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A HPSO for solving dynamic and discrete berth allocation problem and dynamic quay crane assignment problem simultaneously

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A B S T R A C T

Berth allocation problem (BAP) and quay crane assignment problem (QCAP) are two essential seaside operations planning problems faced by operational planners of a container terminal. The two planning problems have been often solved by genetic algorithms (GAs) separately or simultaneously. However, almost all these GAs can only support time-invariant QC assignment in which the number of QCs assigned to a ship is unchanged. In this study a hybrid particle swarm optimization (HPSO), combining an improved PSO with an event-based heuristic, is proposed to deal with two specific seaside operations planning problems, the *dynamic* and *discrete* BAP (DDBAP) and the *dynamic* QCAP (DQCAP). In the HPSO, the improved PSO first generates a DDBAP solution and a DQCAP solution with time-invariant QC assignment. Then, the event-based heuristic transforms the DQCAP solution into one with variable-in-time QC assignment in which the number of QCs assigned to a ship can be further changed. To investigate its effeteness, the HPSO has been compared to a GA (namely GA1) with time-invariant QC assignment and a hybrid GA (HGA) with variable-in-time QC assignment. Experimental results show that the HPSO outperforms the HGA and GA1 in terms of fitness value (FV).

1. Introduction

The demand for marine transportation has significantly increased over the past 20 years [6]. Between 1990 and 2008, container traffic increased from 28.7 million to 152.0 million movements, an average annual compound growth of 9.5% [28]. In the same period, container throughput increased from 88 million to 530 million (an increase of 500%). Also, it is found that more than 60% of maritime transportation employed containers with a steady 6.4% increase each year [22]. The figure even approached 100% for some developed countries. The explosive growth of container shipments indicates the importance of improving the operations in a container terminal (CT).

The operations in a CT can be classified into the three areas: seaside, yard and landside [1,30]. Among them, the seaside operations are critical due to the use of berths and quay cranes, two scarce resources with significant impacts on a CT [17]. In the CT seaside, berth allocation problem (BAP), quay crane assignment problem (QCAP) and quay crane scheduling problem (QCSP) are three essential seaside operations planning problems and they were often solved separately [18,26,34]. A separate study, however, was found likely to result in poor overall system performance due the neglect on their interrelationships. Thus, seaside operations planning problems have been suggested to be solved in an integrated way [1]. This has prompted us to deal with two specific seaside problems, the *dynamic* and *discrete* BAP (DDBAP) and the *dynamic* QCAP (DQCAP), at the same time. The "*dynamic*" indicates that both arrived and incoming ships are to be considered while the "*discrete*" indicates the quay is configured as a set of discrete berths to accommodate calling ships.

Our literature review also shows that there are two ways to assign QCs to a ship: time-invariant or variable-in-time [1]. In the time-variant QC assignment the number of QCs assigned to a ship is unchanged while in the variable-in-time QC assignment the number of QCs assigned to a ship can be further adjusted. Obviously, the two different QC assignments can lead to different results and the variable-in-time QC assignment gains flexibility at the cost of more QC setups and movements. However, the variable-in-time QC assignment is found to have been rarely appeared in past studies.

Various approaches, characterized as exact and approximate type, have been proposed to deal with the BAP and/or QCAP. However, the exact approaches (such as Integer Programming Model (IPM) and Mixed Integer Programing (MIP)) are found incapable of dealing with the two planning problems of big size due to NP-hard [16,20,28]. As a result, the approximate approaches such as heuristic/meta-heuristic, simulated annealing, simulation and GAs have been proposed. Among them, GAs are the most

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popular approach [2]. However, the GAs proposed in past study are found almost support the time-invariable QC assignment, instead of the variable-in-time QC assignment. This has prompted us to focus on developing an approach that can support variable-in-time QC assignment. Recently, particle swarm optimization (PSO) has been proposed [15], and it was found capable of dealing with GAs when come to deal with combinational optimization problems (COPs) [27]. As PSO-based approaches have never been used to deal with the BAP and QCAP simultaneously, this kind of approaches is thus focused in this study.

In this study, a hybrid PSO (HPSO), which combines an improved PSO with an event-based heuristic, is proposed to deal with the DDBAP and DQCAP simultaneously. The HPSO features a variable-in-time QC assignment. In the HPSO, the improved PSO is first used to generate a DDBAP solution and a DQCAP solution with time-invariant QC assignment. Then, the DQCAP solution is further transformed into one with variable-in-time QC assignment. To investigate its effectiveness, the HPSO has been compared to a traditional GA (namely GA1) with time-invariant QC assignment and a hybrid GA (HGA) with variable-in-time QC assignment. The GA1 employs Two-Point Crossover (TPX) operation and Swap Mutation (SM) operation while the HGA is derived by combining the GA1 with the event-based heuristic used in the HPSO. Our experimental results show that the HPSO outperforms GA1 and HGA in terms of fitness value (FV). According to the classification scheme proposed by Bierwirth and Meisel [1], this study can be classified as disc|dyn|QCAP|$\sum(w_1 wait + w_2 tard + w_3 hand)$.

The rest of this paper is organized as follows. Section 2 has a literature review. Section 3 formulates the simultaneous DDBAP and DQCAP. Section 4 details the HPSO. Section 5 describes the GA1 and HGA. Section 6 provides experimental results. Finally, Section 7 concludes this study and suggests some future research directions.

2. Literature review

2.1. The studies focusing on BAP

Brown et al. [3] is a pioneering study on the "*static*" BAP with only arrived ships taken into account. An integer programming model (IPM) was proposed to find optimal ship-to-berth assignments. However, due to the focus on naval port the IPM is not suitable for commercial ports that have different situations. Later on, Imai et al. [11] conducted a study focusing on commercial ports in Japan with ship priority taking into account. Their study concluded that FCFS rule was not suitable for finding an optimal ship-to-berth assignment in terms of throughput. To be more practical, recent studies have increasingly focused on the "*dynamic*" BAP (DBAP) and various approaches have been proposed to deal with it. For example, Imai et al. [12] proposed a subgradient approach. However, as the solution process of this approach was found still too complicated, a GA-based approach was another proposed in a later study [13]. Hansen et al. [10] proposed a variable neighborhood search (VNS) with the aim to find a solution with minimum total cost that includes the sub-costs of waiting, handling and earliness or tardiness of completion. Xu et al. [32] proposed a heuristic to deal with the DBAP. In their study special factors such as water depth and tidal condition were taken into account. They claimed that a better decision can be achieved if these factors are taken into account.

2.2. The studies focusing on simultaneous DBAP and QCAP

Some studies have devoted to the simultaneous BAP and QCAP. Imai et al. [14] first formulated the two problems as an IPM, and then proposed a GA-based heuristic to find approximate solution with minimum total service time for the two problem. The FV of a chromosome (solution) was derived from a crane transfer scheduling based on the algorithm of maximum flow problem. However, the GA-based heuristic did not support variable-in-time QC assignment. Zhou and Kang [35] also proposed a GA to deal with the two problems. Similarly, they first formulates the problems as an IPM with the objective to minimize the sum of waiting time and handling time of every ship. In this study, the arrival times and handling times of calling ships were treated as stochastic variables and physical constraints such as ship length, ship draft, berth length and berth depth have been taken into account. The GA, however, did not support variable-in-time QC assignment. Liang et al. [18] proposed a hybrid GA (HGA) to deal with the two problems. Following the similar procedure, the two planning problems were first formulated as IPMs with the objective to minimize the sum of waiting time, handling time and delay time for every ship. The HGA was found able to find approximate solutions. In this HGA, QCs were allowed to move among berths but still variable-in-time QC assignment was not supported. In a later study, Lisng et al. [19] further improved HGA with QC movement and ship priority taken into account. However, the improved HGA still did not support the variable-in-time QC assignment. Han et al. [9] also treated the arrival times and handling times of calling ships as stochastic variables, and proposed a GA to deal with the two planning problems simultaneously. The resulting solutions were evaluated by simulation with the objective to find a minimal solution taking into account the expected value plus standard deviation of total service time and weighted tardiness time for all vessels. This study had taken constraints such as berth length, berth depth, ship draft and ship length into account and QCs were reassigned when a ship arrives. Giallombardo et al. [8] solved the tactical BAP (TBAP) and QCAP at the tactical level. The TBAP was not simply the obvious one of considering a longer planning horizon, but mainly that of supporting decisions made by terminal managers in the negotiation process with shipping lines. In their study, a mixed quadratic programming (MIQP) formulation and a mixed integer linear programming (MILP) formulation were first formulated, with the objective to maximize the total value of chosen quay crane profiles and the housekeeping costs generated by transshipment flows between ships. Then, a two-level heuristic algorithm combining Tabu search methods with mathematical programming was proposed to solve the two planning problems. In the upper level Tabu search was used to allocate berth while in the lower level the mathematical programming was used to update QCs profile. The proposed heuristic offered solutions with variable-in-time QC assignment. However, the cost of QC setup and movement was not considered.

Our literature review shows that the simultaneous DBAP and QCAP has attracted increasing attention with GAs being as the major approach. However, almost all the GAs proposed in past studies do not support variable-in-time QC assignment.

2.3. PSO-based approaches for solving the seaside operations planning problems

Martin et al. [24] ever proposed a PSO-based approach to deal with COPs with two scenarios being used test the effectiveness of this approach. In one scenario the PSO-based approach was used to assign resources (piers and tanks) to calling tankers, and their experimental results showed the PSO-based approach outperformed a GA. However, their study did not include the QCAP. Wang et al. [31] proposed an improved PSO for scheduling containers to be unloaded from a ship. In their study, a swarm distance was introduced to diversity particles, i.e. particle position values are regenerated if the swarm distance of particles reaches a