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A bi-objective robust model for berth allocation scheduling under uncertainty

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ABSTRACT

This study examines the berth allocation problem with the consideration of uncertainty factors, including the arrival and operation times of the calling vessels. A bi-objective robust berth allocation model, which focuses on economic performance and customer satisfaction, is formulated. The model aims to optimize the robustness of the berth allocation policy, and an adaptive grey wolf optimizer algorithm is developed to solve the proposed model. The performance of the heuristic is evaluated through randomly generated instances. Experimental results show that the proposed heuristic provides good solution quality and calculation efficiency.

1. Introduction

The growth of container terminals worldwide has led to concerns regarding their limited size and the use of various resources, such as quay cranes and crews, prime movers and drivers, and yard resources (Moorthy and Teo, 2006; Liang et al., 2012; Ursavas and Zhu, 2016). Therefore, the exploration of their potentiality, as well as the improvement of their operation and management efficiency, under size and resource constraints is a key to enhance the economic performance and core competitiveness of container terminals. The berth allocation problem (BAP) is one of the most important issues in port scheduling. For a comprehensive overview of BAP, we refer to the works of Vis and Koster (2003), Steenken et al. (2004), Stahlbock and VoB (2008), and Bierwirth and Meisel (2010, 2015). BAP aims to assign berthing position and time for all vessels within a given planning horizon. A good berth allocation strategy can raise the economic efficiency of port scheduling and improve customer satisfaction, thereby enhancing the core competitiveness of container terminals (Moorthy and Teo, 2006; Han et al., 2010).

Generally, a container terminal can be defined as an interface between sea and land transportation. And the berth assignment operations face a complex environment with many uncertainties, including the deviation of arrival time, the loading and unloading operation times of vessels from the original plan, equipment failures, and other unforeseen events. If port planners do not consider these uncertainty factors when making schedules, then the original plan will be changed frequently when executing schedules. Consequently, the port system will be disordered, the transportation cost of related enterprises will increase, and customer satisfaction will decrease.

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The BAP has been receiving extensive attention from researchers given that it is an important decision problem for port planners. In the BAP research, the majority of existing literature has mainly studied how to make decisions under certain conditions. Several scholars, i.e., Moorthy and Teo (2006), Han et al. (2010), Zhen et al. (2011), Zhen and Chang (2012), Ursavas and Zhu (2016), and Liu et al. (2016a), have studied the BAP under uncertainty in recent years. Zhen and Chang (2012) proposed an optimization model for minimizing cost and maximizing robustness of schedules and they also developed a heuristic for solving this model in large-scale problem cases. Ursavas and Zhu (2016) proposed a stochastic dynamic programming method for solving the BAP under an uncertain environment. Unlike in previous research, the current study proposes a bi-objective robust berth allocation model (BRBAM) that focuses on economic performance and customer satisfaction under uncertainties in vessel arrival and operation times. The goal of this model is to optimize the robustness of the berth allocation policy for the two objectives and achieve a trade-off between economic performance and customer satisfaction. BRBAM differs from the previous literature because it simultaneously considers cost and customer satisfaction. An adaptive grey wolf optimizer (AGWO) algorithm is also proposed to solve BRBAM to provide optimal or near-optimal solutions for decision makers. Although the grey wolf optimizer (GWO) is simple and has a few parameters, it has been shown that this algorithm is competitive with other meta-heuristic algorithms, such as genetic algorithm (GA) and differential evolution (Mirjalili et al., 2014). GWO is recommended for a continuous environment, which is consistent with the model proposed in this study. Lastly, the performance of the proposed AGWO is compared with those of previous methods, e.g., the meta-heuristic approach proposed by Zhen et al. (2011), a traditional GA, and CPLEX. The results show that the proposed AGWO demonstrates an advantage in solving the model formulated in this study.

The reminder of this paper is organized as follows. Section 2 provides the related literature review. Section 3 presents the problem description. Section 4 formulates the BRBAM. Section 5 introduces the GWO and Section 6 proposes an AGWO for solving the BRBAM model. Section 7 shows the numerical experiments and Section 8 draws this study.

2. Related work

The goal of BAP research is to assign optimal berthing time and position for arriving vessels. Many scholars have worked on BAP in the past twenty years. Vis and Koster (2003) provided an overview of the classification of decision problems regarding the transshipment of containers and indicated that a combination of various types of equipment should be considered. Steenken et al. (2004) described and classified the main logistics processes and operations in container terminals and presented a survey of operation research models for their optimization. Bierwirth and Meisel (2010) presented an overview and classification of existing optimization models and solutions for BAP. This literature was updated by Bierwirth and Meisel (2015), who surveyed publications related to BAP for the period of 2010–2014.

Imai et al. (1997) studied discrete static BAP to minimize waiting and handling times, and the problem was solved using the Hungarian method. Nishimura et al. (2001) proposed a model to minimize the total service time of incoming ships and developed a GA for solving BAP. Imai et al. (2003) modified the existing BAP formulation to deal with calling vessels with various service priorities and examined a subgradient method using a Lagrangian relaxation technique. Kim and Moon (2003) formulated a mixed-integer linear programming model for BAP to maximize the utilization of a wharf and to satisfy various constraints for berthing container vessels by using an analytical approach. The simulated annealing (SA) algorithm was used to find near-optimal solutions for the problem, and the experiment results showed that the solutions obtained via SA were close to the optimal solutions found using the optimization technique. Guan and Cheung (2004) proposed a general model to allocate berth space to vessels and to schedule vessels to minimize the total weighted flow time, in which the weights reflected the relative importance of vessels. Cordeau et al. (2005) considered two versions of BAP: discrete and continuous cases. A tabu search heuristic was proposed to solve the discrete case, whereas another heuristic was developed for the continuous case. Imai et al. (2005) formulated a model to minimize the sum of service times for all ships, proposed a heuristic for BAP in a continuous location, and conducted various experiments to verify that the heuristic works efficiently in practice. In order to solve BAP, Monaco and Sammarra (2007) developed a Lagrangean heuristic algorithm and Hansen et al. (2008) proposed a Variable Neighborhood Search method. Imai et al. (2008) addressed efficient berth and crane allocation scheduling at a multi-user container terminal and developed a heuristic by employing genetic to find an approximate solution for the problem. Giallombardo et al. (2010) integrated BAP into the quay crane assignment problem and presented two mixed-integer programming (MIP) formulations to maximize the total value of the selected quay crane profiles and to minimize the housekeeping costs generated by transshipment flows among ships. A heuristic algorithm was developed to solve the problem. Zhang et al. (2010) examined the allocation of berths and quay cranes for vessels arriving at container terminals and a sub-gradient optimization algorithm was applied to solving the problem. Lalla-Ruiz et al. (2012) considered dynamic BAP to minimize the total time of vessels staying at ports and proposed a hybrid meta-heuristic combined with tabu search and path relinking to solve the problem. Based on Giallombardo et al. (2010), Lalla-Ruiz et al. (2014) proposed a biased random key GA for solving the Tactical Berth Allocation Problem which was derived from Giallombardo et al. (2010). The computational experiments and the comparisons with other solutions approaches presented in the related literature showed that the biased random key GA is applicable to efficiently solve this difficult and essential container terminal.

Most of the presented research has studied deterministic problems. By contrast, only a few articles have discussed uncertain problems; these articles are summarized in Table 1. Some of the papers that are relevant to the current study are discussed. Moorthy and Teo (2006) studied the trade-off between the service level and the operational cost for moving