# Cargo-mix optimization in Liner Shipping

Jonas Christensen, Dario Pacino, João Fonseca, Harilaos Psaraftis

Department of Transport ; Technical University of Denmark
{jomc, darpa, hnpsar}@transport.dtu.dk

## 1 Introduction

International transportation constitutes one of the biggest challenges in limiting CO2 emission in the world: it is technically hard to find viable alternatives to fossil fuels, and due to the international nature, it is very difficult to regulate CO2 emission of intercontinental trade. Moreover, it is hard to motivate companies to pay for cleaner transport since transportation is not visible to end customers, and therefore cannot justify a higher cost. Hence, optimization may be one of the few options for limiting CO2 emission of international trade. A possible direction is to focus on vessels' utilization. The more containers a vessel carries the smaller is the resulting CO2 emissions per transported ton of cargo. This is what can be seen as a win-win situation. Better vessel utilization will result both in cleaner transport and in better revenue margins for the shippers.

Focus on vessel intake maximization is old news for liner shippers. Container vessels are delivered with a nominal capacity that ship owners know is only theoretical. Unless the cargo weight distribution is perfect, the nominal intake cannot be reached. Stowage coordinators fight this battle everyday. They are the planners of the cargo and have to find a load configuration (*stowage plan*) that both suits the current cargo to be loaded but also guarantees that the vessel can be utilized to its maximum in future ports. The size of nowadays vessels is, however, making this work harder and harder (Pacino et al. (2011)). Moreover, the cargo composition available in the different ports might not be suitable for the full utilization of the vessel. The focus of our work is the analysis of vessels' cargo-mix, in particular finding what cargo composition is needed for a vessel to maximize its utilization on a given service. Such a model can have various applications ranging from driving rate prices, improving fleet composition and network design ((Christiansen et al., 2007; Reinhardt and Pisinger, 2012; Brouer et al., 2014)).

## 2 The liner shipping cargo-mix problem

Given a liner service, a vessel and the expected cargo flows, the liner shipping cargo-mix problem aims at finding an optimal cargo-mix for the vessel at each port of call which fulfills the stability requirements, respects the expected cargo flows, minimizes overstowage and maximized the cargo intake. Overstowage occurs when a container destined to a later port is stowed above a container to be discharged at an earlier port.

When stowing a container vessel there are numerous constraints that must be satisfied for the vessel to be deemed sea worthy. Stacking rules impose e.g. that 20-foot containers cannot be stowed on top of 40-foot ones, that refrigerated containers (*reefers*) must be stowed where power plugs are available. The weight of the container stacks must also be within limits. Line of sight rules and the presence of hatch-covers (metallic structures dividing the on and below deck part of a vessel) also impose hight limits on the stacks.

Stacking rules are not enough to ensure the sea worthiness of a vessel. The weight distribution on the vessel must obey the hydrostatics of the vessel. The more weight we load on the vessel the deeper a draft it will have. The draft must be within the operational limits of the ports the vessel will visit. Consider Figure 1 (a). The difference between the draft at stern and at bow is called *trim* which must be within limits to ensure safe sailing. Figure 1 (b) shows the transversal section of a vessel. The distance between the point $M$ (*metacenter*) and the point $G$ (the center of gravity) is called *metacentric height*, which must also be within operational limits to ensure that the vessel will not capsize. Moreover stress forces such as *shear forces* and *bending moments* must also be held at bay.

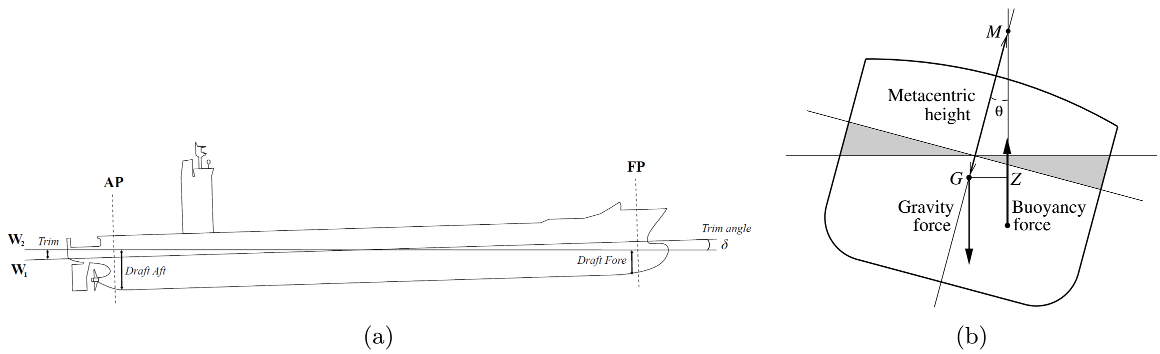


Figure 1: *Longitudinal section of a vessel showing trim, draft and waterline.*

Implementing an optimization model that does not take all of those requirements into account will not be able to accurately calculate the optimal intake of a vessel. This poses a challenge. Assume we allow to stow one extra container on each stack due to an imprecise calculation. Given the size of todays vessel this will result in an error of ca. 1000 containers.

# 3 Approach

Academic work on the liner shipping cargo-mix problem is very limited. The fist formal description was presented in the Ph.D. thesis of Delgado (2013). A integer programming model was presented. In order to achieve scalability, the author proposes the same decomposition as in earlier stowage planning work (Pacino et al. (2011)). Tested on 360 instances, on a services of up to 10 ports, the approach was able to solve 91.7% of the instances, with a time limit of 60 minutes. The application of the model, however, requires faster solving times since the problem must be solved several times so that different scenarios and analysis can be done. This motivates our effort on identifying an efficient heuristic procedure that can reach near optimal solutions in very short times.

Our hypothesis is that the stability requirements and the multi-port nature of the problem makes the discovery of heuristic rules difficult. In this work we are trying to combine what we have learned from the literature. Stability requirements are easily satisfied by linear programming (Pacino et al. (2011)), while actual container distribution requires heuristic methods (Ambrosino et al. (2010)). With this in mind, we proposed an iterative two-phase approach for the liner shipping cargo-mix problem. Initially the algorithm ensures the feasibility of the stability constraints solving a linear programming model that distributes the weight along the vessel. This ensures that the vessel is seaworthy and that stress forces are within limits. Successively a heuristic procedure tries to find a container assignment that follows the given weight distribution. The resulting cargo-mix is then analyzed and parts of the vessel are allowed to diverge from the original weight distribution if they can improve the vessel intake. Those deviations are then send back to the linear program in the form of constraints. The idea is to iteratively use the linear program as guidance for the satisfiability of the stability constrains. During the talk we wish to present a more concrete description of the algorithm an some preliminary result.

## References

Ambrosino, D., Anghinolfi, D., Paolucci, M., and Sciomachen, A. (2010). An experimental comparison of different heuristics for the master bay plan problem. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 6049 LNCS:314–325.

Brouer, B. D., Alvarez, J. F., Plum, C. E. M., Pisinger, D., and Sigurd, M. M. (2014). A Base Integer Programming Model and Benchmark Suite for Liner-Shipping Network Design. *Transportation Science*, 48:281–312.

Christiansen, M., Fagerholt, K., Nygreen, B., and Ronen, D. (2007). Chapter 4 Maritime Transportation.

Delgado, A. (2013). *Models and Algorithms for Container Vessel Stowage Optimization*. PhD thesis, IT University Copenhagen.

Pacino, D., Delgado, A., Jensen, R. M., and Bebbington, T. (2011). Fast generation of near-optimal plans for eco-efficient stowage of large container vessels. In Böse, J. W., Hu, H., Jahn, C., Shi, X., Stahlbock, R., and Voß, S., editors, *Computational Logistics*, volume 6971 of *Lecture Notes in Computer Science*, pages 286–301. Springer Berlin Heidelberg.

Reinhardt, L. B. and Pisinger, D. (2012). A branch and cut algorithm for the container shipping network design problem. *Flexible Services and Manufacturing Journal*, 24:349–374.