	*VC(k)*	*MC(k)*	*Z*
1	2858.3	428050	430908.3
2	2858.3	213700	216558.3
3	2869.4	142840	145709.4
4	2858.8	106630	109488.8
5	2865	85370	88235
6	2870.2	71260	74130.2
7	2869.8	61170	64039.8
8	2869.8	53360	56229.8
9	2877.3	47600	50477.3
10	2877.6	42760	45637.6
11	2857.8	38610	41467.8
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

The number of YTs	*VC(k)*	*MC(k)*	*Z*
1	2859.6	428220	431079.6
2	2861.2	213950	216811.2
3	2865.4	142610	145475.4
4	2861.6	106570	109431.6
5	2863.2	85330	88193.2
6	2866.4	71160	74026.4
7	2867.7	61150	64017.7
8	2876.8	53490	56366.8
9	2873.9	47580	50453.9
10	2888.6	42920	45808.6
11	2860.1	38630	41490.1
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

The number of YTs	*VC(k)*	*MC(k)*	*Z*
1	2854.9	427530	430384.9
2	2861	213900	216761
3	2863.3	142530	145393.3
4	2862.6	106770	109632.6
5	2862.5	85320	88182.5
6	2871	71290	74161
7	2862.5	61070	63932.5
8	2871.9	53400	56271.9
9	2877.5	47640	50517.5
10	2881.9	42820	45701.9
11	2843.1	38390	41233.1
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

The number of YTs	*VC(k)*	*MC(k)*	*Z*
1	2862.8	428690	431552.8
2	2859.2	213760	216619.2
3	2860.3	142380	145240.3
4	2863.8	106830	109693.8
5	2866.5	85420	88286.5
6	2873.5	71300	74173.5
7	2864.1	61500	64364.1
8	2875.7	53420	56295.7
9	2873.8	47570	50443.8
10	2880.5	42810	45690.5
11	2854.1	38850	41704.1
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

The number of YTs	***VC(k)***	***MC(k)***	***Z***
1	2853.5	427310	430163.5
2	2861.3	213960	216821.3
3	2862.2	142500	145362.2
4	2863.5	106840	109703.5
5	2864.8	85380	88244.8
6	2862.3	71030	73892.3
7	2866.8	61110	63976.8
8	2877.7	53470	56347.7
9	2874.2	47590	50464.2
10	2885.4	42860	45745.4
11	2862.8	38670	41532.8
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

The number of YTs	***VC(k)***	***MC(k)***	***Z***
1	2856.2	427720	430576.2
2	2863.2	214080	216943.2
3	2859.2	142350	145209.2
4	2862.4	106750	109612.4
5	2864.3	85390	88254.3
6	2868.9	71190	74058.9
7	2866.7	61130	63996.7
8	2874.7	53440	56314.7
9	2873.5	47560	50433.5
10	2884.8	42860	45744.8
11	2868.9	38750	41618.9
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

The number of YTs	VC(k)	MC(k)	Z
1	2858.8	428100	430958.8
2	2861.9	213910	216771.9
3	2863.2	142580	145443.2
4	2864.4	106820	109684.4
5	2864.2	85390	88254.2
6	2866.7	71150	74016.7
7	2867.4	51100	53967.4
8	2877.3	53460	56337.3
9	2871.9	47530	50401.9
10	2883	42840	45723
11	2848.7	38480	41328.7
12	2906.4	35940	38846.4
13	3151.2	35940	39091.2
14	3396.4	35940	39336.4
15	3642	35940	39582
16	3888	35940	39828
17	4134.4	35940	40074.4
18	4381.2	35940	40321.2
19	4628.4	35940	40568.4
20	4876	35940	40816

MATLAB Code

```
%format short

s1=round(rand(100,75)*4);

s2=round(rand(1,50000)*4);

sn=2400;

n=4;

nv=2400/n;nv=round(nv);

d1=1000;

d2=1000;

d3=1000;

dx=12.20;

dy=2.44;

xa=0;ya=0;

n1=100;m1=75;
```

```
n2=100;m2=125;
xb=(m1+m2)*dx;
yb=0;
dt=2;
rt1=1.5;
lt=2;
rt2=1;
v=20;
v=v*1000/60;
vu=0.2;
du=30;
k1=1;
k2=20;
k_3=1;
k_4=1;
k_5=1;
ii=1;
k=k2-k1+1;
vc=zeros(1,k);
dc=zeros(1,k);
z=zeros(1,k);
for kk=k1:k2;
d=zeros(1,kk);
t=zeros(1,kk);
tr=zeros(1,kk);
t1=zeros(1,kk);
nk=nv/kk;nk=round(nk)+1;
for i=1:kk;
```

```
t(i)=(i-1)*dt;
end
n0=0;maxt=0;
for j=1:nk;
k0=0;
while n0<nv & k0<kk
n0=n0+1;
k0=k0+1;
if t(k0)>maxt
maxt=t(k0);
end
end
for i1=1:k0;
x1=0;y1=0;x2=0;y2=0;
for k_1=1:1:7500
if s1(k_1)~=4
x1=k_1/75;
x1=ceil(x1);
y1=rem(k_1,75);
s1(k_1)=s1(k_1)+1;
x1=x1*dx;
y1=y1*dy;
break;
end
end
for k_2=1:1:50000
if s2(k_2)==4
x22=k_2/4;
```

```
x22=ceil(x22);
x2=x22/125;
x2=ceil(x2);
y2=rem(x22,125);
s2(k_2)=0;
x2=x2*dx;
y2=y2*dy;
break;
end
end
if k_2==50000
for k_3=1:1:50000
if s2(k_3)==3
x22=k_2/4;
x22=ceil(x22);
x2=x22/125;
x2=ceil(x2);
y2=rem(x22,125);
s2(k_3)=0;
x2=x2*dx;
y2=y2*dy;
break;
end
end
end
if k_3==50000
for k_4=1:1:50000
if s2(k_4)==2
```

```
x22=k_2/4;
x22=ceil(x22);
x2=x22/125;
x2=ceil(x2);
y2=rem(x22,125);
s2(k_4)=0;
x2=x2*dx;
y2=y2*dy;
break;
end
end;
end;
if k_4==50000
for k_5=1:1:50000
if s2(k_3)==1
x22=k_2/4;
x22=ceil(x22);
x2=x22/125;
x2=ceil(x2);
y2=rem(x22,125);
s2(k_5)=0;
x2=x2*dx;
y2=y2*dy;
break;
end
end
end
d(i1)=d1+d2+d3+abs(xa-x1)+abs(ya-y1)+abs(x1-(x2+m1))+abs(y1-y2)+abs(x2+m1-xb)+abs(y2-yb);
```

```
t1(i1)=t(i1)+dt+d(i1)/v+rt1+rt2+lt;
end;  % for i1=1： k0
tr=sort(t1);
if tr(1)-t(kk)<=dt
tr(1)=t(kk)+dt;
end;
for j1=1:k0-1;
if tr(j1+1)-tr(j1)<=dt
tr(j1+1)=tr(j1)+dt;
end;
end;
for j1=1:k0;
t(j1)=tr(j1);
end;
end;   % for j=1：nk
k3=kk-k1+1;
vc(k3)=0;
for i=1:kk;
vc(k3)=vc(k3)+t(i);
end;
vc(k3)=vc(k3)*vu;
dc(k3)=maxt*du;
z(k3)=vc(k3)+dc(k3);
kkkk(ii)=kk;
ii=ii+1;
 vc
dc
```

```
z
figure
xlabel('kk');
ylabel('vc');
figure
plot(kkkk,dc,'+')
xlabel('kk');
ylabel('dc');
figure
plot(kkkk,z,'+');
xlabel('kk');
ylabel('z')
```

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