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Review of containership stowage plans for full routes

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Abstract: Containership stowage plans are a pivotal teaches in the system of container transportation. With the increasing containers shipping, planning containership stowage has become more and more complicated. So intelligent stowage planning for containerships is of great significance. An effective stowage plan may improve efficiency of transportation system. First, the progress of containership stowage plan at home and abroad is reviewed, including the latest developments, such as the application of various optimization methods and computer techniques to the problem. Then, the complexities of the problem are discussed and areas where investigations are still needed are pointed out. This will provide a reference for further research on the subject.

Keywords: container; container shipping; stowage; full routes; intelligent stowage
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1 Introduction

Container-shipping is a kind of modern transportation which has a lot of advantages in speed, security, and quality comparing with the break-bulk cargo ship. It can increase the level of intelligent management and efficiency of container transportation. Over 60% of general cargoes are transported by containership at present. This mode is deeply accepted by shipper and carrier, and is becoming the main trend of freightage in the world. It shows powerful vitality and promising prospects.

The container stowage plan is a pivotal links to containers transportation, and the objectives of which is to draw a plan of loading and discharging sequence of containers for containership. Actual examples show that containership stowage plans not only influence the income of shipping company from transportation but also have direct relation to the safety of ships and freights. The problem is a combinatorial optimization problem with complicated restrictions and multi-objectives [1], the size of problem depends on the number of containers and ports of the ship calling at. These problems have troubled and aroused the interests of both scholars and commercial shipping organization in many countries since 1970s. With the development of container-shipping, more and more containers are transported by sail. Up to now, no satisfying solution has been found yet. Rapid development of container transportation trade also makes higher demand of the problem.

It is of theoretical and practical significant to apply experts system, genetic algorithm, neural networks and fuzzy logics to developing intelligent investigation on container stowage for solving the hard problems.

2 Characteristics and complexity of the problem

The increasing number of containers transported by ships led to containership enlarging in principal dimension, which makes it more complicated to draw container stowage plan. When we draw the plan, some factors must be considered, such as stabilities of ship, sources of goods and destination ports, strength of hull, quality of freight transported and appropriate stability. And in order to minimize the number of turnovers and reach the best economic profit, how to make the best utilization of loading capacity of ship when it is fully loaded should also be resolved.

To sum up, the following factors should be considered

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when drawing the stowage plan [2]:

1) The number of containers for a regular ship at calling ports, characteristics of containers (such as type, weight and length), position of the container in the yard and its destination port, et al.

2) The structure and performance, length and width and draft, and dead weight of the ship. The number of 20ft and 40ft slots loaded, the weight distribution in different parts of the ship.

3) Ship's stability, longitudinal strength and deck strength, trim and draft, fastening.

4) Minimizing the costs of loading, unloading and transporting cargo, especially the over-stowage.

5) The feature of the special containers waiting for loading (dangerous goods, refrigerate goods and non-standard dimensions containers).

All of these factors are interactive and conflictive each other in the processes of making stowage planning, which make the problem become a combinatorial optimization problem with complicated constraintes. Being a lot of complicated relationships can not be expressed by the mathematic models, it depends on the analysis based on experiences and intelligent reasons to a great extent.

3 International literature survey

The container stowage problem can be divided into two classes: one is management and programming at the container terminal, the other is stowage plan for containership. This paper mainly focuses on the latter.

Since 1970s, the stowage plan problem has been studied by shipping organization for commercial demand. They tried to find a good solution which would satisfy fewer shifting and higher efficiency when loading and discharging containers. According to the collected actual data, those methods can be grouped into the following six main classes: simulation based on probability, heuristic procedures, mathematical modeling, rule based on expert systems, support systems [1,3] and evolutionary computation.

3.1 Simulation based on probability

This method mainly refers to the findings of Nehrling and Shields[3-6]. Ones basic idea was to apply classical Monte Carlo simulation technique to create many different possible stowage plans at random, and then evaluate and compare these plans by actually simulating voyage across a number of legs, one of which would present the smallest number of over-stowage to be chosen.

Dyke and Webster[3] first tried to solve the problem by using computer. They put forward a heuristic algorithm that could create a random stowage plan. But the method could not achieve commercial application because it neglects the constraints concerning the decking, racking, lashing strength and the regulations on hazardous cargo transportation.

Shields[6] introduced a computer-aided preplanning system (CAPS) which had been used by American President Lines. The CAPS produced stowage plan by computer using Monte Carlo theory. Group technique had been used to produce stowage plan, containers with homogeneities (such as the same destination port, the same cargoes) were grouped together, and then the location of each groups of homogeneity was selected. Using this model, some algorithms similar to the ideas of stowage planner were designed and several scheming was brought forward. The scheming is evaluated according to the rules of stowage, and a few of plans are selected. Above-mentioned methods have been applied to the case of one port. If several ports are called at by ship, the number of after ports needs to be known.

3.2 Heuristic procedures

The method uses heuristic rules derived from the experience of loading planners to produce stowage plans. The researches of Scott and Chen[7] Beliech[8], Thieu[9], Martin[10] and Avriel[11] were focused on this view.

Scott and Chen[7] constructed a model, in which containers were sorted into ten classes based on some characteristics (such as type of cargoes, length, height and weight, racking strength and destination) and then three heuristic rules were used to assign gradually each type of containers to slots of the ship by four steps, while the shifting problem had not been considered in their model. Avriel[11] presented a 0-1 binary linear programming formulation based on minimizing the number shifting in a single bay of a ship calling at a given number of ports. However, the formulation of many binary variables and constraints made the working-out of model quite difficult, so in this paper, the Suspensory Heuristic procedure is developed to solve the model.

A general algorithm for Heuristic procedures has not been put forward. The algorithm should be designed based on actual project situation. The characterization of algorithm depends entirely on concrete instance, so the method is very flexible and the solution of the problem is not optimal generally, but it can meet the demand of engineering.

3.3 Mathematical programming approach

Mathematical modelling describes container stowage plan as an optimal problem, included the references below[12-19].

Chao [12] formulated an optimal model of minimum ballast and maximum loading. The model using constrained assignment approach assigned the containers to slots on board the ship, without considering the current port's influence on the plan of next port. In fact, it was a stowage plan model that only considered one port.

Aslidis[14] came from MIT had proposed a model whose objective function was to minimize the loading cost. But the model was merely of academic significance for it only took the constraints of longitudinal moment and metacentric height under advisement.

Botter and Brinati[1] created a model called complete mathematical model for the stowage plan problem, which used binary decision variables to determine the containers unloading and loading sequence for each port. The objective function of this model for the stowage plan involved two important factors: the number of re-stowing along the route and the longitudinal crane movement along the quay during the container loading and unloading operation. The number of over towages along port the ship calling at, weight limiting in one vertical stack, the stability, structural stress and other feasible conditions were considered as constraints. The advantages were that the model considered every port the ship calling at as a different stage of the whole system, which made the model much more correspond to the actual cases. But too many factors were considered in the model, the dimension of formulization was too large to solve because of large number of binary variables and constraints arising in the model. For example, for a container ship of 1000 TEU, calling at 4 ports, the mathematic model would have nearly 10^9 decision variables and approximately 10^6 constraints. Obviously, the solution of this problem cannot be obtained even using the best computer and the integer linear programming computer code. In order to reduce the complexity of the problem, the authors put forward two solutions: one was decomposition of the complete model, and the other was implicit enumeration algorithm though the model was still too difficult to solve the problem in polynomial-time.

From 1997 to 2001, Wilson et al [16-19] had ever discussed the complexities of stowage plan in his a few of papers. In one's paper "Container stowage pre-planning: Using search to generate solutions, a case study", the stowage-planning task was split into two parts. The first step was called strategic planning process which mainly simulated human loading planner's way of assigning containers to a blocked cargo-space according to the type of container (such as destination, category of goods and so on) to achieve the general arrangement of containers. Evaluation of the general arrangement used the following objective functions: minimizing the number of cargo spaces occupied by each destination; maximizing the number of cranes in operation at each port of destination (POD); minimizing the number of hatch lids moved; minimizing the number of re-handling; minimizing the number of cargo blocks occupied by containers. The algorithm used branch and bound search to produce the model. Once the best solution was found, the procedure would turn to the second step called tactical planning process. In the second phase, each container was assigned to a specific slot within blocks determined during the strategic planning phase. In the model, the following objects were considered: minimizing the number of re-handling; grading upwards the container weight, from heaviest to lightest; minimizing the stacks of container with mixed POD. Taboo search was employed to obtain an optimal solution. Wilson's model was feasible for it can change configuration step by step until each container was assigned to specific slot.

Avriel and Penn[20] proposed a brief 0-1 binary linear program formulation to reduce the shifting numbers of loading and unloading. His model supposed that a ship only contained a single bay and called at a lot of ports. It assumed that all the containers could be loaded into the bay. Avriel and Penn expatiated on computational complexity of the container ship stowage and showed that the general optimization problem was NP-complete. Further, they showed that finding the minimum number of columns for which there was a zero shifts stowage plan is equivalent to finding the coloring number of circle graphs.

Describing stowage problem with mathematic algorithm is such a large and hard problem that it is impossible to work out when considering simultaneously all possible constraints such as stability of ship, strength of hull, float states of ship and type of containers. While the model would be unsuitable for practical applications because of too many simplification hypotheses to be made. In this sense, it is difficult to construct a consummate mathematic formulation for optimizing the container stowage plan.

3.4 Decision support system

Decision support system attempts to provide the planner a powerful tool for stowage plan. Conceicao[21] , Sha[22], Saginaw[23] have done much contribution to this field .

Conceicao and Pires[21]established an integrated system for container management containing three subsystems. The system could be used either independently or interconnected to create a net work highly integrated. In the same year, Shao[22] developed an interactive computer program running on HP-9845B for container stowage by heuristic approach. There were menus on user interface to handle container allocation, load and discharge at container terminal, check constraints about containership and display information of port. It was tested successfully for a 618 TEU containership named 'HOLSTEN CRUISER' played between Sousse to Charlesworth in USA.

In 1994, CNS sub-corporation of South-ampton established CNS Boxtrack system based on United Nation's EDIFACT criterion. It was able to transfer stowage plan information by telecommunicating between loading planner of quay and planner of Ship Company. The system also permits operators examine and edit the data with graphic view on their own computers. Once operator receives the renewed stowage plan, the plan of ship could design efficient management project of containers on board the containership and container terminal. It is an information management system which has the characteristics of EDI and has been used in many large container quays.

Decision system would rather offer some original datum and information which can be analyzed and treated in order to provide some insights on the problem, so as to assist loading planner to work out stowage plan instead of attempting to generate an automating stowage planning. This system makes full use of accuracy, speed of computer in processing data and human expertise and creativity, which has lots of application to containership at present.

3.5 Expert systems

Expert system is a most active research and practical field of Artificial Intelligent (AI). Appling expert system to container stowage plan forms stowage expert system. This include the references below[24-27].

Dillingham and perakis[25,26] introduced their researches on expert system of stowage based on rules. Each of the suggested container movements was displayed graphically as the decisions were made. Database in the system could not only accomplish the stowage plan, but also track the location of the container. It was highly interactive, the user could interrupt the system at any time when the planning proceeded and overrode or revoked suggestions that the system had made. This expert system was developed entirely in the PROLOG language containing approximately 2200 lines of PROLOG source code and 26 loading rules. For the purpose of dealing with problem conveniently, two simplifications were done as follows: one did not consider the affection of hatch-lid's separation, the other did not consider reefer and hazardous containers. It must add about 50 to 100 rules even on the condition of unconsidered foregoing simplifications if such a system could be used.

Expert system has superiority when tackling the problems such as requiring experience and very complicated work like stowage plan. But traditional expert system exists 'neck of bottle' of acquiring knowledge and combinatorial explosion problem in reasoning, there are large numbers of study work needed to be done when using expert system to solve stowage plan problem.

3.6 Evolutionary computation

Algorithm of evolutionary computation came from Darwin's biologic theory of evolution. There are two or three branches at present, among which genetic algorithm is used widely. Genetic algorithm is a central issue both in engineering and theoretical fields. The application in engineering has gradually grown up. The researchers who firstly attempted to apply genetic algorithm to the stowage plan were Todd and Sen[28]. They brought forward a multi-criteria complete encoding genetic algorithm for solving the stowage problem. In their approach, different sections of the solution vector corresponded to each port. Each section of the solution contained integer vectors of size P, where P was equal to the total number of container slots in the ship. Each element in such a vector indicated the destination port of the container that occupies the corresponding slot at the given port. The major disadvantage of the approach is that vector of encoding is too long. For example, to encode a ship carrying 1500 containers and visiting 15 ports, a vector of length 22 500 is needed. Such long vectors would cause the search space too large and reduce the convergence rate of the algorithm.

Dubrovsky O. and Levitin G.[29] put forward a compact encoding technique, whose objective was to overcome disadvantages of complete encoding. The compact encoding method just saved the mutative part after the operation of loading and unloading completed along the route of ship calling, rather than holding the complete layout. Since the ship layout has a relatively small number of changes at each port, the size of solution encoding vectors would become much smaller than complete code. So this method would significantly reduce space of solution and advance efficiency of algorithm.

Though the application of artificial intelligence and soft computing based on neural network and genetic algorithm is few in stowage plan at present, it will be a research point at issue in the future.

4 Research in China

The container shipping of our country appeared later relatively than that of European countries, and stemmed from Tianjin port, at which the container transportation business was exploited since 1970s. With the reforming and opening, container shipping has gone through the course of growing out from nothing and from small to large. Domestic foreign trade containers number had achieved 21 million TEU in 2005, about 20% higher than the average level of the world seaborne container capacity. At the same time, we should be aware of that our soft circumstance could not meet the demands of sharply developing of container transportation. This not only affects the efficiency of conveyance of container, but also restricts the regional development of hinterland. Some researchers and scholars were not conscious of the essentiality of stowage problem until the end of 1980s and they started some investigation on stowage models for container ship using computer.

JIANG Shixin[30] presented the container stowage analytic way and ideas of designing the system. He also put forward a mathematic model for computing the stability of containership. XU Dongping[31] introduced the main design ideas of the stowage application software, and presented a general frame of stowage system and partial algorithms. LIU Shi-ning, et al[32] developed a self-loading expert system for the containerships of 'Bing City' and 'Song City' that belonged to Shanghai Ocean Corporation. WAGN Zhaoning[33] put forward an integrative information management system with expert system and used the method of transforming from low to high to probe into design and realization of auto-stowage system for containership. WANG Yu and XING Yuehua[34] introduced a decision supporting system of loading and unloading operation of container for Tianjin port. The main function of this system was to support production managing, help dispatcher making plan for general and single ship, manage container terminal, implement operation dispatch and accomplish operation statistics. Dr. HAO Jumin[35-37] coming from

Dalian University of Technology raised a concept of mixed sequence operation for container terminal BAY, then constructed three optimization models for mixed sequence operation container terminal under containers arrived at random. The models settled preferably the import containers stacking in BAY in container terminal. His solution had supported a sound foundation for the next stowage of containership. On the basis of optimization of quay terminal, using genetic algorithm based on fuzzy evaluation of multi-criterion function optimization and genetic algorithm based on isolation niche technique, the author constituted the containership stowage model, achieved practical use for one port. WANG Hongpeng[38] designed a frame of auto-stowage planning expert system using knowing-reasoning and had developed some modules of the system. Professor QIU Wenchang developed training simulator system for working out containership's stowage plans, which could be applied to training and examination for sailors in the evaluating item "cargo stowage and securing" according to IMO's STCW78/95 convention. YANG Xing[39]designed an optimal stowage plan model, in which stability and hydrostatic moment were objective functions for optimization. DUAN Chenghua[40] established a stowage model of single Bay calling at multi-ports. FAN Tiecheng, et al[41] used Pareto genetic algorithm to solve the model of minimum number of shifts and maximum packing volume and give optimal loading sequence from container yard to ship.

ZHANG Wei-ying et al[42] brought forward a stowage model of export containers based on optimal routing algorithm of yard trucks. ZHANG Wei-ying, et al[43] gave a model and algorithm for containership stowage pre-planning based on bin packing problem. ZHANG Wei-ying, et al[44] set up an optimization model of containers loading operation in export containers terminal and put forward a solution based on minimum-spanning tree. ZHANG Wei-ying, et al[45] established a model of bay layout for containership based on the least shifting.

Domestic researchers for container ship stowage mainly considered stability, floating status and structure strength of ship etc. in their disquisitions, whereas they inadequately considered about re-stowing problems when containers were loading and unloading. Over-stowage increases charges of container shipping and time ship berthes on the port, which is of no economic benefit for container transportation. Re-stowing should be mainly considered when designing the stowage plan.

5 Intelligent containership stowage plan system — a new stowage research direction

Intelligent stowage system is a technological innovation in contrast with traditional stowage method. It can improve the ability of decision-making management system of container shipping by means of artificial intelligence, information technology, communications and computer technology.

Stowage problem for containership is a complex process that involves a large number of decisions related fuzzy and random factors, and it is a topical combinational optimization but it also belongs to NP complete problems. Conventional computing method seems to be useless to the problem like this. Artificial intelligence, represented by neural network, genetic algorithms, fuzzy logic, and expert system, has sprung up since 80 s last century, and has been widely used in the field of engineering. Artificial intelligence offers a new method for NP complete problem.

Intelligent optimizing technique prefers using 'satisfying solution' than using optimization as rules. It has the priority in simple computing steps, and can be easily realized without advanced complex theory knowledge. It needs a little operations, and rules of solution embodying of intelligence etc. It offers an effective way for many engineering technologies and management problems.

Expert system is a system of computer that could accomplish special task with expert's knowledge level. The system can simulate human expert's method used in solving the problems and has been applied in many engineering fields. Application of lots of new technologies including neural network, fuzzy logic, roughsets theory, non-exact reasoning, and imperfection knowledge reasoning makes the expert system preferably flexible when the expert system is used to solve large and complex engineering problem. The reasoning mode is more close to human being expert thinking manner, so it can be used to solve such problem as stowage plan for containership [46]. Today, the containership has become bigger and bigger in volume. The efficiency of transportation has been greatly improved. EDI has been widely adopted in container transportation. Human loading plan is not enough for the development of container transport. Human loading will be replaced by intelligent stowage system based on modern information technology and artificial intelligence.

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1. 外文期刊 Antoine Fremont Fifty years of organisational change in container shipping: regional

shift and the role of family firms

Spectacular growth has marked the industry initiated by Malcolm McLean with the sailing of the Ideal-X in 1956. While the growth of container shipping has been typically seen in terms of technological advances, increasing vessel capacity, traffic growth, financial performance and competitiveness, it has been shaped also by organisational transformations. This paper provides an overview of the major companies that make up the container shipping industry, tracing the rapid adoption of containerisation by American carriers to its diffusion to Europe and then Asia. While several carriers belong to business conglomerates, the most dynamic in recent years have been those that are those that possess a family structure. About 12 of the present top 20 carriers are largely family controlled, including 4 out of the top 5. Unlike other capital intensive industries, where the power has shifted towards corporate governance, the container shipping industry retains a strong individualistic entrepreneurial character. At a time when North American ownership in container shipping is no more, the spirit of innovation began 50 years ago by an American visionary is still evident in the entrepreneurial dynamism of many of the industry leaders.

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India has a long coastline and large number of ports. Approximately 95% of India's international trade (ie, export and import) by volume and 70% by value is traded via its maritime routes. This makes shipping a crucial activity for the growth of Indian economy, and its development is pivotal to the overall growth of the Indian economy. Containerization of cargo has increased in recent times, and now a large portion of world's sea transportable goods is transported through containers. In this paper, the Indian ports have been analyzed in the overall context of the development of an integrated container shipping model for Indian ports. The paper discusses a methodology to examine the Indian ports for their readiness to accommodate future container traffic. Finally based upon the analysis, desired changes have been recommended in the Indian port operational structures for India to grow at a fast pace.

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The objective of this study is to examine the relationships between corporate social responsibility (CSR) and organisational performance in container shipping in Taiwan. Three dimensions of CSR are identified from the results of a factor analysis. These factors include 'community involvement and environment', 'disclosure', and 'employee and consumer interests'. With respect to organisational performance, both financial and non-financial performances are used as independent variables in this study. Findings indicate that CSR aspects of the 'community involvement and environment' and 'disclosure' dimensions have positive effects on financial performance, whereas the 'employee and consumer interests' dimension positively influences non-financial performance.

6.期刊论文 XU Hua.JIN Feng-jun Ship Size and Service Configuration in Container Shipping -西南交通大学学报(英文版)2009,17(1)

This study analyzes the effect of ship size on the liner service configuration by establishing an economic model.The service configuration is characterized by the distance of service and the number of calling ports.A study case is presented for illustration.At last such a conclusion is drawn that given a fixed profit,the ship size will change with the extension of service in the same direction,while the change rate of ship size is a little higher than that of the extension of service.

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一、2005年至2009年国际集装箱运输主要干线航线的增幅
从上表可看出,从实际与预测来看,亚洲→欧洲集装箱主要干线航线的增幅基本在10%以上,欧洲→亚洲集装箱主要干线航线的增幅为6%～7%.

8.外文会议 Krile. S. Application of the minimum cost flow problem in container shipping

In This work the efficient algorithm for optimal cargo transport of N types of containers with limited ship capacity, minimizing the transport costs, is being developed. It can be applied for transport planning on a voyage route with multiple loading ports and multiple ports of discharge. The problem is solved with network optimization approach that can be seen as the minimum cost multicommodity flow problem (MCMCF). The implemented algorithm is able to find appropriate load planning sequence and to ensure minimal loading, discharging and transshipment costs, but with fulfillment of cargo demands in a number of destination ports on the voyage route. Application of this efficient tool may significantly reduce transport costs and ensure maximal possible profit. It may improve the operation process in maritime transport technology.

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