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A new continuous berth allocation and quay crane assignment model in container terminal

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ABSTRACT

Over the past decades, Chinese ports throughput grew rapidly, and more and more concerns were shown on the operational efficiency and effectiveness. Many studies have been made for scheduling berth and quay cranes, which are the critical resources in container terminals. In this paper, a two-phase model for berth allocation and quay crane assignment is proposed. In the first phase, according to the relationships of time and space between vessels, a new continuous berth allocation model is established, in which not only the common restricts but the coverage area of quay crane are considered. Then in the quay crane assignment phase, a multi-objective programming model is proposed, in which the first objective is to minimize the range of maximum and minimum quay cranes used for resources saving, and the second one is to minimize the movements of quay cranes so as to improve the efficiency. A particle swarm optimization algorithm for BAP was developed. The results of numerical experiments show that the proposed approach can improve the essential operations in container terminal.

1. Introduction

The competition among container terminals has increased due to the significant growth on major seaborne container routes. Facing the fierce challenge, in order to attract more ship carriers, container terminal operation have tried to provide more intensive logistics services. And meanwhile, they struggle to reduce costs by utilizing resources efficiently, including human resources, berths, container yards and various equipment. Among all the resources, berths and quay cranes are the most important ones, good berth allocation and quay crane assignment scheme can improve customers' satisfaction and increases port throughput, leading to higher revenues of port. The relationships among planning problems in container terminals can be shown as Fig. 1.

In the past decades, there have been several studies on how to allocate berths for coming vessels in the literatures. Basically, Berth Allocation Problem (BAP) can be categorized into two classes: discrete BAP and continuous BAP. For discrete version, the quay is viewed as a finite set of berths. Usually, a berth can only serve one ship at a time. On the contrary, continuous BAP model allows vessels to berth anywhere along the quay so as to sufficiently utilize the quay resources. In this study, a continuous berth allocation model with the objective of minimizing the total stay time and the added costs which are depending on the ships' berthing location in the quay is proposed. In the model, the constraints of quay cranes' coverage area are considered. And based on the result of BAP, a quay crane assignment model is suggested, which is addressed as a multi-objective programming where the first objective is to minimize the range of maximum and minimum quay cranes used in the planning horizontal, and the second one is to minimize the movements of quay cranes.

This paper is organized as follows. The next section carries out a simple literature review of the existing studies on BAP and related issues. The continuous berth allocation problem and quay crane assignment problem formulation are defined in Section 3, followed by Section 4 in which a particle swarm optimization algorithm for BAP model is suggested. And in Section 5 a computational experiment is performed, and in Section 6 the paper's conclusions are presented.

2. Literature review and related issues

2.1. Literature review

There are many studies for various berth allocation problem and quay crane assignment problem. Lim (1998) addressed a problem with the objective of minimizing the maximum amount of quay space used at any time with the assumption that once a ship is berthed, it will not be moved to any other places along the quay

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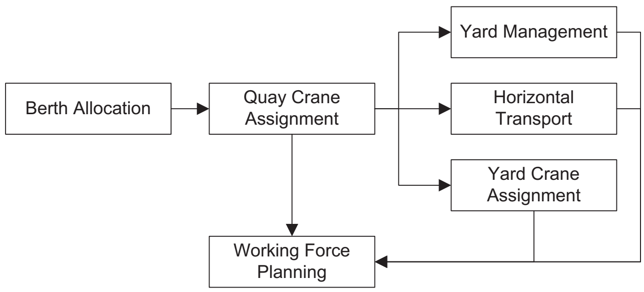

Fig. 1. Planning problems in container terminals.

before it departures. Guana, Xiaob, Cheungb, and Lib (2002) developed a heuristic for the BAP with the objective that minimize the total weighted completion time of ship services. It is noticed that all the above BAP studies assume the ship handling time is independent from the berthing location unlike Imai, Nishimura, and Papadimitriou (2001). Imai et al. (2001) addressed a BAP in which the handling time depends on the berthing location of ship. They developed a heuristic for that problem in conjunction with a heuristic for the dynamic BAP in Imai et al. (2001) and Imai, Sun, Nishimura, and Papadimitriou (2005). Kim and Moon (2003) addressed the continuous BAP as a mixed integer linear program to determine the berthing times and positions, and in the model the ships' preferred position is considered, but in this article the operation time is assumed fixed. Imai, Chen, Nishimura, and Papadimitriou (2008) addressed the simultaneous berth and quay crane allocation problem in multi-user container terminals and employed genetic algorithm to solve it. Xu, Li, and Leung (2012) considered a berth allocation problem in container terminals in which the assignment of vessels to berths is limited by water depth and tidal condition and modeled the problem as a parallel-machine scheduling problem. Yang, Wang, and Li (2012) gave an approach to solve the coupling of berth allocation and quay crane assignment in a multi- user container terminal. Bierwirth and Meisel (2010) made an intensive review on berth allocation and quay crane scheduling problem. According to the research, in most situations, the entire terminal space is partitioned into several parts (or berths) and the allocation is planned on the divided berth space, under this approach, ships are allowed to be served wherever the empty spaces are available to physically accommodate the ships via a continuous location system. Barros, Costa, Oliveira, and Lorena (2011) developed and analyzed a berth allocation model with tidal time windows, where ships can only be served during those time windows. Buhrkal, Zuglian, Ropke, Larsen, and Lusby (2011) studied several mathematical programming models of the dynamic BAP and formulated the problem as a generalized set partition problem (GSPP). They solved the problem with CPLEX and obtained the optimal solutions on those instances from Cordeau, Laporte, Legato, and Moccia (2005). de Oliveira, Mauri, and Nogueira Lorena (2012) presented a clustering search (CS) method with simulated annealing heuristic to solve the continuous BAP. Ting, Wu, and Chou (2014) focuses on the discrete and dynamic berth allocation problem, and suggested a PSO approach to solve he model.

Most of the previous studies did not consider the covered area of quay cranes during the berth allocation and quay crane assignment, which are really playing a role in practice. This paper will allocate berth and quay cranes simultaneously under continuous berth situation considering the QCs covering area. And during the quay crane assignment phase, not only the movements but also the balance of quay cranes used in each shift are considered, which will lead to energy saving during operation.

2.2. The covered area of quay cranes

Due to the length of cable, each quay crane has a covered area, which is shown as an arrowed line in Fig. 2.

It can be seen from Fig. 2 that quay crane 1# covers from 18 to 500 m, and quay crane 2# covers from 40 to 588 m, and so on. Thus the quay side from 73 to 588 m can be covered by 3 quay cranes, and the quay side from 104 to 500 m can be covered by 4 quay cranes, and so on, which are shown as horizontal bar in Fig. 2. Obviously, if one ship needs 4 quay cranes, it must be berthed in the scope of 104–500 m. Therefore, the BAP should take the covered area into account. And BAP has deep relationship with quay crane assignment problem, they should be considered at the same time.

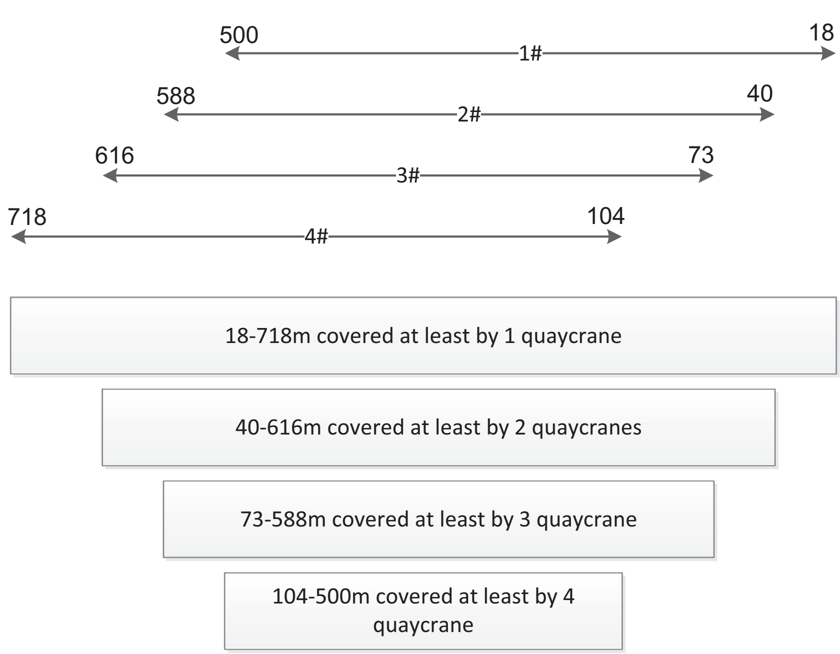

Fig. 2. The areas covered by quay cranes.