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A robust optimization approach to the integrated berth allocation and quay crane assignment problem

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ABSTRACT

This paper investigates the integrated berth allocation and quay crane assignment problem in container terminals. A deterministic model is formulated by considering the setup time of quay cranes. However, data uncertainties widely exist, and it may cause the deterministic solution to be infeasible. To handle the uncertainties, a robust optimization model is established. Furthermore, to control the level of conservativeness, another robust optimization model with the price constraints is proposed. A genetic algorithm and an insertion heuristic algorithm are suggested to obtain near optimal solutions. Computational experiments indicate that the presented models and algorithms are effective to solve the problems.

1. Introduction

In the background of economic globalization, transportation logistics is rapidly developing. Container transportation industry has become to a mainstay of the transportation and logistics, and container terminals play an indispensable role in the multi-modal transportation network. Major operational problems faced in seaside operations are comprehensively described by Vis and Koster (2003), Steenken et al. (2004), and Stahlbock and Voß (2008), which can be typically identified as the berth allocation problem (BAP), the quay crane assignment problem (QCAP), and the quay crane scheduling problem. The BAP and the QCAP are two decision problems that are highly dependent on each other, the quay crane (QC) capacity demand is influenced by the berthing position, and the handling time varies with the QC assignment. Berths and QCs are two types of the scarce and expensive resources, whereas they are also the key resources in the BAP and the QCAP. Therefore, it is an urgent problem for container terminals to reasonably configure and to effectively utilize these resources.

In some practical situations, the QC setup time cannot be negligible in the decision-making process due to the QC speed limitations of shifting along the quay. These situations include emergency situations, priority level, long shoreline, complex layout, etc. Besides, the QC setup time influences the starting and ending time of service, so it is influential on the QC assignment and may lead to the infeasible schedule. Hence, taking the QC setup time of shifting along the quay into account, a deterministic model is proposed in this paper for the integrated berth allocation and quay crane assignment problem (BACAP).

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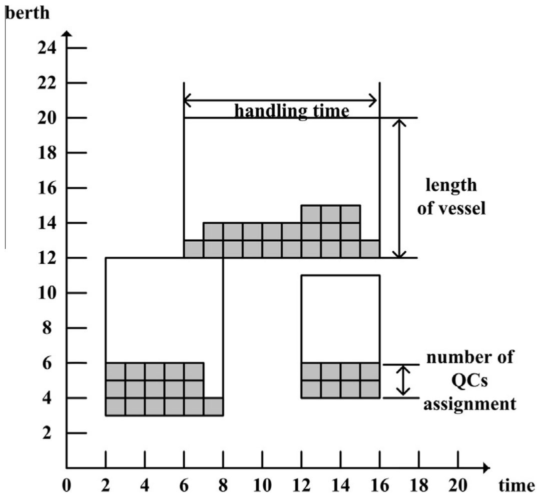

Fig. 1. An illustrative example for the BACAP.

In addition, the operational environment of QC is in the open air, so the QC productivity is affected by a variety of external factors, including ambient temperature, humidity, degree of salt spray, icing, wind power, etc. These external factors occur frequently, which often make the planned schedule infeasible. Temporary adjustments of scheduling will decrease the efficiency and increase the cost. Therefore, it is necessary to develop approaches capable of handling these data uncertainties to improve the robustness of plan. This paper proposes two robust optimization models to solve the BACAP under data uncertainties in QC productivities.

The BACAP can be depicted as a space-time diagram, as is shown in Fig. 1. In our paper, it divides the time in periods of 1-h and the quay in segments of 10-m length. The height of each rectangle corresponds to the length of a vessel and the width corresponds to the required handling time. The lower-left vertex of a rectangle shows the vessel's berthing position and the starting handling time. A gray rectangle represents a QC assignment to the vessel, and the number of gray rectangles corresponds to the number of QC assignment. From the computational complexity point of view, the BACAP is quite complex, since the BAP is an $\mathcal{NP}$-hard problem (Park and Kim, 2003). It is more difficult to deal with the BACAP under data uncertainties. To effectively solve the large scale BACAP, it is necessary to develop effective solution algorithms.

In this paper, considering the QC setup time of shifting along the quay, we propose a deterministic model for the BACAP. Recognizing that the common uncertainties may cause the deterministic solution to be infeasible, two robust optimization models are proposed to deal with data uncertainties. Due to the computational complexity, we develop a genetic algorithm (GA) and an insertion heuristic algorithm to obtain near optimal solutions.Computational experiments show that the solution quality and the computational time of the GA and the insertion heuristic algorithm are all comparable, even for the large-scale instances. Comparing these two algorithms, the GA is more competitive in term of solution quality, while the insertion heuristic algorithm is time-efficient in term of computational time. In addition, the proposed robust optimization method is risk-averse so that the solution will have robustness to uncertainties. We can adjust the price constraint to control the robustness of the model, thus the failure probability of plan can be decreased.

The following of this paper is organized as follows. In Section 2, related literatures are reviewed. Problem description and model formulation are given in Section 3. A GA and an insertion heuristic algorithm are developed in Sections 4 and 5, respectively. To test the efficiency of the proposed method, computational experiments are conducted in Section 6. Finally, Section 7 concludes this paper.

2. Literature review

The BAP plays an important role in container terminal operations. According to the layout of berths, the BAP can be classified into the discrete BAP and the continuous BAP. Lai and Shih (1992) proposed a discrete BAP inspired by the usage of more efficient terminal in Hong Kong International Terminal, and the problem was solved by a heuristic algorithm. Imai et al. (1997) studied the statistic discrete BAP to minimize the sum of the waiting time and the handling time taking the priority order into consideration. Then Imai et al. (2001) proposed a dynamic BAP with the same objective function as Imai et al. (1997), and the problem was solved by a Lagrange relaxation algorithm. Kim and Moon (2003) proposed a mixed-integer-linear programming model for the continuous BAP to minimize the penalty