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World Maritime University

Shanghai, China

Research Proposals

"Study on Optimization of Container Stowage Based on Pre-Stowage Operation"

By Gu Fei

Assessor: Professor Zhen Hong

International Transportation and Logistics 2010

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.

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(Gu Fei)

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Abstract

Title of Dissertation: **Study on Optimization of Container Stowage Based on Pre-Stowage Operation**

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

Container stowage is a core part of container transportation. Container stowage is mainly to solve the problem of container loading in the port and make the plan of where to locate the containers in the vessel, based on the ensuring safety and economy of ship operation. This form the order of container loading and unloading. The quality of container stowage plan will directly affect the safety of ships and the efficiency of terminals operation. Research on container stowage optimization problem will have extensive application value of modern container terminal management and container shipping.

The problem is due to the constraints with complex multi-objective combinatorial optimization. With the increase of boxes ship loaded and loading of the ship and the diversity of port yard, the problem is becoming bigger and more complex. Many experts at home and abroad studied a lot in this area, but most are based on the perspective of multi-objective optimization, that is, so many factors should be considered but do not have a deep study on container stowage. The author work out an optimized model, starts on the decrease of container restow.

This paper is the study of the how to distribute container group on container yard to the cell blocks on ships, based on the restrictions of pre-stowage plan and combined with yard situation, let a group of container in the yard assigned to the ship cell block. That makes the most rational allocation of stowage, improves the utilization of equipment. In accordance with the characteristics of the problem and the actual loading rules, this article designs corresponding heuristic algorithm, then uses numerical results verify the feasibility of the model and algorithm.

The author studied a large number of loading problem. In order to achieve a breakthrough on the basis of previous studies, this paper tries to build a new optimization model and explores a new optimization ideas and methods. This is also the principal innovation of this article. According to the characteristics of the problem, a mathematical programming model is established, algorithms and numerical examples are given, so as to confirm the feasibility of this research methodology, which has made a useful attempt.

KEYWORDS: Container stowage, Optimized model, Stability, Ship trim, Ship strength, Heuristic algorithm

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Chapter One Introduction

1.1 Background

Container transportation refers to the modes of transportation which stuff some single piece of cargo into a special standard cabinets as delivery unit transportation. Container transportation, which rose in the sixties, is gradually replacing the bulk modes of transport. It has some advantages as follows: simplified packaging, significant saving packaging costs, reducing freight cargo damage, improving the quality of freight transport, decreasing operating costs, lowering transportation costs and so on.

Container stowage is an important part of maritime transportation, it is mainly to solve the specific location of containers on board, during the process of container loading and unloading as well as on the basis of container stowage principles and guaranteeing the stability and strength of container vessels. That forms the order of container loading and unloading.

In traditional method, container stowage is manually completed by artificial experience, but with the increasing capacity of container ships, stowage issue has become increasingly complex, various research institutions and companies began to study the use of computer to solve the container loading problem with the hope that through the development of scientific and reasonable stowage plan for improving the efficiency of terminal operations and shipping.

1.2 Literature Review

Container transport is the goods packed in containers, with a container as a cargo collection. Container can be used as a module for handling the transport process and transport organization, with loading and unloading high efficiency, low labor intensity and ensuring cargo safety and quality, saving packaging costs, reducing transport costs of goods. In conclusion. It will help to organize a variety of modes of transport and integrated transport and other advantages. With the acceleration of economic globalization and regional economic integration process, there already have more than 60% of general cargo with container transport. This has become an important symbol of modernization and ensure the optimal mode of transport in international trade.

Container stowage is an important link in the sea transportation. It is mainly to determine the specific location of containers in the vessels in complying with the basic principles and guarantees contained in the ship stability and strength when loading and unloading container. It is a key link in container operation process with ensuring safety of the ship, cargo security. With the increasingly fierce market competition, how to determine the rational distribution of containers in the ships has always played an important role in shipping in order to reduce operating costs and improve the efficiency of container transport.

Since the development of large-scale vessels and increasing number of loading and unloading containers, container stowage problem has become more complex. Many scholars have done analysis and argument of this issues. Israel Institute of Technology Mordecai Avriel (2000) proved that container stowage problem is a NP-complete problem. University of Glamorgan United Kingdom Wison (1999) put forwarded portfolio planning optimization theory, heuristic algorithm research on container stowage problem. As the container loading is a complex multi-objective combinatorial optimization problems, involving statics ship, ship design principles, operational research, artificial intelligence, computational geometry and other fields of study. Therefore, studies on container stowage of modern optimization algorithms apply techniques such as Genetic Algorithms, Fuzzy, Nerual Networks, Tabu Search which can has important theoretical and practical significance in solving more difficult issues.

1.3 Research Methodology

Heuristic algorithm is a frequently used method in the works for a large number of impossible or very difficult mathematical problem. Some complex problems abandon the search for the optimal solution which provides near-optimal solution using the method, based on experience or judgments. This is known as heuristics. It does not have a fixed description of the algorithm and constructing the strategy is decided by specific engineering problems. The solution is not generally seek the global optimal solution, but the practical application of engineering to meet the requirements of the application of engineering which can solve more complex optimization problem. In general it can be recognized engineering practice.

The actual container stowage in the application of heuristic algorithms mainly used manual experience as heuristic rules to encode, resulting in stowage plan. The main work was done by several people as follows.

Webster and Van Dyke (1969) for the first time applied computer to the container stowage problems, used manual stowage experience as a heuristic algorithm to interact with the computer to randomly generate stowage plans. Since the algorithm ignores a lot of constraints, ultimately it is not widely applied in the practical business. But this opens up the precedent use of computer stowage.

Martin (1988) proposed heuristic loading method considering container yard operations on the assumption of some conditions to observe, analyze and build models. The study found that the efficiency of loading effects and guidelines for determining the importance of loading sequence as follows: least number of inverted boxes taken by gantry crane operation; gantry crane moving distance at least; shore mobile crane at least.

Avriel (1993) took container stowage problem as a two-dimensional stacking problem. He designed a single bay anchored stowage model with target of the least number of inverted containers by each port and a suspension heuristic algorithm.

Qiu Wenchang, Wu Shangang (2000) in the Windows environment using C language compiled a set of container ship stowage system. The system was using manual with visual window boxes and computer-aided calculation to achieve the container load.

Wang Hongpeng (2002) used knowledge reasoning technique to design container ship stowage expert system for automatic distribution, but only developed part of the module; Yang Xing, Ji Yongqing (2002) studied the container ship stowage with the target of stability in the most appropriate and least pressure load,.

Chen Haiyan, Wang Xiao (2005) put forward reasonable container loading order algorithm. Fan Tiecheng, Ma Zi (2005) used Rareto genetic algorithm to solve the container loading optimal problem with the least amount of inverted boxes, maximum amount of goods.

1.4 Structure

Chapter 1 is the introduction of container stowage and the method used in the analysis of container stowage utilization.

Chapter 2 gives the description of different types of containers and features of container vessels, sums up the principals and process of container stowage.

Chapter 3 describes the factors of container stowage and some kind of calculation of each container ship characteristic

Chapter 4 designs the model of container stowage optimization and the numeric method to calculate the model based on heuristic algorithm

Finally, chapter 5 gives the conclusions that have been derived from the research. Also, recommendations which the author wishes to recommend to container stowage optimization will be present.

Chapter Two   Container Stowage Characteristics

2.1 The concept of container

Container is a box that has certain strength, stiffness and specifications exclusively for the use of large quantity cargo. Using container to transport cargo, shipper can directly stuff the cargo in the warehouse and unload the cargo in the consignee's warehouse. There is no need to take the goods from container during the process of shipping, trucking.

Container unit (twenty-feet equivalent units), also known as 20 feet conversion unit which to calculate the number of container units. Most of the current national container transport use 20 feet and two 40 feet container. In order to unify Container calculation, 20-foot container is defined as a unit and 40-foot container as two units. That can facilitate the reunification of container volume calculation.

There has many different types containers. Divided by the cargo loaded: grocery containers, bulk containers, liquid containers, reefer containers, etc.; by material, wooden containers, steel containers, aluminum containers, glass containers, stainless steel containers, etc.; by structural, foldable container, fixed containers, etc., fixed container can be separated into full container, open top containers, flat rack containers, etc.; by the total weight, 30 tons of containers, 20 tons of container, 10 tons of container, 5 tons of container, 2.5 tons of container, etc.

2.2 Container ship types and structural characteristics

2.2.1 Classification

Container ship is a new type of shipping unit developed from the late 50s of last century. The current container ships are: LoLo type, Ro-Ro type, floating container ship and other several categories. Each category can be divided as follows:

(1) LoLo Container ship include: dual-purpose container ships, semi container ships and full container ships;
(2) Ro-Ro Container ships include: multi-deck Ro-Ro, Ro-Ro / lifting dual-use vessel;
(3) floating container ships include: general barges, Regency-style barges and catamaran barges.

Currently, the majority type of container ship is hoisting container ship. Most of these ships do not have handling equipment, they use container crane to complete loading and unloading operations

2.2.2 Structural Features

(1) single flat deck
International standard container design requires to achieve the strength of withstanding eight full containers layers. The current design of large container ship can stack 10 layers, so it is not necessary to set the multi-layer in the inner of container ships to reduce the load from the upper boxes. In addition to the cabin load, there also need a considerable amount of containers stowed on deck, usually 3 to 5 layers, deck is designed as flat side deck without girder and arch, so as easy to stack containers.

(2) large hatch
In order to enable the container stowed in the cabin straight up straight down directly without horizontal movement. Container ships with large hatch have the same width of the hole. The width of ship hatch is up to 70% to 90% of the ship width and its both sides is ballast tank.

(3) double-shell ship

To make up the adverse effects on hull structural strength from the single-deck design. Container ships usually have double wall, double bottom transverse bulkheads of double hull body structure, in order to enhance the ship longitudinal strength, transverse strength and torsional strength. This structure also provides a large capacity for ship ballast compartment to adjust gravity height when loading a large number of containers.

(4) tail model

Container ships' cabin is set in the rear of the ship, the middle part of the ship forms the place where can stow containers so as to improve the utilization of the ship's space.

2.3 Ship coordinate system and container location in the ship

In order to accurately represent the location of each container in the ship, each container location in the ship should be expressed harmonized with international code number. Currently container ship box-digit code number is set by ISO/TC104 Committee. With the premise of longitudinal containers on board, each box position is represented with six digits.

First two digit is row number (Bay No., From bow to stern, the slot loading 20ft containers on the turn is 01,03,05 ... ... odd number, 40ft containers, take two spaces of 20ft containers, are used with even number), the next two digits stands for column number (Column No., container column stowage position in the ship . There are two labeling methods: one is mark containers from the port side to the right side: 01,02 ... ... the other is from around middle to each side. portside is set by single number, compiled from the midline to the left is: 01,03,05 ... ..., from the midline to the right is.: 02,04,06 ... ..., if containers stored in a midline, 00 is used to indicate the column)

The last two digits suggests layer number (Tier No., Numbering divides into deck number and cabin number. Deck numbers are complied from top to bottom and use "D" word in front of the numbers. Cabin numbers are the same but put "H" word before the numbers.

In order to load containers on board, a standard positioning method should be used, ISO09711-1: 1990 indicates each container on board with three-dimensional positioning, that is Bay, Row and Tier numbers are set to locate containers, usually six digits, as follows:

2.4 The process and principles of container ship stowage

2.4.1 Manual stowage process

Container ship manual loading processing is divided into four steps:
(1) Box Collection. After terminal receives distribution notice from other logistics company, export containers stowing yard begins to be cleaned up and then export yard plan will be made. When containers sent to the terminal, the operation control room will specify a location in the yard. Each box is shipped with a packing list

(2) Verification and Classification. Container Stowage is requested for a range of accurate and complete data, so after all containers loaded into the yard, packing lists and export documents should be checked for the port of destination, container size, container type and so on. Containers will be verified according to the port of destination of each container, size and weight.

(3) Make ship stowage plans and shipping order. Planners will decide a pre-loading solution according to the goods, pre-loading principles and ship data, then map

pre-stowage plan. After that, develop actual stowage plan and shipping schedule based on the flow of goods, pre-loading plan, stowage principles and different types of terminal equipments.

(4) After actual stowage plan confirmed, terminal will start loading and unloading operation followed by the actual stowage plan.

2.4.2 Principles of container stowage

Broad definition of container ship stowage (including pre-loading, loading) is a complex and comprehensive problem and needs to meet the shipping transport requirements, that is safe navigation of ships, containers, the quality of cargo during the sea transport and cost-effective operation, container terminal handling technology and operation method also should be considered. This can improve the efficiency of the whole terminal system so that terminals can be reasonable, orderly, and efficiently organized. Detailed analysis as follows

Ensure good ship stability

Stability is a characteristic refers to the ship tilted by the external force (such as wind, surge), when the external force disappears ship will automatically return to its original equilibrium position. Stability is an important measure of safety navigation, especially under the condition when large number of containers loaded on the deck, ship gravity will make hither and that will cause decrease of ship stability. In all, making stowage plan must take full consideration of ship stability and meet the container ships stability requirements.

Maintain proper draft of ship.

Draft is the difference between ship bow and ship stern, proper trim can make ship navigation with good performance, save fuel, make full use of engine power. It should be noted in the loading of container volumes and weight of vertical allocation in order to meet the vessel's draft requirements. Different ports and terminals need different draft requirements when loading containers.

Meet hull strength requirements.

First, the accumulation of cargo weight allows no more than the ship loading capacities. Cabin and deck of container ship is designed to the requirements of loading capacities. When making container stowage plan, total weight of each column can not exceed its allowable load accumulation, or it would affect the structural strength of the ship, endangering the safety of navigation. This must pay much attention to the overweight box. Second, we should prevent the hull in the arch.

Full use of the ship loading capacity

There has two main indicators to measure the loading capacity of container ships: slot utilization and loading weight utilization. These two indicators will directly influence the operation of the economic benefits of shipping companies. Ships loaded with full space but not full weight or full weight but not full space conditions often occur. A balance should be found in these two conditions to follow the principle of maximum benefit.

Avoid restow

Container liner operators usually call at more than one port and containers are loaded and unloaded in each port. Therefore, much consideration should be taken on reduce the phenomenon that first discharge port containers block the next port containers, so as to decrease the possibility of restow box and lowering handling rate. Avoiding each discharge port boxes gather together can use as much as possible with the quay cranes to operate at the same time, thus can improve overall handling efficiency and reduce ship harbor time in one port. Generally it requires 2 BAY apart for two cranes working together, so when a large amount of boxes will be discharged in one port, if all the boxes are more than one subdivision, they should be at least separated by 2 BAY configuration, so that 2 sets of crane can work and ensure efficient handling and shipment.

Avoid "one-sided" stowage.

The so-called "one-sided" stowage refers to allocate a number of boxes in one side of the ship. "One-sided" stowage does harmful for both loading or unloading, especially in the discharging port, it will result in ship heeling in the short period of time which makes it difficult in loading and unloading and operation speed. Therefore making stowage plan must avoid "one-sided" stowage and separate boxes into two sides of the ship symmetrically. Because of the structural characteristics size or weight of special containers(such as open top, flat rack, etc.), stowage plan should meet the specific needs of special containers, such as reefer containers must be stowed in a refrigerator areas; dangerous goods containers must meet the requirements of mutual spacing with other general boxes and ship restrictions on dangerous goods requirements; boxes must be loaded at ultra-high location in the cabin or the top level on the deck and so on. These special containers slot matching, lashing, storage and other considerations must satisfy with "IMDG" , "Cargo Securing Manual" other special provisions of ports.

Rules of collecting containers in the yard

Different handling technology and operation machines in container terminal causes different container collection rules. In making loading plans, the rules of the terminal should be taken into account box to prevent frequent restow and shipment delay.

Consistent with single-vessel operating requirements

Single-vessel operating plan is a detailed mission statement of single ship handling, including berthing time, commencement and completion time, total loading/unloading container volume, crane number, mechanical equipment and the tasks and progress of working classes, etc. the overall single-vessel operating plan requirements must be considered in container stowage. Among these, the most important is the number of operation cranes worked in the ship at the same time. The largest container ship's capacity volume is more than 10,000 TEU, BAY number is more than 70. reasonably arrange containers into each BAY according to the ship berth location and export container place in the yard for avoiding the operating cross and seeking the shortest distance of transportation, especially in multi-channel operations. Stowage planner should carefully arrange discharge boxes of each port, so as to avoid conflicts of containers operating in the yard, all types of machinery and the conflicts in the truck transport. All the operation should be arranged continuously in an orderly manner.

Ensure that the machine is reasonable, and orderly move. Container stowage should be considered as far as possible to use the alongside cranes, reduce restow box in the yard and make the shortest routes of moving machines in order to ensure the reasonable and order machine moving, improve operational efficiency. The most important thing is not let machines move back and forth frequently.

These principles is the basis for development of pre-stowage plan, but some of the above principles may be contradictory. So comprehensive analysis and balance should be reached considering the importance of each principle and to find relatively good stowage plans

Chapter Three Principles and Calculation of Container Stowage

In the work of container ship stowage, it involves the performance of ships, cargo type, shipping routes, weather, storms and other complex conditions which must meet the container ship's stability, strength, trim and make full use of container ship loading capacity requirements and meantime ensure the quality of container cargo transportation, reduce the loss of cargo quantity and quality and ensure the safety of containers on the deck and convenience of cargo loading and unloading in the port. Container ship loading has many similarities with other ships, but there also has many differences which determine its load requirements and general requirements are both similar and different with others.

3.1 Full use of the packing capacity of container ships

3.1.1 The packing container ship capacity indicators

When there has many containers loaded/discharged in one port, checking whether the packing capacity of container ships correspondent with number of booking listed containers plays an important role in the preparation of pre-stowage plan. Characterization of packing capacity of container ships indicators include:

(1) 20ft capacity

20ft capacity means the maximum number of 20ft container carrier in container ship. In order to improve the space utilization of container ships, 20ft slot is often designed in the place where there will change greatly of ship structure. Such slots can only be placed with 20ft box.

(2) 40ft capacity (FEU)

40ft capacity means the maximum number of 40ft container carrier in container ship. Some slot of container ships are designed only for 40ft containers, such as the aft deck is often designed with vertical span of 40ft loading base. The slot can only be loaded with 40ft container. This can not calculate into the maximum capacity of 20ft containers.

(3) special container capacity

The maximum number of carriage of dangerous containers, refrigerated containers and other non-standard containers.

Capacity of carrying hazardous cargo box is limited. Some of the space is not allowed any dangerous box loaded, while others are designed only for several types of dangerous cargoes listed in "IMDG". Therefore, selection for large container ship cabin stowage is limited to the dangerous cargo containers.

(4) Panama Canal limitation

Panama Canal authorities declared any ship go through the canal shall not be stowed in the level which the cargo blocks the sight of observation in the deck. Most container ships have some slots which are higher than the observation sight. So these slots should not be occupied when going through Panama Canal which means it will reduce the capacity of container ship.

3.1.2 Method of make full use of container ship capacity

(1) take advantage of container ship capacity

Take full advantage of container slot capacity among which the most important is choosing the suitable total weight of the cargo. When container's weight is close to the average standard, it is easy to calculate the number of containers can carried in the ship. The greater the mean weight of containers, the smaller the number of containers carried when fully loaded. Choosing the right number of light and heavy containers is the key element of making full use of container ships. There have some points should be noted as follows:

(A) Doing pre-stowage plan should make consistency between 20ft, 40ft containers box number listed in the booking sheet and 20ft, 40ft containers number loaded on the ship, in order to improve the slot utilization of the ship.

(B) To improve the carrying capacity of ship and reduce or avoid the restow container operations, the slot selection should try to maintain independent according to different container discharge port or put containers of the same port gathered in the same slot vertically.

(C) In condition of adequate loading containers, it should minimize the loss of box spaces when allocating special containers. For example, when conditions permitted, over height containers can be put in the top of the deck instead of the cabin, that can reduce the loss of the slot space.

(2) Full use of net loading weight of container ships

When the total weight of container ship is very heavy or carrier draft is limited, checking the total booking container weight and the total net weight of container ship is quite important. The formula calculating the net weight is:

$$\mathrm{NDW} = \mathrm{DW} - \sum GW - \mathrm{BW} - \mathrm{C}$$

In the above formula, GW——the weight of spare parts in the ship, BW——retained weight of ballast water to ensure the ship's stability. Constant C is usually larger, including all non-fixed equipment weight.

When container ship is close to full loading capacity, the ship gravity is often high. At this moment, in order to obtain proper stability a large number of ballast water is needed to enter into the ballast tanks. Container ship stability characteristic decides the need for ballast water used, the more fully loaded container ship, the worse its stability, the greater the amount of ballast water required, which makes it impossible to generate economic benefits loading the ballast water transported from one port to another, resulting in waste of capacity and energy. Therefore, we should find the optimal ship stowage plans to minimize the amount of ballast and raise the ship's container carrying capacity and reduce the ship navigation resistance in the premise of ensuring security conditions of personnel, ships and cargo. Therefore, we must make efforts to improve the quality of container ship stowage plan and reasonably determine the allocation proportion of different discharging containers with different weight on the deck and in the cabin, reduce the quantity of ballast water required for lowering gravity of the ship. All of these are main measures to make full use of container load capacity.

3.2 Reduce the number of restow box

The efficiency of container ship transport depends largely on the container handling efficiency in the port. On average, about 60% of shipping time is in the port[1], ship berthing time depends on the number of handling container, port operational efficiency and handling equipment operating efficiency and the distance between container ship and loaded containers in the yard. All these factors will have impact on the operation speed. While the restow box an important element which always affects transport efficiency and cost. In general, restow box is inevitable, but how to decrease restow box has become a concern in the container terminal. Therefore, reducing restow box is very essential in order to meet the container loading speed and fast loading and unloading requirements, ensure the safety of the ship.

3.2.1 Restow container

[1] Steenken D, Stefan V, Rober S. Container terminal operation and operations research: a classification and literature review. OR Spectrum, 2004, 36: 3-49

The cause of restow box causes has something to do with container ship structure, berthing port number and the ship's stability. Container loading unit is a container, characteristic of which is only vertically hung in and hung out. Therefore, the containers can only access from the top in vertical stacking. If some latter discharging containers are loaded upon the former containers, the latter containers must be unloaded first and then load again. This is called restow container.

Handling restow box will increase container operation costs, extend the time for the ship in port. If restow box is under the deck, the handling price will be even greater. Because containers on the deck should first be removed and then open the hatch to get to the unloaded boxes. The following example will illustrate this problem.

3.2.2 Cause of restow container

In terminal operations, restow container is always occurred in loading and unloading operation, this is mainly caused by the following three factors

1. As the quantity of loading containers and berth port become bigger. It is difficult to seek an optimal solution during operation process.

2. Experienced stowage planner will be actively exchange some container locatio in order to minimize the number of restow containers in the following ports.

3. In order to meet the needs of ship’s draft and intensity demands, restow containers are inevitable during the voyage. But well done container stowage plan can reduce the number of inverted boxes. This is one the main problems when doing the container stowage plan..

3.3 Meet the requirements of container ship stability

3.3.1 Stability

Stability definition: stability is a characteristic of ship when ship tiltes from the outside force, as the force disappears, ship will automatically reach the original balance. Stability classification: longitudinal stability and static stability divided by tilting direction. The role of external torque by the nature of a static stability and dynamic stability. Divided by the size of angle, static stability and stability can be divided into three large angle stability. On the stability problem of this study only considers the static stability of ships, including the ship's initial stability, large angle stability and dynamic stability. Actual loading of ships under the stability should also be balanced to meet the standard requirements of these three.

3.3.2 Container ship stability

Capsule-shaped container ship structure makes it decrease in ship's capacity utilization. To improve the packing capacity, 1/3 to 1/2 container slots of container ships are arranged on the deck. For example, the largest capacity of one container ship is 1800TEU, where the deck capacity is 862TEU, the cabin is 938TEU. This will cause the high level of container ship gravity when ship is fully loaded and the rise in ship area by wind above the waterline. These will result in adverse ship stability and a high center of average containers gravity height, even higher than the fully loaded container ship horizontal height. Therefore, the container ship stability requirements are more stringent than that of general cargo vessel. In the bulk ship, in order to enhance the net loading weight, ballast water should be emptied as much as possible, while container ships aims to load more containers should set a large number of ballast tanks. Ballast tanks can reduce gravity height and meet the requirements of ship stability to obtain seaworthiness. In addition, container ships should keep with enough stability, but it is not appropriate to maintain a high degree of initial stability, so as to avoid sharp swings of the ship in the storm. That will bring about negative effects on solid equipment for larger inertia of containers.

In practice, ensuring the stability of moderate load is usually based on experience and relevant information. According to ship stability requirements, we can estimate the maximum allowable loading weight and the ship distribution weight of containers on deck and in cabin. To achieve this, related information should be accumulated in the actual production data. General approach is based on the specific circumstances of the ship and past load data, firstly estimate the approximate formula, and then re-calculate the actual stability. Ship stability calculations on the data is an important basis. Tka an example of 3400TEU container ship, a ship loaded full slot requirements: the average weight of container in the cabin is 12 ton/ TEU; the average weight of container on deck below black is 8 ton/TEU; while the weight on deck above black box is 2.5 ton/TEU or 3ton/TEU empty box. This layout is suitable for the requirements of lowering goods gravity height. Under these conditions, in addition to meet the needs of fuel, fresh water for full set sail and it will be loaded into the corresponding need of ballast water, it can achieve full load, full slot, but also satisfy the moderate stability, strength, trim requirements .

3.3.3 Ship stability calculation

Ship's stability includes static stability and dynamic stability, static stability is usually divided into the initial stability and large angle stability.

1. Initial stability calculation

When ship is micro-tilting, the stability is referred to as initial stability (the ship's tilt angle is less than $10^{\circ}-15^{\circ}$). All the ship's small angle stability can be measured on initial stability. The initial ship stability equation is as follows:

$$M_r = 9.81 \cdot \Delta \cdot GM \cdot \sin q$$

M_r ——Righting moment（$kN \cdot m$）

Δ ——Displacement（t）

GM ——Initial stability height (m)

q ——ship titling angle

From this, initial stability is proportional to GM. For positive righting moment, that is ship has the ability to restore the initial balance, GM must be positive. Initial GM height can calculated by the following formula:

$$GM = KM - KG - dGM_f$$

KM ——Ship metacentric height away from the baseline (m), it can look up from ship hydrostatic curves according to the mean draft or displacement of the ship;

KG ——The ship center of gravity away from the baseline height (m);

dGM_f ——The correction value of initial stability height (m)

KG can be calculated as follows

$$KG = \frac{\sum P_i \cdot Z_i}{\Delta}$$

P_i ——The item i loading weight of the total ship weight (t)

Z_i ——Load gravity of P_i away from the baseline height (m);

dGM_f can be calculated as follows:

$$dGM_f = \frac{\sum r_i \cdot i_{xi}}{\Delta}$$

r_i ——Liquid density of number i liquid tank (t/m^3)

i_{xi} ——Heel axis of moment of inertia from liquid free surface area of number i cabin (m^4), this value has something to do with the shape of the horizontal section of liquid compartment

2. Large Angle Stability Calculation

Large angle stability refers to static stability whose angle is greater than $10^{\circ}-15^{\circ}$. In case of large angle tilted, the shape of the underwater section of the ship changed obviously, the moment of inertia in the heel axis values change as the ship tilted to face the waterline before and after, stability radius also changes and static stability is no longer fixed, therefore. So initial stability GM can not be used as indication of large angle stability, but righting lever or righting moment instead.

$$M_r = 9.81 \cdot \Delta \cdot GZ$$

$$= 9.81 \cdot \Delta \cdot (KN - KH)$$

GZ ——Righting lever (m)

KH ——Weight stability arm (m)

KN ——Shape stability arm (m), can look up in the cross stability curve based on displacement and the horizontal angle

From the above formula, different tidal values correspond to different GZ value. according to the function $GZ = KN - KG \cdot \sin q$, one can draw a smooth curve, called the static stability lever curve. This curve can be said in a loading state of the ship, the horizontal angles of any moment of its recovery (or arm) and its trend.

Static stability curve has the following characteristics to indicate important parameters of several ship stability:

(1) static equilibrium position and the static angle

Assumed external force gradually push on the ship, when external torque equals to righting moment and no further increase, the ship is in static equilibrium. At this time heeling angle is called static angle q_s.

(2) Righting lever $GZ|_{q=30^{\circ}}$ corresponds to heeling angle 30°

The maximum angle during Ships during the sea voyage is usually not exceeding 30° caused by the static moments, $GZ|_{q=30^{\circ}}$ can be used to characterize large angle static stability.

(3) The maximum righting lever corresponding to the heeling angle $q_{S\max}$

The highest point of the horizontal abscissa value of static stability curve is $q_{S\max}$, it also known as the limit of static angle. To guarantee the safety of ships, this value is usually large.

(4) Angle of vanishing stability q_v

When the righting moment is 0, this is the corresponding heeling angle, the static stability curve of which is over the highest point. As the heeling angle over q_v, the ship's righting moment is negative, ship will continue to tilt until the ship capsized. The range between 0° and q_v is called ship's stability range.

(5) Angle of entrance from deck edge q_{im}

There has an inflection point between the origin and the highest point in static stability curve, the point corresponding to the angle of heel is angle of entrance from deck edge.. q_{im} will slow down after the stability curve increase.

$GZ|_{q=30^{\circ}}$ 、 $q_{S\max}$ 、 q_v these three indicators are used as a measure of the ship's large angle static stability.

3. Dynamic stability calculation

Ship's dynamic stability refers to the stability calculated by angle of inclination speed and acceleration when ship is forced by dynamic external force. Stability criteria K is used as a measure of dynamic stability indicators. K value is defined as follows:

$$K = \frac{M_q}{M_f} = \frac{\Delta \cdot l_q}{\Delta \cdot l_f} = \frac{l_q}{l_f} \qquad (K \geq 1)$$

M_q——The minimum overturning moment considering the combined effects of wind and waves

M_f——Wind heeling moment

l_q——The minimum overturning arm

l_f——Wind heeling arm

M_q (l_q) calculation can obtained by mapping the dynamic stability curve. The final results required K value should not be less than 1, which shows that wind heeling moment on board the ship can not be greater than the minimum overturning moment.

3.3.4 Checking ship's stability

According to "IMO suitable for all types of ships on the integrity of stability regulations A.749 (18)" stability criteria of container ship whose length is more than I00m is regulated in the following:

l) The area of righting lever curve between 0°—30° horizontal angle should be not less than 0.009 / C m • rad

2) The enclosed area of the lower of $0^\circ - 40^\circ$ horizontal angle and entrance angle q_f in righting lever curve should not be less than 0.016/Cm • rad;

3) The enclosed area of the lower of $30^\circ - 40^\circ$ horizontal angle and entrance angle q_f in righting lever curve should not be less than 0.006/Cm • rad;

4) Righting lever of horizontal angle 30° should be greater than or equal to

0.033/Cm • rad;

5) The maximum righting lever should be greater than or equal to 0.042/Cm • rad;

6) The enclosed area between horizontal angle 0° and entrance angle q_f of righting lever curve should not be less than 0.029/Cm • rad.

3.4 Ship trim

Floating is an ability to float in the water or maintain a balanced position in certain loading conditions of the ship. It is one of the basic performance of the ship. Ship floating on the hydrostatic equilibrium is called floating state.

Floating state can be indicated with trim under balanced waterline of the ship. Trim the ship is the difference between the head draft of the ship and tail draft, with the symbol t to represent. When head draft equals tail draft, trim is called average draft, that means the ship is in the upright state.

3.4.1 Trim calculation

When ship's trim angle is small, trim the formula is as follows:

$$t = \frac{\Delta \times (x_g - x_b)}{100 \times MTC}$$

x_g ——distance between gravity and the center of the ship (m)

x_b ——distance between center of buoyancy and the center of the ship (m)

MTC——cm trim moment（$9.81\, kN \bullet m/cm$）

The first draft d_f and the last draft d_a can respectively calculated as follows.

$$d_f = d_m + \left(0.5 - \frac{x_f}{L_{bp}}\right) \times t$$

$$d_a = d_m - \left(0.5 + \frac{x_f}{L_{bp}}\right) \times t$$

d_m——mean draft

L_{bp}——distance of perpendicular line

x_f——distance between center of floating and the center of the ship

3.4.2 Trim adjustments

1. Longitudinal movement of goods

Vertical movement of goods on board will have trim moment, the moment will allow the ship to change the trim. The change in amount is:

$$dt = \frac{p \times (x_2 - x_1)}{100 \times MTC}$$

P——cargo weight (t)

x_2, x_1——The beginning and the final goods longitudinal coordinates (m)

（$x_2 - x_1$）——The distance between longitudinal movement of goods (m), （$x_2 - x_1$）> 0, goods move to the bow; （$x_2 - x_1$） <0, goods move to the stern.

New draft after cargo movement

$$d_f = d_f + \left(0.5 - \frac{x_f}{L_{bp}}\right) \times dt$$

$$d_a = d_a - \left(0.5 + \frac{x_f}{L_{bp}}\right) \times dt$$

d_f, d_a——ship first and final draft before cargo moves（m）

Application of the above formula should pay attention to the amount of movement of goods is not greater than 1/10 of the displacement

2. Trim when small amount of handling

Put small amount of cargo p loaded in the vertical position x_p on board, the ship will have a sink and trim. This process can be divided into two steps in theory, that is installed p on the floating center x_f, the ship will move down then moved down dd.

$$dd = \frac{p}{100 \times TPC}$$

P will be moved from x_f to x_p, the change in trim dt can be calculated as follows:

$$dt = \frac{p \times (x_p - x_f)}{100 \times MTC}$$

New first and final draft after cargo movement:

$$d_f = d_f + dd + \left(0.5 - \frac{x_f}{L_{bp}}\right) \times dt$$

$$d_a = d_a + dd - \left(0.5 + \frac{x_f}{L_{bp}}\right) \times dt$$

Application of the above formula should pay attention to the amount of movement of goods is not greater than 1/10 displacement.

3. Trim when large amount of handling

If handling large quantities cargo, gravity and displacement can be re-calculated, accessing the buoyancy center, floating center, every centimeter pitch torque and other parameters to calculate the ship's draft and trim.

3.5 Meet container ships strength requirement

From the perspective of ship loading, the primarily part to ensure strength of the ship from damage is to ensure the ship's longitudinal strength and local strength without injury. But for container ships, in addition to longitudinal strength and local strength, we should also note torsion strength.

3.5.1 Ensure longitudinal strength

Longitudinal strength of the ship is a capability to avoid longitudinal deformation and damage in the longitudinal direction to resist bending and shear. Container ships of various loading conditions are in the state of arch, longitudinal strength is poor. According to this feature of container ships, when making stowage plan, we should seek to reduce arch moment. Heavier containers should be allocated into latter discharged containers into the middle of the ship, in order to prevent the weight of intermediate part in the ship too light.

3.5.2 Ensure local strength

Local strength is a capacity of deformation and damage when hull resist against external force. For ship operation, local strength must be controlled in the allowable range. Local loading weight of container ships can be suggested with safe load and container stacking capacity per unit area.

1) Safe load per unit area
Safe load per unit area is the maximum load can withstand in the bilge, deck, terrace deck and hatch per unit area.

2) Container stacking capacity
Container stacking load is the maximum weight 20ft or 40ft container base can bear in container ship's deck, hatch or bilge.

3.5.3 Ensure torsional strength

For container ships, torsional strength should also be taken into consideration when doing stowage plan. The approach to ensure torsional strength is to take on both sides of symmetrical coordination of container weight in the same line position.

Chapter Four   Optimization Model of Container Stowage

4.1 Constraints of container stowage

4.1.1 Container-related constraints

(1) Constraints of container type and load position

Container type can be classified into 11 categories, In order to make it simple, containers can be divided into three categories, general containers, reefer containers and hazardous goods containers. Different types of containers are loaded on board in different positions, Such as reefer containers are loaded in a position of external power supply, dangerous goods containers should meet the safety requirements. Location for loading reefer containers on board is fixed, so the location of reefer containers is basically determined.

In "International Maritime Dangerous Goods Code", clear regulations are made for isolation of dangerous goods containers. So stowage of dangerous goods containers should meet the requirements of isolation. In addition, ship structure should be taken into account of restrictions, for example, some container ships do not have protective equipment for dangerous cargo container, therefore, the loading locations of these dangerous goods containers should be indicated by chief officer.

(2) Constraints of container size

There are many dimensions of international standard containers, the majority of current national container, 20ft and 40ft containers. 40ft containers need two slot of 20ft containers, if the adjacent Bays of 20ft containers position have been loaded with 40ft containers, the adjacent bay can not load 20ft containers.

(3) Constraints of discharging port

Container ship will call for many ports in the voyage. We should consider ports sequence in container stowage plan so as to prevent restow containers.

(4) Constraints of container weight

Weight of containesr varies greatly, the weight of empty container is only 2-3t, while the weight of heavy 20ft containers is up to 28t, and that of 40ft containers is up to 32t. Different weight containers are loaded on different positions of the ship, To ensure the stability of ships, heavy containers should be placed in the cabin or lower position, light containers should be placed on the deck or the upper position. Light and heavy containers should be put in reasonable positions and ensure ship stability requirements.

4.1.2 Constraints of ship stability

As the loading characteristics of container ships, container ship stability requirements are more stringent than general cargo vessel. GM and floating state are very important to the of the ship security operation and economic benefit. Here, we consider three indicators GM, heel and trim

(1) GM

In any case, ship must ensure certain initial stability. Container ships are often in a state of lacking stability, In order to have better stability, container the total height of gravity must be low as far as possible. The bigger GM, the better stability, but the increase of GM will result in ship sway.

(2) Remain balanced on container the distribution of container weight

Heel is caused by uneven lateral distribution of container weight, in order to maintain horizontal floating state, the weight of containers must be distributed along the horizontal symmetry, that is about maintaining a balanced weight distribution.

(3) Moderate trim remains in container weight distribution

Trim is caused by uneven vertical distribution of cargo weight, trim is usually expressed in trim t.

4.1.3 Strength-related constraints

(1) shear strength

Most container ship is tail models, buoyancy is relatively small near the tail part of the ship. Unreasonable stowage will result in have a greater shear in the vicinity, but this rarely happens.

(2) Lateral strength and torsional strength

Horizontal framework of ship is able to support hull and deck, ship is usually equipped with ballast tanks. Under normal circumstances, lateral strength is adequate.

(3) longitudinal strength

Taking into account of the maximum load quantity of containers and fast loading requirements, container ships are designed with hatch system, such a large deck hatch damages vertical continuity, so its longitudinal strength is weak.

4.2 Container ship pre-stowage optimal Model and Analysis

4.2.1 Model features

In this model, the problem of pre- stowage of container ship is divided into two phases. In the first phase, goods in terminal or yard should be classified, and then loaded into each container, Using "staining packing" of the heuristic algorithm to load goods as little as possible; In the second phase, containers are allocated along the vertical configuration on board the ship. Here, the ship's Bay position can be regard as a box with capacity C_i, (i = 1,2, ..., n), similar group boxes loaded in one port can be regarded as the cargo will be loaded into the box s_j (s_j is the number of containers with similar box set) This model aims to operate the least amount of restow containers and uses optimized strategy to distribute each container into different Bays of the ship.

4.2.2 Basic concepts and definitions

(1) definition of container stowage matrix, P is container stowage matrix:

$$\mathrm{P} = \begin{bmatrix} \mathrm{P}_{12} & \mathrm{P}_{13} & \Lambda & \mathrm{P}_{1n} \\ \mathrm{P}_{22} & \mathrm{P}_{23} & \Lambda & \mathrm{P}_{2n} \\ & & & \\ \mathrm{P}_{n2} & \mathrm{P}_{n3} & \Lambda & \mathrm{P}_{n-1,n} \end{bmatrix} = \begin{bmatrix} \mathrm{P}_{12} & \mathrm{P}_{13} & \Lambda & \mathrm{P}_{1n} \\ 0 & \mathrm{P}_{23} & \Lambda & \mathrm{P}_{2n} \\ & & & \\ 0 & 0 & \Lambda & \mathrm{P}_{n-1,n} \end{bmatrix}$$

Among them, $\mathrm{P}_{i,j}$ means the number of containers, its loading port is i (i = 1, 2, ..., n -1), discharging port is j (j = 2, 3, ..., n), when i ≥ j, $\mathrm{P}_{i,j}$ = 0, so container stowage matrix is an upper triangular matrix. Suppose in a particular voyage, the ship anchored four ports, the container stowage matrix is

$$\mathrm{P} = \begin{bmatrix} \mathrm{P}_{12} & \mathrm{P}_{13} & \mathrm{P}_{14} \\ \mathrm{P}_{22} & \mathrm{P}_{23} & \mathrm{P}_{24} \\ \mathrm{P}_{32} & \mathrm{P}_{33} & \mathrm{P}_{34} \end{bmatrix} = \begin{bmatrix} 18 & 32 & 23 \\ 0 & 24 & 45 \\ 0 & 0 & 16 \end{bmatrix}$$

Among them, P_{12} = 18 shows the number of containers is 18, with first loading port and second discharging port.

(2) Similar containers group

We call the following three conditions similar containers set.

(a) cargo compatibility

(b) same container size

(c) the same loading and discharging port

The weight of the same container set can be different

4.2.3 Assumptions

As container ship stowage involves many constraints, many factors will affect stowage results. This paper only consider some significant impacts on the stowage, Such as decrease the number of restow containers, taking into account the longitudinal strength of ships and draft requirements. Based on this, the following stowage gives some optimal model assumptions.

(1) Container ports information is known, including the number of handling containers in each port, container size, cargo type and weight of container.

(2) Ship calls for P ports, the first port is set as the initial port. In the first ports ,all slots are empty. Containers will be unloaded in each port and load other containers of following discharging port. All containers will be discharged in the final port.

(3) Assumes that all containers can be loaded in a voyage.

(4) Stowage planner directly specifies the location of reefer containers and hazardous goods containers;

(5) 40ft containers should be allocated first before 20ft containers, 20ft and 40ft containers can not be mixed;

4.2.4 Variables and parameters

C_i (i=l，2，⋯，n) is the number of slots in number i Bay

e_{pi} (I = l, 2, ⋯, n) is the empty slot number in iBay in port p (p = 2,3, ..., P)

W_{pi} (i=1，2，⋯, n)is the total container weight of iBay in port p

T_{pd} (p=1，2，⋯，P，d=p+1，⋯，P)is the container number which loaded in port p and unloaded in port d

$$x_{pij} = \begin{cases} 1 \\ 0 \end{cases}$$

x_{pij}=1 means the same container set is located in iBay in port p. x_{pij}=0 means other conditions

y_{pij} is the set j of containers stowed in iBay in port p

$$z_i = \begin{cases} 0 \\ y_{pij} \end{cases}$$

z_i=0 means no restow containers，$z_i = y_{pij}$ means the number of restow containers in iBay

4.2.5 Target function

$$\min f_1 = \sum_{p=1}^{P}\sum_{i=1}^{n}\sum_{j=1}^{k} x_{pij} z_i \quad (4\text{-}1)$$ the less restow container, the better

$$\min f_1 = \sum_{p=1}^{P}\sum_{i=1}^{n}\sum_{j=1}^{h} x_{pij} \quad (4\text{-}2)$$ the less Bay containers of each port occupy, the better

4.2.6 Constraints

$$\sum_{i=1}^{n} x_{pij} \le 1;\ j=1,2,\ldots,h;\ p=1,2,\ldots,P \quad (4\text{-}3)$$

$$\sum_{i=1}^{n} e_{pi} \ge \sum_{d=p+1}^{P} T_{pd} \quad p=1,2,\ldots,P;\ d=2,3,\ldots,P \quad (4\text{-}4)$$

$$\sum_{p=1}^{P-1}\sum_{p=1}^{d} T_{pd} - \sum_{p=1}^{P-1}\sum_{i=d+1}^{P} T_{pd} \ge 0 \quad p=1,2,\ldots,P;\ d=2,3,\ldots,P \quad (4\text{-}5)$$

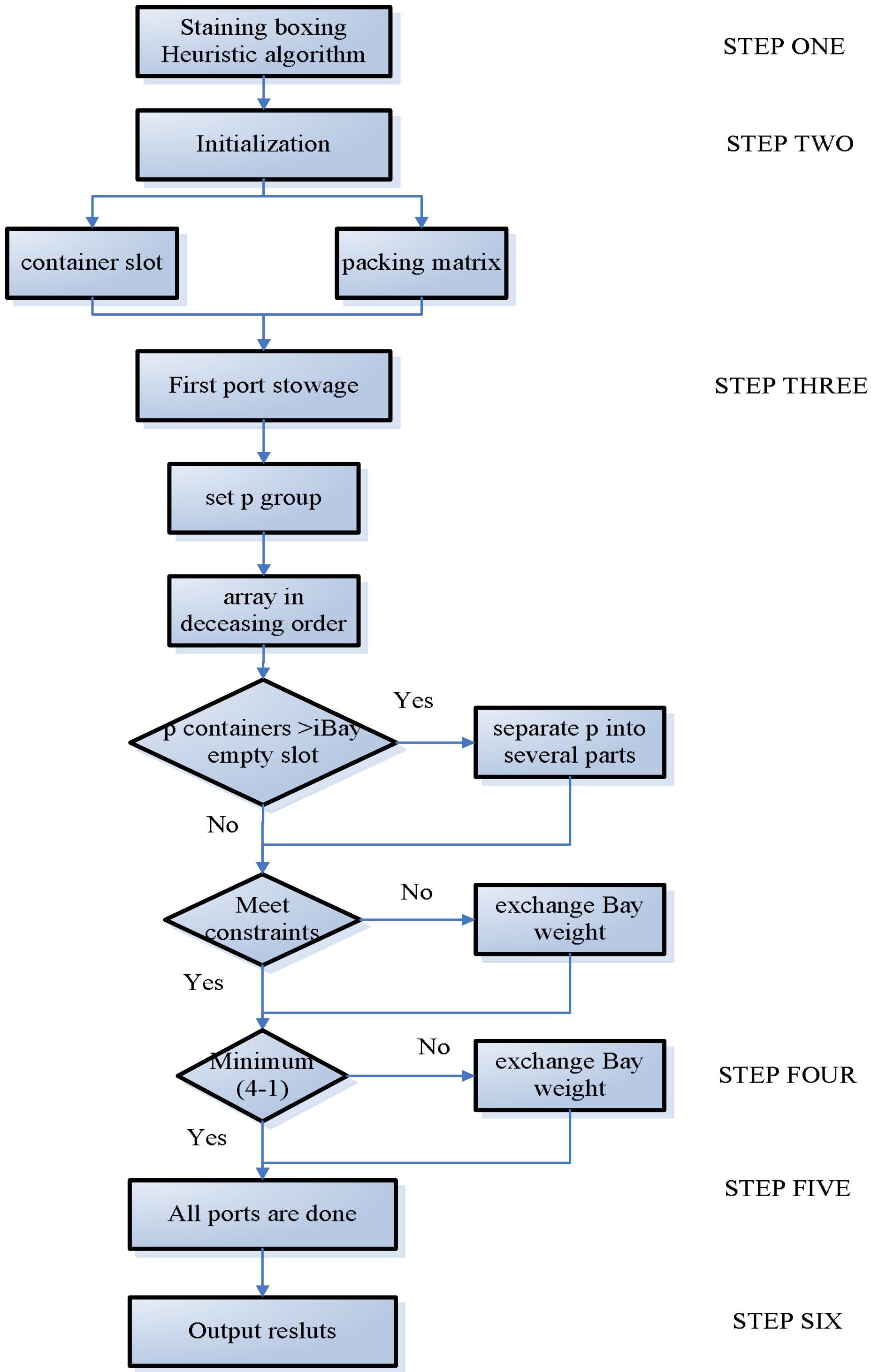
$$\sum_{i=1}^{n}\sum_{j=1}^{k} x_{pij} y_{pij} \le c_i \quad \text{i=1,2,…,n ; j=1,2,…,k ; p=1,2,…,P} \tag{4-6}$$

$$\frac{9.81\times\left(W_h \cdot m + W_m \cdot x + \sum P_i \cdot \bar{x} - \Delta \cdot CL_{BP}\right)}{2} \le M_s \tag{4-7}$$

$$t \le \frac{\sum_{i=1}^{n} W_{pi} \cdot LCB_i}{B \cdot L^2} \le 0 \quad \text{i=1,2,…,n ; p=1,2,…,P} \tag{4-8}$$

(4-3) indicates that each slot can only be occupied once in the current port. (4-4) is the limit to the number of slot, empty spaces should be larger than the port loading volume; (4-5) indicates the unloading boxes are greater than loading quantity; (4-6) indicates the number of containers in some Bay should not be more than the number of bits in the Bay; (4-7) and type (4-8) are the constraints for longitudinal strength and trim.

4.2.7 Algorithm Strategy



Char 4-1　Algorithm strategy process

Step one, use "stain packing" of the heuristic algorithm

Step two, Initialization of cargo space and packing matrix

(1) Initialize loading space, array space by Bay number from bow to stern, assign value to each Bay

(2) Create initial packing matrix $P_{i,j}$

Step three, make stowage plan for the first container load port;

(1) Container according to destination, separate the same box set into p groups, p = (1,2, ..., p), p is the number of ports the ship anchored;

(2) Array p groups in decreasing order according to the port of destination, that is the farthest destination box set came in the first, the second farthest in the second, and so on; The furthest destination of similar box set should be installed first, and so on;

(3) Calling packing algorithms to load containers on the current port; If container number of one port is greater than all the empty spaces of one Bay, then these containers will be divided into two parts for loading until the left can be loaded up in one Bay;

(4) Check if it meets the vertical restraints. If not satisfy the constraint conditions, exchange container weight with the same size Bay until constraints are met;

Step four, the state of all containers unloaded in current port is the initial state of current port. Update the capacity and the number of boxes and, put the same type container box set in decreasing order by port and then call packing algorithms. Set (4-l) as evaluation function for loading. If (4-l) is not zero, that means the current Bay is not suitable for loading container of this port, then re-find other places. So the minimum value of (4-l) and meeting the constraints is the optimal loading position;

Step five, all current containers have completed loading, switch to step five; otherwise transfer to step four;

Step six, output load results, the end.

4.3 Samples of stowage

Take a small container ship as an example.

Major parameters are as follows (Table 4-1)

Total length	Depth	Width	Displacement	Draft	TEU
100.9 m	8.35 m	19.2 m	2988 t	2.65 m	510 TEU

Table 4-1 Major parameters of ship

Volumes of each Bay are listed in Table 4-2

Bay	01	03	05	07	09	11	13	15	17	19	21	23	25
TEU	9	22	40	40	46	46	12	53	53	46	46	40	40

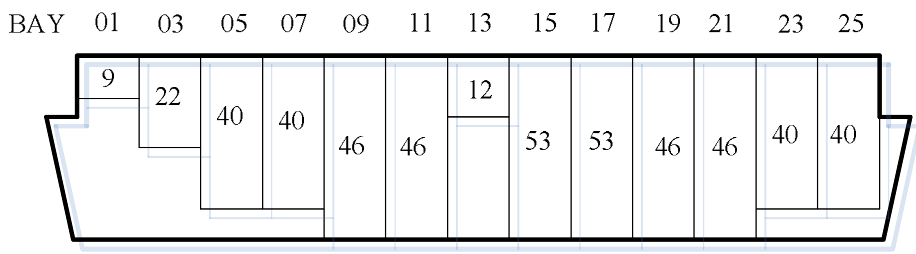
Table 4-2 Volumes of each Bay

Ship starts from port A and calls for port B, C, D. 275 TEU will be loaded in the first port. Table 4-3 shows the loading and unloading conditions of the ship

Discharging port / Loading port	B	C	D
A	150	50	75
B		120	90
C			65

Table 4-3 Loading and unloading TEU

(1) Initialize loading space, see Char 4-2 (the number in the picture means empty space)



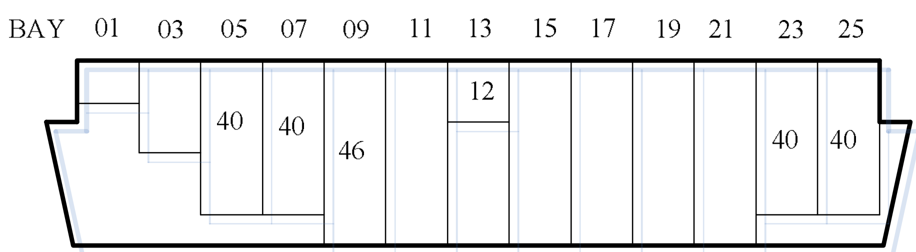
Char 4-2 The initial slot condition of ship

(2) According to Table 4-3, all routes packing matrix can be seen in the below

$$P=\begin{bmatrix} 150 & 50 & 75 \\ 0 & 120 & 90 \\ 0 & 0 & 65 \end{bmatrix}$$

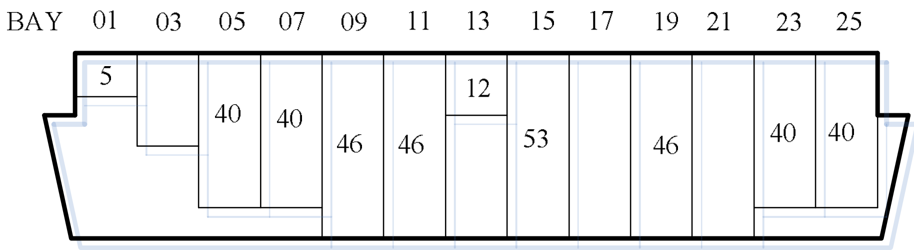
(3) Similar box sets are separated into 3 groups by port and set them in decreasing order based on port order. Port D containers will be loaded first and so on.

(4) Using packing algorithm to load port A containers, the result is Char 4-3



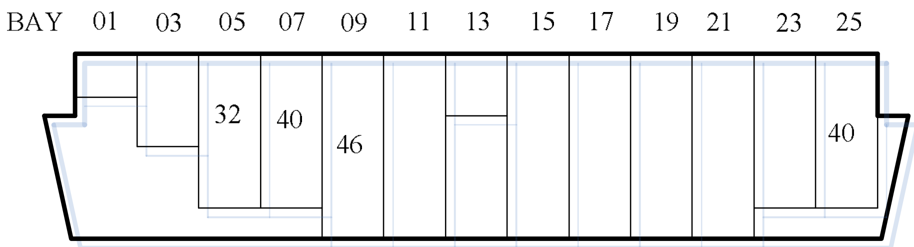
Char 4-3 Slot condition after loading in port A

(5) Ship received port B, Char 4-4 is the status when containers of port B are unloaded.



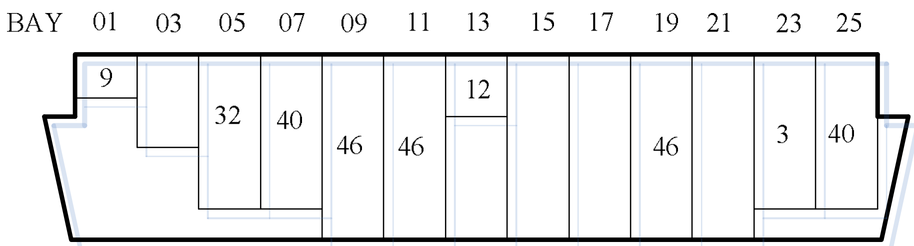
Char 4-4 Slot condition after unloading in port B

(6) Char 4-5 is the status after cargo are loaded in port B



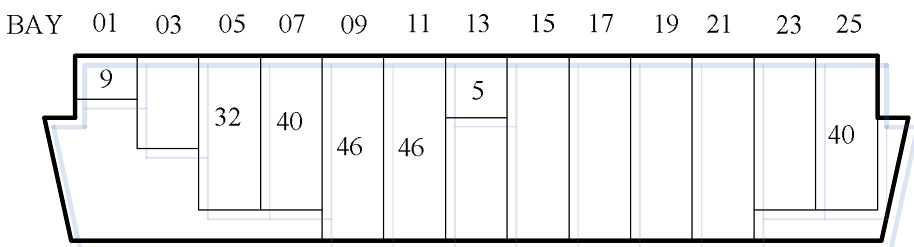
Char 4-5 Slot condition after loading in port B

(7) Char 4-6 is the status after cargo are unloaded in port C



Char 4-6 Slot condition after unloading in port C

(8) Char 4-7 is the status after cargo are loaded in port C



Char 4-7 Slot condition after loading in port C

(9) Finally, ship reaches port D, all the cargo are discharged.

According to the loading algorithm, the optimized stowage results are in table 4-4

Port \ Bay	01	03	05	07	09	11	13	15	17	19	21	23	25
A load	**9**	**22**				**46**		**53**	**53**	**46**	**46**		
B unload	**4**	**22**							**53**		**46**		
B load	**9**	**22**	**8**			**46**	**12**	**53**	**53**	**46**	**46**	**40**	
C unload		**22**						**53**	**53**			**37**	
C load		**22**			**4**		**12**	**53**	**53**		**46**	**40**	

Table 4-4 Optimized stowage results

Chapter Five Conclusion

Container ship stowage problem has high academic value, but also has broad applications. However, due to the actual variety of container stowage conditions, not only ship stability, strength and trim indicators should be considered, but also the maximization of slot utilization and reduction in restow containers. It is difficult to make a full, reasonable container stowage. In order to make it simple, this paper simplifies the problem and makes detail description of restow containers in pre-stowage plan.

Main research work of this article as follows:

Established an optimization model for container ships pre-stowage with minimum number of inverted containers, largest slot utilization and meeting longitudinal strength and draft conditions.

Because of the time limitation, this paper only consider a small number of optimization constraints for pre-stowage optimization model, actually there have some impacts on container stowage, such as how to deal with ballast water and space utilization, isolation of dangerous cargo containers. For container ship stowage system, as network technology and artificial intelligence are now rapidly developing, we can use internet-based system and agent technology for remote container loading and develop an intelligent stowage system.

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