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A GRASP algorithm for the container stowage slot planning problem

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ABSTRACT

This work presents a generalization of the Slot Planning Problem which raises when the liner shipping industry needs to plan the placement of containers within a vessel (stowage planning). State-of-the-art stowage planning relies on a heuristic decomposition where containers are first distributed in clusters along the vessel. For each of those clusters a specific position for each container must be found. Compared to previous studies, we have introduced two new features: the explicit handling of rolled out containers and the inclusion of separations rules for dangerous cargo. We present a novel integer programming formulation and a Greedy Randomized Adaptive Search Procedure (GRASP) to solve the problem. The approach is able to find high-quality solution within 1 s. We also provide comparison with the state-of-the-art on an existing and a new set of benchmark instances.

1. Introduction

Over the past two decades there has been a continuous increase in demand for cost efficient containerized transportation. In order to meet this demand, shipping companies have deployed larger container vessels, which can nowadays transport up to 19,000 TEUs (Twenty-Foot Container Equivalent Units). These vessels sail from port to port loading and unloading thousands of containers. Minimizing the time a vessel spends in port involves, among other issues, an efficient stowage plan; a plan that describes where each container should be loaded on the vessel.

Container vessels are ships specially designed for the transportation of large amounts of containers with a small crew. Containers are metal boxes designed to withstand significant outer forces. They are particularly robust to high vertical compression, which makes it possible to create high stacks. All containers are fitted with corner castings designed to support the container's weight, and to which security fittings can be attached. ISO standard containers are usually 20′, 40′, or 45′ long. In the US trade it is also possible to find 48′ or 53′ containers (although they are not standard in liner shipping). ISO containers are 8′ wide and 8′6″ high, with the exception of high-cube containers, which are 1 foot taller. High-cube 20′ foot containers are rare and we assume they do not exist when modeling the slot planning problem. Longer containers, such as 45′ containers, are equipped with two extra sets of castings at a 40′ distance. The extra castings allow the longer containers to be stacked on top of 40′ containers. No castings, however, exist at the 20′ position, which means that 20′ containers cannot be stacked on top of longer containers.

Aside from the standard and high-cube containers, there are a number of specialized containers for different kinds of cargo. Fruits and vegetables, for example, must be transported in refrigerated containers called reefers. Liquids can be

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transported in tank containers, while break bulk cargo is transported on platforms and/or open-top containers (these, however, constitute only a very small percentage of the cargo). Containers transporting dangerous goods are called IMO containers. Depending on the nature of the cargo, a special IMO code is assigned to the container. Strict separation rules apply to IMO containers (Storck, 2015).

The layout of a container vessel is shown in Fig. 1. The figure shows how containers are arranged in storage areas called bays, along the entire length of the vessel. A bay is composed of a number of cells, each indicating a possible stowage position. Cells usually have a capacity of two TEUs (Twenty-Foot Equivalent Units), meaning that they can either stow two 20′ containers or one 40′ (or 45′) container. Each TEU position within a cell is referred to as a slot. Slots toward the bow of the vessel are called Fore slots and those towards the stern are called Aft slots. Cells are identified by a stack number, indicating its horizontal position within a bay, and a tier number indicating its vertical position. In general there is a distinction between on-deck and below-deck areas of a bay. The below-deck areas are closed by hatch-covers (or hatch-lids), which are tight metallic structures that prevent water from entering. Note that often 45′ containers are only allowed on-deck, and that the below-deck part of a bay is sometimes also called the hold. Fig. 1 also shows how only a subset of the cells have access to electric power (or reefer plugs).

A feasible stowage plan has to satisfy high-level constraints ensuring that the vessel is stable and seaworthy, and low-level constraints concerning the way in which each container is loaded into a position on the vessel. Using this constraint classification, state-of-the-art stowage planning typically follows a 2-phase hierarchical decomposition of the problem (Pacino et al., 2011; Ambrosino et al., 2015; Kang and Kim, 2002; Wilson and Roach, 2000). In the first phase, called Master Planning, containers are distributed to subsections of the vessel called locations. The distribution of containers must satisfy seaworthiness requirements. The draft of the vessel (the immersion depth) must be within limits; e.g. to ensure that the propeller is under water or that the vessel does not run aground when at port. The center of gravity must also be controlled in order for the vessel to be stable and to adjust the trim (the difference between the draft at stern and bow). The uneven cargo distribution and the shape of the vessel's hull result in different opposing forces that stress the structure of the vessel. Example of those are shear and bending moments which must also be within tolerance. One of the main objectives of the Master Planning phase is to minimize hatch-overstowage, meaning the number of containers on deck that need to be removed to get access to containers placed below deck. Since this is not the focus of this study, we refer the reader to Pacino et al. (2011) for a detailed description. The second phase of the decomposition, Slot Planning, refines the container distribution and identifies the exact position of each container in each vessel location. This phase is concerned with low-level constraints governing the physical position of the containers, ensuring that weight and height capacities are satisfied, and that reefers (refrigerated containers) are assigned to positions where a power outlet is available.

Fig. 2 depicts the decomposition approach. Master Planning requires a loadlist and port and vessel data. The loadlist includes the containers to be loaded at the current port and a forecast of those to be loaded at later ports. Vessel and port data include information about the layout of the ship and the depth of the ports of call. As its output is a class-based stowage plan (where only container types are taken into account), it is possible to solve an independent Slot Planning Problem for each location on the vessel. Though this might seem to be a simplification of the problem, the reason for following this path is rooted in the container terminal part of the optimization. Given a class-based stowage plan, terminals can optimize the load sequencing of the containers and thus further reduce the ship's time in port (Monaco et al., 2014).

Since the Master Planning does not take stacking constraints into consideration, there is the possibility that the resulting Slot Planning problems are not feasible. Pacino et al. (2011) handle this issue with a post-optimization procedure whereby containers are removed from the solutions until a feasible slot plan is reached. The authors also show that the number of rolled out containers is so low that more iterations of the decomposition are not needed.

Since solving the stowage planning problem over multiple ports requires the use of forecasts, stowage planners wish to be able to analyze different forecast scenarios. According to Pacino et al. (2011) and Pacino and Jensen (2012) 10 min is the maximum time the industry deems acceptable for stowage planning software to complete computations, which in turn leaves an estimated time of 1 s to solve each Slot Planning Problem.

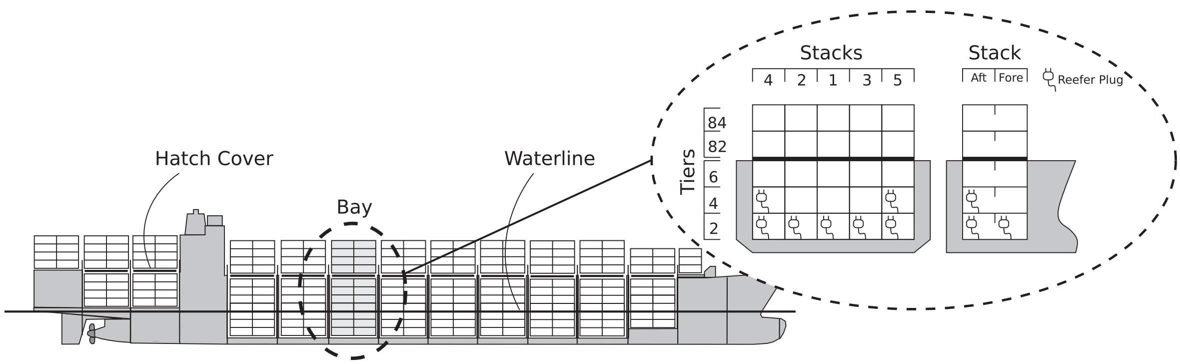

Fig. 1. The layout of a container vessel.