An Automated Stowage Planning System for Large Containerships

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Abstract

The purpose of this study is to develop a system to automatically generate stowage plan for large containerships. The system consists of three modules: stowage plan generator, stability module and optimization engine. This paper presents the architecture and the work of the first module - stowage plan generator, which is used to automatically generate a feasible stowage plan with reasonable crane intensity (CI) and the number of rehandles and ready for the stability checks and adjustments. Our experimental results with real-world containership voyage data show that our system is able to efficiently generate feasible stowage plans comparable to human planners in terms of the number of rehandles and CI, which are crucial to shipping operations.

Keywords: Automation, Stowage Planning, Containership

1. Introduction

Stowage planning is an important task in the container transportation business and the quality of stowage plans greatly affects a shipping line's operating cost. For example, if a stowage plan enables a more balanced workload among the quay cranes in their loading and unloading operations at a port, the vessel turnaround time at the port will be reduced. This will bring great savings for the shipping line. Currently, stowage planning in all major shipping lines worldwide is still carried out manually by human planners. The quality of the stowage plan generated depends very much on the experience of the stowage planners who have gone through years of training onboard ships. Shipping lines are experiencing an increasing shortage of experienced planners. With the capacity of the bigger containerships rising from the relatively small 350 TEU (Twenty Foot Equivalent Unit) to ten thousand TEU, shipping lines face the increasing challenge to generate efficient and safe stowage plans for their ships as they move between ports.

In order to deal with the stowage planning for large containership, the subject of our study is to develop a fully automated system for stowage planning (see Figure 1). The framework of the system is: given the input data which consists of a list of loading and unloading containers for each port on a multi-port voyage, the stowage plan generator uses a list of heuristic strategies to generate a feasible stowage plan that fulfill a set of constraints excluding the consideration of the ship stability. Then the stability module checks the stability of the feasible stowage plan and adjusts it to satisfy the stability requirements. Finally, the optimization engine takes the feasible stowage plan adjusted by stability module and optimizes it based on some specific objectives (such as minimize the number of rehandles). While in this paper, we only present the related work about the stowage plan generator. The work with reference to the

Fig. 1. System of automated stowage planning.

other parts in the system is still in progress and will be shown in the future.

This paper is organized as follows. Section 2 reviews the related literature. In section 3, we present some definitions of stowage planning. The architecture of stowage plan generator is presented in Section 4. In Section 5, we present a simple test and show some computational results. Section 6 concludes the paper and outlines some future work.

2. Literature Review

Since the 1970s, the problem related to container stowage planning has been studied by shipping lines and researchers, see, e.g., [1-13]. The existing research is mostly focused on the container loading problem, which can be formulated into a combinatorial optimization problem. The size of the container loading problem depends on the ship capacity and the shipping demand at each port. Even for a medium size containership, the problem is nontrivial due to the large number of variables. Moreover, the problem has been proved to be NP-hard, which is to say that it is very unlikely to guarantee an optimal solution in a reasonable processing time. Meanwhile, a few researchers try to develop heuristic driven computerized methodologies to provide workable solutions to the stowage planning. A brief review of some relatively recent research follows.

The early study about the container loading problem can be traced back to the work by Aslidis (1989) and Aslidis (1990). The author examined the stack overstowage problem of small size problem under certain assumptions. Aslidis's work leads to a set of heuristic algorithms which were used to solve the container loading problem without stability. Another early work was carried out by Imai and Miki (1989) who considered the minimization of the loading-related rehandles.

Avriel and Penn (1993) formulated the stowage planning problem into a 0-1 binary linear programming. They found that the general algorithm is too slow even after some preprocessing of the data. Averiel et al. (1998) developed a heuristic procedure called the suspensory heuristic procedure with the objective of minimizing the number of container rehandles. However, they assumed that the ship only has a large cargo bay without considering the hatch covers and stability. Also, Averiel et al. (2000) showed that the stowage planning problem is NP-complete and showed a relation between the stowage problem and the coloring of circle graphs problem.

Wilson and Roach (1999, 2000) developed a methodology for generating computerised stowage plan. The methodology embodies a two stage process. First they use branch-and-bound algorithms for solving the problem of assigning generalized containers to a bay's block in a vessel; in the second step they use a tabu search algorithm to assign locations for specific containers. Wilson et al. (2001) presented a computer system for generating solutions to the stowage pre-planning problem using a genetic algorithm approach. Dubrovsky et al. (2002) used a genetic algorithm technique for minimizing the number of container movements of the stowage planning process. The authors developed a compact and efficient encoding of solutions to reduce the search space significantly.

In the papers of Ambrosino et al. (1998, 2004, 2006), the stowage planning problem is called the Master Bay Plan Problem (MBPP). Ambrosino and Sciomachen (1998) reported the first attempt to derive some rules for determining good container stowage plans, where a constraint satisfaction approach is used for defining the space of feasible solutions. Ambrosino et al. (2004) described a 0-1 linear programming model for MBPP. They presented an approach consisting of heuristic preprocessing and prestowing procedures that allow the relaxation of some constraints of the exact model. Ambrosino et al. (2006) presented a three phase algorithm for MBPP, which is based on a partitioning procedure that splits the ship into different portions and assigns them to containers on the basis of their destination. However they assumed that the ship starts its journey at a port and visits a given number of other ports where only unloading operations are allowed, which means the loading problem is only considered at the first port.

Since most of the above mentioned studies were carried out under some simplistic assumptions, they can hardly be applied by shipping companies to

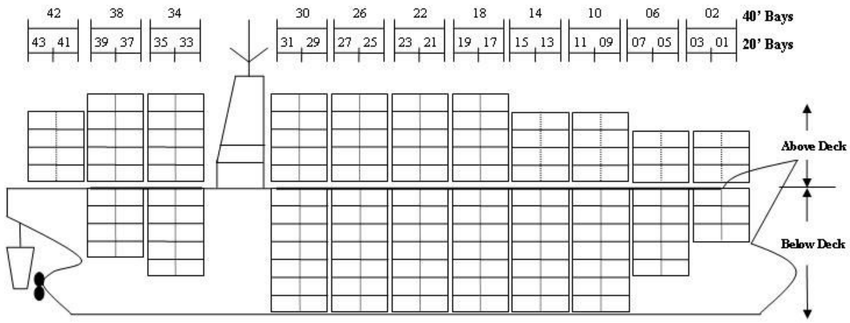

Fig. 2. Side view of a containership

generate stowage plan in real life.

3. Problem Definition

3.1. The Containership Structure

From the side view of the containership (see Figure 2), a containership contains a number of bays with number increased from bow to stern. In particular, each 40 foot (40') bay is numbered with an even number, i.e. bay 02, 06, 10, etc., while a 40' bay is associated with two 20' bays with two contiguous odd numbers, i.e. bay 06 = bay 05 + bay 07. Usually a bay is divided by hatches into two sections, below deck and above deck.

From the cross section view of a bay (see Figure 3), every bay contains a set of slots. Each slot is identified by three indices:

- bay, that gives the bay it is located in;
- row, that gives its position relative to the vertical section of the corresponding bay (counted from the center to outside);
- tier, that gives its position relative to the horizontal section of the corresponding bay (counted from the bottom to the top).

Usually, the containers are divided by size into two types: 20' container and 40' container. A 20' slot for the stowage of a 20' container (referred to as a Twenty-Foot Equivalent Unit or TEU) is indexed with the number of the corresponding 20' bay; while a 40' slot (usually is yield by two 20' slots) for the stowage of a 40' container is indexed with the number of the corresponding 40' bay.

As for the second index, the location has an even number if it is located on the seaside, i.e. row 02, 04, 06, and an odd number if it is located on the yard side, i.e. row 01, 03, 05, etc. Finally, for the third index, the tiers are numbered from the bottom of the containership to the hatch with even number, i.e. tier 02, 04, 06, etc., while in the above deck from hatch to the top of the container ship, the numbers are 82, 84, 86, etc. Thus, for instance, slot 180406 refers to the slot in bay 18, row 04 and tier 06.

3.2. The Objective of Stowage Planning

The containership profile together with the list containing all the characteristics of the containers to be loaded at a given port, are the input data for generating the stowage plan. The evaluation of a stowage plan can be judged by considerations, such as stability, economic reason, and safety. In this paper, the objective is to generate a set of computerized feasible stowage plans that minimize the number of rehandles and maximizes the crane intensity (CI) over a set of ports.

3.3. Rehandle

Due to the structure of the containership, the containers are stowed in vertical stacks. When a container is unloaded, the containers above it in the same row must be unloaded first. Moreover, if the container is stowed below a hatch, to open the hatch, all containers above this hatch must also be unloaded. In stowage planning, a common situation is that, at port I, the container with POD J (after port I) must be unloaded and reloaded at port I in order to access the container below them with POD I. This is called "overstow" or "forced rehandle". Another situation is that, although a container with POD J does not block any container with POD I, to prevent costlier rehandles in future ports or other reasons, the ship planner still decide to unload it and reload it at port I. This is called "voluntary rehandle". Usually, rehandling a container costs tens or up to a hundred of US dollars according to the port tariff. Moreover, rehandle operations also increase unnecessary workload of stowage planning and prolong the port stay of ships. A simple heuristic to reduce the number of rehandles is to load the containers in order of their PODs, i.e., for stowing containers at port I, first load the containers with POD K (port K is the farthest port from port I in a voyage), then load the containers with POD K-1 (the second farthest port) and so on. Finally load the containers with POD I+1 (port I+1 is the next port after port I in the voyage).

3.4. Crane Split

At a port, the ship will be served by a given number of (usually 3-5) quay cranes to unload and load containers. The bays of the ship will be partitioned into several areas. Each area will be served by one quay crane. This is called crane split. For operating safety, there should be a separation between two adjacent working cranes. The distance of the separation is defined as follows: if a crane is working at bay i, the neighboring crane has to be working at bay i+8 or further (see Figure 3). Therefore, if the working areas of two adjacent cranes are too close, one crane has to wait until the other crane finishes its work and move to a bay at a safe distance. The waiting time is called the "crane idle time".

The quality of a crane split is measured by crane intensity (CI). CI is calculated by the following formula: CI equals to the total working time of all cranes divided by the longest crane working time. The duration a ship is berthed in a port is mainly decided by the crane split and the longest crane working time.

4. The architecture of stowage plan generator

In this section we describe the system architecture

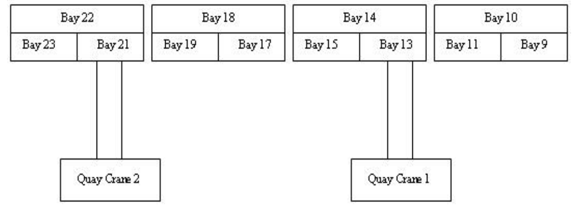

Fig. 3. Minimum crane separation distance

of stowage plan generator which is shown in the Figure 4. The stowage plan generator is made up with three parts: basic loading module, hazardous cargo adjustment module and stack weight adjustment module. In the following we describe in detail the functions of these three modules.

At a port, given the input data which contains the ship profile and loading container list, the basic loading module will generate the stowage preplan according to a heuristic approach called "block stowage". The main idea of "block stowage" is: first partition all the locations of a containership to several blocks with each block containing all the locations above or below a hatch; then divide all the containers in the loading list into different groups by size, type and POD. Instead of stowing the containers one by one, we load the containers group by group into the blocks according to a set of rules. In the basic loading module, we also develop a set of rules to guide the loading in order to generate a stowage plan with reasonable rehandles and CI. At this stage, most of the stowage constraints are considered except stability, stack weight and hazardous segregation.

For hazardous containers, there are many constraints from the hazardous segregation table and specific requirement of shipping lines. Given the stowage preplan generated by the basic loading module, the hazardous cargo adjustment module will adjust the positions of the hazardous containers in the

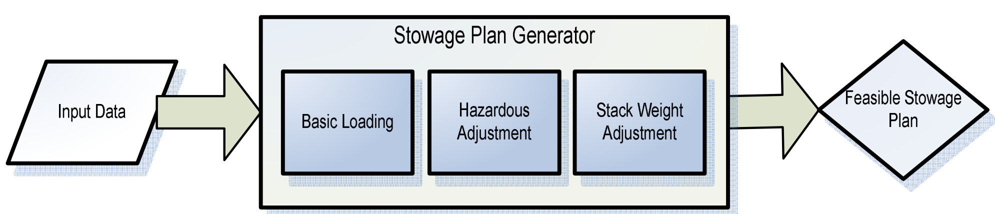

Fig. 4. System architecture of stowage plan generator

Table. 1. Workload at each port

Port	A	B	C	D	E	F	G	H
Unload	904	236	57	770	1605	459	1266	254
Load	1146	1212	339	422	1194	651	6	399

Table. 2. Comparison of two stowage plans

Port	A	B	C	D	E	F	G	H
Crane Number	5	4	3	4	4	4	4	4
CI (Plan A)	4.69	3.65	2.04	3.40	3.72	3.23	3.58	3.10
CI (Plan B)	4.58	3.06	2.25	2.70	3.78	3.24	3.39	1.78
tmax (Plan A)	875	794	389	701	1504	688	711	421
tmax (Plan B)	895	948	358	894	1480	703	751	732
r (Plan A)	0	0	0	0	0	0	0	0
r (Plan B)	0	1	3	8	0	14	0	0

stowage preplan to satisfy these constraints.

Depending on the ship structure, every stack has a stack weight limit which cannot be exceeded. Since stack weight is not taken into account in the basic loading module, there are always some stacks that exceed the stack weight limit in the stowage preplan. The stack weight adjustment module is used to solve these problems.

After the hazardous cargo and stack weight limit constraints are resolved, the stowage preplan generated by the stowage plan generator is a feasible stowage plan. The first step of the stowage planning system is completed. The remaining issue in the stowage plan will be solved by the stability module and optimization engine.

5. Case Study

In our testing, we consider a containership with capacity of 5000 TEUs. The voyage of the containership is given as H-A-B-C-D-E-F-G-H. At every port, a number of containers are unloaded and loaded (see Table 1).

In Table 2, we compare our computerised stowage plan (Plan A) with the plan made by human planner (Plan B), with respect to the crane intensity, the longest crane working time (t_{max}) and the number of rehandles (r). From the table, we can see that the automated method is competitive. Moreover, the entire set of stowage plans for *all* the ports in the voyage can be generated within one minute.

6. Conclusion

In this paper we present the stowage plan generator which is developed to generate feasible stowage plan automatically. Compared with the human planner, the stowage plan generator exhibits very good performance in terms of time, the number of rehandles and CI. However, currently we have not considered the stability yet, which will be our next step. Furthermore, we also plan to develop an optimization engine to minimize the cost or maximize the profit of the stowage plan.

Acknowledgements

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