8-23-2014

Storage space allocation in container terminals with mixed storage mode under uncertain conditions

Jia HU

SHANGHAI MARITIME UNIVERSITY

WORLD MARITIME UNIVERSITY

Shanghai, China

STORAGE SPACE ALLOCATION IN CONTAINER TERMINALS WITH MIXED STORAGE MODE UNDER UNCERTAIN CONDITION

By

HU JIA

China

A research paper submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(INTERNATIOANL TRANSPORT AND LOGISTICS)

2014

DECLARATION

I certify that all the material in this dissertation that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

(Signature): …………………….

(Date) …………………….

Supervised by

Professor Liu Wei

Shanghai Maritime University

ACKNOWLEDGEMENT

First and foremost, I would like to extend my deepest gratitude to Professor Liu Wei, my supervisor, who has provided me constant encouragement and insightful guidance in every stage of research and writing of this thesis. Without his supervision and help, I could not have imagined accomplishing this thesis.

My sincere thanks also goes to the professors and staffs from World Maritime University and Shanghai Maritime University whose lectures and guidance helped me to make academic progress during the two years.

Finally, I am very grateful to my friends and family for all the supports and understanding that you have given which inspire me to face and fight against the difficulties to strive towards my goal.

ABSTRACT

Title of the thesis: **Storage Space Allocation in Container Terminal with Mixed Storage Mode under Uncertain Condition**

Degree: **Master of Science in International Transport and Logistics**

This thesis studied the storage space allocation problem (SSAP) about the container terminals with mixed storage mode under uncertain condition. The SSAP is decomposed into two sections to allocate the storage space for containers.

The first section is block and bay allocation which decides the number of different types of containers of each berth that are allocated to each block and bay in order to improve the efficiency of handling equipments and to avoid congestion. Based on rolling planning horizon approach, the solution is obtained by two stages with two mathematic programming models respectively. The first stage aims at balancing total workload among different bays, and the second stage is to balance the berth related workload and to minimize the distance traveled by internal trucks.

The second section is slot allocation which is for allocate slots for individual containers under uncertain condition in order to minimize the total number of containers to be reshuffled.. A two-stage methodology is proposed which contains the initial slot allocation planning and the slot re-allocation planning. A NP model is formulated in the initial allocation stage and is solved by heuristic algorithm. In the re-allocation stage, another heuristic algorithm is developed to re-allocate the slots for the containers to arrive in terminal and the containers to be reshuffled.

KEYWORDS: Container terminal, Storage space allocation problem, Mixed storage mode, Uncertain condition

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

SSAP	Storage Space Allocation Problem
CY	Container Yard
IB	Inbound Containers
OB	Outbound Containers
TC	Transshipment Container
D Containers	Vessel Discharge Containers
P Containers	Container Yard Pickup Containers
G Containers	Container Yard Grounding Containers
L Containers	Vessel Loading Containers
TD Containers	Vessel Discharge Transshipment Containers
TL Containers	Vessel Loading Transshipment Containers

1 INTRODUCTION

1.1 Background

Container terminal plays an important role in the maritime transport and even the entire logistic system. How to improve the working efficiency in a container terminal is a cruel issue. Nowadays with the development of the international trade, there are some opportunities and challenges faced by terminals.

First of all, the volume of the international transport and world economy shows a growing trend. As can be seen from Table 1.1, the volume of the world merchandise trade and GDP experienced a growth since the year of 2010, especially in the developing economics and CIS of which the growth is more significant. Container transport, as an important means of cargo transportation, takes a large proportion of the international transport, which is an opportunity for container terminal.

Table 1. 1 - World merchandise trade and GDP, 2009-2014

Annual % change

	2009	2010	2011	2012	2013P	2014P
Volume of world merchandise trade [b]	-12.5	13.8	5.4	2.3	2.5	4.5
Exports						
Developed economies	-15.2	13.3	5.1	1.1	1.5	2.8
Developing economies and CIS	-7.8	15.0	5.9	3.8	3.6	6.3
Imports						
Developed economies	-14.3	10.7	3.2	0.0	-0.1	3.2
Developing economies and CIS	-10.6	18.2	8.1	4.9	5.8	6.2
Real GDP at market exchange rates	-2.4	3.8	2.4	2.0	2.0	2.6
Developed economies	-3.8	2.7	1.5	1.2	1.2	1.9
Developing economies and CIS	2.1	7.4	5.5	4.7	4.5	4.9

Source:World Trade Organization. (2013,September 19). *WTO sees gradual recovery in coming months despite cut in trade forecasts.*

Moreover, with the concern of the economies of scale, vessels are built larger and larger. As presented by Figure 1.1, the size of the largest available containership increased dramatically from the year of 1970 till 2013. The evolution of the largest containerships is a stepwise process. The representative ships class in different stages are: L "Lica" Class (1981; 3,430 TEU), R "Regina" Class (1996; 6,000 TEU), S "Sovereign" Class (1997; 8,000 TEU), E "Emma" Class (2006; 12,500 TEU), and “Triple E” Class (2013; 18,000TEU). It is indicated that the largest containership in 2013 is nearly 5 times larger than the largest containership in 1970. With the growing trend, the volume of the containers loaded and unloaded in a container terminal is also increasing consequently.

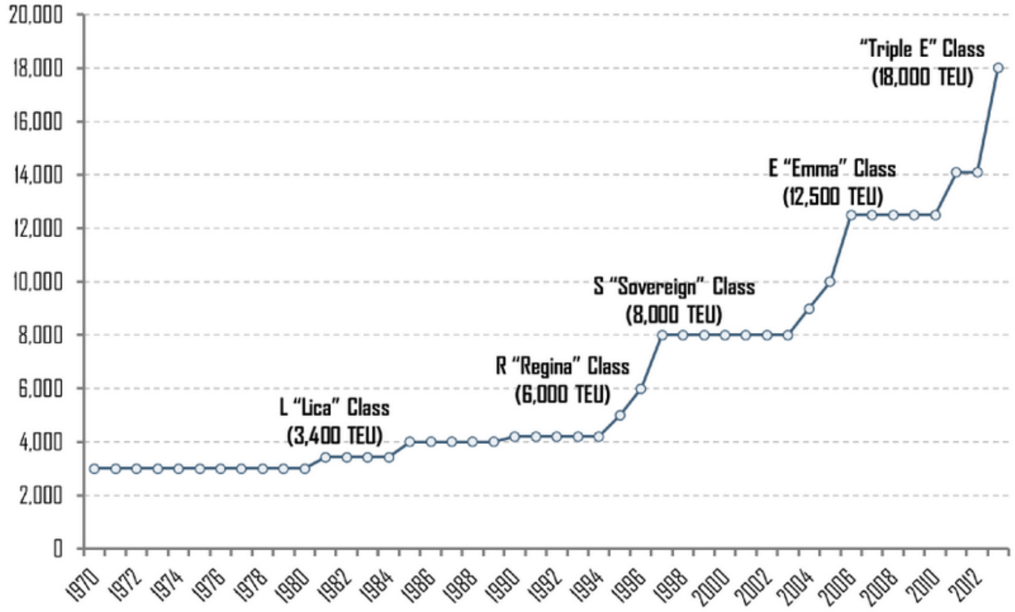

Figure 1. 1 - The Largest Available Containership, 1970-2013 (in TEUs)
Source: Rodrigue, J.P. (2013), *The Geography Of Transport Systems*. Retrieved June 3, 2014 from the World Wide Web: https://people.hofstra.edu/geotrans/eng/ch3en/conc3en/largestcontainerships.html

The growth of internal trade and containership size has brought port operators considerable economic benefits, but it also posed some problems to the capacity of the container terminals. The first problem is that the restricted storage space and the berths of a container terminal cannot hold enough containers and vessels. Second, larger throughput means more containers need to be handled, however the number and the operating efficiency of the cargo handling equipment is also restricted. Finally, the rate of container reshuffle is relatively higher because of the inappropriate allocation of containers. These issues have a direct impact on the traffic of the handling equipment. Consequently, the growth of the container throughput, the turnaround time of vessels and waiting time of external trucks, the reliability of shipping schedule and the operating cost will suffer.

To obtain the competitive advantage of a container terminal, these problems need to be solved to improve the operating efficiency and service of the terminal. There are several ways for terminal operators to consider about: (a) enlarging the container yard to provide more storage space; (b) extending the container terminal with more berths; (c) adding more cargo handling equipments or bringing in advanced equipments. It is no doubt there theses manners are efficient, however they are also the costly ways which only can be realized in medium and long term. In the short term, a more efficient way is to optimize the utilization of the handling equipments and storage space in the terminal to improve the capacity of the terminal.

1.2 Research objectives and significance

Since one of the most important functions of a container terminal is the temporary storage for containers, where the containers can be stacked in the container yard is crucial issue. In order to optimize the utilization of the handling equipments and storage space in the terminal, this thesis will discuss about the storage space allocation problem in a container terminal. There are some difficulties faced by terminal operator that cannot be neglecting to make the storage space allocation decision.

The first difficulty is that the number of containers in a container terminal is large and the types are various, which makes container handling operation and allocation difficult to be fulfilled. In particular, with the growth of the container throughput, the storage space demand is higher than the storage supply in some container terminal. To deal with the imbalance between supply and demand, some of the terminal operators made some adjustment for the container storage mode. Briefly speaking, there are two ways in the container terminal to stack containers. The traditional one is the separate storage mode that inbound and outbound containers are stacked separately in different bays, while the other one is the mixed storage mode which allows the inbound and outbound containers in the same bay. Mixed storage mode can mitigate the problem of the insufficient storage space for terminal; however it also leads to a higher rate of container reshuffle since different containers are mixed up in bays which is more complicated to allocate containers properly.

In addition, the uncertainty of the delivery and pickup time of containers is also one of the difficulties for port operators to deal with. Even though there is a reserved delivery or pickup time of containers, the unpredictable factors still have the possibility to be happened to the customers, which cause the actual time cannot comply with the reserved time. Under the uncertain condition, the Storage space occupation in a containers terminal is always changing rather than under a stable condition. Therefore the reshuffle rate in a container terminal will be higher if the uncertainty cannot be properly solved.

All in all, the management of the containers in the container terminal is very complicated due to the reasons as follows: (a) the types of containers are various and the requirement of storage environment for each type of containers might be different as well; (b) the operating scheduling of different containers are different; (c) and the delivery and leaving time are uncertain. All the issues presented above shows that a scientific storage space allocated approach is needed otherwise the containers cannot be stacked properly, the reshuffle rate will be relatively higher, productivity of handling equipments will be lower, and the waiting time of trucks and vessels will be longer and terminal will suffer congestion. Allocating the containers should be realized scientifically and precisely to ensure the productivity of the terminal and the reliability and efficiency of the logistic system, and to gain competitive advantage for terminal.

To deal with the issues which are presented above, this thesis will establish non-linear programming models to discuss the storage space allocation problem for containers in container terminal based on the mixed storage mode considering about the arrival and leaving uncertainties.

1.3 Literature review

Regarding the Storage Space Allocation problem (SSAP) in Container Terminal, different studies focus on different aspects. (a) According to the layout of the container yard, SSAP can be divided into three parts including container block allocation problem, container bay allocation problem and container slot allocation problem. (b) Based on the storage mode of the container terminal and the types of the containers, SSAP can also be decomposed by three categories: SSAP for inbound containers, SSAP for outbound containers and SSAP for mixed storage mode of containers. (c)Furthermore, there are two sub-categories for each aspect of the studies, which are the study under stable condition and under uncertain condition.

Generally the way to solve SSAP is to establish an optimal programming model with the objectives such as the lowest ratio of container reshuffle, the workload balance in the space that is studied and the shortest travel distance for the internal trucks or quay crane. The illustration and analysis of the former studies based on the storage mode is presented below:

1.3.1 SSAP for inbound containers

Castillo et al (1993) focused on container inbound operations at marine terminals. It presents methods for measuring the number of handling effort required when two basic strategies are adopted, one that tries to keep all stacks the same size and another than segregates containers according to arrival time. Kim & Kim (1999) analyzed the space allocation for each arriving vessel considering about the constant, cyclic, and dynamic arrival rate of inbound containers to minimize the reshuffle rate. Block allocation for inbound containers in a modern automatic container terminal was studied by Yu et. al (2013). According to the different strategies of containers storage, a non-segregation model, a single-period segregation model, and a multiple-period segregation model are established respectively to solve the block allocation problem. Li Pi-an(2013) studied the slot allocation for inbound containers considering about the uncertain condition. In this article, picking up order models are established under stochastic and uncertain condition which are solved by heuristic algorithm. Afterwards, to make an adjustment of the original slot allocation plan and minimize the disturbance, a disruption management model is formulated.

1.3.2 SSAP for outbound containers

Kim et al (2000) analyzed the storage allocation for outbound containers dynamically with a programming model. The objective of the model, which takes the weight of containers into consideration, is to minimize the rate of reshuffle for the loading operation. A decision tree is proposed to acquire the optimal real-time solution in real time. The programming model established by Preston et al (2001) aims at the minimum turnaround time of container ships to allocate storage space for outbound containers. Afterwards, a genetic algorithm is proposed to solve the model. Kim et al(2003) developed a nonlinear programming model to utilize space efficiently and make loading operations more efficient which is solved by two heuristic algorithms based on the duration-of-stay of containers and the sub-gradient optimization technique separately. Yan et al (2009) formulated a model for block allocation with the objectives of the minimum total distance transported by internal trucks between storage blocks and berthing locations, the balanced workload among all the blocks. To get the optimal solution, a heuristic rule and a parallel genetic algorithm are designed to be combined as an algorithm. Li et al (2012) established a stack allocation model for outbound containers and implemented particle swarm optimization algorithm as the solution methodology.

Regarding the uncertainties of the delivery sequence of outbound containers, P.F. Zhou, & P.A.Li et al(2013) established a two-level dynamic stochastic programming model to allocate blocks and stacks which aims at minimizing the travel distance of cranes on the two stages and the rate of container reshuffles respectively. A heuristic algorithm is proposed to solve the model with the combination of the designed priority rules for the selection of blocks and stacks. In the article of P.F.Zhou,& Fang(2011), a similar model was developed which was solved by an algorithm w based on Tabu-search. Besides, considering about the delivery uncertainties, a two-stage model was established to allocate slots for containers. The two stages are the initial slot allocation plan and re-allocation plan for containers. To deal with the uncertain delivery sequence of containers, Shao (2013) forecasted the sequence by Markov prediction methods according to the reservation information of customers. Based on the prediction, a NP model was developed to minimize the number of container reshuffle and was solved by a genetic algorithm. Jin, Mao, & Li (2011) considered the bay and slot allocation of containers which is under uncertain condition as a dynamic shortest path problem. The sequential recurrence algorithm and the inverted recurrence algorithm are integrated to quire the allocation solution.

Different from the researches on delivery uncertainties, Wei (2010) studied the case that the weights of container are unpredictable. Mathematic model were developed to allocate slot for containers in a specific bay and the solution was acquired by heuristic algorithm.

1.3.3 SSAP with mixed storage mode

Zhang et al.(2003) researched on the block allocation problem based on rolling-horizon approach. There are two stages to solve the problem with two mathematical programming models respectively. The first stage aims at balancing two kinds of workload to decide the number of different types of containers allocated to each block. In the second stage, the number of containers associated with each vessel that constitutes the total number of containers in each block in each period was decided with a mathematic model of which the objective is to minimize the total transport distance of containers between the corresponding berths and the storage blocks. Bazzazi et al. (2009) established a mathematic programming model as well to make the block allocation decision. An efficient genetic algorithm was proposed in this article to solve the model. Sharif, & Huynh (2013) established a model with the aim of the balanced workload among blocks and the minimum distance traveled by inter trucks between blocks and bays. An ant-based control method was developed to get the solution. Dong (2011) decomposed the SSAP into two parts, namely, the block allocation, and the bay and slot allocation. In the block allocation section, a NP model was developed with the aim of balancing the two kinds of workload. To allocate bay and slot for containers, another model was established to minimize the reshuffle rate in the container yard. Afterwards, the models are solved by simulated annealing algorithm and a heuristic algorithm separately. J. Zhou (2012) solved the block and bay allocation which were decided by two levels gradually with the aims of the balanced workload and the minimum distance. Then slot allocation was solved with a mathematic model of which the objective is to minimize the reshuffle rate of containers. A block and bay problem was solved by Fan (2013) with a NP model in order to balance the workload associate to vessels and to minimize the transport distance of internal trucks. The solution was obtained by Lingo software. Cui et al (2013) focused on the study of block allocation. A multi-objective programming model was developed to balance two kinds of workload among different blocks and was solved by CPLEX software.

1.3.4 Summary

For the SSAP with mixed storage mode, there are three levels involved to allocated containers-----block allocation, bay allocation and slot allocation. Most former studies solve the SSAP on one or two of the levels of the allocation problem. On each level, mathematic models are usually formulated to get the optimal solution. In general, the objectives set for the models are: (a) to balance the total workload among different blocks (or bays); (b) to balance the workload associate with the vessels among different blocks (or bays); (c) to minimize the total distance transported by internal trucks between blocks (or bays) and the berth allocation; (d) to minimize the total reshuffle rate of containers in a container yard.

As we can see from the former studies presented above, most of the studies are based on the assumption that the grounding time and the pickup time of containers are predictable and fixed rather than under a dynamic condition. Besides, mostly articles focus on the SSAP for the terminals in which the outbound or inbound containers are stacked separately instead of mixed storage mode which has become a trend of the development of container terminals. All in all, there is not sufficient studies focus on the mixed storage mode with dynamic environment which is a gap for this thesis to fill in.

1.4 Research content and framework of this thesis

1.4.1 Research content

This thesis developed mathematic programming models and proposed corresponding algorithms to solve the storage space allocation problem for the terminals with mixed storage mode under uncertain condition. Numerical experiments were designed afterwards to verify the methodology. This thesis composes of 7 chapters:

Chapter 1 is introduction which introduces the research background, the research objectives and significance, the literature review, the research content, the research frame work, and the innovation of this thesis.

Chapter 2 illustrates the container handling operation in container terminal. Basic concepts including the classification of containers, the container terminal layout, the composition units of the storage space, container storage mode in a container yard, and the container handling technology are given in this chapter. Afterwards, the container reshuffle operation including circumstances and reshuffle rules are discussed.

Chapter 3 gives an outlook of the storage space allocation problem (SSAP). After illustrating the basic concepts and theories of SSAP, the factors of storage space allocation, the basic decision making process of SSAP, and the framework of SSAP modeling are given.

Chapter 4 develops methodology to solve the SSAP on block and bay level. Based on the analysis of the block and bay allocation problem, two mathematic models are established in two stages respectively. In the first stage, a NP model is formulated with the aim of balancing the total workload among different bays to decide the number of container to be assigned to each block and bay. In the second stage, in order to decide the number of container assigned for each berth in each bays, multi-objective programming is developed with the objectives of the balanced workload associated with each berth and the minimum total distance transported by internal trucks from bays and berth location.

Chapter 5 focuses on the slot allocation problem which is divided into two stages as well. In this chapter, the slot allocation problem is described and analyzed in the first place, which is followed by the illustration of container reshuffle issue. Afterwards, a model is established in the first stage of the slot allocation for the initial slot allocation planning and is solved by a heuristic algorithm. In the second stage, which is the stage for slot re-allocation planning, another heuristic algorithm is proposed to decide the slot allocation dynamically under uncertain condition.

Chapter 6 presents two numerical experiments which are solved by the methodologies of the block and bay allocation and the slot allocation illustrated in this thesis in order to evaluate the methodologies.

Chapter 7 is the summary and prospect of this thesis which points out the main contribution and the shortage of the thesis, and then suggests the future study direction.

1.4.2 Framework

The framework of this thesis is presented in figure 1.2.

1.5 Innovation of this thesis

The innovation of the thesis, first of all, is that it gives a research on the SSAP with mixed storage mode of containers which has not been widely discussed in the previous studies. Secondly, the container allocation study in this thesis not only regarding blocks but also the bay and exact slot.

Moreover, different from the mostly previous articles that established the model based on the assumption of the stable environment, this thesis considers about the dynamic condition with container delivery and pickup uncertainties in the real word by two-stage approach, which ensures the result is more closed to real-world cases to obtain the actual optimal result.

Finally, in the slot allocation section, this thesis proposed a methodology to re-allocate slots for the containers that need to be reshuffled.

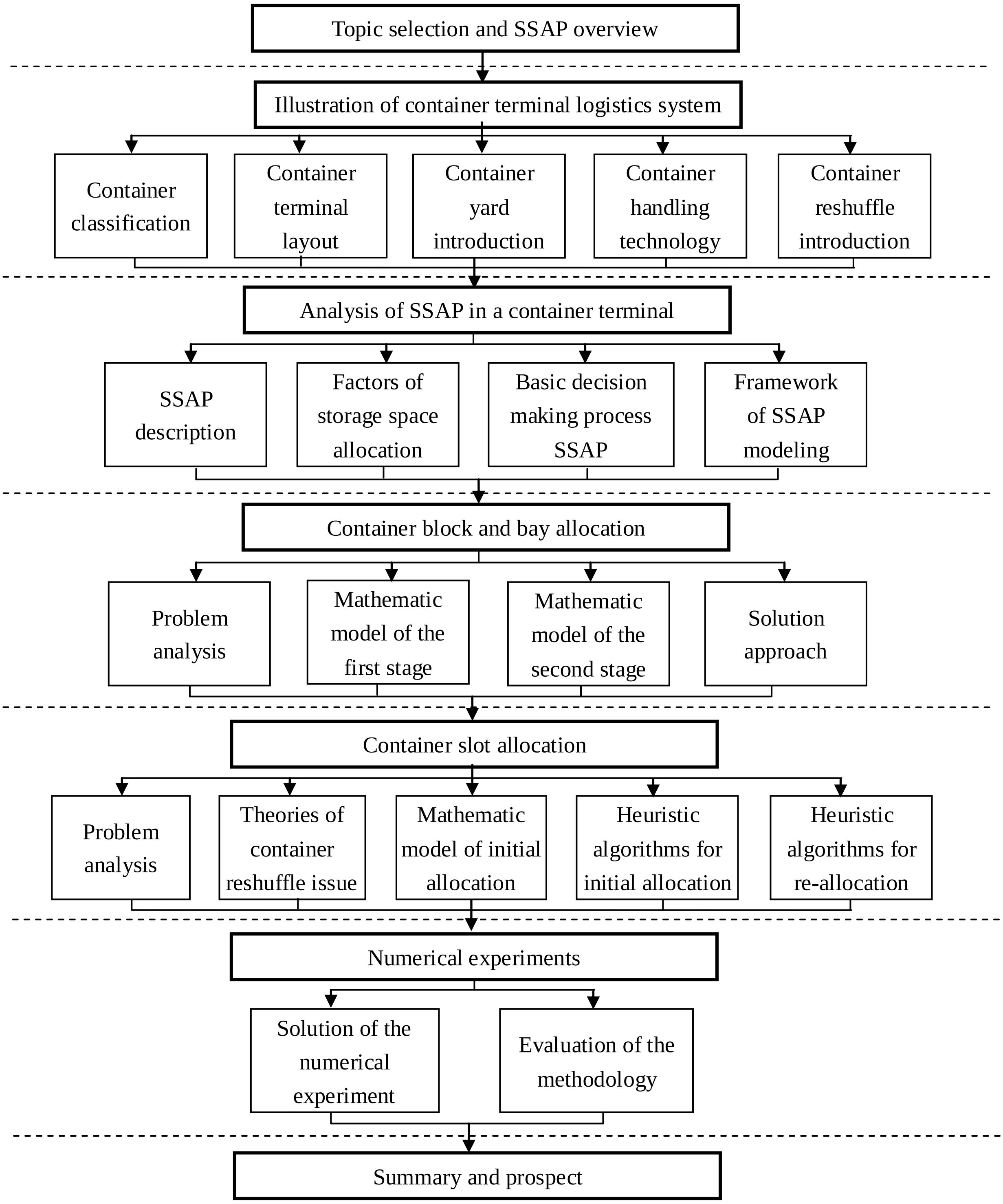

Figure 1. 2 - The framework of this thesis

2 CONTAINER TERMINAL LOGISTICS SYSTEM

2.1 Container classification

Container is the re-sealable standardized transportation box which can be stacked up and handled by standardized equipments. Containers can be classified in various ways. According to the size of the containers, the most common ones are twenty-foot equivalent unit (TEU) and fourty-foot equivalent unit (FEU). Moreover, the goods and items inside also results different types of containers. To be specific, there are dry containers, bulk containers, refrigerated containers, dangerous containers, open-top containers, platform-based containers, tank containers, car containers, empty containers and so on. Different types of containers have different limitations and requirements to the container terminal. For instance, refrigerated container must be stacked in the block which enable it access to the power-supply facilities; dangerous containers is required to be allocated separately and kept enough distance with other containers; empty containers cannot be stacked under full containers. This thesis discusses about the storage allocation of regular containers which only follow the regular rules to be stacked.

Besides, when it comes to the containers in a container terminal, there are three types of containers: inbound, outbound, and transshipment containers according to the types of container flow.

a) An inbound container (IB) are a container which is discharged from the vessel at berth and stored in the container yard temporarily----usually for 1 to 10 days---until being picked by customer.
b) An outbound container (IB) is a container in the container terminal that is delivered by customer and stacked there since several days before the arrival of

the vessels until it is loaded onto the corresponding vessels.

c) A transshipment container (TC) is a container which is discharge from the vessels at berth and stored in the container yard temporarily until it is loaded onto another vessel.

Furthermore, inbound and outbound containers also can be classified into the following four types according to their status at different handling stages (Zhang et al., 2003):

a) Vessel discharge (D) containers: IB containers which are on board and waiting for being discharged and allocated to the container yard.
b) Container yard pickup (P) containers: IB containers which are staying in the container yard and will be picked by customers. D container will turn to P container after it is allocated to the yard.
c) Container yard grounding (G) containers: OB containers which have arrived at the gate of container terminal and waiting for the yard storage space allocation.
d) Vessel loading (L) containers: OB containers allocated in the yard already and will be loaded onto corresponding vessels. G container will turn to L container after it is allocated to the yard.
e) Vessel discharge transshipment (TD) containers: TC containers on board until they are discharged and allocated to the yard.
f) Vessel loading transshipment (TL) containers: TC containers which are waiting in the yard before they are loaded onto other vessels. TD containers will turn to TL containers at the time when it is allocated to the yard.

This thesis focuses on the storage space allocation for the containers illustrated above except the TC containers.

2.2 Container terminal layout

Container terminal is an essential facility for container to be transshipped between different vehicles --- not only vessels, but also trucks and trains etc. --- and for container vessels to berth and load or discharge containers. It is stated that container terminal plays an important role for the whole logistic systems to enhance the efficiency of container handling and transportation, and to decrease the turnaround time of vehicles and the operating cost. The main resources in a container terminal are storage space resources and container handling recourses which are container yard and containers handling equipments respectively.

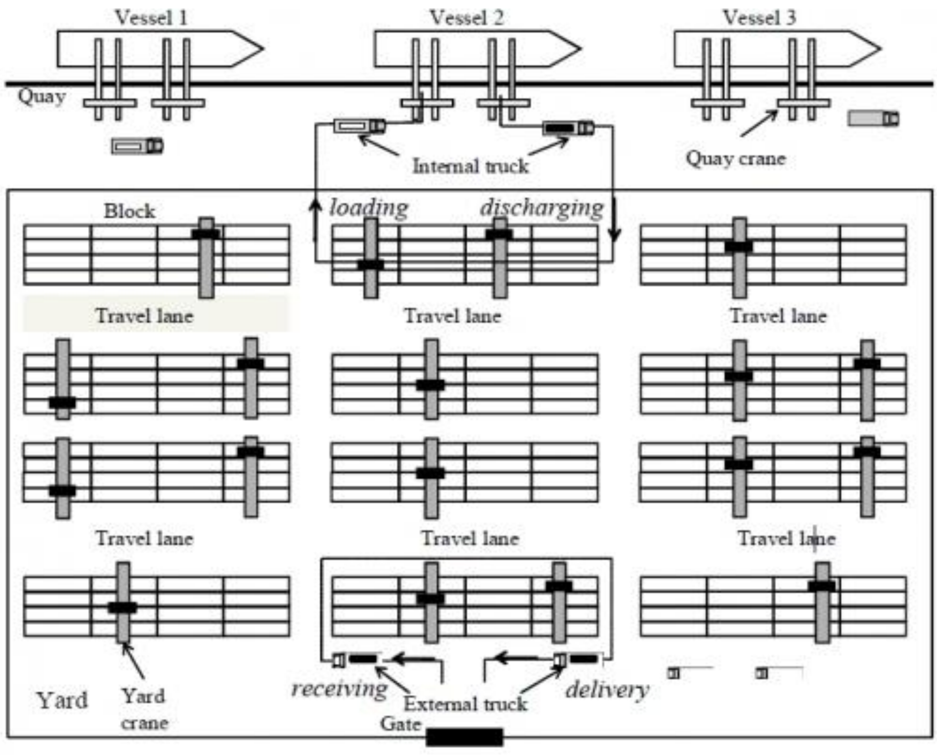

Figure 2. 1 - Layout of a container terminal

Source: Jeong,Y., Kim,K.H., Woo,Y.J., & Seo, B. H.(2012), A simulation study on a workload-based operation planning method in container terminals. *Industrial Engineering & Management Systems*, 11(1), 103-113.

2.3 Container yard

2.3.1 Composition units of the storage space

Container yard, which occupies the main area of a container terminal, is the space for storing containers temporarily. The working efficiency in the container yard is crucial to the benefits of terminal, shipping lines and customers.

Containers yard is divided into different areas for different functions. For instance, according to the goods and item inside the containers, there are areas for regular containers, dangerous containers, refrigerated containers and special containers etc. In some container terminal, the storage space is divided into inbound container area and outbound container area.

In each area, there are several blocks and every block is composed by certain number of bays which is on the transverse direction of the block, as presented in Figure 2.2. A bay is formed by several rows and tiers which are the lengthwise dimension and vertical layer of the block respectively. A group of containers stacked vertically in an exact bay and rows are called a stack. The basic storage space unit is slot, which can fit one container. The number of the rows and tiers in a bay depend on the size of the container yard and the container handling equipments. Generally full containers can be stacked up with 3 to 5 layers while empty containers can be stacked with 7 layers. (Fang, 2010)

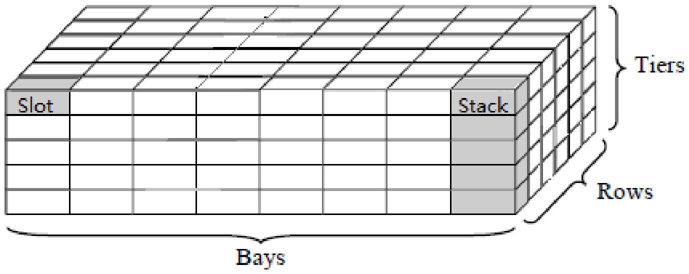

Figure 2. 2 - Composition units of a container block

2.3.2 Container storage modes

This thesis only takes regular containers into consideration. Other types of containers such as empty containers and dangerous containers will not be discussed. There are two typical types of container storage modes, one is separated storage mode, and the other is mixed storage mode.

2.3.2.1 Separated storage mode

Separated storage mode is a traditional container storage mode. In the container terminal with separated storage mode, different types of containers are stacked wither in different blocks or in different bays separately. One typical case of separated storage mode is the terminals with marshalling yard and container yard which is common to see in the countries such as China. Marshalling yard is constructed closed to the water side of the terminal in order to speed up the loading and discharging efficiency of quay crane. Container yard is the storage space which allows containers to be stored for a relatively longer time. To be specific, outbound containers will be stacked in the container yard first in the blocks or bays for outbound containers when they are delivered to the terminal by customers. Afterwards, they will be moved to the marshalling yard in advance before the arrival of the corresponding vessels according to the loading sequence. Regarding inbound containers, firstly they will be stacked in the marshalling yard temporarily at the time when they are discharged from the vessel. And then at the appropriate time, the inbound containers will be stored in the container yard separately from outbound containers to prepare to be picked up by customers.

Even though stacking different types of containers separately can improve the efficiency of quay crane by reducing the rate of container reshuffle, the drawback should not be neglected. Based on this storage mode, the utilization of the storage space cannot be maximized which is not appropriate for the terminal with limited capacity and growing throughputs. Furthermore, stacking containers separately will also lead to the consequence that more container handling equipments are required which will increase the cost of container terminals.

2.3.2.2 Mixed storage mode

The definition of mixed storage mode varies from different articles. In this thesis, the mixed storage mode is defined that inbound containers, outbound containers and transshipment containers are stacked together in the same blocks and the same bays.

Mixed storage mode is more economical compared with separate storage mode because the utilization of storage space is efficient and the number of container handling equipments that are demanded is lower. Nowadays the container throughput is increasing dramatically, which requires more storage space and more container handling equipments in the terminal to improve the capacity of the terminal. Expanding the area of the terminals and investing in more handling equipment would a way to solve the problem. However it is costly and cannot be fulfilled easily in a short term. Hence the mixed storage mode is widely used in the terminal which has a growing trend of container throughput but the storage space is limited such as Hong Kong port.

It is noted that the disadvantage of mixed storage mode is that the storage space allocation for containers is more complicated and is more easily to cause reshuffle problem. The problems will occur since different types of containers are stacked together directly without being stacked in the marshalling yard first. Consequently the operation efficiency of container handling equipments will be reduced and the terminal will suffer congestion.

This thesis will allocate the blocks and bays under mixed storage mode with the aim of the balance of the workload among bays and the shortest transport distance of inter trucks to optimize the utilization of the resources in container terminal.

2.4 Container handling technology

The main container handling equipments are quay crane, internal trucks, external trucks and yard crane in general. All the equipments should be allocated to cooperate with each other in the container terminal to complete the cargo handling operation efficiently. Quay crane is used to discharge containers from or load containers onto vessels. Internal truck is the vehicles provide transportation service between storage space and quay cranes. External truck is used by customers to transports containers into or picks up them from storage space. Yard crane in general is used to handle the containers in the storage space; it can load containers from internal trucks or external trucks and stack them to the container stack, or retrieves containers from stacks and load them onto trucks. (Zhang et al. 2003).

Different types of containers need different processes of handling operations, which is illustrated in Figure 2.3.

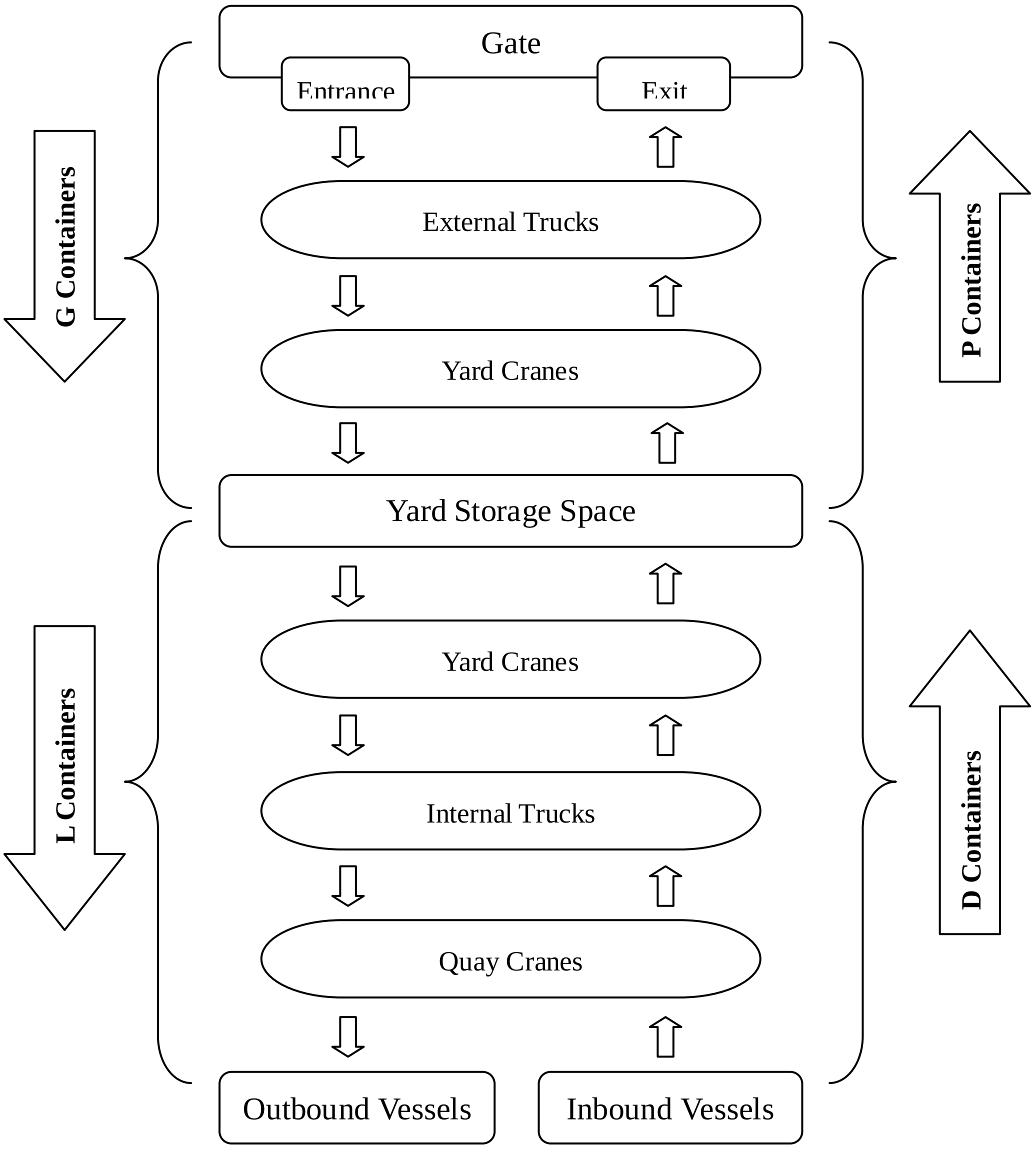

Figure 2. 3 - Container handling operation process

2.5 Container reshuffle

2.5.1 Definition

Containers are metal boxes with standard sizes, which make it more convenient to stack containers stacked on top of each other. However the reshuffle problem caused by stacking containers together cannot be neglected. As a container that is delivered to the container yard first will be stacked to a slot first, other containers that allocated later will be stacked above it if the top tier is still not beyond the limit maximum tier. In other words, the earlier a container comes, the lower tier it is allocated. If there is a container that is not on the top of a stack needs to be retrieved earlier than the containers above it, the containers above needs to be reallocated to other stacks in order to ensure yard crane access to the retrieved container. The re-allocation of the containers is called reshuffle and the reallocated containers are called obstacle containers.

Since it is time consuming to accomplish the container reshuffle operation, whether the reshuffle rate is lower or higher means a lot to the operation efficiency of container terminal. For instance, if a group of L containers in a container yard need to be loaded on board but there are a lot of obstacle containers above them which have to be reshuffled first, the direct affect of the reshuffle operation is that more time and more container handling equipments are needed. Consequently, congestion in the CY will occur, the handling operation efficiency will suffer, and the departure time of the corresponding vessels will be delayed. Furthermore, if the obstacle container is not reallocated to a proper slot, reshuffle problem will be happened again. Therefore, taking method to avoid container reshuffle is significant to improve terminal operation efficiency, to cut down the operation cost and to enhance the economic performance for a container terminal.

2.5.2 Circumstances of reshuffle

Container reshuffle happens to L and P containers when they are retrieved to be loaded onto vessels or picked up by customers. There are several circumstances that may lead to container reshuffle.

a) The schedule of a shipping line has changed.

Any changes to the container vessels, such as the delay of berthing time and adjustment of the shipping route, will influence the loading sequences of containers. If the delay of the vessel has happened and the corresponding containers have to be postponed to be loaded, then the containers probably have to be reallocated to ensure the yard crane to access to other container below. Considering about the reliability of shipping line, in thesis we assume that the schedule of it is stable.

b) The uncertainties of the container grounding time.

Even though container terminal may have reservation information of container grounding in advance, sometimes customers still cannot comply with the reserved time to deliver containers to the terminal. The factors that lead to the delay are unpredictable. For instance, external trucks stuck in the traffic jam on the way to the terminal, or the shipper is not able to send out the goods on time (Shao,2013). Hence the allocation of containers is not in accordance to the planning allocation which might reshuffle.

c) The uncertainties of pickup time of containers.

Sometimes the time when customers pick up containers is different from the planned time. No matter customers pickup the containers earlier or later than the reserved time, reshuffle would be happened.

d) The actual allocation of containers cannot comply with the allocation planning. Since sometimes there is not enough space to stack containers, some containers have to be stacked on the places that are reserved for others containers. In other words the actual allocation is not same as the optimal allocation planning. Therefore the reshuffle problem will occur.

2.5.3 Container reshuffle rules

When a container needs to be reshuffled and reallocated to a new slot, there are some rules to be followed.

Firstly, re-allocation of a container should be operated in the same bay since yard crane cannot move a container from one bay to another concerning about the safety issue. Yard carne is used for handling a container in one bay only and internal trucks is responsible for transporting containers among bays. Therefore, in order to ensure the safety issue and to minimize the transportation distance, reshuffle should be operated in the same bay by yard crane.

Secondly, shortest path to reallocate containers should be selected. The re-allocation of containers in bays should be the stack where yard crane can access to with a short path. In other words, the obstacle containers should be reallocated to the stacks nearby to reduce the waiting time of internal trucks and to avoid yard congestion.

3 SSAP IN A CONTAINER TERMINAL

3.1 SSAP description

Container loading and discharging operation is the core operation in a container terminal. Whether the operation can be undertaken efficiently or not is crucial for the economic performance of the terminal, shipping lines and customers since a container terminal with low efficiency will lead to longer dwell and turnaround time of external trucks. In order to enhance the efficiency of the terminal, invest on enough corresponding container handling equipments that are needed is the basic requirement. Besides, terminal operator should also optimize the scheduling and utilization of the storage space resources and container handling recourses in the terminal. The optimization of the storage space resources is known as storage space allocation problem (SSAP). This thesis discusses the SSAP in the container terminal with mixed storage mode under uncertain condition. The ultimate goal of SSAP is to make the containers handling operation in terminal more efficient which consists of three sub-objectives.

The first one is to shorten the total transport distance traveled by internal trucks between berths and bays in a specific period of time. It is desirable to minimize the distance traveled by internal trucks between bays and berth because the transporting time for each container will be reduced and the productivity of each internal truck will be enhanced. Consequently, less internal trucks will be needed to handle the same number of containers and operating efficiency can be improved as well.

Second, to balance the total workload and the berth related workload among different blocks and bays. If the workload in some bays is higher while in the others are lower, namely the workload is imbalanced, more yard cranes have to be relocated to the bays with higher workload from the bays with lower workload. It will be time consuming to relocate yard cranes which will cause the interruption of the handling operation to wait for the re-allocation. Moreover, since more internal trucks are needed to handle more containers, the traffic volume in the container terminal road network will be imbalanced too. Therefore terminal congestion will take place as a consequence. Similarly, the balance of the berth related workload among different blocks and bays also important as it will make full use of the quay cranes and the internal truck among blocks and berths, and it will avoid the congestion of the berth and container yard.

Last but not least, to minimize the rate of container reshuffle operation. Stacks are ‘last-in, first-out’ storage structures where containers are stocked in the order they arrive. In order to improve the retrieval operation and to optimize the berthing time of the vessels, containers should be retrieved from the stack in the order they should be shipped (Molins,etc.,2012).

With the objectives noted above, SSAP generally can be divided into two parts: the block and bay allocation as the first part, and the slot allocation as the second part. The allocation on block and bay level is for deciding the volume of each type of containers assigned to each blocks and bays to minimize the total transport distance of internal trucks and the workload balance among blocks and bays. Moreover, the slot allocation aims at deciding exact slots for individual containers to be stacked in to ensure the minimum reshuffle rate.

3.2 Factors of storage space allocation

The storage space allocation for containers mainly affects by four aspects, namely, the schedule of shipping lines, the information of customers, the attributes of containers, and the attributes of the terminal (Jia,2013):

a) The schedule of shipping lines. Information including the berthing time and leaving time of vessels, the specific berth assigned to the vessel, and the number of the containers to be loaded onto or discharged from and the berth influence the allocation solution.

b) The information of customers. The grounding time and number of G containers; and the pickup time and number of P containers are needed to solve SSAP.

c) The attributes of containers. Besides the grounding time, pickup time, loading time and discharging time is the result of the schedule of customers and shipping lines which has been illustrated above, some other particular attributes of containers also has an impact on the SSAP. The weight and the discharging port of G and L containers should be taken into consideration to comply with the allocation scheduling of containers in the corresponding vessels.

d) The attributes of the container terminal. Capacity of the storage space, the facility and equipments that are available, the construction structure of the containers terminal especially the container yard should be considered to decide the storage space allocation.

3.3 Basic decision making process of SSAP

To allocate storage space for containers, the decision making basically follows the process as below:

a) For outbound containers, terminal operator needs to gather the reservation information of the containers including the grounding time, number, container size, weight, and discharging port from customers and the schedule of the corresponding shipping lines. For inbound containers, terminal operator needs to decide the maximum storage time of the P containers in the container yard, to get the information of the reserved pickup time from customers, and the number, size and weight of the containers to be discharged from shipping lines.

b) Make the storage allocation scheduling plan based on the information collected in the last step and the historical records of customers. Since the stacks are ‘last-in, first-out’ storage structures, the sequences of container delivery and pickup operated by customers is crucial for the storage space allocation. It is notable that the delivery and pickup sequences is not fixed as the reserved information. Oppositely, it always changes due to the changes of the actual delivery time or pickup time caused by some customers.

c) When the containers have arrived in the terminal, transport and stack the containers to the exact slot according to the storage space allocation plan.

3.4 Framework of SSAP modeling

In this thesis, the SSAP are divided into two sections: the block and bay allocation section and the slot allocation section. In each part, the allocation problem will be solved by two-stage approach with mathematic programming models to assign storage space for containers under mixed storage mode as is shown in Table 3.1.

In the block and bay allocation section, the aim is to decide the number of different types of containers that are allocated to each blocks and bays in a specific period of time. To obtain the solution, two models are established in two stages separately based on rolling horizon approach which will be illustrated in Chapter 4. In the first stage, the objective of the NP model is to balance the total workload among all the blocks and bays. In the second stage, we established a multi-objective function to minimize the total transport distance traveled by internal trucks between each berth and bay and to balance the berth related workload among different blocks and bays.

Regarding the slot allocation, which will be since the container delivery and pickup sequences differs from the reservation information in some circumstances and the reshuffle operation happens in the container yard, the slot that is assigned for a container might be unavailable or nonoptimal. Therefore the optimal storage space allocation solution is not in a stable condition, which has not been discussed widely for the terminals with mixed storage mode. To solve the problem of the uncertainties, this thesis will allocate slots for containers dynamically. However, since the decision making is time consuming, it is not reliable to decide the slot allocation only when the containers have arrived or need to be reshuffled. Hence the decision will be made by two stages as well with the aim of minimizing the total number of obstacle containers in the container yard. In the first stage, based on the rolling horizon approach, we established an NP model before the arrival of customers to make the initial slot allocation scheduling with the reservation information and historical records. In the second stage, at the time when a group of containers arrive in the terminal or some containers need to be reshuffled, we will re-allocate the slot to make some adjustment according to the actual arriving or leaving information of containers. Models and solution methodology are presented in Chapter 5.

Table 3. 1 - Summary of SSAP modeling

SSAP		Problem description	Objective(s)	Factors
Block and Bay Allocation	**Stage 1**	To decide the number of each type of containers allocated to each block and bay	To balance the total workload among blocks and bays	a) Shipping lines: berthing time and leaving time, allocated berth, the number of containers to be loaded onto or discharged from the vessel; b) Customers: grounding /pickup time and the number of containers; c) Terminal: Storage space capacity, equipments and facilities, construction structure.
	Stage 2	To decide the number of each type of containers of each berth that are allocated to every block and bay	(a) To minimize the total transport distance traveled by internal trucks between each berth and bay. (b) To balance the berth related workload among blocks and bays	
Slot Allocation	**Stage 1**	Initial allocation planning: To make the slot allocation planning in advance before the arrival or retrieve of containers based on reserved information	To minimize the total number of obstacle containers in a container yard	a) the reserved arriving and leaving time of containers in a container terminal; b) the information of weight and discharging port of G and L containers provided by customers
	Stage 2	Re-allocation planning: To make the adjustment for the initial allocation planning when a group of containers are to be allocated or retrieved based on the actual information	To minimize the total number of obstacle containers in a container yard	a) the actual arriving and leaving time of containers in a container terminal; b) the actual weight and discharging port of G and L containers

4 CONTAINER BLOCK AND BAY ALLOCATION

4.1 Analysis of block and bay allocation problem

4.1.1 Problem description

This chapter discusses about the methodology to solve the block and bay allocation problem in the container terminal with mixed storage mode by developing nonlinear programming models in order to optimize the utilization of the resources including storage space, internal trucks, quay cranes, and yard cranes. As is illustrated in the last chapter, generally speaking, there are three objectives that should be pursued: (a) the balanced total workload among different blocks and bays; (b) the balanced berth related workload among different blocks and bays; (c) the minimum total distance traveled by internal trucks between each berths and bays. With the three objectives, we can obtain the optimal solution by developing mathematic programming model. Since it is not easy to satisfy the three objectives in one objective function, the problem is divided into two stages in this thesis and each stage is formulated as mathematic programming model. The model in the first stage aims at objective (a) to decide the total number of each type of containers assigned to each block and bay during a specific period of time. in the second stage, a multi-objective model is formulated with the objective (b) and (c) to decide the total number of each type of containers, which are associated with each berth, allocated in each block and bay during a specific period of time.

4.1.2 Rolling planning horizon approach

The information collection and decision making of block and bay allocation problem is made based on a specific time unit. As a container terminal operates all year round, how to set time unit is an essential issue. In this thesis we use rolling-horizon approach: at each planning epoch, we plan for a fixed horizon in immediate future and execute the plan accordingly up to the next planning epoch; then we formulate a new plan based on the latest information; this pattern goes on continually (Zhang et., al, 2003). The information of the arriving containers, which are needed for the model to allocate containers over the planning horizon, is knowable. According to the information, the allocation decision is made for each period in the rolling horizon by terminal operators. However, operators only implement the decision for the first day to allocate containers. On the next day, since the rolling horizon goes on continually, a new decision is made based on the lasted information in the new rolling horizon (Figure 4.1).

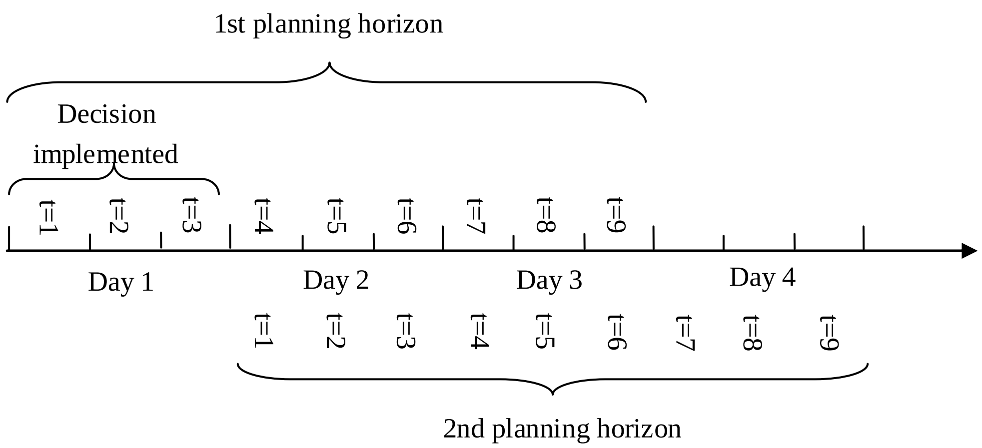

Figure 4. 1 - Rolling planning horizon

The length of the chosen planning horizon is a double-edged sword. If the planning horizon is short, it means that the containers to be allocated are less, hence the computation will be less complicated; however the predictive power for the future will be weak. While if the planning horizon is long, the computation will be complicated and the plan might be invalid because of the uncertainties happened. Based on the pervious analysis (J.Zhou,2012), over 54% of inbound containers and over 75% of outbound containers are kept in a port at most in 3 days. Therefore this thesis settles on a planning horizon of three days, with each day being divided into three 8-hour periods.

4.2 Mathematic model of the first stage

4.2.1 Assumptions of the model

In each planning horizon, the assumptions are as follows:

a) The berthing and leaving time of the corresponding vessel is known;

b) Regarding P containers and G containers, the information including type, weight and the number of the containers, and the time when the container will be picked up from CY or be delivered to CY is predictable.

c) For the L containers and D containers, the loading and unloading time, types, weight and the number of them is knowable.

d) All the containers are TEUs.

4.2.2 Model parameters and decision variables

4.2.2.1 Input parameters

T the total number of the time periods in a rolling panning horizon

t the serial number of the time periods in a rolling horizon ($t=1,2,3,\ldots,T$)

I the total number of blocks in the container yard

i the block number ($i=1,2,3, \ldots ,I$)

J_i the total number of bays in block i

j the bay number in a block ($j=1,2,3,\ldots, J_i$)

C_{ij} the storage capacity of block i bay j ($1 \leq i \leq I$, $1 \leq j \leq J_i$)

A_{ij1} the number of containers stored in block i bay j at the beginning of a rolling planning horizon ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le t \le T$)

L^0_{ijt} the number of L containers that are initially stored in block i bay j at the beginning of the planning horizon and to be loaded on board during the period t ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$)

P^0_{ijt} the number of P containers that are initially stored in block i bay j at the beginning of the planning horizon and to be picked up by customers during period t ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le t \le T$)

D_{tk} the number of D containers that are discharged from corresponding vessels during period t and to be picked up by customers during period t+k ($1 \le h \le H$, $1 \le t \le T$, $0 \le k \le T\text{-}t$)

D_{te} the number of D containers that are discharged from corresponding vessels during period t and to be picked up by customers beyond the planning horizon ($1 \le t \le T$)

G_{tk} the number of G containers that are delivered to the container yard during period t and to be loaded on board during period t+k($1 \le h \le H$, $1 \le t \le T$, $0 \le k \le T\text{-}t$)

G_{te} the number of G containers that are delivered to the container yard during period t and to be loaded on board beyond the planning horizon ($1 \le t \le T$)

4.2.2.2 Decision variables

D_{ijtk} the number of D containers allocated to block i bay j during period t that are discharge from the corresponding vessels and to be picked up by customers during period t+k ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$, $0 \le k \le T\text{-}t$)

D_{ijte} the number of D containers allocated to block i bay j during period t that are discharge from the corresponding vessels and to be picked up by customers beyond the planning horizon ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$)

D_{ijt} the number of D containers allocated to block i bay j that are discharge from the corresponding vessels during period t ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$, $0 \le k \le T\text{-}t$)

G_{ijtk} the number of G containers allocated to block i bay j delivered to the terminal by customers during period t and to be loaded on board during period t+k ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$, $0 \le k \le T\text{-}t$)

G_{ijte} the number of G containers allocated to block i bay j delivered to the terminal by customers during period t and to be loaded on board beyond the planning horizon ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$)

G_{ijt} the number of G containers allocated to block i bay j delivered to the terminal by customers during period t ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$)

L_{ijt} the number of L containers stored in block i bay j that are loaded on board during period t ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$, $0 \le k \le T\text{-}t$)

P_{ijt} the number of P containers stored in block i bay j that are picked up by customers during period t ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le h \le H$, $1 \le t \le T$, $0 \le k \le T\text{-}t$)

A_{ijt} the initial inventory of containers in block i bay j at the beginning of period t ($1 \le i \le I$, $1 \le j \le J_i$, $1 \le t \le T$)

4.2.3 Objective function

The aim in this stage is to balance the total workload among blocks and bays in the rolling planning horizon which can be measured by the sum of absolute difference between the total workload in each block and bays and the average workload.

$$f_1=\sum_{t=1}^{T}\sum_{i=1}^{I}\sum_{j=1}^{J_i}\left|M_{ijt}-AVM_t\right| \tag{4.1}$$

$$M_{ijt}=D_{ijt}+L_{ijt}+G_{ijt}+P_{ijt} \tag{4.2}$$

$$AVM_t=\frac{\sum_{i=1}^{I}\sum_{j=1}^{J_i}M_{ijt}}{\sum_{i=1}^{I}J_i} \tag{4.3}$$

M_{ijt} is the total workload in block i bay j during period t; AVM_t is the average workload during period t.

4.2.4 Constraints

4.2.4.1 Constraints on D containers

$$D_{tk}=\sum_{i=1}^{I}\sum_{j=1}^{J_i}D_{ijtk} \tag{4.4}$$

$$D_{ijt}=\sum_{k=0}^{T-t}D_{ijtk}+D_{ijte} \tag{4.5}$$

$$D_{te}=\sum_{i=1}^{I}\sum_{j=1}^{J_i}D_{ijte} \tag{4.6}$$

Constraint (4.4) ensures that the number of D containers discharged during period t and to be picked during period t+k is the sum of these containers assigned to all the blocks and bays. Constraint (4.5) denotes that the number of D containers discharged and allocated to block i bay j during period t, D_{ijt}, is the sum of the total number of these containers to be picked up during period t+k, D_{ijtk}, and of these containers picked up beyond the planning horizon, D_{ijte}. Constraint (4.6) ensures that the number of D containers discharged during period t and to be picked up beyond planning horizon is sum of these containers allocated to all of the blocks and bays.

4.2.4.2 Constraints on G containers

$$G_{tk} = \sum_{i=1}^{I} \sum_{j=1}^{J_i} G_{ijtk} \tag{4.7}$$

$$G_{ijt} = \sum_{k=0}^{T-t} G_{ijtk} + G_{ijte} \tag{4.8}$$

$$G_{te} = \sum_{i=1}^{I} \sum_{j=1}^{J_i} G_{ijte} \tag{4.9}$$

Constraint (4.7) indicates that the number of G containers delivered to container terminal by customers during period t and to be loaded on board during period t+k is the sum of those containers that are allocated to all of the blocks and bays. Constraint (4.8) denotes that the number of G containers delivered by customers and allocated to block i bay j during period t, G_{ijt}, is the sum of the total number of these containers to be loaded on board during period t+k, G_{ijtk}, and of these containers loaded on board beyond the planning horizon, G_{ijte}. Constraint (4.9) ensures that the number of G containers delivered to the terminal during period t is sum of these containers assigned to all of the blocks and bays.

4.2.4.3 Constraints on container flow

$$L_{ijt} = L_{ijt}^{0} + \sum_{k=0}^{t-1} G_{ij(t-k)k} \tag{4.10}$$

$$P_{ijt} = P_{ijt}^{0} + \sum_{k=0}^{T-1} D_{ij(t-k)k} \tag{4.11}$$

Constraint (4.10) denotes that he number of L containers stored in block i bay j that are loaded on board during period t, L_{ijt}, consists of two parts. The first part is the number of L containers that are initially stored in block i bay j at the beginning of the planning horizon and to be loaded on board during the period of t, L_{ijt}^{0}. The second part is the sum of containers transferred from corresponding G containers that arrived in the terminal from the beginning of the planning horizon till the period t, $G_{ij(t-k)k}$. Constraint (4.11) ensures that the number of P containers stored in block i bay j that are picked up by customers during period t, P_{ijt}, consists of two parts. The first part is the number of P containers that are initially stored in block i bay j at the beginning of the planning horizon and to be picked up by customers during period t, P_{ijt}^{0}. The second part is the sum of the number of container transferred from corresponding D containers that are discharged and from the beginning of the planning horizon till the period t, $D_{ij(t-k)k}$.

4.2.4.4 Inventory constraints

$$A_{ij(t+1)} = A_{ijt} + (D_{ijt} + G_{ijt}) - (L_{ijt} + P_{ijt}) \tag{4.12}$$

$$A_{ijt} \leq C_{ij} \tag{4.13}$$

Constraint (4.12) represents that the total number of containers stored in block i bay j at the beginning of period t+1 results of the changes of the inventory during the period t. Constraint (4.13) ensures that the total number of containers stored in block i bay j at the beginning of period t will not exceed the capacity of block i bay j.

4.2.4.5 Integer constraint

D_{ijtk}, D_{ijte}, D_{ijt}, G_{ijtk}, G_{ijte}, G_{ijt}, L_{ijt}, P_{ijt} are nonnegative integers. (4.14)

4.3 Mathematic model of the second stage

Based on the solution of the first stage, this stage decides the number of each type of containers of each berth that are allocated to every block and bay. The model established in this stage is a multi-objective NP model to balance the berth related workload and to minimize the distance traveled by internal trucks. The assumption of the model is as same as the one of the model in the first stage.

4.3.1 Model parameters and decision variables

4.3.1.1 Input parameters

H the total number of the berths in the terminal

h the berth number (h=1,2,...,H)

d_{hij} the transport distance traveled by internal trucks between berth h and block i bay j ($1 \leq i \leq I, 1 \leq j \leq J_i$)

d_{min} the minimum transport distance of the shortest route between berths and bays traveled by internal trucks.

$$d_{min} = \min\{d_{hij} | 1 \leq h \leq H, 1 \leq i \leq I, 1 \leq j \leq J_i\}$$

D_{ht} the number of D containers that are discharged from the vessel in berth h during period t ($1 \leq h \leq H, 1 \leq t \leq T$)

G_{ht} the number of G containers that are delivered to the terminal during period t and to be loaded onto the vessel which is in berth h ($1 \leq h \leq H, 1 \leq t \leq T$)

L_{ht} the number of L containers that are loaded onto the vessel in berth h during period t ($1 \leq h \leq H, 1 \leq t \leq T$)

L^0_{hijt} the number of L containers that are initially stored in block i bay j at the beginning of the planning horizon and to be loaded to the vessel in berth h during the period of t ($1 \leq i \leq I$, $1 \leq j \leq J_i$, $1 \leq h \leq H$, $1 \leq t \leq T$)

4.3.1.2 Decision variables

D_{hijt} the number of D containers allocated to block i bay j that are discharged from berth h during period t ($1 \leq i \leq I$, $1 \leq j \leq J_i$, $1 \leq h \leq H$, $1 \leq t \leq T$)

D_{hijtk} the number of D containers allocated to block i bay j that are discharged from berth h during period t and to be picked by customers during period t+k ($1 \leq i \leq I$, $1 \leq j \leq J_i$, $1 \leq h \leq H$, $1 \leq t \leq T$, $0 \leq k \leq T-t$)

D_{hijte} the number of D containers allocated to block i bay j that are discharged from berth h during period t and to be picked by customers beyond the planning horizon ($1 \leq i \leq I$, $1 \leq j \leq J_i$, $1 \leq h \leq H$)

L_{hijt} the number of L containers which are stored in block i bay j and to be loaded onto the vessel in berth h during the time period t ($1 \leq i \leq I$, $1 \leq j \leq J_i$, $1 \leq h \leq H$, $1 \leq t \leq T$)

G_{hijt} the number of G containers that are allocated to block i bay j during period t and to be loaded onto the vessel in berth h ($1 \leq i \leq I$, $1 \leq j \leq J_i$, $1 \leq h \leq H$, $1 \leq t \leq T$)

4.3.2 Multi-objective function

On the second stage, we formulated multi-objective NP model to combine the two objectives as presented below:

$$\min\ f = \min\ [w_1 \cdot f_1 + w_2 \cdot f_2] \tag{4.15}$$

$$(w_1 + w_2 = 1)$$

f_1 is one sub-objective function with the objective of the minimum transport distance traveled internal trucks between berths and bays. f_2 is the other sub-objective function to balance the workload between bays and berths. w_1 and w_2 are the weights of the sub-functions in the general function which are decided by terminal operator. In order to ensure the dimension of the each sub-objective function is on a similar range, the sub-objective function should be transferred to be nondimensional by ratio. To be specific:

$$f_1 = \sum_{t=1}^{T}\left[\frac{\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{j=1}^{J_i}\left[d_{hij}\bullet(D_{hijt}+L_{hijt})\right]-\sum_{h=1}^{H}\left[d_{\min}\bullet(D_{ht}+L_{ht})\right]}{\sum_{h=1}^{H}\left[d_{\min}\bullet(D_{ht}+L_{ht})\right]}\right] \tag{4.16}$$

$$f_2 = \sum_{t=1}^{T}\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{j=1}^{J_i}\left|\frac{(D_{hijt}+L_{hijt})-AVDL_t}{AVDL_t}\right| \tag{4.17}$$

$$AVDL_t = \frac{\sum_{h=1}^{H}(D_{ht}+L_{ht})}{I\bullet(\sum_{i=1}^{I}J_i)\bullet H} \tag{4.18}$$

Formula (4.16) presents the sub-objective function f_1 which is measured by the difference between actual distance and the shortest path distance. Formula (4.17) indicates the sub-objective function f_2 which is for measuring how balanced the vessel loading and discharging workload assigned to the bays for berth is. It is measured by the difference between the workload in each bay and the average workload. Formula (4.18) denotes the average vessel loading and discharging workload among all the blocks and bays during the period of t.

4.3.3 Constraints

4.3.3.1 Constraints on D containers

$$D_{ijtk} = \sum_{h=1}^{H} D_{hijtk} \tag{4.19}$$

$$D_{ijte} = \sum_{h=1}^{H} D_{hijte} \tag{4.20}$$

$$D_{hijt} = \sum_{k=0}^{T-t} D_{hijtk} + D_{hijte} \qquad (4.21)$$

$$D_{ht} = \sum_{i=1}^{I} \sum_{j=1}^{J_i} D_{hijt} \qquad (4.22)$$

Constraint (4.19) ensures that the number of D containers allocated to block i bay j during period t that are discharge from the corresponding vessels and to be picked up by customers during period t+k, D_{ijtk}, equals the sum of the these containers which are discharged from all the berths. Constrains (4.20) indicates that the total number of D container allocated to block i bay j that are discharged from the corresponding vessels during period t and to be picked up beyond the panning horizon, D_{ijte},equals the sum of the these containers which are discharged from all the berths. Constraint (4.21) denotes that the total number of D containers discharged from berth h and allocated to block i bay j consists of two parts: the first is that the corresponding containers to be picked up during period t+k, and the second part is that the ones to be picked up beyond the planning horizon. Constraint (4.22) indicates that the number of D containers that are discharged from berth h during period t is the sum of these containers that are allocated to all the blocks and bays.

4.3.3.2 Constraints on G containers

$$G_{ijtk} = \sum_{h=1}^{H} G_{hijtk} \qquad (4.23)$$

$$G_{ijte} = \sum_{h=1}^{H} G_{hijte} \qquad (4.24)$$

$$G_{hijt} = \sum_{k=0}^{T-t} G_{hijtk} + G_{hijte} \qquad (4.25)$$

$$G_{ht} = \sum_{i=1}^{I} \sum_{j=1}^{J_i} G_{hijt} \qquad (4.26)$$

Constraint (4.23) denotes the number of G containers allocated to block i bay j that delivered to the terminal by customers during period t and to be loaded on board during period t+k is the sum of these containers loaded onto all the vessels in all of the berths. Constraint (4.24) indicates that the number of G containers allocated to block i bay j delivered to the terminal by customers during period t and to be loaded on board beyond the planning horizon are the sum of those containers to be loaded on all the vessels in all of the berths. Constraint (4.25) presents that the number of G containers that are allocated to block i bay j during period t and to be loaded on the vessel in berth h are the sum of the those containers that will be loaded on board during period t+k and of the ones that will be loaded beyond the planning horizon. Constraint (4.26) ensures that the number of G containers that are delivered to the terminal during period t and to be loaded onto the vessel which is in berth h is the sum of these containers that are allocated to all the blocks and bays.

4.3.3.3 Constraints on container flow

$$L_{hijt} = L^{0}_{\mathrm{hijt}} + \sum_{k=0}^{t-1} G_{hij(t-k)k} \tag{4.27}$$

$$\mathrm{L}_{ht} = \sum_{i=1}^{I} \sum_{j=1}^{J_i} L_{hijt} \tag{4.28}$$

Constraint (4.27) denotes that he number of L containers stored in block i bay j that are loaded onto the vessel in berth h during period t, L_{hijt}, consists of two parts. The first part is the number of L containers that are initially stored in block i bay j at the beginning of the planning horizon and to be loaded to berth h during the period of t, L^{0}_{hijt}. The second part is the sum of containers transferred from corresponding G containers that arrived in the terminal from the beginning of the planning horizon till the period t, $G_{hij(t-k)k}$. Constraint (4.28) ensures that the numbers of L containers that are loaded onto the vessel in berth h during period t are the sum of theses containers to be loaded on to all the vessels in all the berths.

4.4 Solution approach

Two-stage allocation approach of the block and bay allocation problem are proposed in this chapter. To obtain the optimal allocation solution, we implemented LINGO software to solve the two mathematic programming models which is presented in chapter 6.

5 CONTAINER SLOT ALLOCATION

5.1 Analysis of slot allocation problem

5.1.1 Problem description

Containers should be allocated properly not only on block and bay level but also on slot level. The container that is allocated to an improper slot might cause container reshuffle operation which will affect the operation efficiency of the container terminal directly. Consequently, economic performance of the terminal, the shipping lines and the customers will suffer. Based on the solution about the amount of containers allocated to each block and bays, this chapter aims to allocate every individual container to an exact optimal slot to minimize the number of reshuffle operation.

Most of the articles regarding slot allocation under mixed storage mode are under the assumption that the delivery time and pickup time is known and fixed, but neglected the uncertain condition in the real world. In fact, it is uncertain that when a container will be delivered to CY or picked up from CY by customers, hence the sequences of containers to be allocated to CY and to be retrieved also is unknown. In order to ensure the accuracy of the allocation, this thesis will implement a two-stage allocation approach to allocate containers dynamically. The first stage is the initial planning to make a slot allocation solution in advance based on the rolling horizon approach with the reservation and historical information. The first stage is the re-allocation which is undertaken at the time a group of containers has arrived in the terminal to obstacle container need to be reshuffled. Through the two-stage approach, the uncertainties will be eliminated.

5.1.2 Uncertainties of container delivery and pickup

Container handling operation in a container yard will take place when a container needs to be allocated or to be retrieved. As has been illustrated in the Table 5.1 below, allocation operation happens to D containers, and G containers while retrieve operation is about L containers and P containers. Considering about the reliability of the schedule of liner shipping, we regard the handling time in a CY of D and L containers in CY are knowable. Nevertheless, due to the unpredictable factors such as the bad weather and traffic jam which affect the scheduling of customers, the delivery and pickup time of G and P containers is uncertain.

Table 5. 1 - Container operation in a container yard

Operation \ Time	Knowable	Uncertain
Container allocation	D container	G containers
Container retrieve	L containers	P containers

The traditional optimal slot allocation solution is obtained based on the rolling horizon approach with the information gathered from customers' reservation information and historical records. If the delivery time or pickup time of a container is different from what is gathered information, which means the actual sequence of container to be handled in the terminal will also be changed. Consequently the actual situation of storage space occupation will differ from the planning and the optimal slot allocation solution will not be stable as well. Therefore the possibility of reshuffle will be higher if there is no appropriate method to make an optimal slot allocation planning to deal with the uncertainties.

5.1.3 Two-stage slot allocation approach

There are two types of sot allocation that are needed to be undertaken. The first one is the allocation for G containers and D containers, the other one is the re-allocation for the obstacle containers. Considering about the uncertainties, we need to allocate slots for containers by a dynamic approach. In order to dynamically make the allocation solution, we can make the allocation decision for the containers at the time when G and D container have arrived in the terminal or obstacle containers are to be reshuffled. Since the information is real-time, the allocation solution will be an optimal one compared with the allocation solution made before the arrival or reshuffle operation of containers. However problems will also arise if we take this approach since the calculation is time consuming which has a negative impact on the economic performance of the container terminal, shipping lines and customers. To eliminate the problems, we made the slot allocation scheduling through two stages: initial allocation planning for all of the containers and re-allocation planning for individual containers including new arrivals and obstacle containers.

As is presented in Figure 5.1, in the first stage, we make the initial slot allocation planning based on the rolling planning horizon for D container and G containers before they have arrived in the terminal. The information including arriving or leaving time, weight and discharging port that is used to make the decision comes from the historical record, the reservation of customers, the schedule of shipping lines, and the planning pickup schedule. The aim of the first stage is to make a general optimal planning in the whole planning horizon into consideration. Since the slot utilization situation is changeable, we make the initial slot allocation scheduling for the planning horizon but only implement the decision made for the first time period in the rolling horizon and a new allocation decision will be updated in the next period. In the next period, since the rolling horizon goes on continually, a new decision is made based on the lasted information in the new rolling horizon.

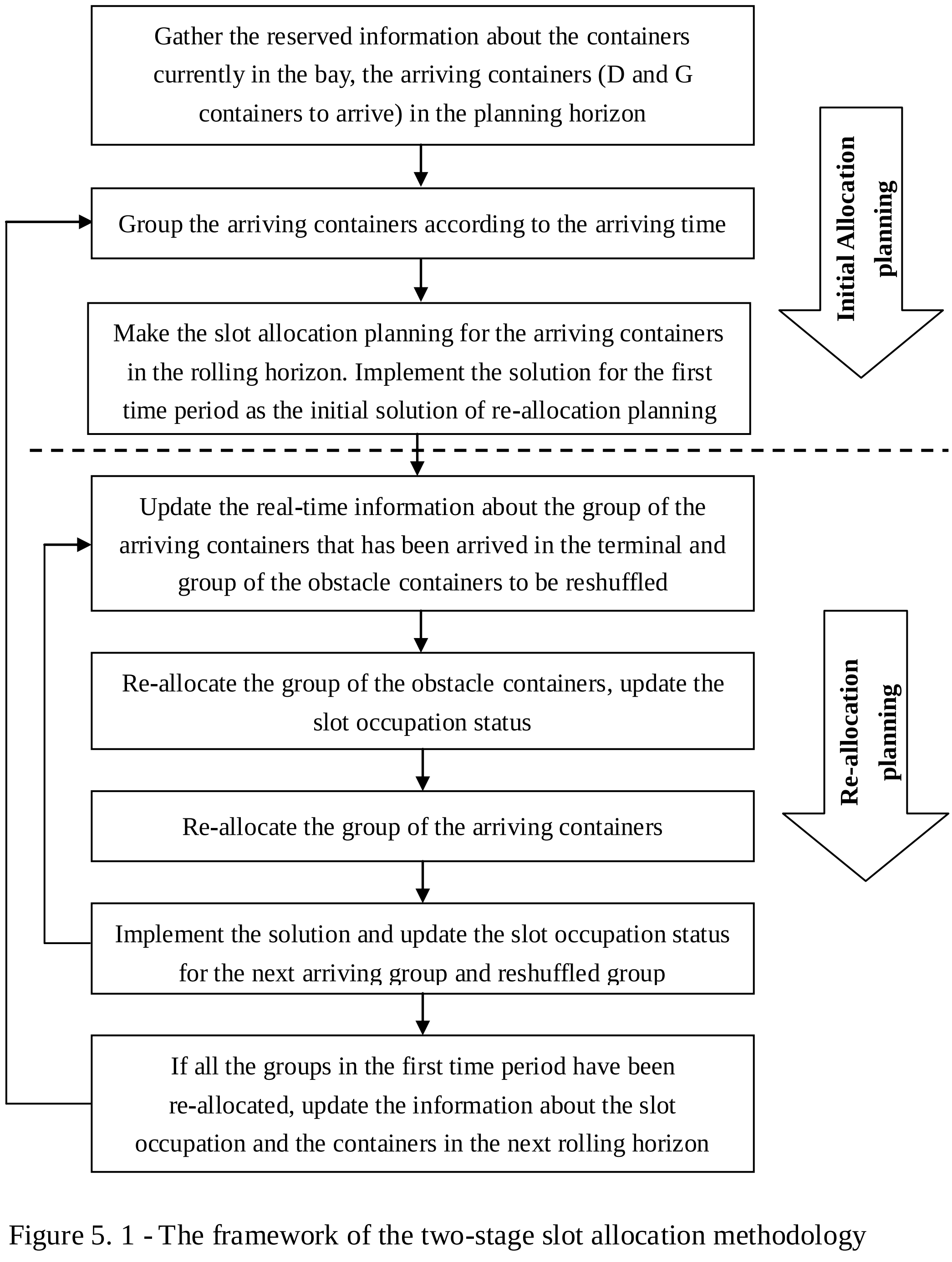

Figure 5. 1 - The framework of the two-stage slot allocation methodology

In the second stage, the re-allocation planning is made for individual containers ----

not only G and D containers that have arrived in the terminal but also the obstacle containers to be reshuffled. The re-allocation planning aims at making adjustment for the initial allocation planning based on the realtime information of the containers. Arriving containers (G and D containers) need to be re-allocation considered about two scenarios. The first scenario is that the slot decided in the initial allocation planning stage now is already unavailable due to container reshuffle. Moreover, the containers in a specific group might have been changed since some of them cannot arrive in the terminal on time, which will lead the sequence of the containers based on their priority level changed and the actual slot occupation situation will be changed as well. Because of the reasons, the initial slot allocated for the arriving container might be unavailable or it may not be the optimal allocation solution. Regarding the obstacle containers, since the reshuffle operation changes the slot occupation condition, the new slot that it is reallocated for the obstacle containers has an impact on the slot allocation planning made for other containers. Therefore the obstacle containers have the priority to be reallocated compared with the group of the arriving containers that needs to be allocated in the same period.

The solution obtained in the first stage is used as the initial solution in the second stage. However, different from the initial allocation planning which is made based on the rolling horizon approach, the re-allocation planning goes group by group. In other words, the basic unit of the containers to be re-allocated in the relocation stage is the group of obstacle containers to be reshuffled and the group of arriving containers to be allocated. Since the containers to be allocated in the researched bay which are delivered by one customer or discharged from one vessel has the closed allocation operation schedule, we gathered these containers in one group to gather the real-time information and make the re-allocation planning. As the number of containers allocated to one bay is limited and the containers with same schedule normally are from the same customer or vessel, grouping containers is possible. After the allocation planning has been accomplished and the real-time containers of the next group has obtained, decide the re-allocation planning for the next one.

5.1.4 Principle of slot allocation

As has been briefly illustrated in chapter 3, there are several main factors that should be taken into account to allocate slot for containers. Neglecting any one of them might lead to container reshuffle problem. Based on the factors, the slot allocation should follow the principles below:

Firstly, the container with earlier retrieve time in container yard has priority to be stacked higher. In this thesis, the retrieve time is defined as the loading time of L containers, and the pickup time of P containers. It is the main factor which influences the allocation arrangement. The containers which will be retrieved earlier should be stacked on a higher tier than other containers, otherwise yard crane cannot access to the objective containers unless it moves the above containers which has a later retrieve time.

Secondly, the heavier outbound container has the priority to be stacked higher. The allocation of containers in container yard should be complied with the stacking plan of containers on board to avoid reshuffle. Due to the consideration of vessel stability, heavier containers should be allocated below the lighter containers in a vessel to lower the centre of gravity. On the contrary, the containers with heavier weight should be allocated above the lighter containers in a container yard.

Thirdly, for the outbound containers, the one with the father discharging port is prior to be stacked higher. A container vessel carries a large number of contains which will be discharged in different discharging port on the shipping line. When a vessel has arrived in one port, the corresponding containers will be retrieved and discharges, and then the vessel will continue sailing with the remained container. For the stacking plan on board, the earlier a container will be discharged or the nearer the discharging port is, the higher tier it should be stacked on. Therefore, the allocation of containers in container yard should be inversed---- the father the discharging port or the later the discharging time is, the higher place it should be allocated.

5.2 Theories of container reshuffle issue

5.2.1 Reshuffle issues regarding different containers

According to the principles of the slot allocation, different containers have different impacts on the reshuffle operation as some have fixed handling schedule while some others have random schedule.

a) Allocation for D containers will not lead to reshuffle. However the loading time, weight and discharging port of L containers, and the pickup time of the P containers should be taken into account when it is to be allocated in order to avoid reshuffle problem.
b) G containers will not lead to reshuffle problem. But the assignment of the allocation should be based on the operating time of L containers and the pickup time of P containers.
c) P containers and L containers always cause re-shuffle problem which is influenced by the allocation of other types of the containers.

5.2.2 Priority value of containers

The value of the priority is measured for each container in a rolling horizon period. In this thesis, the priority value of containers decides whether a container has the priority to be stacked on another container to avoid reshuffle. It is noticeable that the span of the rolling planning horizon for measuring the value of priority is different from the one of slot allocation models. When it comes to the value of priority of containers, the span of the planning horizon is the maximum storage period for containers to be stored in the container yard which is allowed by terminal operators. According to the criteria of container allocation, the priority value is measured by two criteria. One is the time period in a planning horizon in which the container will be retrieved in container yard. The other is the weight and discharging port of outbound. Based on the two criteria, the priority value of a container is decided. The lower the priority value is, the higher priority the container has.

To be specific, criterion 1 is the time priority which is measured by the time period when the container will be retrieved in container yard to. The container that will be retrieved in the earlier period has the higher priority to be allocated to a higher place. For instance, if the maximum duration of container storage in the CY is 5 days and each day is divided into 3 periods, the periods can be numbered as 1, 2, …, 15 from the first period to the last period. The value of time priority is as same as the number of the time period. When the first period has passed, the rolling horizon will roll to the second period as the beginning of the new rolling horizon, accordingly the time priority is measure by the new rolling horizon.

The second criterion is the attribute priority which is measured by the weight and discharging port of outbound containers. In each time period of the planning horizon, the priority of a container is decided by the weight and discharging port. Since the weight and discharging port does not influence the allocation of inbound containers, here we measure the priority of inbound containers as 0. The measurement of the outbound containers is presented as following. A containers with heavier weight has higher priority hence it should be stacked above the lighter containers. The weight of containers can be classified into 5 levels: level 1 (over 20t), level 2(15-20t), level 3(10-15t), level 4(5-10t), level 5(0-5t). (Zhou,2012). When it comes to the discharging port, the priority can be measured by the order of the discharging operation or the discharging port. The sequence of the discharging port should be sorted from the nearest discharging port to the farthest one which is counted from 1 till the end. Both the weight and discharging port should be taken into consideration to measure the priority in a certain time period. Therefore a weighted priority which is named as attribute priority is formulated as below. (Shao, 2013)

$$C_n = w_n + Wd_n$$

C_n is the attribute priority, w_n is the weight level of container n, d_n is the sequence number of the discharging port in which container n will be discharged, W is the highest weight level, here in this thesis W equals 5. About P containers and D containers, C_n equals 0.

Based on the two criteria above, the value of the priority of containers can be decided. All the containers should be sorted by the time period first, afterwards the containers that will be retrieved in the same period should be ordered according to C_n. For instance, there are 5 outbound containers A, B, C, D and E. the retrieved period is 1, 1, 3, 4, 5 respectively; and the value of C_n are 5, 4, 3, 2 and 1. Hence the priority level for each containers 1-5, 1-4, 3-3, 4-2, and 5-1. The priority value can be sorted as 1-4, 1-5, 3-3, 4-2, and 5-1 from the highest priority level to the lowest one.

Therefore the priority value of each container is 2,1,3,4 and 5 separately.

5.2.3 Calculation of the number of obstacle containers

The container with higher priority value should be allocated below the containers with lower value, otherwise reshuffle will take place and the container above with higher priority value will be obstacle containers. Therefore the number of obstacle containers is the calculation is the sum of containers with higher priority value which are allocated above the one with lower value (Dong, 2011). Figure 5.2 shows each container's priority value in a bay and the obstacle containers are highlight in gray. Therefore the numbers of obstacle containers are 1, 0, 2, 2, 1, and 2 from left to right.

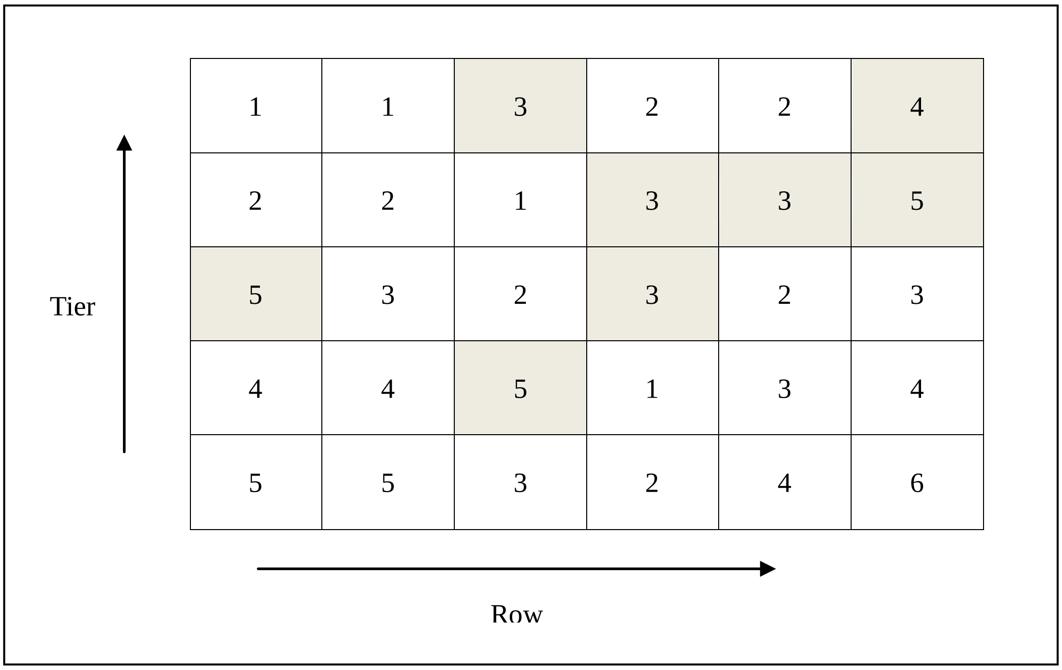

Figure 5. 2 - Priority value and obstacle containers in a bay

5.3 Mathematic model for initial allocation planning

5.3.1 Assumptions of the model

a) The number of containers allocated to each blocks and bays in a rolling planning horizon has been decided, the slot allocation in this section is analyzed in a specific bay.

b) The weight and discharging port of G containers and L containers is known.

c) The planning arriving time of G and D containers, and the planning leaving time of P and L containers is known.

d) The time difference between the actual arriving (pickup) time and the planning arriving (pickup) time follow normal distribution.

e) All the containers to be allocated are TEUs.

5.3.2 Input parameters

N	the total number of containers to be allocated in the planning horizon
n	the serial number of containers to be allocated, n=1,2,…,N
Y	the total number of rows in the researched bay
y	the row number in the bay, y=1,2,…Y
Z	the maximum tier of a stack (assume all the stacks have the same maximum tier)
p	the priority value of the containers in the bay, p=1,2,3,…
Z_{yn}	the tier number that the *n*th container to be allocated in row *y*
Z_{yn}^{b}	the topmost tier of row y before the *n*th container has been allocated
Z_{yn}^{a}	the topmost tier of row y after the *n*th container has been allocated
Z_{ynp}	the lowest tier of the containers with *p* as priority value in row *y* after the *n*th container has been allocated to row *y*,

Z_{rn1}=1,2,…,Z; Z_{rn2}=1,2,…,Z-1; … ; Z_{rnp}=1,2,…,Z-p+1;

U_{ynp} the total number of containers with p as priority value in row y after the *n*th container has been allocated in this row

R_{yn} the total number of obstacle containers in row y after the *n*th container has been allocated in this row

R the total number of obstacle containers in the bay

$$H_{1n} = \begin{cases} 1, & \text{if } Z_{yn} \geq 2 \\ 0, & \text{if } Z_{yn} < 2 \end{cases}; \qquad \text{y=1,2,3,…,Y}$$

$$H_{pn} = \begin{cases} 1, & \text{if } Z_{yn(p-1)} - 1 \geq 2 \\ 0, & \text{if } Z_{yn(p-1)} - 1 < 2 \end{cases}; \qquad \text{y=1,2,3,…,Y}, \quad p = 2, 3, 4, ...$$

5.3.3 Objective function

As is denoted by function (5.1), the objective of slot allocation is to minimize the total number of obstacle containers in the bay in the planning horizon to minimize the rate of container reshuffle. Referring to Dong (2011), the number of obstacle containers in row y in the bay after the *n*th container has been allocated to the row y can be measured as function (5.2).

$$R = \min \sum_{n=1}^{N} R_{yn} \tag{5.1}$$

$$R_{yn} = \left\{ H_{1n} \left[Z_{yn} - U_{yn1} - \left(Z_{yn1} - 1 \right) \right] + \sum_{p=1}^{P} H_{pn} \left[\left(Z_{yn(p-1)} - 1 \right) - U_{ynp} - \left(Z_{ynp} - 1 \right) \right] \right\} \tag{5.2}$$

5.3.4 Constraints

$$Z_{yn} = Z_{yn}^{b} + 1 \tag{5.3}$$

$$Z_{yn} \leq Z \tag{5.4}$$

$$\sum_{r=1}^{R} Z_{yn}^{a} \leq Y \cdot Z - (Z-1) \tag{5.5}$$

Constraint (5.3) ensures that the slot assigned for the *n*th container is not occupied by other containers or it is not above an empty slot. Constraint (5.4) indicates that the tier number where the container is to be allocated is no more than the maximum tier in the bay. Constraint (5.5) indicates that some slot should be reserved for reshuffle rather than being fully occupied. It is because the number of reserved slots should at least satisfy the reshuffle operation for the initial containers.

5.4 Solution methodology of initial allocation planning

5.4.1 Heuristic algorithms introduction

To solve complex problems, we can use computers by developing an algorithm. Compared with some exact algorithms which might be time consuming to obtain the solution, heuristic algorithms are approximate techniques which have low time complexity. Referring to Heuristic Algorithms (2014), the definition of heuristic algorithms is:

"The term heuristic is used for algorithms which find solutions among all possible ones, but they do not guarantee that the best will be found, therefore they may be considered as approximately and not accurate algorithms. These algorithms, usually find a solution close to the best one and they find it fast and easily."

A heuristic algorithm is a mental short cut which can speed up the procedure to solve problems, while it also introduces errors and cannot ensure the result is the optimal decision. Therefore, it can lead us to a good decision mostly in the cases below:

a) if the time is limited and decision maker need the solution in a short time;

b) for some optimization problem which is difficult to acquire enough information and/or it takes a very long time to get the optimal solution which makes the approach costly and invalid;

c) the accuracy of the decision is not that important.

On the contrary, if the decision maker can access to the related information easily or he needs to make an exactly optimal decision or he has plenty of time to undertake a time consuming algorithm, heuristic algorithm will not be the best choice.

Regarding the slot allocation, we implement heuristic algorithm for both initial allocation planning and re-allocation planning based on two considerations. On the one hand, as it is a decision making issue in one bay of which the space is limited, the approximately solution obtained through heuristic algorithm will be closed to the optimal one. On the other hand, since it take a long time to make the block and bay allocation, we have to speed up the slot allocation to ensure the efficiency of the whole decision making process especially in the slot re-allocation planning stage which needs to be decided instantly when a container has arrived in a terminal and needs to be allocated.

5.4.2 Heuristic algorithm for initial allocation planning

5.4.2.1 Variables

N total number of containers to be allocated in the planning horizon

n the serial number of the containers to be allocated in the researched bay, n=1,2,…,N

r the row number in the researched bay;

k the serial number of the feasible solution of the *n*th contianer;

R_k the total number of obstacle containers of the *k*th feasible solution.

5.4.2.2 Procedures

To decide the allocation of the containers that will arrive in the first day of the rolling planning horizon, several processes should be taken as follows:

Step1: Update the stack information of the storage space of the bay, and measure the priority value of each container in the next arriving group and the containers that already has been stacked in the bay. According to the priority value of the containers in the reserved arriving group, sort all of the containers from larger value to smaller value. The container with larger priority value will be allocated first to avoid reshuffle.

Step2: Initialize: n=1,r=1,k=0, go to step3;

step3: allocate Container n to Row r to check if there are feasible solutions; if it is true, compare the value of R_k and the last feasible solution R_{k-1} (if there is), if $R_k \geq R_{k-1}$, then $R_{yn}=R_{k-1}$, otherwise $R_{yn}=R_k$, and update k to k+1; if there is no feasible solution in Row r, undertake step4;

Step4: let r=r+1, if the updated r is less than R, implement step 3 to acquire R_{yn} for the new row; otherwise end the whole procedure;

Step5: Decide whether n=N. If it is not, let n=n+1, then go to step 3. If it is, go to step 6.

Step6: Stop the algorithm, calculate the sum of the R_{yn} of all the containers which has been allocated to obtain the total number of obstacle containers from the beginning till now, that is： $T=\sum_{n=1}^{N} R_{rn}$. T is the minimum total number of obstacle containers and the solution obtained is the optimal solution.

5.4.2.3 Flowchart of the initial planning algorithm

The flow chart of the heuristic algorithm to deal with the initial allocation planning is presented in Figure 5.3

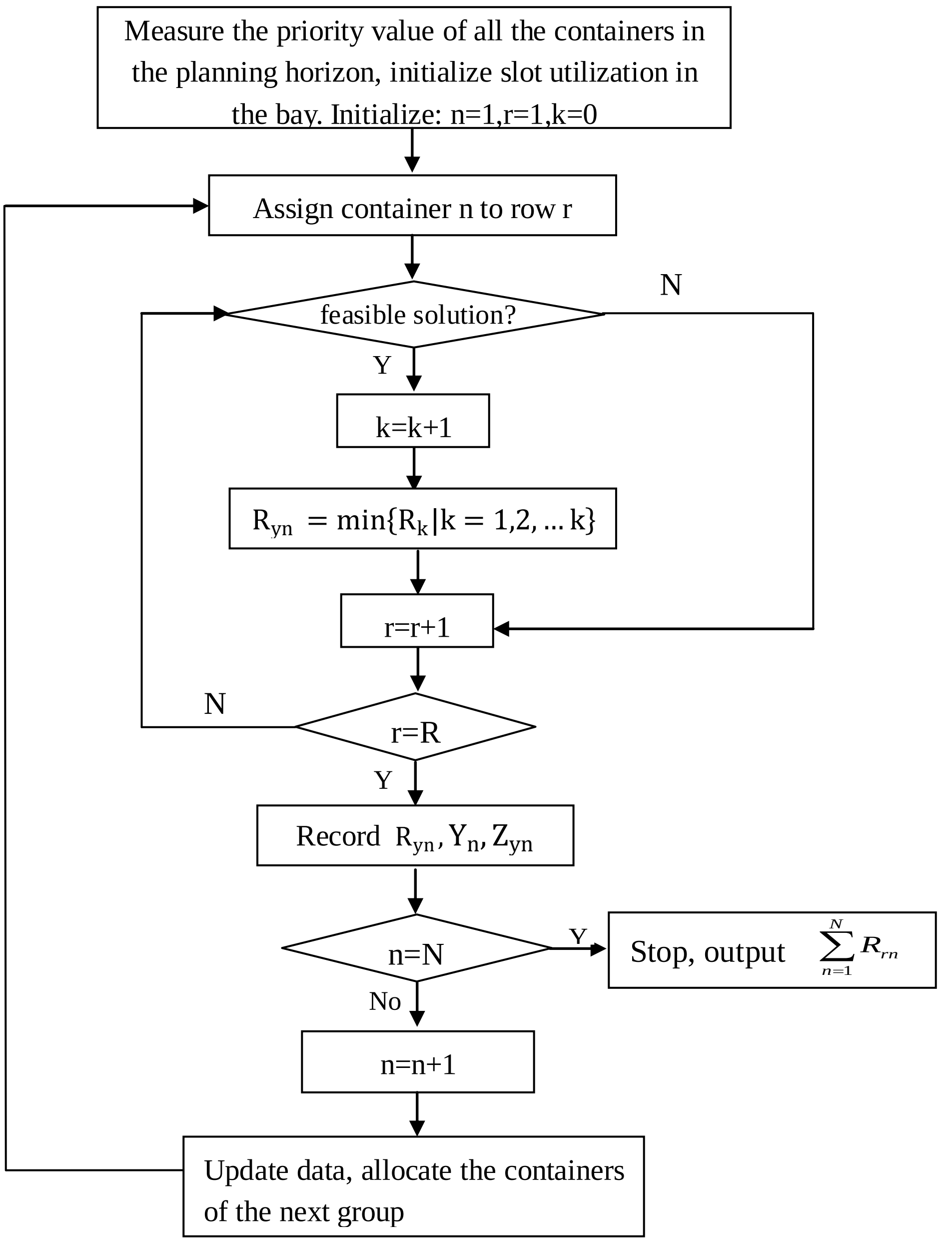

Figure 5. 3 - Flowchart of the heuristic algorithm for initial allocation planning

5.5 Heuristic algorithm for re-allocation planning

5.5.1 Introduction

Re-allocation planning is a real-time planning which is undertaken when the obstacle containers or a group of arriving containers are going to be allocated. To obtain the real-time information of containers and to ensure the efficiency of the re-allocation planning, we divided the containers in a planning horizon into several groups according to the actual arriving time and reshuffle time.

On the second stage which is to make a slot re-allocation planning for containers will also implemented heuristic algorithm to ensure the efficiency of decision making. The general methodology is: (a) Reshuffled containers has the priority to be allocated first if there are as. Then update the slot allocation situation for following arriving containers in this group the initial slot layout; (b) Reallocate every arriving container when it is to be stacked into a bay and update the allocation scheduling for the rest of the containers in this group.

In addition, for a G containers or D container that has arrived in the terminal and needs to be allocated to a slot, the possible situation is as follows: (a) the planned allocation that is made in advance is still the optimal one; (b) the allocated space is occupied or the tier below is empty so the container cannot be stacked there; (c) the planned allocation is available but it is no longer an optimal decision. To ensure the efficiency, re-allocation planning is made in the same bay in which the arriving container is initially allocated or the obstacle container is stored.

5.5.2 Variables

I the actual total number of containers in the arriving group to be allocated

i the actual serial number of the arriving contains of the group

R the total number of the rows in a bay

r the row number

T total number of the tiers in each row in a bay

t the tier number

Q the initial planning allocation sequence of the reserved arriving group

Q_n the *n*th container which is initially planned to be allocated

C the actual allocated sequence of the arriving containers in the group

C_i the *i*th container in the actual allocated sequence

E the sequence of obstacle containers to be reallocated in one reshuffle operation

E_j the *j*th container in the reshuffled sequence

$f(B_{ir})$ the number of obstacle containers in row r before the ith container has been allocated to the row, r=1,2,…,R

$f(C_{ir})$ the number of obstacle containers in row r after the *i*th container has been allocated to the row, r=1,2,…,R

$f(B_{jr})$ the number of obstacle containers in row *r* before the *j*th container has been allocated to the row, r=1,2,…,R

$f(E_{jr})$ the number of obstacle containers in row *r* after the *j*th container has been allocated to the row, r=1,2,…,R

$$a = \begin{cases} 1, & \text{if the planning slot is unavailable} \\ 0, & \text{else} \end{cases}$$

$$h = \begin{cases} 1, & \text{if the objective contaienr is an obstacle container} \\ 0, & \text{if the it is an arriving containers} \end{cases}$$

5.5.3 Procedures

In a planning horizon, divide the containers into several groups according to arriving time or reshuffle time of the containers in the researched bay. First all of, based on the reserved information, group the arriving containers (G and D containers) which have closed arriving time as group Q. The grouping for Q can be undertaken in the stage of initial allocation as well. Secondly, according to the reserved arriving group Q in the initial allocation stage, update the real-time information of the actual containers in this group as group C. Finally, gather the real-time information of the obstacle containers which need to be reshuffled during the time period of the allocation of the group C, and group them as group E.

According to the priority value of the containers, sort all the containers from larger value to smaller value in each group. Re-allocate the obstacle containers in group E then re-allocate the arriving containers in group C. The procedure of slot allocation decision is made group by group as follows:

Step1： Update the actual slot occupation of the last arriving group of containers as the initial state of heuristic algorithm for re-allocation planning. Initialize i=0,j=1, a=0;

Step2: Determine whether h=0, if it does, go to step3; if h=1, go to step 7;

Step3: Determine whether i=I, if it does, end the heuristic algorithm, the re-allocation for all of the containers has been made; otherwise let i=i+1;

Step4: Determine the value of a, if a=0, go to step5; if a =1, go to step 6;

Step5: Determine whether Q_n and C_i are equal, if they are, allocate the container according to the initial allocation planning and then move to step3; otherwise go to step 6.

Step6: Searching for new feasible slot for the *i*th arriving container in the bay, calculate $\Delta f = f(C_{ir}) - f(B_{ir})$ for every row and allocate the container i to the row with minimum Δf . If there are more than one row in which the Δf is minimum, allocate the container to anyone of them. Record the slot allocation decision, go to step 3.

Step7: Determine whether j=J, if it does, stop the reshuffle operation, then update the slot occupation situation and move to step 3; otherwise let j=j+1.

Step8: Searching for new feasible slot for the *j*th obstacle container in the bay, calculate $\Delta f = f\left(E_{jr}\right) - f(B_{jr})$ for every row and allocated the container *j* to the row with minimum Δf . If there are more than one row in which the Δf is minimum, allocate the container to anyone of them. Record the slot allocation solution for obstacle containers, and then go to step 7.

5.5.4 Flowchart of re-allocation planning algorithm

The flowchart of the heuristic algorithm to deal with the re-allocation planning is presented in Figure 5.4

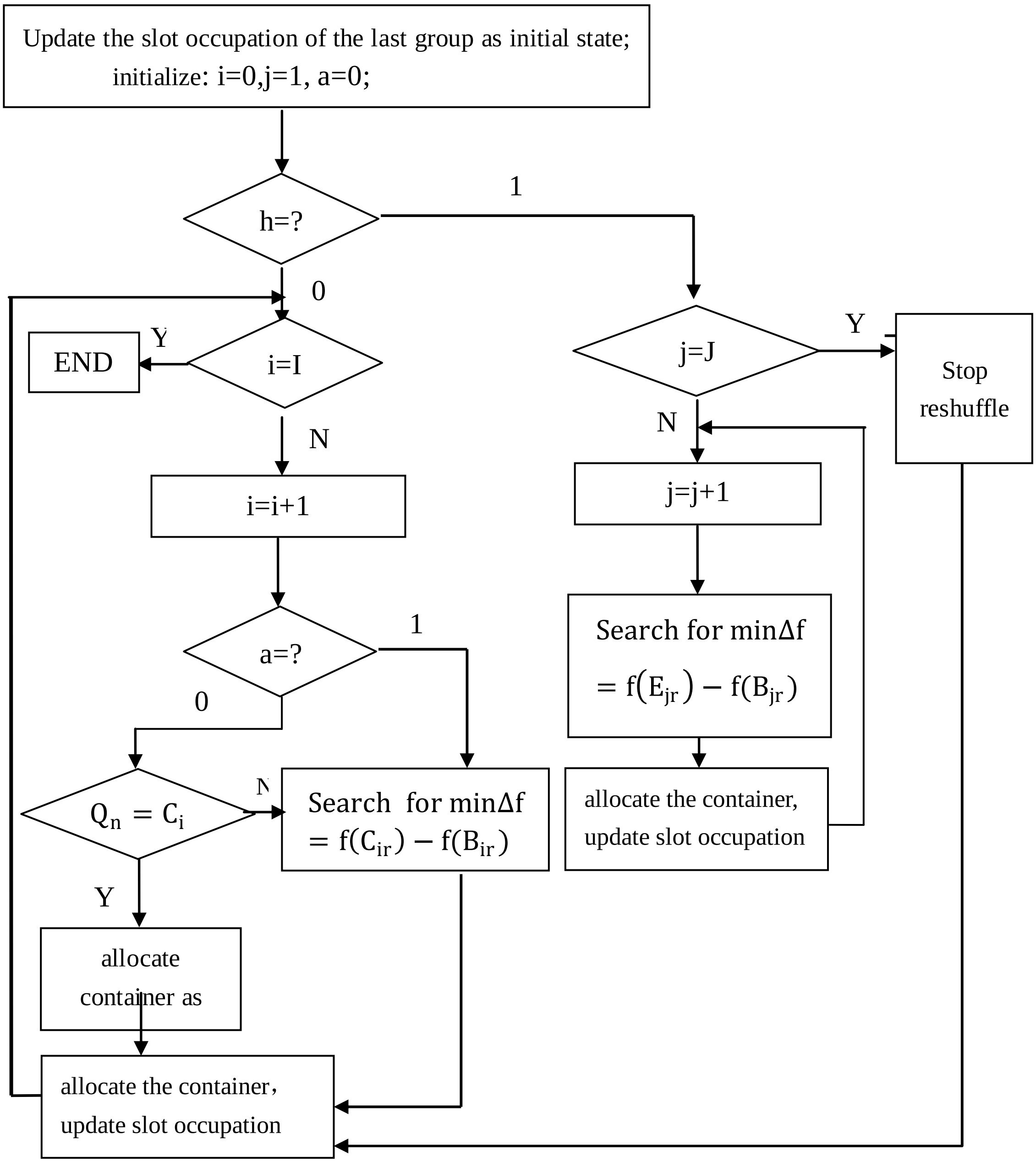

Figure 5. 4 –Flowchart of the heuristic algorithm for re-allocation planning

6 NUMERICAL EXPERIMENTS

In this chapter we evaluated the methodology proposed in this thesis with a hypothetical container terminal. Assumed there are 2 blocks in a terminal, 6 bays in each block, and 2 berths. In every bay, the maximum tier is fixed as 5 and the number of the rows is 8. Hence the capacity of a bay is 40 TEU. In addition, the maximum period for container to be stored in the container terminal is 7 days.

6.1 Numerical experiment of block and bay allocation

6.1.1 Data

The data needed to decide the block and bay allocation are presented from Table 6.1 to Table 6.12.

Table 6. 1 - Total number of containers that are initially stored in block i bay j at the beginning of the planning horizon

A_{ij1}	j=1	j=2	j=3	j=4	j=5	j=6
i=1	6	10	10	8	10	8

Table 6. 2 - Total number of P containers initially stored in block i bay j at the beginning of the planning horizon and to be pick up by customers during period t

P^0_{ijt}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
i=1,j=1	1	0	0	0	1	0	0	0	0
i=1,j=2	1	0	2	1	0	0	0	0	0
i=1,j=3	0	0	0	0	1	0	0	2	0
i=1,j=4	0	3	0	0	0	0	0	0	0
i=1,j=5	2	0	1	0	0	1	0	0	0
i=1,j=6	0	1	0	0	0	0	0	0	2

Table 6. 3 - Total number of L containers initially stored in block i bay j at the beginning of the planning horizon and to be loaded on board during period t

L_{ijt}^{0}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
i=1,j=1	2	0	0	0	0	0	0	0	1
i=1,j=2	2	1	0	0	0	0	1	0	0
i=1,j=3	0	2	0	0	0	3	0	0	0
i=1,j=4	0	0	2	0	0	0	0	2	0
i=1,j=5	2	0	0	0	0	3	0	0	0
i=1,j=6	0	0	3	0	0	0	0	1	0

Table 6. 4 - Total number of D containers which are discharged from vessels during period t and to be picked up by customers during period t+k

D_{tk}	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7	k=8
t=1	5	4	6	3	2	4	3	5	5
t=2	3	3	5	8	4	3	5	4	-
t=3	5	6	6	3	4	5	5	-	-
t=4	5	4	5	8	3	8	-	-	-
t=5	6	6	3	4	6	-	-	-	-
t=6	4	8	6	5	-	-	-	-	-
t=7	4	8	6	-	-	-	-	-	-
t=8	5	6	-	-	-	-	-	-	-
t=9	3	-	-	-	-	-	-	-	-

Table 6. 5 - Total number of G containers which are transported to terminal from customers and waiting to be allocated to bay

G_{tk}	k=0	k=1	k=2	k=3	k=4	k=5	k=6	k=7	k=8
t=1	8	8	9	6	5	6	3	4	4
t=2	10	5	9	8	9	7	8	6	-
t=3	6	10	2	6	3	5	6	-	-
t=4	9	6	8	4	7	8	-	-	-
t=5	5	3	6	7	2	-	-	-	-
t=6	3	4	3	7	-	-	-	-	-
t=7	7	8	4	-	-	-	-	-	-
t=8	3	5	-	-	-	-	-	-	-
t=9	8	-	-	-	-	-	-	-	-

Table 6. 6 - Total number of D containers that are discharged from vessels during period t and to be picked up by customers beyond the planning horizon

D_{te}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
Quantity	5	6	8	7	7	8	6	5	6

Table 6. 7 - Total number of G containers that arrive in the terminal in period t and to be loaded on board beyond the planning horizon

G_{te}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
Quantity	6	7	7	4	3	6	8	5	5

Table 6. 8 - Transport distance traveled by internal trucks between berth h and block i bay j

d_{hij}	j=1	j=2	j=3	j=4	j=5	j=6
h=1,i=1	410	360	310	260	210	160
h=2,i=1	160	210	260	310	360	410

Table 6. 9 - The number of D containers that are discharged from berth h during period t

D_{ht}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
h=1	15	10	18	25	22	15	10	6	3
h=2	27	31	24	15	10	16	14	10	6

Table 6. 10 - The number of G containers that are delivered to the terminal during period t and to be loaded onto the vessel in berth h

G_{ht}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
h=1	20	39	20	23	15	11	13	6	7
h=2	39	30	25	23	11	12	14	7	6

Table 6. 11 – The total number of L containers that are loaded onto the vessel in berth h during period t

L_{ht}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
h=1	20	37	19	22	12	11	8	5	4
h=2	39	28	24	20	11	12	12	6	5

Table 6. 12 - Total number of L containers initially stored in block i bay j at the beginning of the planning horizon and to be loaded onto the vessel on berth h during period t

L^{o}_{hijt}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
h=1,i=1,j=1	1	0	0	0	0	0	0	0	1
h=1,i=1,j=2	1	1	0	0	0	0	0	0	0
h=1,i=1,j=3	0	2	0	0	0	1	0	0	0
h=1,i=1,j=4	0	0	1	0	0	0	0	2	0
h=1,i=1,j=5	1	0	0	0	0	1	0	0	0
h=1,i=1,j=6	0	0	2	0	0	0	0	0	0
h=2,i=1,j=1	1	0	0	0	0	0	0	0	0
h=2,i=1,j=2	1	0	0	0	0	0	1	0	0
h=2,i=1,j=3	0	0	0	0	0	2	0	0	0
h=2,i=1,j=4	0	0	1	0	0	0	0	0	0
h=2,i=1,j=5	1	0	0	0	0	2	0	0	0
h=2,i=1,j=6	0	0	1	0	0	0	0	1	0

6.1.2 Solution

In this section, the optimal solutions are obtained by Lingo11 software on a Personal Computer including two Intel Core i5, 2.5GHz. The process takes 16 minutes.

6.1.2.1 Solution of the first stage

Table 6.13 and Table 6.14 present solution of the first stage which aims to balance the workload in every bay from each block. The numbers shown in the table cell are the number of D containers and G containers that are assigned to block i bay j at period t respectively.

Table 6. 13 - The number of D containers to be allocated to block i bay j during period t

Dijt	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
i=1,j=1	11	3	3	1	6	6	7	0	2
i=1,j=2	1	5	0	20	12	0	1	3	0
i=1,j=3	5	4	2	8	2	10	4	6	0
i=1,j=4	2	14	1	10	10	3	9	1	1
i=1,j=5	9	9	22	1	2	9	0	6	2
i=1,j=6	14	6	14	0	0	3	3	0	4

Table 6. 14 - The number of G containers to be allocated to block i bay j during period t

Gijt	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
i=1,j=1	10	14	9	11	3	4	5	7	3
i=1,j=2	12	11	11	3	3	8	6	1	3
i=1,j=3	9	13	11	6	8	2	0	0	3
i=1,j=4	13	7	14	5	0	1	4	0	2
i=1,j=5	8	9	0	11	4	0	6	1	2
i=1,j=6	7	15	0	10	8	8	6	4	0

6.1.2.2 Solution of the second stage

In the second stage, noticing the model is a multi-objective model with w_1 the weight of the difference between the actual total transport distance and the minimum distance, and w_2 the weight of the weight of the imbalance of the imbalance of berth related containers, we need to decide the value of w_1 and w_2 first. To figure out how they affect the objective of the model, numerical experiments with different value of w_1 and w_2 were made as is shown in Table 6.15. From the first experiment in which w_1 and w_2 are set as 1 and 0, to the 7th experiment with w1=0.6 and w2=0.4, we can see that f_1 and the total transport distance reduce by 0.18 and 2300m while f_2 and the berth related workload imbalance is stable. Since the 8th experiment when w1=0.7, f2 and berth related workload imbalance start to increase while f1 and total transport distance declined slightly. In the case when $w_1 = 1$ and $w_2 = 0$, f_2 and the berth related workload imbalance increased dramatically while the decrease of f_1 and the total transport distance is insignificant compared with the former experiment.

Table 6. 15 - Comparison of different value of w_1 and w_2

w1,w2	**f1**	**f2**	**Total distance /m**	**Berth related workload imbalance /TEU**
w1=0,w2=1	6.95302	28.40868	163070	137.5
w1=0.1,w2=0.9	6.772102	28.40868	160770	137.5
w1=0.2,w2=0.8	6.772102	28.40868	160770	137.5
w1=0.3,w2=0.7	6.772102	28.40868	160770	137.5
w1=0.4,w2=0.6	6.772102	28.40868	160770	137.5
w1=0.5, w2=0.5	6.772102	28.40868	160770	137.5
w1=0.6, w2=0.4	6.772102	28.40868	160770	137.5
w1=0.7,w2=0.3	6.731547	28.49519	160170	138.1667
w1=0.8,w2=0.2	6.655584	28.73828	159470	139.3333
w1=0.9,w2=0.1	6.30682	31.17207	155470	154
w1=1, w2=0	4.234681	77.37659	133770	409.5

Note: workload imbalance= $\sum_{t=1}^{T}\sum_{h=1}^{H}\sum_{i=1}^{I}\sum_{j=1}^{J_i}\left|(D_{hijt} + L_{hijt}) - AVDL_t\right|$

According to the experiments, it can be stated that the optimal transport distance and balanced berth related workload cannot be achieved together because they are contradicting with each other. To ensure the shortest transport distance, containers have to be allocated to the bays which are closed to the berth which means the number of containers cannot be assigned to every bay evenly, vice versa. Considered that optimal total transport distance is as important as berth related workload balance, since both of them has a direct impact on the waiting time of the vessels, the value of w_1 and w_2 is set as 0.5 respectively. It reasonable since the berth related workload imbalance is still the minimum one when we just aims at satisfying this object while the total transport distance is lower than the extreme experiment, which means the solution of the former experiment is better than the later one. The number of D and G containers that are allocated to block i bay j for berth h during period t, which is the solution in the case when we set w_1 and w_2 to 0.5, are shown in table 6.16 and 6.17.

Table 6. 16 - The number of D containers allocated to block i bay j that are discharged from berth h during period t

D_{hijt}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
h=1,i=1,j=1	0	0	1	0	5	3	4	0	0
h=1,i=1,j=2	1	0	0	13	7	0	1	1	0
h=1,i=1,j=3	5	3	0	7	2	4	0	2	0
h=1,i=1,j=4	0	1	0	5	6	2	4	0	0
h=1,i=1,j=5	1	0	10	0	2	6	0	3	1
h=1,i=1,j=6	8	6	7	0	0	0	1	0	2
h=2,i=1,j=1	11	3	2	1	1	3	3	0	2
h=2,i=1,j=2	0	5	0	7	5	0	0	2	0
h=2,i=1,j=3	0	1	2	1	0	6	4	4	0
h=2,i=1,j=4	2	13	1	5	4	1	5	1	1
h=2,i=1,j=5	8	9	12	1	0	3	0	3	1
h=2,i=1,j=6	6	0	7	0	0	3	2	0	2

Table 6. 17 - The number of G containers allocated to block i bay j that are discharged period t and to be loaded on the vessel which is in berth h

G_{hijt}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
h=1,i=1,j=1	4	8	4	6	0	2	0	3	2
h=1,i=1,j=2	4	7	4	0	3	4	3	1	1
h=1,i=1,j=3	0	4	6	0	4	0	0	0	1
h=1,i=1,j=4	6	7	6	3	0	0	4	0	1
h=1,i=1,j=5	6	9	0	7	3	0	2	0	2
h=1,i=1,j=6	0	4	0	7	5	5	4	2	0
h=2,i=1,j=1	6	6	5	5	3	2	5	4	1
h=2,i=1,j=2	8	4	7	3	0	4	3	0	2
h=2,i=1,j=3	9	9	5	6	4	2	0	0	2
h=2,i=1,j=4	7	0	8	2	0	1	0	0	1
h=2,i=1,j=5	2	0	0	4	1	0	4	1	0
h=2,i=1,j=6	7	11	0	3	3	3	2	2	0

6.1.3 Evaluation of the block and bay allocation methodology

About the objective of the total workload balance among bays that is set to achieve in the first stage, we can evaluate the model by total workload in every bay (M_{ijt}) as is illustrated in table 6.18. As can be seen from the table, the total number of containers that is allocated to each bay during the same period are on a similar level, in another words, the total workload among bays is balanced.

Table 6. 18 - Total workload in block i bay j during period t

M_{ijt}	t=1	t=2	t=3	t=4	t=5	t=6	t=7	t=8	t=9
i=1,j=1	28	31	25	25	18	16	15	9	6
i=1,j=2	28	31	24	25	18	16	14	9	6
i=1,j=3	28	31	24	25	19	16	14	9	6
i=1,j=4	28	31	24	24	18	16	14	9	6
i=1,j=5	29	31	25	24	18	16	14	10	6
i=1,j=6	28	31	25	25	18	16	15	9	6

To verify the approach taken in the second stage with the value of w_1 and w_2 as 0, we can apply the result shows in Table 6.15. Considering that the two extreme experiments, which are set one of the weights w_1 or w_2 to 0, neglects either the minimum transport distance or the balanced berth related workload as an objective to be solve, we can compare our solution with the results of the extreme experiments to evaluate how well the value of the objective function has been reduced. As can been seen from the first table of Table 6.19, the first experiment is the case that we just set the minimum transport distance traveled by internal trucks as an objective. If we consider about both of the objectives, f_1 will decreased by 2.6% while f_2 will not change. In another words, our solution reduced the total transport distance without sacrificing the balanced berth related workload. Similarly, according to the second table in table 6.19, compared with the first experiment which does not take the balanced workload into consideration, the solution utilized in this thesis reduced the imbalanced workload rate by 63.29% while introduced 59.92% of the growth of the total transport distance traveled by internal trucks between berth and bay. Hence the solution is the optimal one compared with the two extreme experiments and the methodology is effective.

Table 6. 19 - Reduction rate compared with the extreme experiments

w_1,w_2	f_1	f_2	Reduction rate of f_1	Reduction rate of f_2
w1=0,w2=1	6.9530	28.4087		
w1=0.5, w2=0.5	6.7721	28.4087	2.60%	0.00%

w_1,w_2	f_1	f_2	Reduction rate of f_1	Reduction rate of f_2
w1=1, w2=0	4.2347	77.3766		
w1=0.5, w2=0.5	6.7721	28.4087	-59.92%	63.29%

Combining with the analysis of the solution of the first stage, we can make a conclusion that the two-stage methodology in this thesis to allocate block and bay is valid.

6.2 Slot allocation

6.2.1 Data

The slot occupation situation at the beginning of a planning horizon period is shown in Table 6.20 and the value in the table is the priority value of the containers stacked in the researched bay. For instance, in row 1 tier 1, there is a container of which the priority level is 36 while the slot in row 1 and tier 5 has not been occupied. The maximum tier in every row is 5 layers. The first group of containers that are planned to arrive in the terminal is presented in table 6.21 with priority value of each container. Table 6.22 shows the actual arriving sequence of the first group which is the same with the planning sequence. In addition, when the group of containers have arrived in the terminal, according to the real-time information, there is a P container which is stacked in row 8 tier 1 with 55 as its priority value will be picked up at the beginning of the rolling horizon due to some reason; therefore the two containers above it have to be reallocated to other slots. Table 6.23 presents the reshuffle sequence before the arrival of group 1.

Table 6. 20 - Slot occupation situation and priority value of the containers in a bay at the beginning of the planning horizon

P_{tr}	r=1	r=2	r=3	r=4	r=5	r=6	r=7	r=8
t=5								
t=4								
t=3	22							12
t=2	30	2		32		10		13
t=1	36	6		51	28	23		55

Table 6. 21 - Planning arriving sequence of the first group

Q_n	n=1	n=2	n=3	n=4	n=5	n=6	n=7	n=8
P_n	52	40	38	25	17	15	7	2

Table 6. 22 - Actual arriving sequence of the first group

C_i	i=1	i=2	i=3	i=4	i=5	i=6	i=7	i=8
P_n	52	40	38	25	17	15	7	2

Table 6. 23 - Reshuffle sequence of the obstacle containers before the arrival of the first group

Ej	j=1	j=2
Pj	12	13

6.2.2 Solution

The initial slot allocation planning is solved optimally by heuristic algorithm with Matlab 7.0 software on a Personal Computer including two Intel Core i5, 2.5GHz. The process takes 1 second. The solution is presented in table 6.24 with shading table cell. We can see from the table that there are no obstacle containers.

Table 6. 24 - Solution of initial slot allocation scheduling

	r=1	r=2	r=3	r=4	r=5	r=6	r=7	r=8
t=5							17	2
t=4							25	7
t=3	22						38	12
t=2	30	2		32	15	10	40	13
t=1	36	6		51	28	23	52	*55*

When the group of containers has arrived in the terminal, we updated the real-time information and made the re-allocation planning based on the solution of the initial allocation. Since during this period, the container stacked in row 8 tier 1 are to be retrieved earlier than the planning pickup time, the two containers above have to be re-allocated to new slots and the initial slot allocation planning should be adjusted. The solution of slot re-allocation planning is made through heuristic algorithm, which is shown in table 6.25.

Table 6. 25 - Solution of slot re-allocation planning

	r=1	r=2	r=3	r=4	r=5	r=6	r=7	r=8
t=5							17	
t=4							25	
t=3	22			***13***	***12***		38	
t=2	30	2		32	15	10	40	2
t=1	36	6		51	28	23	52	7

6.2.3 Analysis

6.2.3.1 Two comparative slot allocation method

To verify the solution methodology about slot allocation illustrated in this thesis, we will compare the two-stage solution with other slot allocation approach.

The first way is to assign slots for containers randomly without taking the priority level of containers into account. One possible slot allocation result with the maximum number of obstacle containers is shown in table 6.26. The number of obstacle containers introduced by this solution is 7.

Table 6. 26 - Result of random slot allocation

	r=1	r=2	r=3	r=4	r=5	r=6	r=7	r=8
t=5							***<u>38</u>***	
t=4		2				***<u>17</u>***	***<u>40</u>***	
t=3	22	***<u>7</u>***				***<u>25</u>***	***<u>52</u>***	
t=2	30	2		32		10	***<u>13</u>***	
t=1	36	6		51	28	23	***12***	

The other way is to allocate containers according to initial slot allocation solution only without making the re-allocation planning, which is named as pre-allocation.

Arriving containers including G containers and D containers are to be allocated according to the initial allocation planning. If the slot that is assigned to an arriving D or G container is above an empty slot, the container will be stacked on the tier slot in this row. If the slot is occupied by other containers, the container will be stacked above the topmost container in this row. If the slot that is occupied has reached the limit maximum tier (tier 5), the container will be allocated to other stacks. Regarding the obstacle containers to be reshuffled, the re-allocation will be assigned randomly without searching for an optimal solution. For instance, as has been shown in Table 6.27, the obstacle container on row 8 tier 3 and tier 4 are relocated to row 7 tier 1 and tier 2 respectively. When the containers of which the priority value is 52,40,38 have arrived in the terminal, they have to be stacked on row 7 tier 3,4,5 respectively since initial slot allocated for it below has been occupied. However, for the containers with priority value 25 and 17, as the initial slot allocated for them is unavailable and stack has reach the maximum tier, they have to be allocated besides this row. In this experiment, they are allocated to row 8 tier 1 and tier 2 respectively. Similarly, when the containers of which the priority value are 7 and 2 are to be allocated, the slot allocated in the initial planning is occupied, they have to be re-allocated to row 8 tier 3 and tier 4 respectively. The total number of obstacle containers introduced in this slot allocation approach is 4.

Table 6. 27 - Result of slot pre-allocation

	r=1	r=2	r=3	r=4	r=5	r=6	r=7	r=8
t=5							***38***	
t=4							***40***	2
t=3	22						***52***	7
t=2	30	2		32		10	***13***	17
t=1	36	6		51	28	23	***12***	25

6.2.3.2 Evaluation of two-stage slot allocation approach

To summarize, there are three slot allocation methods illustrate in this thesis: the two-stage allocation approach, the random allocation, and the initial allocation only. As has been presented in Table 6.28, the maximum number of obstacle containers that is possible to be introduce by random allocation is 7, while the number caused by initial allocation only and two-stage allocation is 4 and 0 respectively. It is to say that two-stage allocation approach introduces the minimum number of obstacle containers.

Table 6. 28 - The comparative results of the slot allocation methods

	Random allocation(max)	Pre-allocation	Two-stage allocation
Number of obstacle containers	7	4	0
Reduction rate	0%	(7-4)/7=42.86%	(7-0)/7=100%

As both the pre-allocation and the two-stage allocate are the approaches aim at deciding the optimal slot for containers, we calculated the reduction rate of the obstacle containers for each approach to see to what extend the two approaches can reduce the amount of the obstacle containers occurred compared with the random slot allocation. The result in Table 6.28 shows that through pre-allocation, the number of obstacle containers is reduced by 42.86% compared with the random allocation. While the number introduced in the two-stage approach is reduced by 100% by comparison to the random allocation.

Therefore it is evident that the slot allocation solution obtained though two-stage methodology is the optimal and efficient approach to minimum the number of obstacle containers and to avoid container reshuffle.

7 SUMMARY AND PROSPECT

7.1 Main contributions

The storage space and the container handling equipments are the important resources of a container terminal. To gain the completive advantage for the terminal, terminal operator should optimize the utilization of the resources. This thesis is a research on the storage space allocation problem (SSAP) in the container terminal, which focuses on the SSAP in the terminal with mixed storage mode under delivery and pickup time uncertainties. To be specific, the main contributions of this thesis are summarized as follows:

First of all, this thesis introduces a two-stage approach to allocate storage space for containers on the block and bay level. In each stage, a mathematic programming model is formulated. The block and bay allocation decides the number of different containers of each berth to be allocated in each block and bay with the objectives of balancing the total workload among different blocks and bays, balancing the berth related workload among bays, and minimizing the transport distance traveled by internal trucks.

Moreover, based on the concern of the delivery and pickup time uncertainties, which has not been widely discussed in the previous studies, another two-stage methodology is proposed to decide the exact slots for the G containers and D containers to be allocated and the obstacle containers to be reshuffled. It has been proved by numerical experiments that the two-stage slot allocation methodology presented in this thesis can minimize the total number of the obstacle containers and the frequency of the reshuffle operation.

Through the methodology of the storage space allocation, the storage space and the handling resources are allocated properly, the efficiency of the handling equipments can be improved, the capacity of terminal can be developed, and consequently the more economic performance can be gained by the terminal, the shipping lines, and the customers.

7.2 Prospects

Due to the limited capacity and time of the author, the research can be developed on the following aspects:

(a) The integrated scheduling of the space resources and handling resources.

This thesis assumes that there are sufficient handling facilities for container handling, which is an ideal condition. In the real-world cases, the operation in the terminal is also restricted by the number and quality of the handling facilities that are supplied. Therefore, the limitation of the facilities such as internal trucks and quay crane can be taken into consideration to make a research on the SSAP.

(b) Predictions about the delivery and pickup time of containers

The initial slot allocation in this thesis is based on the reservation and historical records. Since a more precise solution of the initial allocation planning can cut down the time consumed in the re-allocation planning stage, a further study can be made to predict the delivery and pickup time of containers based on the reservation and historical information.

REFERENCE

Bazzazi,M., Safaei,N., & Javadian,N. (2009). A genetic algorithm to solve the storage space allocation problem in a container terminal. *Computers & Industrial Engineering*, 56 (2009) 44–52.

Castillo, B.D., & Daganzo, C.F.(1993). Handling strategies for import containers at marine terminals. *Transportation Research Part B: Methodological,*27(2), 151-166.

Cui,D.F. ,& Liang C.J.(2013). Dynamic storage space allocation strategy for containers based on hybrid stack mode. *J. of Anhui University of Technology (Natural Science),* 30(2), 214-218.

Dong, J. (2011). *A researched on the key resource dispatch optimization in the mode of mixed stackage of the container yard.* Unpublished master's thesis, Dalian Maritime University, Dalian,China. .

Fan J.J.(2013).Space allocation for container terminal based on mixed storage model. *Journal of Zhejiang University of Science and Technology,* 25(3), 168-175.

Heuristic Algorithms, Retrived May16, 2014 from the World Web Web: http://students.ceid.upatras.gr/~papagel/project/kef5_5.htm (2014)

Jeong,Y., Kim,K.H., Woo,Y.J., & Seo, B. H.(2012), A simulation study on a workload-based operation.planning method in container terminals. *Industrial Engineering & Management Systems,* 11(1), 103-113.

Jia,H.X.(2013). *The model of the storage space allocation in outbound container in container terminal yard.* Unpublished master's thesis, Dalian Maritime University. Dalian,China. .

Jin,Z.H., Mao,J.,& Li,N.(2011). Scheduling of relocating containers within a bay in container yard based on hybrid dynamic programming. *Journal of Transportation Systems Engineering and Information Technology*. 11(6), 131-136.

Kim,K.H., & Park,K.T. (2003). A note on a dynamic space-allocation method for outbound containers. *European Journal of Operational Research*, 148 (2003) 92–101.

Kim,K.H., & Kim, H. B. (1999). Segregating space allocation models for container inventories in port container terminals. I*nternational Journal of Production Economics*, 59(1-3).,415-423.

Kim,K.H., Park,K.T.,& Ryu,K.R. (2000). Deriving decision rules to locate export containers in container yards. *European Journal of Operational Research*, 124(1), 89-101.

Li.M.,, & Zhai,J.G.(2012). Export container stack allocatoinbased on PSO. *Port & Waterway Engineering*, 472(11), 42-46.

Li,P.A. (2013). *Slot optimization disruption management model and algorithm of import containers in container yard.* Unpublished master's thesis, Dalian University of Technology, Dalian,China. .

Molins,M.R., Salido,M.A., & Barber,F. (2012). Intelligent planning for allocating containers in maritime terminals. *Expert Systems with Applications.* 39 (2012) 978–989.

Preston,P. & Kozan,E. (2001). An approach to determine storage locations of containers at seaport terminals. *Computers & Operations Research,* 28(10), 983-995.

Shao, Q. Q. (2013). *Storage optimization for export containers in container yard with delivery sequence uncertainties.*. Unpublished master's thesis, Dalian Maritime University. Dalian,China. .

Sharif, O., & Huynh,N. (2013). Storage space allocation at marine container terminals using ant-based control. *Expert Systems with Applications*,40 (2013) 2323–2330.

Wei, J.J.(2010). Optimization of Positioning Export Containers in Yard. Journal Of Chongqing Jiaotong University(Natural Science), 129(3),470-473.

World Trade Organization. (2013,September 19). *WTO sees gradual recovery in coming months despite cut in trade forecasts.* Retrived June 3,2014 from the World Wide Web: *http://www.wto.org/english/news_e/pres13_e/pr694_e.htm*

Yan,W., X,C., & Chang, D.F.(2009). Yard allocation strategy for container terminals based on parallel genetic algorithm. J*ournal of Shanghai Maritime University*, 30(2), Jun 2009.

Yu,M.Z.,& Qi,X.T.(2013). Storage space allocation models for inbound containers in an automatic container terminal. *European Journal of Operational Research*,226 (2013) 32–45.

Zhang,C. al(2003).Storage space allocation in container terminals. *Transportation Research Part B,* 37 (2003) 883–903.

Zhou,J. (2012).*Research on the allocation model of container yard space resource*. Unpublished master's thesis, Hebei university of Technology,Tianjin,China.

Zhou,P.F., & Fang,B.(2011). Modeling and algorithm research on export container slots allocation under dynamic environments. *Control and Decision*,26(10),1572-1576.

Zhou,P.F., & Li,P.A.(2013). Stack allocation for Export Containers in Container Yard with Arrival and Leaving Time Uncertainties. *Industrial Engineering Journal, 1*6(1),25-30.