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Flexible ship loading problem with transfer vehicle assignment and scheduling

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A B S T R A C T

This paper presents the flexible containership loading problem for seaport container terminals. The integrated management of loading operations, planning of the transport vehicles to use and their scheduling is what we define as the Flexible Ship Loading Problem (FSLP). The flexibility comes from a cooperative agreement between the terminal operator and the liner shipping company, specifying that the terminal has the right to decide which specific container to load for each slot obeying the class-based stowage plan received from the liner. We formulate a mathematical model for the problem. Then we present various modelling enhancements and a mathematical model to obtain strong lower bounds. We also propose a heuristic algorithm to solve the problem. It is shown that enhancements improve the performance of formulation significantly, and the heuristic efficiently generates high-quality solutions. Results also point out that substantial cost savings can be achieved by integrating the ship loading operations.

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1. Introduction

Maritime freight transport constitutes an important part of the global logistics systems. Benefiting from rapid globalisation, the containerised freight transport has been steadily growing over the past decade apart from the year 2009 with the global financial crisis. The leading 100 container terminals handled 539.2 million Twenty Equivalent Units (TEUs) in 2015 (UNCTAD (2016)) with an increase by 6.8% from 2014. Therefore, the increasing container handling volumes make operations planning a more complex and significant challenge for container terminals.

Liner shipping companies have adapted to the growth in the transport volumes by increasing the capacity of their services. This is done by deploying mega vessels of over 20,000 TEUs and planning more frequent visits to the container terminals. Capacity is, however, not enough. A reliable shipping service ensures that the cargoes arrive on time, so container terminals are required to supply reliable and agile operations for their customers. The increase in vessels size intensifies the pressure on the container terminals. Meanwhile, shipping companies also expect terminals to minimise the vessel turnaround (handling) times.

Vessel turnaround times might be reduced by deploying more Quay Cranes (QCs) and Transfer Vehicles (TVs) on each vessel, however, this does not guarantee an improvement in the service quality. There is a limited number of equipment that can be assigned to a vessel. Also, inefficient management of this equipment can bring more congestion and deterioration

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in the overall performance. Considering that QCs and TVs are limited resources with high operating costs, terminals should rather optimise the use of these resources.

We refer readers to the literature reviews on decision problems in seaside operations (Carlo et al., 2013; Bierwirth and Meisel, 2015), transport operations (Steenken et al., 2004; Carlo et al., 2014b) and yard operations (Li and Vairaktarakis, 2004; Carlo et al., 2014a) in terminals. Literature reviews such as Kim and Lee (2015) note that there is a need for flexibility in operations, and possible collaboration with the liner shipping company can bring some flexibility in the ship loading related operations.

The efficient loading of containers to the vessel has become a more complicated problem due to the increase in vessel size, vessel numbers and complex technicalities. The high degree of industrial requirements (e.g. lashing patterns, vessel stress forces and staff working hour regulations) along with all other mentioned challenges, make efficient ship loading an even more complicated problem. It also often happens that some of the containers are ready to be loaded earlier but have to wait since they would be out of the planned load sequence. Due to the mentioned complexities and limited handling equipment, most attempts to improve the loading operations could benefit from optimisation methods.

Some liner shipping companies are aware of the challenges that container terminals face and have actively started to adapt their *stowage plans* in such a way that gives the terminal operator more freedom to optimise the usage of their equipment. A stowage plan describes the arrangement of containers on the vessel. In recent years, there has been a shift in the stowage planning policy which is based on increasing collaboration between the terminal and the liner shipper. The liner provides the terminal with the stowage plan based on container classes (a container class is defined by the port of discharge, physical container dimensions, weight, etc.) which we refer to as *class-based stowage plan*. The terminal has the flexibility of determining the position of specific containers of the same class obeying the class-based stowage plan, and this ensures the flexible loading operations (Monaco et al., 2014). In this study, we integrate the assignment and scheduling of transfer vehicles and container load sequencing with the assignment of specific containers to the vessel positions. We call the entire problem the Flexible Ship Loading Problem (FSLP). We aim at reducing service times of the handling equipment and meeting the deadlines on the finishing time of the loading.

The contribution of the study is multi-fold. First, we introduce a new integrated container terminal problem to improve the efficiency of the loading operations. The problem addresses many realistic and important aspects of the loading operations. We formulate a mathematical model to solve the problem and some enhancements to improve this formulation. Then we suggest a model to obtain lower bounds for the problem. We also propose a heuristic method to solve it. Computational results show that the enhancements on the model significantly improve its performance, but still, the mathematical model is intractable for large-scale instances. The results for the heuristic show that it outperforms the mathematical model with respect to both solution quality and computation time, and instances, with up to 1000 containers to be loaded, are solved very efficiently. We also show that there are significant cost savings by integrating these problems rather than solving them in a hierarchical manner.

The remainder of the paper is organised as follows. Section 2 briefly presents relevant literature. Section 3 includes the problem definition. Section 4 provides the mathematical model and enhancements on this formulation, while Section 5 presents a new method to obtain lower bounds. The heuristic is detailed in Section 6. The results are discussed in Section 7, and finally, the conclusions and future research perspectives are presented in the last section.

2. Relevant literature

The problem studied in this paper is related to the ship loading operations, and it covers aspects such as stowage planning, load sequencing, and handling equipment assignment, routing and scheduling. A detailed literature review on all of these problems can be found in Iris and Pacino (2015).

The stowage planning problem has been addressed in two different ways in the literature. Some papers aim at minimising handling costs ensuring stability and seaworthiness of a ship in its route containing multiple ports. These studies agree that the problem belongs to the liner shipping company (see Pacino et al., 2011; Parreno et al., 2016). In this paper, we review studies that consider the stowage planning problem for a single container terminal. Imai et al. (2002) study the stowage planning at a single terminal with the aim of minimising yard re-handles and the stability measure GM (i.e. the distance between the centre of gravity and the metacentre). Imai et al. (2002) call this problem the containership loading problem. In comparison to Imai et al. (2002), our work ensures that the stowage plan satisfies a class-based stowage plan that comes from the carrier. Later, Imai et al. (2006) include trim and heeling to the objective function, and they also extend the problem by covering multiple rows in the yard. In Ambrosino and Sciomachen (2003), a stowage planning problem is solved in the first stage, and then two yard-handling strategies are evaluated with the suggested stowage plan. The vessel stability is addressed by balancing the front-back and right-left side of the ship (the details of the stowage planning problem are in Ambrosino et al. (2004)). Recently, Monaco et al. (2014) distinguish between the stowage planning problem solved by the liner shipping company (resulting in a class-based stowage plan) and the specific container assignment problem of the terminal (called *operational stowage planning problem*). They solely study the operational stowage planning problem and solve it through a two-phase tabu search method. None of the above studies integrates the planning of the yard transport equipment with the stowage planning which is subject of investigation in our paper. For such integrated planning, Steenken et al. (2001) is the pioneering work. In comparison to our work, Steenken et al. (2001) approach the problem with a just-in-time method. They solve a model that assigns each container to a specific position and a specific Straddle Carrier

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