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Integrating berth allocation and quay crane assignments

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ABSTRACT

In this study, a dynamic allocation model using objective programming for berth allocation and quay crane assignments was preliminarily developed based on rolling-horizon approach. Afterwards, a hybrid parallel genetic algorithm (HPGA), which combined parallel genetic algorithm (PGA) and heuristic algorithm, was employed to resolve the proposed model. Furthermore, a simulation was conducted to evaluate the HPGA and to execute relevant gene repair techniques. Eventually, the numerical experiments on a specific container terminal were applied to illustrate the proposed models and algorithms. In so doing, the effectiveness of the proposed approach was verified.

1. Introduction

As a hinge of global economy and trade, container terminals play an important role in a worldwide competition environment. Accordingly, it is an imperative to improve operational efficiency of existing container terminals. However, the green transportation tends to be one of the future trends on today's economic globalization. In this respect, the reduction of energy consumption has become a critical obligation for port enterprises. Therein, the operations of loading and discharging equipments, e.g. quay cranes, yard cranes and internal trucks, significantly impacts on the energy consumption of container terminals. In particular, the reduction of energy consumption could be achieved by efficient scheduling of quay cranes and yard cranes, rational allocation of storage spaces and berths, and effective reduction of traffic jams. Further elaborated, the berth allocation and quay crane assignments secure a crucial position in operational efficiency of container terminals, that is, an effective planning on berth allocation and quay crane assignments could obviously shorten the overall shipping service time, reduce the total terminal energy consumption, and promote the total container terminal capacity. As a result, an integration of berth allocation and quay crane assignments has been proposed in this study.

2. Literature review

Up to present, a number of researchers attempted to deal with the problems with regard to the operational efficiency of container terminals, e.g. the berth allocation problem (BAP) and quay crane assignments problem (QCAP) (Dirk et al., 2004; Robert and Stefan, 2008; Meisel and Bierwirth, 2009). Specifically for berth allocation, Imai et al. (2001) explored a dynamic BAP strategy to minimize the service time, and meanwhile improve the service order using discrete berths. Similarly, Legato

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and Mazza (2001) developed a queuing net handling model for ships arrival, berthing and departure. Alternatively, Dai et al., 2007 resolved the BAP by simulated annealing. Furthermore, Imai et al. (2007) established a new formulation of integer linear programming for fast calculation, and thereafter extended this model to a terminal with indented berths. In the same manner, Imai et al. (2008) proposed the BAP for a multi-user container terminal to minimize the total service time of ships regarding a limited quay capacity.

On the other hand, Guan et al. (2002) explored a heuristic algorithm to minimize the totally-weighted completion time of ship services. Due to the undesirable service order and additional complexity in terms of container handling, Park and Kim (2002) postulated a BAPC using the simulated annealing technique to minimize the delaying cost of departure ships. In the same fashion, Kim and Moon (2003) introduced a BAP model via the sub-gradient optimization method. Moreover, Imai et al. (2005) speculated a BAP model based on continuous berth space. Further studied, Chang et al. (2008) synthesized the dynamic berth allocation and yard planning for inbound containers, which combined the heuristics algorithm and simulation optimization.

Pertaining to the integration of the BAP and QCAP, Peterkofsky and Daganzo (1990) proposed a static quay crane scheduling strategy to minimize the delaying cost of aggregate ships. In addition, Park and Kim (2003) took into account the cost for early or late start of ship handling against the estimated time of ship arrival. Meanwhile, Lee et al. (2006) considered the quay crane operation with feasible berth planning via the genetic algorithm (GA). To minimize the average waiting time of ships, Zhou and Kang (2008) developed a combined berth and quay-crane allocation model under a stochastic environment. Furthermore, Liang et al. (2009) postulated a dynamic scheduling problem via the hybrid evolutionary algorithm.

However, following issues have not been well addressed.

1. The operational efficiency, rather than the energy consumption, for container terminals was pinpointed in existing literatures; and
2. The effective approaches were still lacking to resolve the NP-complete problem occurring within such operational problems as the BAP and QCAP.

Based on these understandings, a combination of berth allocation and quay crane assignments was proposed via the rolling-horizon model and objective programming. This was aimed at minimizing the berthing location deviation, total penalty and energy consumption of quay cranes. Then, a hybrid algorithm, which employed the heuristic rules and parallel genetic algorithm (PGA), was employed for such problems as the BAP and QCAP. Subsequently, a simulation model using hybrid PGA (HPGA) was developed to evaluate the proposed HPGA and repair the unfeasible individuals generated by HPGA. Consequently, the numerical experiments on a specific container terminal were used for system illustration and verification. To this end, it was indicated from the computational results that the proposed approach could efficiently resolve both BAP and QCAP.

3. Modeling for the BAP and QCAP

3.1. Problem description

Particularly for arrived ships, the berthing time, berth location, number of quay cranes served for ships, and number of containers on ships served by quay cranes can be described in terms of berth planning and quay crane assignments. In Fig. 1, a ship berthing process contains several periods, whereas the turnaround time of ships experiences all periods. In this case, the berth allocation problem (BAP), which involves a discrete and dynamic stochastic process, is critical to entire container terminal planning. In particular, a ship is arranged for the available berths without any collisions, viz., the quay length should be aligned with the ship length.

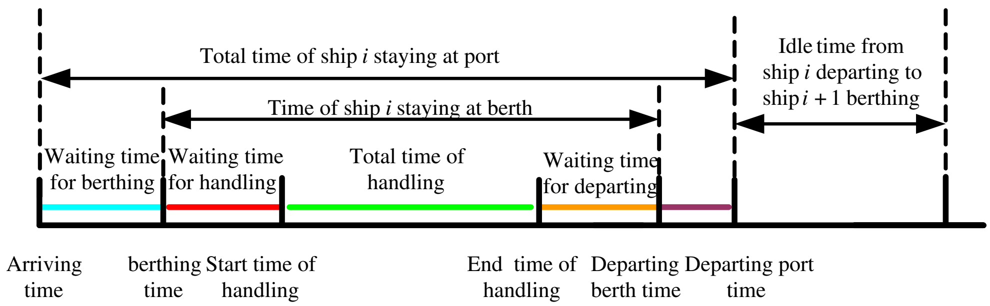

Fig. 1. Periods of ship berthing process.