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Multi-objective genetic algorithm for berth allocation problem considering daytime preference

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ABSTRACT

Maximization of operational efficiency and minimization of cost are pursued by terminal operators, whereas daytime preference is increasingly emphasized by governments, terminal operators and workers. Daytime preference in berth allocation schedule refers to schedule the workloads in nights as fewer as possible, which improves working comfort, safety, and green and energy-savings degrees, but may decrease the throughput and total operational efficiency. By extending existing dynamic discrete berth allocation model, a bi-objective model considering daytime preference is established to minimize the delayed workloads and the workloads in nights. Based on the well known NSGA-II algorithm, a multi-objective genetic algorithm (moGA) is developed for solving the bi-objective model by using a two-part representation scheme. The sensitivities of the algorithmic parameters and tradeoffs between daytime preference and delayed workloads are analyzed by numerical experiments. The algorithmic aspects of the proposed approach and the effects of daytime preference on solutions are all examined. Finally, the managerial implications are discussed.

1. Introduction

Maritime transport is increasingly important for international trade and emphasized by coastal countries, whereas shortage of sophisticated workers, environmental problems and energy savings are problems faced. Daytime preference is an objective that is beginning to be pursued in the following situations. First, many big ports is facing the problems including increasing labor cost, energy consumption and shortage of young specialized workers. Second, to cater for the increasing throughput, shiftwork is used, whereas few workers want to work at nights for many reasons, such as considerations of comfort, health and family. Third, the operations safety declines because of problems related to fatigue and sleepless, and nightshift apparently costs electricity power. These factors add new challenges to traditional berth allocation problem (BAP).

In the view of port operators, to decrease the port handling cost and the service quality for the calling vessels, BAP is significant in strategic and operational levels. The optimization objectives of BAP are primarily to accommodate and minimize the waiting and service times of vessels. The decisions for BAP concern the position and time of the vessels that should moor (Imai, Nishimura, & Papadimitriou, 2001). BAP has a lot of physical restrictions such that it can be formulated in different ways. As for spatial aspects of berths, the BAPs can be modeled as discrete, continuous or hybrid BAPs (Imai, Sun, Nishimura, & Papadimitriou, 2005). In discrete cases, the quay is divided into several berths and only one vessel is serviced at a time in every berth, regardless of their sizes. In continuous cases, no division of the quay exists, and thus the vessels can moor at any position. Moreover, if BAP considers the arrival times of vessels, it can be treated as static or dynamic BAPs (Imai et al., 2001). The static case assumes that all vessels already in port for the service, while the dynamic case allows ships to arrive at any time. The dynamic discrete berth allocation problem (DDBAP) is the base of this work. Operational cost in the decision view of terminal operators, and waiting time in the view of shipping companies are two objectives widely used in the models of BAPs, and a few studies begin to consider energy consumption, fuel consumption and vessel emissions (Du, Chen, Quan, Long, & Fung, 2011), operational safety (Lee & Chen, 2008) and even green ports (Chang & Wang, 2012). According to the investigations into the large-scale ports in China (e.g., Shanghai Port, Ningbo Port and Qiangdao Port), due to the lack of operative employees, increasing labor and fuel costs, the terminal operators are trying to find new methods to decrease the operational cost and increase the welfare (e.g., working comfort) of terminal workers. Daytime preference is considered in such backgrounds.

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Daytime preference refers to minimizing the workloads operated at nights in this study. Because of various problems of night-shift, few people want to work at night (Williams, 2008). Sophisticated technique employees are short in ports and shipping industries (Maloni & Jackson, 2005), especially the drivers of quay cranes, yard cranes and yard trucks. To persuade the workers to work in nightshifts, the labor costs are usually increased (Horwitz & McCall, 2004). Apparently, the nighttime operations causes low working efficiency when safety is considered. For the operations of cranes and trucks, eyesight is still the main factor to guarantee the operational accuracy and safety (Dorrian, Baulk, & Dawson, 2011). To improve the nighttime working comfort and safety, it can be seen that the lights are all on in container terminals at nights. Although the ratio of the nighttime light electricity power consumption is not focused on in this study (the data for specific port is demanded to be secret by cooperation contract), shifting the work from night to day is a valid strategy to save electric energy. The relation between the above aspects and the deduced penalty to the workers and the port operators is complex and may depend on the operating devices and technologies in the ports. In this study, the workloads operated at night (representing daytime preference) and the delayed workloads are two objectives to be minimized in a bi-objective BAP optimization model. However, although moving the vessels' handling tasks to the daytimes for these issues is apparently beneficial, daytime preference is just mainly an objective to be pursued at present because the BAP involves too many stakeholders.

In this paper, a BAP in maritime terminals is considered, in which daytime preference is considered based on a DDBAP model. Comparing the literature on BAP, the most direct contribution of this study involves of the identification of daytime preference in BAP. To the best of our knowledge, daytime preference is firstly incorporated into BAP formulations. Moreover, To solve large-scale problem and examine the tradeoff between the delayed workloads and the workloads operated at night, a multi-objective genetic algorithm (moGA) is developed. The solution procedure works particularly in the following format: Given a certain tentative list of calling vessels, the berthing sequence of vessels and their berthing times are encoded as chromosomes in the moGA, which are evolved as the algorithm runs, providing estimates of performance measures. The moGA is capable of developing improved solutions. The approach is tested by the application to illustrative problem instances of practical scales. The parameter sensitivities and the tradeoff between the two objectives are analyzed. The research is motivated by the investigation of Chinese big ports and the challenge of sustainable and green port development. Therefore, the study aims at a start of synthesizing the economic, environmental and social costs in maritime logistical systems.

The rest of the paper is organized as follows. The next section reviews the related literature on BAP, daytime preference and multi-objective optimization. In Section 3, the problem is formulated as a bi-objective model. In Section 4, a moGA is designed. Numerical experiments are performed and the results are presented in Section 5, as well as the managerial implications. Some concluding remarks are provided in Section 6.

2. Related work

2.1. Berth allocation problem

It is necessary to design workable and friendly BAP schedules as there is a great throughput of container terminals while the human resource costs, service quality and safety are increasingly concerned by terminal operators, workers and customers. The optimal BAP schedule in this work considers daytime preference, minimizing delayed workloads comparing to estimated time of departure (ETD) and the workloads operated in nights.

In BAP, the berth layout of a maritime terminal together with a set of calling vessels that have to be served within the planning horizon is given. For each vessel, additional data like the vessel's length including clearance, the estimated time of arrival (ETA), the handling time and the ETD can be given. All vessels must be moored within the boundaries of the quay. They are not allowed to occupy the same quay space at a time. BAP is to assign a berthing position and a berthing time to each vessel, such that given objectives are optimized, while as an NP-hard problem BAPs are difficult to solve (Bierwirth & Meisel, 2010).

The constraints involved in BAPs lead to a multitude of BAP formulations. Spatial and temporal constraints are two prominent types that are used to classify the literature. Spatial constraints restrict the feasible berthing positions of vessels according to a preset partitions of the quay into berths. Imai et al. (2005) distinguished discrete, continuous and hybrid layouts of berths. The discrete layout partitions a quay into a number of sections, called berths. At most one vessel can be served at each berth at a time. The continuous form does not partition the quay, and vessels can berth at arbitrary positions within the boundaries of the quay. Continuous layout has the advantage of utilizing quay space. The hybrid layout also partitions the quay into berths, but large vessels may occupy more than one berth while small vessels may share a berth. Temporal constraints restrict berthing times and departure times of vessels. Imai et al. (2001) distinguished static and dynamic arrival times. Static arrival indicates that no arrival time is given for a vessel or merely a soft constraint is imposed on berthing times. Dynamic arrival indicates that fixed ETAs (practically time-windows) are given for vessels. Hence, vessels cannot berth before the ETAs. Accompanied with ETAs, usually ETDs are also given such that the entire service to a vessel must be executed within a time window. Except for tidal effects on berth allocation (Xu, Chen, & Quan, 2012), few studies focused on the available or unavailable intervals of berths or terminals. Daytime preference tends to treat daytime intervals in higher priority than nighttime intervals.

The temporal constraints classify the researches related to discrete BAP intro two streams: static and dynamic cases. In a early formulation of discrete static BAP, the vessels' waiting and handling times are minimized, as well as the differences between the arrival order of vessels and the service order (Imai, Nagaiwa, & Tat, 1997). Subsequently, Imai, Nishimura, and Papadimitriou (2008) studied the minimization of the weighted number of vessel rejections by using genetic algorithm (GA). A vessel is rejected at a terminal if it cannot be served without overshooting a due date, represented by a maximum acceptable waiting time. Imai et al. (2001) formulated the DDBAP as a mixed-integer program with regard to the stay times of vessels at terminals. Buhrkal, Zuglian, Ropke, Larsen, and Lusby (2011) compared the performances of five formulations of DDBAPs, and found that the model by Christensen and Holst (2008) is superior to the other models. Cordeau, Laporte, Legato, and Moccia (2005) formulated a DDBAP with due dates, and devised a Tabu search algorithm that outperformed the first-come first-served rule and also Cplex.

A certain number of quay cranes has to be assigned to each vessel even in a discrete BAP (Imai et al., 2008). Han, Lu, and Xi (2010) devised a nonlinear stochastic mixed-integer program for BAP with ETA and handling time uncertainties of quay cranes. Song, Cherrett, and Guana (2012) formulated the integrated BAP and quay crane scheduling problem as a bi-level program.

Various objective functions are developed in BAP formulations. Models to minimize the sum of the waiting and handling times of vessels clearly prevail. Other objectives include minimizing the