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Bi-objective optimization for the container terminal integrated planning

Ming Liu [a], Chung-Yee Lee [b,*], Zizhen Zhang [c], Chengbin Chu [a,d]

[a] School of Economics & Management, Tongji University, Shanghai 200092, P.R. China
[b] Department of Industrial Engineering & Logistics Management, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong
[c] School of data & computer science, Sun Yat-sen University, Gangzhou 510275, P.R. China
[d] Laboratoire Génie Industriel, Centrale Supélec, Université Paris-Saclay, Grande Voie des Vignes, 92290 Châtenay-Malabry, France

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ABSTRACT

In this paper, we study the joint optimization of the tactical berth allocation and the tactical yard allocation in container terminals, which typically consist of berth side and yard side operations. The studied two objectives are: (i) the minimization of the violation of the vessels' expected turnaround time windows with the purpose of meeting the timetables published by shipping liners, and (ii) the minimization of the total yard transportation distance with the aim to lower terminal operational cost. We propose a bi-objective integer program which can comprehensively address the import, export and transshipment tasks in port daily practice. Traditionally, a container transshipment task is performed as a couple of import and export tasks, called *indirect-transshipment mode*, in which the transit container are needed to be temporally stored in the yard. As the way of transferring containers directly from the incoming vessel to the outgoing vessel, called *direct-transshipment mode*, has potential to save yard storage resources, the proposed model also incorporates both indirect- and direct-transshipment modes. To produce Pareto solutions efficiently, we devise heuristic approaches. Numerical experiments have been conducted to demonstrate the efficiency of the approaches.

1. Introduction

World container port throughput increased by an estimated 3.8% to 601.8 million 20-foot equivalent units (TEUs) in 2012. The world fleet has more than doubled since 2001, reaching 1.63 billion deadweight tons in 2013. In 2013, the worldwide container trade accounts for about 22% of the 6.7 billion tons of dry-cargo trade, and all loads are being transported by vessels via container terminals. Recent statistics show that total container trade volumes reached 160 million TEUs in 2013 with a growth of 4.6% (c.f., UNCTAD (2015)). In line with the increase of global economy and containerized trade, one of general trends is that seaport experiences a strong growth in transit container volume, which may spur greater inter-port competition and increased port performance. Port managers have been making continuous effect on increasing resource utilization and reducing operational cost, to maintain margins as well as meet the timetables published by shipping companies.

* Corresponding author.
E-mail address: cylee@ust.hk (C.-Y. Lee).

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In world-class ports, common container activities include import, export and transshipment container tasks. Even though container ports can be generally divided into gateway ports and transshipment hubs, but also the boundary between these two kinds of ports is fuzzy. This is because (i) even in the worldwide largest transshipment hubs, such as Singapore Port, the import and export tasks also pose around 20% among all tasks, and (ii) in the gateway ports, such as Shanghai Port, the transshipment tasks occupy about 20%. Therefore, useful management systems or operational optimization softwares for container ports should be capable to handle all the three kinds of container tasks.

In recent trends of container port development, the optimization of transshipment modes receives much attention. Transshipment activities can be performed in two ways: (i) direct-transshipment mode, which transfers transit containers from one vessel to the connecting vessel directly without yard storage but requiring contingent vessel berthing times (see Fig. 3a), and (ii) indirect-transshipment mode, which temporally stores the transit containers in the yard and then load them to the connecting vessels. For comparison, direct-transshipment mode could save yard resources but require contingent berthing time of vessels, whereas indirect-transshipment mode could relieve the contingent vessel berthing time restriction but consume yard storage and incur yard transportation cost. Port managers prefer performing a transshipment task via direct-transshipment mode, as it requires no yard storage and thus helps relieve port congestions and reduce yard transportation cost, at the price of violating timetables published by shipping liners. According to our interviews with Shanghai Port's managers, direct-transshipment mode is applied in port daily practice and it possesses a relatively small percentage of all transit activities. Therefore, a better container terminal planning system should well balance the violation of timetables of shipping liners and the cost of yard transportation distance.

Generally speaking, the terminal operations planning system can be classified into two levels: tactical and operational (Moorthy and Teo (2006)). Tactical problems include the tactical berth allocation problem (TBAP) and the tactical yard allocation problem (TYAP). In the TBAP, the terminal managers try to satisfy the expected turnaround time windows or intervals of vessels by allocating berths and quay cranes. With the consideration of transshipment modes, port operators also need to determine the mode (i.e., direct-transshipment or indirect-transshipment mode) for each transshipment activity. In the TYAP, which is also known as yard template planning (Zhen et al. (2011)), the consignment strategy is widely utilized and only indirect-transshipment mode is adopted. This strategy stores transit containers to be loaded on a specific vessel at the dedicated storage locations allocated for that vessel. In the TYAP, terminal managers attempt to minimize the yard transportation distance.

The TYAP and the TBAP are intertwined. On one hand, the yard storage allocated in the TYAP affects the best berthing positions for vessels; on the other hand, the berthing positions allocated in the TBAP impact the assignment of yard storage locations to vessels. In particular, the direct-transshipment decisions must be made under the integration framework of the TYAP and the TBAP, because if contingent berthing times can be allocated for two vessels connected by a transshipment container task (in the TBAP) the direct-transshipment mode can be applied which could significantly reduce yard transportation distance (in the TYAP); otherwise, the terminal operators must assign some appropriate yard storage for transit containers which must incur the increase of yard transportation distance (in the TYAP).

Motivated by the need of world-class container ports, i.e., to balance the violation of timetables of shipping liners and the yard transportation distance, this work investigates the joint planning of tactical berth allocation and tactical yard allocation, and solve the integration problem via bi-objective optimization approaches. On one hand, port operators make schedules, greatly conforming with timetables of shipping liners, to increase their satisfaction. On the other hand, port managers attempt to lower port operational cost. These two aims are measured in dimensions of (timetable violation) times, and (truck traveling) distances, respectively, according to our interviews with Shanghai Port's managers. To balance these two objective values, bi-objective optimization techniques are employed in this work.

To the best of our knowledge, we are the first to establish a bi-objective mathematical model

(i) to address import, export and transshipment tasks simultaneously,
(ii) to comprise both the direct- and indirect-transshipment modes,
(iii) to balance dissatisfaction of shipping companies and operational cost of container terminals.

These three features make the container terminal integrated planning even more complicated. To solve the problem efficiently, we devise bi-objective methods to obtain approximate Pareto front solutions. Numerical experiments have been conducted to demonstrate the efficiency of the proposed approaches.

The remainder of the paper is organized as follows. In Section 2, a brief literature review is given. Section 3 states the studied problem, and a mathematical formulation is proposed in Section 4. In Section 5, we devise a promising heuristic solution approach. Numerical experiments have been conducted in Section 6. We conclude the work and indicate further research directions in Section 7.

2. Literature review

There is a vast number of literature dedicated to the study of maritime logistics, as it is vital to the world trade and economy. The related literature mainly includes container assignment problems (e.g., Bell et al. (2011); Bell et al. (2013); Wang et al. (2015)), liner shipping problems (e.g., Liu et al. (2014); Meng et al. (2015)) and terminal operation planning problems (e.g., Lee et al. (2014); Tao and Lee (2015)). Our work falls in the group of terminal operation planning, where the integrated planning problems have been receiving more and more investigation recently. For details, interested readers