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An investigation into knowledge-based yard crane scheduling for container terminals

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ABSTRACT

To resolve the problems of operational efficiency, energy consumption and operational cost of an entire container terminal, the yard crane scheduling secures a crucial position during terminal operational process. Accordingly, it is imperative to develop an efficient yard crane scheduling strategy. In this study, the knowledge acquisition was initially conducted. Subsequently, a knowledge sorting process, including the taxonomic tree generation and organization of acquired knowledge, was completed. Afterwards, the rules were extracted for the purpose of yard crane scheduling. Furthermore, a mechanism was deployed for knowledge reasoning. Consequently, a knowledge-based system was established with regard to yard crane scheduling. To this end, a case study was used to illustrate the proposed knowledge-based system.

1. Introduction

Owing to intensive competitions amongst sea-ports, container terminals are encountering such pressures as improving quality of service, saving energy consumption, reducing the service cost and increasing the cargo throughput. Therein, it is imperative to reduce the total service time of ships in terminal, as well as improve the operational efficiency of container terminals. Typically, container terminals are operated using three loading and discharging equipments, i.e., quay cranes, yard cranes and internal trucks. Fig. 1 illustrates the loading and discharging processes based on these equipments in a container terminal. Accordingly, the operational efficiency of an entire container terminal could only be achieved by efficient scheduling of quay cranes and yard cranes, rational allocation of storage spaces and berths, and low rate of traffic jams. Furthermore, the yard crane scheduling occupies a prime in operational efficiency of container yards. Therefore, an effective yard crane scheduling could significantly shorten the turnaround time of external trucks, save energy consumption of terminals, reduce overall shipping service time, lower the rate of traffic jam, and promote the total operation efficiency of container terminal. As such, it is necessary to develop an efficient strategy for yard crane scheduling.

2. Literature review

Up to present, intensive researches were attempted in the area of container terminal operation, such as the berth allocation, storage space allocation, quay crane scheduling, yard crane scheduling and internal truck scheduling [7,13,18,20,25,30]. So far, the ultimate objective of abovementioned resource scheduling approaches was aimed at improving the operational efficiency of container terminals, particularly time- and cost-efficiency. Amongst them, Murty et al. [24] developed a decision support system to improve the operational efficiency of container terminals. Nishimura et al. [27] proposed a trailer assignment method called dynamic routing to achieve cost savings for container handling in a terminal. Imai et al. [16] speculated a berth allocation problem approach for a multi-user container terminal with a limited quay capacity to minimize the total service time of ships. Since container terminal operation was associated with an NP-hard problem, the heuristic algorithm was frequently applied to resolve this problem. Accordingly, Bish [1] developed a heuristic algorithm to formulate the problem as a transshipment problem. Kim and Park [17] proposed a mixed-integer programming model and developed a heuristic search algorithm, namely greedy randomized adaptive search procedure, to resolve quay cranes scheduling problem. Chang et al. [6] deployed a berth allocation strategy using heuristics algorithm and simulation optimization.

Owing that the yard crane scheduling secured a crucial position in operational efficiency of container terminals, a number of studies were completed. For this purpose, the integer programming

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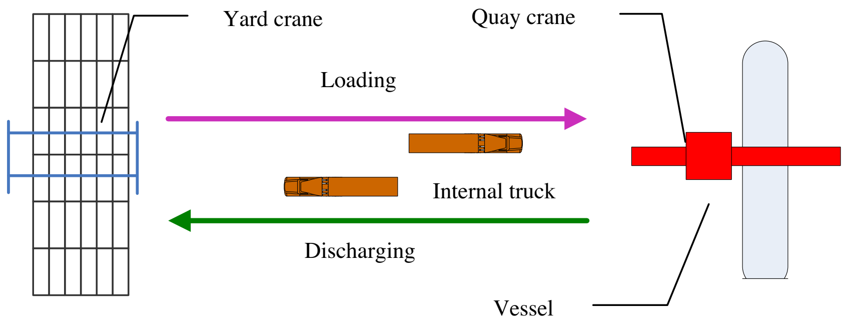

Fig. 1. Illustration of typical equipments used in container terminals.

model was broadly employed together with other algorithms. For instances, Zhang et al. [34] developed a mixed integer programming and Lagrangian relaxation model for yard cranes scheduling. Alternatively, Chen et al. [11] developed an integrated scheduling and Tabu searching model for container handling. By providing an operational strategy for the double-rail-mounted gantry crane systems to load outbound containers, Cao et al. [5] explored a combined greedy heuristic algorithm and simulated annealing algorithm. Further studied, the simulation model was investigated together with other techniques. To optimize the yard crane scheduling, Yan et al. [33] analyzed the dynamics and heuristics of yard crane deployment by comparing the results between hill-climbing and best-first-search algorithms. Mi et al. [23] employed the heuristics rules and distributed genetic algorithm to allocate the storage yard for outbound containers. He et al. [14] developed a dynamic programming model and hybrid genetic algorithm.

To obtain an exact solution of yard crane scheduling, Ng and Mak [26] formulated a branch-and-bound algorithm. Due to the computational intractability, Cao et al. [4] proposed the general and combinatorial Benders' cut-based methods to resolve an integrated problem of yard truck and yard crane scheduling. However, these approaches could only tackle some simple assumptions for yard crane scheduling, that is, the effective approaches were still lacking to resolve the NP-complete problem regarding the yard crane scheduling [29]. Based on this notion, the knowledge-based system became an efficient approach for yard crane deployment. Accordingly, previous researches were frequently applied in science and engineering disciplines [10,12,15,19,21,22,28,31,32]. In addition, some initial work was attempted, e.g., the rule-based and knowledge-based berth allocation and quay crane assignment strategy [8,9]. Hence, a more generic modeling was not well addressed, and a more systematic method was demanding.

To resolve these problems, a knowledge-based yard crane scheduling was proposed for container terminals in this study. In details, the knowledge acquisition was initially conducted. Subsequently, a knowledge sorting process, including the taxonomic tree generation and organization of acquired knowledge, was completed. Afterwards, the rules were extracted for the purpose of yard crane scheduling. Furthermore, a mechanism was deployed for knowledge reasoning. Consequently, a knowledge-based system was established with regard to yard crane scheduling. Eventually, a case study was used to illustrate the proposed knowledge-based system.

3. Problem description

The yard crane scheduling delivers a great significance on the operational efficiency of yard cranes, typically shortening the moving distance of yard cranes, reducing the times that yard cranes move from one to another block, and eliminating the delayed workloads of yard cranes. Further elaborated, the yard crane scheduling can promote operational efficiency and reduce the energy consumption of the entire terminal. Due that the rubber tired gantry crane (RTGC) are normally employed in the container terminals, they are logically taken into account in this study. In this manner, the RTGCs move on rubber tired wheels spanning over a block space. Although the RTGCs possess lower storage capacity, they can be transferred among blocks with higher handling flexibility. Because of their high mobility and handling flexibility, the RTGCs become the preferred selection for container storage yard operation.

In general, the container yard is divided into a number of blocks, where the container storing and retrieving in each block are operated by yard cranes. To fully utilize the yard cranes and overcome the workload imbalance among blocks, a yard crane needs to move from one to another block, viz., follows a specific route. As shown in Fig. 2, if two adjacent blocks are longitudinal aligned, e.g., for Blocks 1 and 2, the yard crane will move straightly without any turning; otherwise, a yard crane has to finish twice 90-dgree-turn before arriving at the target block, e.g., for Blocks 2 and 3. As the large-size yard cranes are slowly moved, they occupy quite big space yet long operation time in the process of moving from one to other block. This may cause traffic jam, operation delay and reduction of operational efficiency. In the actual container stacking and shuffling process, two yard cranes are often collided. For instance, the yard crane at Block 1 moves to Block 4 while the yard crane at Block 3 moves to Block 2, a collision occurs during crossover. In this respect, the optimal scheduling of yard cranes secures critical position in container yard operation.

Usually, the yard crane includes four states as follows: viz., (1) storing import containers at storage locations, denoted as SI; (2) storing export containers at storage locations, denoted as SE; (3) retrieving import containers from yard, denoted as RI; and (4) retrieving export containers from yard, denoted as RE. Generally, the yard crane scheduling is executed once every 6 h, i.e., one period, together with the following two decisions: (1) the block that each yard crane should be deployed to in a period; and (2) in case of emergency, the yard crane that should be deployed to some blocks when additional yard cranes are needed at once. Specifically, the former decision is related to an off-line planning, the later decision is associated with a real-time scheduling. In this study, a knowledge-based system was developed for yard crane scheduling based on the experience and knowledge of domain experts.

4. Knowledge-based system establishment for yard crane scheduling

A knowledge-based system for yard crane scheduling was established including four phases, i.e., the knowledge acquisition,