A Mixed Integer Programming Model for Cargo Composition Problem Including Containers with Dangerous Goods

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1 Introduction

Today, maritime transportation is the most important and cheapest mode of transportation in the international trade. Equally, the introduction of containers in the maritime transportation have irreplaceable role in modernization of the international trade. The maritime transportations are owned by different shipping companies. Despite the world economic crisis few years back, the demand for maritime transportation is increasing, as a result, each shipping company has to be competitive. The demand for efficient and cheap transportation and a fierce competition have driven shipping rates down, making it paramount for the carriers to utilize their vessels as efficiently as possible. Focus on vessel intake maximization is a daily activity for the shipping lines. Theoretically, the shipping companies know the nominal intake capacity of their container vessels to be delivered. However, the nominal intake capacity cannot be reached, unless the stability of the container vessel is ensured. The ship size and available cargo compositions in different ports make this work hard. The focus of this paper is the *Cargo Composition Problem*(CCP), which determines the cargo composition needed for a vessel to maximize its utilization on a given service. Differing from stowage planning, where a list of pre-selected containers must be stowed on the vessel, the CCP aims at selecting the quantity of containers of each type that should be loaded on a vessel to maximize its intake. The earliest formal description of the problem was presented in the PhD thesis by Delgado [2], where a mixed integer programing model was presented. The author considered standard and reefer of length $20'$ and $40'$ containers and a decomposition approach similar to stowage planning problem in paper [4], that was applied to achieve scalability of the problem. Another paper in this area is, the paper by Christensen J. et al.[1], in which they considered $20'$ dry and reefer containers, $40'$ dry and reefer containers both normal height and high-cube. The block stowage requirement was strictly enforced in their Cargo Composition Problem, thus the containers in each location must have the same discharge port. The authors proposed a compact formulation of the problem based on the state-of-the-art heuristic decomposition which was shown not to be able to solve the extended problem, thus a matheuristic approach that can achieve high quality results in a matter of seconds was presented. The presented models, however, did not include IMO containers into consideration.

2 Problem Description

A container ship is partitioned into bays. Each bay is divides into on deck and below deck parts using hatch covers. Both the on-deck and below deck parts of the vessel are partitioned into *cells*. Each cell contains two *Twenty foot Equivalent Unit* (TEU) or a single *Forty foot Equivalent Unit* (FEU) containers. The containers stowed in a row form a *stack* which is one container wide, and is composed of two TEU bays and a single FEU

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bay, which implies an even bay consists of a set of stacks. A *location* is a bay section which consists of a set of stacks that are either on or below deck, the stacks are adjacent and they coincide with the same hatch cover for bays with three hatch covers, as depicted in Figure 1a, or they coincide with two or three adjacent hatch covers for bays with seven hatch covers, as depicted in Figure 1b.

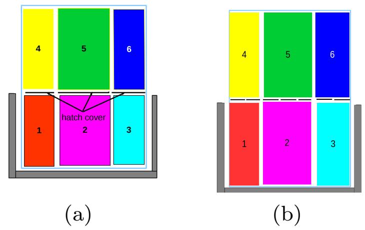

Figure 1: Locations in a bay with three hatch covers(a). Locations in a bay with seven hatch covers(b).

When a container ship is ready to leave a port it must be declared seaworthy, which means that all loaded items, i.e., cargo, ballast water, fuel, etc., must be distributed along the vessel such that its initial stability is acceptable, all stress forces, the *draft, trim* and *metacentric height* of the ship are within limits. The constraints related to stability in this paper are similar to those in [3].

Our version of the Cargo Composition Problem extends these models by including $20'$, $40'$ and $45'$ of dry, reefer and IMO containers with three weight classes, and by splitting the locations as outlined in Figure 1. This definition of locations helps us to handle hatch over-stowage in a more realistic way, as there is no need to remove containers from more than one hatch cover to get access to a given below deck container for container-ships with three hatch covers in each bay and there is no need to remove containers from more than three hatch covers to get an access to a given below deck container for container ships with seven hatch covers in each bay. A feasible solution for the Cargo Composition Problem must then satisfy the following rules.

- **R1:** For each location and each port, the number of containers of length $20'$, $40'$, and $45'$ must be within TEU and FEU capacity limits of the location, respectively.
- **R2:** For each location and each port, the number of reefer containers must be within the reefer capacity limit of the location.
- **R3:** For each port, the numbers and positions of incompatible IMO2, IMO3 and IMO4 containers must be according to the international separation rules.
- **R4:** For each location and each port, the total weight of containers must be within the limits of the location.
- **R5:** For each port, the transversal and longitudinal stability must be secured when loading is completed.

The objective function of the Cargo Composition Problem is to maximize the weighted sum of stowed containers based on the group value of their type and length, and to minimize the weighted sum of costs of hatch over-stowage, the makespan of the cranes along the trip, and stowage of non reefer containers in reefer slots.

3 Computational Results

We have generated 30 random instances which we believe correspond closely to real world scenarios for the CCP related to container ships from 2376 to 18,032 TEUs capacity. The proposed model was implemented in Pyomo and solved with the MIP solver Gurobi 7.50. All the tests were executed on a Linux machine with Intel Core i7-5600U, CPU 2.60GHz $\times 4$ and 16 GB of memory. All instances have been solved by considering the transversal (Q_L) and longitudinal (Q_T) equilibriums equal to 60 tons. A time limit of one hour has been imposed to the solver. Within the time limit 28 instances are solved to optimality with the default Gurobi optimality gap. The remaining two instances are solved with 0.01 optimality gap.

References

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