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The Terminal-Oriented Ship Stowage Planning Problem

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ABSTRACT

The Ship Stowage Planning Problem is the problem of determining the optimal position of containers to be stowed in a containership. In this paper we address the problem considering the objectives of the terminal management that are mainly related to the yard and transport operations. We propose a Binary Integer Program and a two-step heuristic algorithm. An extensive computational experience shows the efficiency and effectiveness of our approach. A classification scheme for stowage planning problems is also provided.

1. Introduction

Apart from the contraction observed in 2009, the container trade volume *expanded at an average rate of 8.2 per cent between 1990 and 2010*, when it *reached 140 million of TEUs* (Twenty-Foot Equivalent Units), *or over 1.3 billion tons* (see UNCTAD Secretariat, 2011, p. 21). To meet the huge demand of maritime transportation, the world fleet of containerships has increased both in number and in total capacity. The last figures related to 2011 (UNCTAD Secretariat, 2011) show that the containership-world fleet counts 9688 vessels, supplies a total capacity of about 12.6 million of TEUs, and includes some vessels with a nominal capacity of 14,770 TEUs. New vessels with a capacity of 18,000 TEUs are going to be delivered to a leading shipping company.

For such large vessels the stowage planning, that is to decide where containers have to be placed within a containership during its journey, becomes a key factor in determining the operative cost of a containership. Actually, as noted by Delgado, Jensen, and Guilbert (2012), the stowage planning is aimed at reducing the staying in port of vessels and, as a consequence, the port fees. Moreover, short turnaround times allow the vessels to reach, within the scheduled arrival times, the downstream ports at lower sailing speeds, reducing by this way also the fuel consumption. The port fees and the costs due to the bunker fuel are the main determinants of the operative costs for a shipping company (Rodrigue, Comtois, & Slack, 2011). Slowing down the vessels has also great environmental benefits, as the reduction of the sailing speed has been recognized to be the most immediate single factor to reduce greenhouse gas emissions (UNCTAD Secretariat, 2011).

The stowage planning is a relevant issue not only for the shipping company, but also for the terminal operators, which are indeed involved in loading, discharging, and storing thousand of containers. The terminal operators are aimed at offering high-level services to the calling containership, through an efficient utilization of the terminal resources as berths, quay cranes, yard spaces and yard machines. Due to the inherent hardness of the underlying planning problems the managerial practice usually resorts to a hierarchical approach, starting from the allocation of berth and quay cranes to the containership, and eventually updating the decisions as the arrival time of the containership approaches, if necessary. Then the scheduling of the quay cranes is defined. Finally, before the loading/discharging process starts, the working sequence of the quay cranes must be designed. As the terminal operator must realize the loading (discharging) instructions provided by the shipping line company, good stowage plans have a great impact on the terminal activities. Moreover the terminal management has the opportunity to take part in the stowage planning process, so as to reduce the terminal operative costs and gain in efficiency.

In this paper we address the Terminal-Oriented Ship Stowage Planning Problem (SSPP), that is the problem of determining stowage plans minimizing the costs related to the yard and transport operations. The outline of the paper is as follows. In Section 2 the problem is described in detail. A classification and a review of the literature are provided in Section 3. A Binary Integer Model for the SSPP is presented and discussed in Section 4. In Section 5 the heuristic solution algorithm is proposed; numerical results

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are analyzed in the following Section 6. Conclusions and future research trends are drawn in the last section.

2. Problem description

Determining the arrangement of containers within a vessel is a very complicated task, and it requires full information on containers and vessel characteristics. For these reasons, the design of a stowage plan consists generally of two consecutive planning phases (Alvarez, 2006; Steenken, Voß, & Stahlbock, 2004), involving two different decision makers. The first phase is executed by the shipping line planners, which have a complete view both of all containers to be loaded and discharged at each port the containership calls during its journey, and the cellular structure of the vessel. The second phase pertains to the terminal planners: it is executed at each port of the ship port rotation, taking into account only the containers to be loaded at that specific terminal. The final aim of the terminal ship planner is to design the sequence of loading operations for the handling equipment (quay cranes and horizontal transport means). The last problem is referred as *ship loading* or *load sequencing problem*. In the following, we sketch out the structure of a containership. More details can be found in Appendix A. Then we analyze the two phases of the stowage planning process.

We can think of a containership berthed at the quay as a box with the longest side parallel to the quay. It consists of several smaller boxes, called slots and capable of holding a twenty-foot container (TEU). A slot, as well as the position of a container within the containership, can thus be identified by three coordinates: *bay*, *row*, *tier*. The bay is the longitudinal coordinate of a slot; the row and the tier represent, respectively, the transversal and vertical ones. Two adjacent slots, sharing the same row and tier coordinates, are used for storing a two TEUs container. The vessels are provided with a Cargo Securing Manual which illustrates the maximum permissible load on each slot, the lashing patterns, and the maximum weight and height of each ship-stack.

2.1. The first planning phase

In the first phase containers are classified on the basis of their attributes, like the dimension (standard, 45-footer, high-cube, oversized), the weight class (light, medium, heavy), the type (reefer, open-top), the load (dangerous, perishable), and the port of destination (POD). Containers of the same class are planned to be stowed into adjacent slots, taking into account a lot of constraints to guarantee static and dynamic equilibrium of the ship. The shipping line aims at maximizing the ship utilization and minimizing the number of on-board shifts, also called re-stows or over-stows, during the port rotation. At a given terminal A, a re-stow occurs when a container with POD B must be temporarily discharged and then reloaded on the same containership, possibly in a different position, in order to discharge some containers with POD A.

We will call *pre-stow plan* the output of the first phase. It is either a rough stowage plan, or a detailed stowage plan. In the first case the shipping line planners indicate, for each ship-slot, a container class, that is a set of attributes of containers which can be stowed in that slot. For this reason such a pre-stow is also referred as class-based stowage plan. An example of class-based stowage plan is shown in Fig. 1. Here the container class is defined by the POD, the dimension, and the type. Any high-cube refer container with POD A can be stowed in any allowed slot at tiers 82 and 84.

A detailed pre-stow plan indicates, conversely, the exact container to be stowed in each slot, as in Fig. 2. The details that can be retrieved by this stowage plan are: the POD (A), the loading port (B), the weight, the operating temperature for reefer containers, the type, the slot coordinates, but also a container code which univocally identifies the container to be stowed in each slot. Note that a detailed pre-stow plan implicitly defines one and only one class-based stowage plan. We refer to the latter as to the class-based stowage plan *induced* by the detailed one. On the contrary a class-based pre-stow plan can originate many different but compatible detailed plans. Thanks to the latter property, the terminal management plays an active role in planning the stowage of containerships while optimizing the operative costs. This is the subject of the next subsection.

2.2. The second planning phase

The pre-stow plan is sent via an Electronic Data Interchange (EDI) file to all the ports the containership will visit. It acts as an input datum for the second phase carried out by the terminal planner. At a given port the input consists of: the containers loaded at the previous ports and to be discharged elsewhere (*remaining on board containers*); the containers to be discharged; the pre-stow plan restricted to the containers to be loaded. The second planning phase transforms the pre-stow plan into an *operative plan* and results in defining a detailed working list for each quay crane operating on the containership.

The objective of the terminal planner is to minimize the ship turnaround time and the terminal operative costs. It is worth observing that the turnaround time is mainly determined by several hierarchical decisions, both at the tactical and operative levels, namely: the berth allocation, the quay crane assignment, and the quay crane scheduling. The interested reader is referred to Meisel (2009), Sammarra, Cordeau, Laporte, and Monaco (2007) and Monaco, Moccia, and Sammarra (2009) on these topics. At the time when the terminal planner faces the SSPP, the above decisions have already been taken. Therefore, in designing the operative stowage plan, the main concern of the terminal planner is to reduce the operative costs due to the yard-to-quay transport of containers, taking into account possible reshuffles. Reshuffles, or yard-shifts, are very time-consuming unproductive moves, which occur whenever some containers on the top of a stack have to be removed (and then re-stacked) in order to pick up a container located below in the same stack.

When the pre-stow is class-based, the operative stowage plan can be obtained by choosing the minimum cost plan, among the detailed plans compatible with the pre-stow. The basic constraints the terminal planner has to comply with are related to the stability of the containership. When completed, the stowage plan must be validated or reviewed by the vessel captain. Once accepted, it becomes an operative plan for the terminal and the loading lists can be designed.

In case of a detailed pre-stow plan, the terminal planner seems to have no way to reduce the operative costs. Indeed, he can accept the pre-stow as the operative plan, eventually resorting to the pre-marshalling policy (Lee & Chao, 2009). Pre-marshalling is to reallocate the export containers in yard areas near to the berthed vessel, so as to reduce the transportation time (and cost) during the loading operations and to avoid reshuffles. Pre-marshalling may be, sometimes, neither feasible nor profitable. Feasibility depends on the time and resources (equipment and working teams) available to reallocate containers before the loading starts. Furthermore, yard areas close to the quay represent a strategic terminal resource and managerial practice is aimed at reducing reallocations, because they are in any case costly (Moccia, Cordeau, Monaco, & Sammarra, 2009). Therefore, the adoption of the pre-marshalling policy must be decided on the basis of the cost/benefit analysis. Alternatively the planner could retrieve from the pre-stow the class-based induced plan, looking, as before, for a different compatible solution to be approved by the vessel captain. The