Expert Systems with Applications 42 (2015) 2464–2487

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Integrated internal truck, yard crane and quay crane scheduling in a container terminal considering energy consumption

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ARTICLE INFO

Article history:
Available online 18 November 2014

Keywords:
Container terminal
Integrated scheduling
Mixed integer programming
Energy consumption
Simulation-based optimization

ABSTRACT

Container terminals mainly include three types of handling equipment, i.e., quay cranes (QCs), internal trucks (ITs) and yard cranes (YCs). Due to high cost of the handling equipment, container terminals can hardly purchase additional handling equipment. Therefore, the reasonable scheduling of these handling equipment, especially coordinated scheduling of the three types of handling equipment, plays an important role in the service level and energy-saving of container terminal. This paper addresses the problem of integrated QC scheduling, IT scheduling and YC scheduling. Firstly, this problem is formulated as a mixed integer programming model (MIP), where the objective is to minimize the total departure delay of all vessels and the total transportation energy consumption of all tasks. Furthermore, an integrated simulation-based optimization method is developed for solving the problem, where the simulation is designed for evaluation and optimization algorithm is designed for searching solution space. The optimization algorithm integrates genetic algorithm (GA) and particle swarm optimization (PSO) algorithm, where the GA is used for global search and the PSO is used for local search. Finally, numerical experiments are conducted to verify the effectiveness of the proposed method. The results show that the proposed method can coordinate the scheduling of the three types of handling equipment and can realize the optimal trade-off between time-saving and energy-saving.

1. Introduction

As an interface of shipping and land transportation, container terminals play an important role in the global supply chain. Their service level is critical to the efficiency and cost of global supply chain. Specially accompanied with the world economic crisis, the competition among container terminals has been getting fiercer and fiercer. Container terminals have to improve their service level to attract more customers in the fierce competition environment. Moreover, with the increase of sizes of container vessels, container terminals are encountering another challenge, i.e., the rapid handling of containers for mega-vessels. Thus, container terminals must shorten the vessel turnaround time, which is an influential factor of their service level. However, due to high cost of the handling equipment, i.e., quay cranes (QCs), internal trucks (ITs) and yard cranes (YCs), container terminals can hardly purchase additional handling equipment to promote the productivity. Therefore, the reasonable scheduling of three types of handling equipment, especially coordinated scheduling of the handling equipment, is critical to the service level of container terminals.

During the past decades, the acceleration of environmental pollution and energy consumption has become a world-wide concern (Hatzigeorgiou, Polatidis, & Haralambopoulos, 2008). Besides climate problems, we are facing the resource depletion issue, especially energy resources. Because of the considerable number of pieces of large handling equipment, container terminals play a significant role in the energy consumption and emission of global supply chain. The operators of container terminals are facing the pressure on energy-saving and emission reduction. Therefore, the concept of green port has caused wide concern in academe, society and port industry. Admittedly, we should improve the service level of container terminals as much as possible, but it cannot be implemented at the expense of the cost of the environment. Thus, another goal of container terminals is how to save energy and reduce emission without reducing service level. Since the main energy consumptions of container terminals are contributed by handling equipment, we can save energy consumption by using

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http://dx.doi.org/10.1016/j.eswa.2014.11.016
0957-4174/

clean energy or energy-saving devices. However, this paper focuses on how to realize energy-saving at the operational level without additional equipment investment. In detail, we explore the coordinated scheduling of the three types of handling equipment for the purpose of energy-saving of container terminals.

Generally, most studies on port operations refer to only one type of handling equipment, and solely aim to improve the efficiency of container terminals (see Section 2). To fill the gap in the literature, this paper seeks an appropriate approach for the problem of integrated QC scheduling, IT scheduling and YC scheduling by considering the trade-off between efficiency and energy consumption, where the objective is to minimize the total departure delay of all vessels and the total transportation energy consumption of all tasks.

The remainder of the paper is organized as follows. Section 2 reviews relevant literature. In Section 3, the integrated scheduling problem is described and formulated as a MIP model. A simulation-based optimization is proposed in Section 4. Numerical experiments are conducted in Section 5 to evaluate the effectiveness of the proposed solution methods, and conclusions and future research are given in the last section.

2. Literature review

To date, there are numerous studies on scheduling of various handling equipment in container terminals, such as QC scheduling, IT scheduling and YC scheduling (Steenken, Voβ, & Stahlbock, 2004; Stahlbock & Voβ, 2008). Most of these studies have been devoted to increase the throughput of terminals, or to promote the handling efficiency to shorten the vessel turnaround time (Cao, Lee, Chen, & Shi, 2010). However, energy-saving of container terminals at the operational level is rarely addressed. Only a few literatures have referred to this issue. Moreover, although the coordinated scheduling of handling equipment in container terminals is imperative, most significant researches have only concerned with scheduling each type of handling equipment separately. In this section, only a brief review of studies highly related to QC scheduling, IT scheduling, YC scheduling and energy-saving of container terminals are provided.

2.1. Equipment scheduling at container terminals

For QC scheduling, Meisel and Bierwirth (2009) developed a construction heuristic, local refinement procedures, and two meta-heuristics to resolve a combined problem of berth allocation and crane assignment in container terminals. Lee, Wang, and Miao (2008) provided a MIP model for a quay crane scheduling problem considering interference between quay cranes. A genetic algorithm is proposed to obtain near optimal solutions. Tavakkoli-Moghaddam, Makui, Salahi, Bazzazi, and Taheri (2009) presented a novel MIP model for the QC scheduling and assignment problem, and a GA is proposed to solve the problem for the real-world situations. Zhang and Kim (2009) attempted to minimize the number of operation cycles of a QC for discharging and loading containers in a ship-bay, which is equivalent to maximizing the number of dual cycle operations. A formulation in QC scheduling problem was proposed as a MIP model. A hybrid heuristic approach is proposed to solve this model. Bierwirth and Meisel (2009) proposed a method to modeling safety distances and the non-crossing requirement of QCs in QC scheduling problem, and proposed a heuristic algorithm to solve the problem with respect to the impact of crane interference. Similarly, Legato, Trunfio, and Meisel (2012) developed a rich model for QC scheduling that considered important practical issues, such as QC-individual service rates, ready times and due dates for QCs, safety requirements, and precedence relations among tasks. For solving the problem, they proposed bound scheme with respect to strong lower bounds and branching criteria as well as a new Timed Petri Net model for the evaluation of partial and complete schedules. Unsal and Oguz (2013) developed a constraint programming model for the QC scheduling problem with realistic constraints such as safety margins, travel times and precedence relations. Furthermore, Diabat and Theodorou (2014) developed a model for the quay crane assignment and scheduling problem with respect to positioning conditions. Fu, Diabat, and Tsai (2014) analyzed the integrated quay crane assignment and scheduling problem with respect to the travels of QCs from one vessel to another vessel. Chen, Lee, and Goh (2014) further addressed the unidirectional cluster-based quay crane scheduling problem. Kaveshgar, Nathan Huynh, and Rahimian (2012) addressed the QC scheduling problem by utilizing the genetic algorithm (GA) and proposed some approaches to improve the efficiency of GA search. Nguyen, Zhang, Johnston, and Tan (2013) developed a priority-based schedule construction procedure to generate quay crane schedules, and proposed hybrid evolutionary computation methods based on GA and genetic programming (GP) for resolving.

For YC scheduling, Cao, Lee, and Meng (2008) developed an integer programming model to obtain an efficient strategy for the double-rail-mounted gantry crane systems to load outbound containers, and the model was solved by a greedy heuristic algorithm, a simulated annealing (SA) algorithm and a combined scheduling heuristic. Li, Wu, Petering, Goh, and de Souza (2009) presented a mixed integer linear programming model for YC scheduling, which considered realistic operational constraints. They also proposed heuristics and a rolling-horizon algorithm to obtain near optimal solutions in seconds. Petering and Murty (2009) developed a simulation model to investigate the relationship among a terminal's long-run average quay crane rate, the block length and deployment of yard cranes among blocks in the same zone. He, Chang, Mi, and Yan (2010) studied an objective programming model for a YC scheduling problem based on a static rolling-horizon approach, and a hybrid algorithm was designed for finding solutions and a simulation model was developed for evaluating the solutions. Furthermore, He, Huang, and Yan (2014) proposed an integrated simulation optimization for YC scheduling problem. Boysen and Fliedner (2010) proposed an exact polynomial-time solution procedure to determine yard crane allocation, so that the workload could be equally distributed among cranes. Yan, Huang, Chang, and He (2011) developed a YC scheduling method based on a knowledge-based system for efficiently obtaining a feasible solution. Chang, Jiang, Yan, and He (2011) developed a dynamic rolling-horizon strategy for YC scheduling, which can obtain near optimal solutions.

For IT scheduling, Vis, Koster, Roodbergen, and Peeters (2001) proposed a minimum flow algorithm to determine the number of automated guided vehicles (AGVs) required at a semi-automated container terminal. Kim and Bae (2004) presented an AGV dispatching problem by considering information about locations and times of future delivery tasks, and a heuristic algorithm was designed for solving the problem. Similarly, Nguyen and Kim (2009) addressed an automated lifting vehicle dispatching problem. Bish (2003) proposed new IT dispatching policies, in which a set of vehicles can be pooled among vessels. A simple heuristic called the transshipment problem based list scheduling heuristic, which could provide solutions to large-sized problems in reasonable computational times, was developed. Nishimura, Imai, and Papadimitriou (2005) addressed the IT routing problem at a maritime container terminal, and proposed a more efficient IT assignment method called "dynamic routing". Angeloudis and Bell (2010) presented an AGV dispatching problem under various conditions of uncertainty. He et al. (2013) presented a novel strategy for sharing internal trucks among multiple container terminals in