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A genetic algorithm for optimization of integrated scheduling of cranes, vehicles, and storage platforms at automated container terminals

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HIGHLIGHTS

- A new genetic algorithm for the integrated scheduling of handling and storage equipment was developed.
- The control parameters of the GA were examined.
- The proposed GA was compared against a previously developed algorithm.
- Integrated and non-integrated scheduling methods were examined in large scale test cases.
- Three various dwell point policies for the storage platforms were examined.

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ABSTRACT

Commonly in container terminals, the containers are stored in yards on top of each other using yard cranes. The split-platform storage/retrieval system (SP-AS/RS) has been invented to store containers more efficiently and to access them more quickly. The integrated scheduling of quay cranes, automated guided vehicles and handling platforms in SP-AS/RS has been formulated and solved using the simulated annealing algorithm in previous literatures. This paper presents a genetic algorithm (GA) to solve this problem more accurately and precisely. The GA includes a new operator to make a random string of tasks observing the precedence relations between the tasks. For evaluating the performance of the GA, 10 small size test cases were solved by using the proposed GA and the results were compared to those from the literature. Results show that the proposed GA is able to find fairly near optimal solutions similar to the existing simulated annealing algorithm. Moreover, it is shown that the proposed GA outperforms the existing algorithm when the number of tasks in the scheduling horizon increases (*e.g.* 30 to 100).

1. Introduction

As the world trade market resolves more barriers every day, containers become more important to transport goods from countries and continents to anywhere in the world. Many researchers believe that all over the world, container terminals are

Abbreviations: ACT, Automated container terminal; AGV, Automated guided vehicle; ASC, Automated stacking crane; EAV, Earliest available vehicle; FCFS, First come first service; GA, Genetic algorithm; IS, Integrated scheduling; L/U, Loading/unloading; NIS, Non-integrated scheduling; QC, Quay crane; SAA, Simulated annealing algorithm; SP-AS/RS, Split-platform automated storage/retrieval system.

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facing steadily increasing pressure for an upsurge in their transportation capacities and demands for a quick turnaround of vessels [1–3]. Automation of container handling equipment is a response to this ever-increasing container traffic. Automated container terminals (ACTs) have been introduced to reduce operational costs, especially the labor costs, and to increase throughput of the container terminals. In recent years, modern layouts of the container terminals are considered as a solution to increase their performance. For example, Imai, Nishimura and Papadimitriou [4] have developed two new layout designs for container terminals to serve mega containerships; and Zheng, Lu and Sun [5] have developed a heuristic algorithm for yard allocation and stowage plans in addition, which is especially designed for automated container handling systems invented by ZMPC®, in which the vehicles has been removed from their layouts. However, Yu, Cai and Zhao [6] stated that in addition to implementing advanced handling and storage equipment, new strategies and scheduling methods would improve the performance of the ACTs.

In ACTs, the vessels dock on the berths and a predetermined number of quay cranes (QCs or simply cranes) are assigned to the vessel. On the other side of the terminal, in storage yard, commonly the containers stacks on top of each other using the automated stacking cranes (ASCs), while the automated guided vehicle (AGVs or simply vehicles) connect the berth and the storage areas. Chen, Huang, Hsu, Toh and Loh [7] proposed split-platform automated storage/retrieval system specially designed to handle containers. This storage system uses separate platforms for high-speed vertical and horizontal movements, called VPs, and HPs, respectively [8]. It has been calculated that this storage system is more efficient in using the land space compared to the conventional storage yards. Hu, Huang, Chen, Hsu, Toh, Loh and Song [9] and Vasili, Tang, Homayouni and Ismail [10] calculated the expected travel time for the SP-AS/RS using three various dwell point policies (*i.e.* stay in place, return to middle, and return to start policies). Vasili, Tang, Homayouni and Ismail [10] showed that stay in place dwell point policy gained a lower expected travel time compared against other policies.

One of the most recent strategies to improve the performance of the ACTs is the integrated scheduling method. Integrated scheduling of two equipment in the container terminal is a common research area in the literature. For example, Wu, Luo, Zhang and Dong [11] have proposed integrated scheduling of storage operations and vehicles; Homayouni and Tang [12] have developed a mixed integer-programming (MIP) model and a genetic algorithm for the integrated scheduling of cranes and vehicles; and Chen, Langevin and Lu [3] have developed an integrated method for the crane scheduling and yard truck operations. On the other hand, the integrated scheduling of all three equipments engaged in handling and storage operations of ACTs gained fewer considerations in the literature. Meersmans and Wagelmans [13] seem to be the first among researchers considering integrated scheduling of cranes, vehicles, and ASCs. An MIP model for the integrated scheduling of cranes, yard trucks, and yard cranes was formulated by Chen, Xi, Cai, Bostel and Dejax [14]. Furthermore, Liang, Lu and Zhou [15] proposed an MIP model for the integrated scheduling of cranes, inner trucks and yard cranes. They assumed that trucks are not the bottleneck of the scheduling processes. Therefore, the famous Johnson's rule for scheduling of two independent sets of processes was applied to this integrated scheduling problem. Zeng and Yang [16] developed a hybrid simulation–optimization method for this problem. The required simulation time would be decreased using a neural network algorithm in which objective functions of the proposed sequences are predicted, and potentially bad solutions are filtered out.

In the above-mentioned literature, it is assumed that the loading and unloading tasks for the vessels are executed separately [13–16]. However, Lau and Zhao [17] stated that to decrease the empty travelling of the vehicles, loading and unloading tasks can be performed concurrently for a vessel according to a predetermined list of tasks for the cranes. Lau and Zhao [17] have formulated the scheduling of cranes, vehicles, and ASCs minimizing delays in tasks of cranes, and travel time of ASCs, and vehicles. First, the SP-AS/RS involved in the integrated scheduling of container handling and storage equipment by Homayouni, Vasili, Kazemi and Tang [18]. They formulated the problem as an MIP model, and a simulated annealing algorithm (SAA) was developed to minimize the travel time of platforms in the SP-AS/RS, and the vehicles, in addition to the delays in loading and unloading tasks of the cranes.

The main objective of the current paper is to propose a genetic algorithm to optimize the integrated scheduling of cranes, vehicles, and the platforms of the SP-AS/RS. The proposed GA finds near optimal solutions for the problem in relatively low computational time. The control parameters for the proposed GA are well investigated, and the performance of the GA is compared against the optimal solutions found by the MIP model developed by Homayouni, Vasili, Kazemi and Tang [18] and their proposed SAA. In the last step, dwell point policies suggested by Vasili, Tang, Homayouni and Ismail [10] are examined in the proposed scenario of this paper.

The integrated scheduling of cranes, vehicles and platforms of the SP-AS/RS is described in Section 2. Section 3 is dedicated to describe a brief review on the principals of the genetic algorithms. Moreover, the proposed GA to optimize the integrated scheduling problem is stated in this section. Several tests on the parameters used in the proposed GA have been executed and their results are reported in Section 4. Moreover, near optimal solutions found by the proposed GA has been compared with those from literature, and the results are described in Section 4. Final notes and conclusion remarks in addition to the recommendations for further researches are presented in Section 5.

2. Problem definition

Vessel operations primarily consist of the unloading and loading tasks. The unloading task is a set of operations for discharging a container from the vessel and storing it in the storage yard. In unloading tasks, the crane moves from its dwell point to the vessel. Cranes may shuffle the containers in the hold, and pick up the desired container. The container is