Computers & Industrial Engineering 97 (2016) 258–275

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Behavior perception-based disruption models for berth allocation and quay crane assignment problems

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ARTICLE INFO

Article history:
Received 9 October 2015
Received in revised form 21 January 2016
Accepted 9 April 2016
Available online 19 April 2016

Keywords:
Container terminals
Berth allocation
Quay crane assignment problem
Disruption environment
Prospect theory

ABSTRACT

Berth allocation and quay crane assignment problems are frequently encountered in container terminals and the scheduling problems usually exist in a disruption environment. This paper focuses on the rescheduling problem dealing with the disruption that a quay crane breakdowns unexpectedly in the middle of the execution of a planned schedule. Considering that the rescheduling action normally affect the conflicting objectives of port planner, vessel owners and crane operators, this paper aims to reschedule the system with the objective to minimize their negative deviation from the originally planned schedule. The problem is divided into two phases and the behavior perception-based disruption models are constructed for each phase based on prospect theory. Furthermore, an MIP-based relax-and-fix algorithm is proposed to obtain optimal solutions for Phase I and a dynamic programming technique is applied to solve Phase II. Finally, extensive numerical experiments are conducted to test the performance of the proposed models and solution approaches.

1. Introduction

With the development of containerization, *container terminals* (CTs) play a more and more important role in the global transportation (Bierwirth & Meisel, 2015). Facing the fierce competition, CTs must provide a high-efficiency service to the calling vessels. Therefore, an appropriate schedule which can help terminal operators reduce operational costs and improve efficiency is needed.

It is widely known that the construction cost of a berth is very high comparing to the investment costs for other facilities in the CTs (Park & Kim, 2003). Therefore, the berth is the most critical resource and numerous papers dealing with the application of *operation research* (OR) methods address seaside operations planning. One issue is *berth allocation problem* (BAP) which is to assign quay space and service time to vessels that have to be unloaded and loaded at a CT. The transshipment of containers between a vessel and the wharf is generally performed by quay cranes (QCs), which are mounted on rail tracks alongside the wharf. The assignment of these QCs to vessels and the work plans for the QCs addresses a further problem, namely the *quay crane assignment problem* (QCAP). QCAP and BAP are basically interrelated, because solving the QCAP can have a strong impact on the vessels' operation times. The duration of berthing of a vessel depends on the number of QCs allocated to the vessel. When the number of QCs allocated to a vessel increases, the duration time is reduced. This is why BAP and QCAP are considered simultaneously.

Numerous studies have been conducted regarding the improvement of the efficiency of BAP and QCAP. Many models and algorithms have been developed to optimize BAP and QCAP. However, during operation, the scheduling environment is full of uncertainties and CTs are therefore actually existed in the disruption environment (Zeng, Yang, & Hu, 2011). The planned schedules often have to be revised because of disruptions caused by severe weather, equipment failures, technical problems, machinery breakdowns and other unforeseen events. Once these disruptions happen, the initial plan may be infeasible, and modification of current or future schedules should be undertaken to minimize the negative impacts of the disruption, which is called *disruption management* (DM). Existing literatures, which we will review later in Section 2 always studied the deterministic problems. Although some papers, e.g., Han, Lu, and Xi (2010), Zhen, Lee, and Chew (2011a) and Zhen and Chang (2012), have considered the disruption such as the delay of arrival time, the deviation of operation time, to the best of our knowledge, the issue, considering the disruptions those have arisen due to the machinery breakdowns of QCs, has not been dealt with in other literature. Thus, this paper focuses on cases in which disruptions have arisen due to the

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http://dx.doi.org/10.1016/j.cie.2016.04.008
0360-8352/

machinery breakdowns of QCs. QCs are the major tools to unload and load containers from the vessels. Before making a schedule, it is often assumed that QCs can work regularly. However, machinery breakdowns of QCs commonly exist in actual operation. As a result of the machinery breakdowns of QCs, the original schedule cannot be executed as smoothly as anticipated which may even result in huge adjustment costs. Therefore, it is necessary to study the disruptions caused by the machinery breakdowns of QCs in seaside operations planning.

A major issue in the planning and operations management of such system is to reschedule vessels so that the negative deviation from the originally planned schedule could be minimized. In practice, there are several reactive methods to reschedule vessels. For example, *right-pushing* (RP) strategy along the time-axis, but this method may cause chain reactions to other vessels; reschedule vessels with the same method which is adopted to generate the original schedule, but this way may lead to a schedule which is very different from the original schedule. Considering that the rescheduling action normally involves human beings' behavioral performance, therefore, in this paper, we would like to take into account the effect of behavioral perception in the disruption model. Since a reschedule policy normally involves the profit of port planner, vessel owners and crane operators in practical world when the disruptions happen, it is important to contemplate their attitudes towards the disruptions while launching a reschedule policy. Pursuant to the prospect theory, one of the most famous behavioral economic theories, this paper intends to determine when and where the vessels should be moored and the detailed schedule for each QC while minimizing the negative deviation cost incurred by deviating from the originally planned schedule, taking into consideration of the port planner, vessel owners and crane operators' perspectives.

This paper is structured as follows: subsequent to the introduction provided herein; Section 2 reviews the related papers; Section 3 gives the the problem description; the original models and the behavior perception-based disruption models are presented in Section 4; Section 5 employs a relax-and-fix algorithm and a dynamic programming to solve the above problem in large-scale realistic environments; numerical experiments are conducted in Section 6 to validate the effectiveness and efficiency of the proposed method; and Section 7 draws the conclusions.

2. Literature review

Since the early 1990s, CT operations have been intensively studied. For a comprehensive overview, please refer to the review work given by Vis and Koster (2003), Steenken, VoB, and Stahlbock (2004), Stahlbock and VoB (2008), Bierwirth and Meisel (2010) and Bierwirth and Meisel (2015).

BAP and QCAP are widely studied and can be effectively modeled and efficiently solved. Imai, Nagaiwa, and Chan (1997) aimed to minimize not only waiting and operation times of the vessels but also the deviation between the arrival order and the service order. The problem can be reduced to a classical assignment problem, which is solved by the Hungarian method. Park and Kim (2003) discussed a method for scheduling berth and QCs and a two-phase solution is suggested for solving the proposed mathematical model. The first phase determines the berthing time and position as well as the number of QCs assigned to each vessel at each time segment and the second phase aims to construct a detailed schedule for QCs. It is noted that our model is similar to the model in Park and Kim (2003). Guan and Cheung (2004) considered the problem of allocating space at berth for vessels with the objective of minimizing total weighted flow time. Two mathematical formulations were considered where one is used to develop a tree search procedure while the other is used to develop a lower bound that can speed up the tree search procedure. Cordeau, Gaudioso, Laporte, and Moccia (2007) formulated the service allocation problem as a generalized quadratic assignment problem. Liu, Wan, and Wang (2006) studied the problem of scheduling QCs at CTs where incoming vessels have different ready times. A heuristic decomposition approach is proposed to breakdown the problem into two smaller, linked models and two heuristic methods were developed. Imai, Chen, Nishimura, and Papadimitriou (2008) addressed efficient berth and crane allocation scheduling at a multi-user CT. A model is formulated for the simultaneous berth and crane allocation problem and a heuristic is developed by employing a genetic algorithm to find an approximate solution for the problem. Zhang, Zheng, Zhang, Shi, and Armstrong (2010) incorporated crane coverage ranges into a continuous berth allocation problem. They solved the problem by Lagrangian relaxation and sub-gradient optimization. The approach is evaluated in a case study for Tianjin Five Continents International Container Terminal, China. The other papers can refer to Lim (1998), Nishimura, Imai, and Papadimitriou (2001), Imai, Nishimura, and Papadimitriou (2001), Park and Kim (2002), Hansen and Oguz (2003), Kim and Moon (2003), Imai, Sun, Nishimura, and Papadimitriou (2005), Lee, Song, and Wang (2006), Wang and Lim (2007), Lokuge and Alahakoon (2007), Liang, Huang, and Yang (2008), Hansen, Oguz, and Mladenovic (2008), Chang, Yan, Chen, and Jiang (2008), Meisel and Bierwirth (2009), Zhen, Chew, and Lee (2011b) and Zhen and Chang (2012).

Most of the researches presented above are concerned about how to obtain an initial schedule under a static and deterministic situation. However, the scheduling environment is full of uncertainties and CTs are therefore actually existed in the disruption environment. Han et al. (2010) addressed berth and QC scheduling problems in a simultaneous way, with uncertainties of vessel arrival time and container handling time. Zhen et al. (2011a) studied the BAP under uncertain arrival time or operation time of vessels. Later on, Zhen and Chang (2012) proposed a bi-objective model for the robust berth allocation scheduling, in which a heuristic based on the time buffer inserting method was proposed to solve the problem. Zhen (2014) studied the container yard template planning under uncertain maritime market and a model is proposed for yard template planning considering random numbers of containers that will be loaded onto vessels. Zeng et al. (2011) addressed the problem of recovering berth and QC schedules in CTs when disruptions occur after a subset of operations has been processed. Two strategies, namely, QC rescheduling strategy and berth reallocation strategy are proposed to tackle disruptions and recover the berth and QC schedule, and models for the two strategies are developed respectively. Contrary to the above papers, this paper will study the disruptions caused by the machinery breakdowns of QCs.

Another important issue related to this paper is DM. Since DM was proposed, it has been applied in many fields, e.g., airline, supply chain, shipping, logistics and production scheduling. Clausen, Larsen, and Larsen (2010) provided a thorough review of the current state-of-the-art within airline DM of resources, including

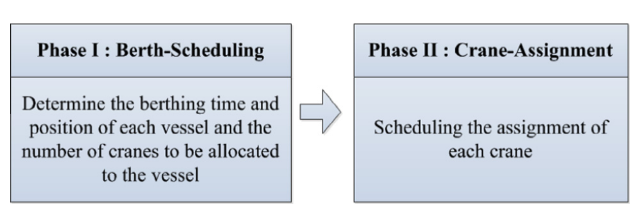

Fig. 1. Two-phase procedure for berth and crane scheduling.