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Genetic mechanism-based coupling algorithm for solving coordinated scheduling problems of yard systems in container terminals

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ABSTRACT

This study develops models and methods utilized for solving the coordination scheduling problem in the yard of a container terminal. Based on the information shared by the yard storage subsystem and the YC scheduling subsystem, and the interaction between these subsystems, a coordination scheduling model, which is composed of a storage subsystem model, a YC scheduling subsystem and a coordinate controller model, is developed. A coupling algorithm, which is based on a genetic mechanism, is developed to solve the coordination scheduling problem. The algorithm adopts the genetic selection, crossover and mutation operations to adjust the yard storage plan and the YC scheduling plan. The performance of the coordination scheduling model and that of the proposed coupling algorithm are confirmed with reference to a numerical example.

1. Introduction

With the rapid increase in economic globalization and import–export trading, China has become the most important supplier of containers worldwide. To meet the increasing demand for containers, while enabling shipping companies to continue to provide the required high levels of service, a highly efficient container transportation system must be established and the efficiency of internal logistical operations at container terminals improved. The transportation bottleneck at a container terminal used to be sea side transfer. However, increases in efficiency due to quay crane (QC) innovation and the realization of simultaneous loading-and-unloading of yard trucks (YT) have eliminated this bottleneck. More recently, QCs have commonly waited for YTs, shifting the bottleneck to yard storage and yard crane (YC) operations. This study concerns the yard storage problem, the YC scheduling problem and the problem of the coordination for the two, which are all critical problems in a container yard that have been studied by several experts.

Many approaches to planning yard storage have been proposed. Zhang, Wan, Liu, and Linn (2003) were the first to formulate the storage space allocation problem (SSAP). Mohammad, Nima, and Nikbakhsh (2009) extended the SSAP such that the types of container affect decisions concerning the allocation of containers to blocks. Kim and Park (2003) formulated a mixed-integer linear programming model to allocate storage space for out-bound containers.

Numerous research papers have addressed the modeling of yard crane scheduling (YCS). Zhang, Wan, Liu, and Linn (2002) addressed the crane deployment problem, whose objective is to find the times and routes of crane movements among blocks that minimize the total delayed workload. Bish (2003) developed a heuristic algorithm that was based on formulating the yard scheduling problem as a transshipment problem. Huang, Liang, and Yang (2009) developed an optimum route method that is based on a genetic algorithm and satisfies such criteria as length, smoothness and clearance between YCs. Li and Han (2005) constructed a non-linear multi-objective programming model to solve the problem of dynamic crane deployment using a function that minimized the time of uncompleted workloads and the time wasted in operation.

Many efforts have been made to solving the SSAP and YCS independently of each other. However, an integrated approach to modeling these two systems is appropriate, given the relationship that exists between them. Kim and Kim (2002) developed a cost model that comprised of the space cost, the investment cost of transfer cranes, and the operating cost of transfer cranes and trucks. Lin, Gen, and Wang (2009) formulated an integrated

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multi-stage logistics network model that took into account the logistics of direct shipment and direct delivery and the associated inventory; they also presented an effective hybrid evolutionary algorithm (hEA) to solve this problem.

This paper studies the coordination scheduling problem for yard subsystems at a container terminal and develops a coordination scheduling model that is based on the interaction and sharing of information between the subsystems. The model is composed of a storage subsystem model, a YC scheduling subsystem model and a coordinated controller model. To apply the model, a coupling algorithm with global searching and probability searching is used. In the proposed coupling algorithm, a chromosome represents a quantity and initial positions of YCs, and after a series crossing operations and mutation operations, an optimal or best solution is obtained. Finally, computational experiments are performed to demonstrate the effectiveness of the proposed coupling algorithm.

2. Description of problem

2.1. Storage space allocation problem

In this paper, a vessel that is served by a quay crane is said to have a working line; a vessel that is served by two quay cranes is said to have two working lines, and so on. To minimize the cost and maximize the effectiveness of container operations, the number of working lines should be optimized. This optimization leads to the working line assignment problem and scheduling problem. In the daily operations of a container terminal, the number of working lines depend on the allocation of berths and the number of loaded/unloaded containers. Working line scheduling is the allocation of loading/unloading jobs to quay cranes to minimize time and cost. Working line scheduling systems are playing an increasingly important role at container terminals. The input of such a system is the number of loading/unloading containers and the availability of quay cranes, and its output is a scheduling schema that contains a series of job sets for each quay crane. The complex relationships between the working lines and the allocation of inbound/outbound yard space require a sophisticated dispatcher. With respect to the operating procedures at a container terminal, obeying a storage plan without considering the working line may lead to chaos when multi-working lines are used to perform loading/unloading containers simultaneously. First, outbound containers will been operated by a single working line may be dispersed to different blocks, making YC scheduling more difficult because of the reshuffle. Second, inbound containers from different working lines may be allocated in the same block, potentially leading to the blocking of YTs. As stated above, the relationship between the working lines and the allocation of container yard space resources in a container terminal is an important topic of research.

2.2. YC scheduling problem

In this study, a yard crane (YC) can move from one yard zone to another, supporting the handling efficiency in yard. Since YCs are bulky and slow, effective scheduling is essential to reducing the waiting time of trucks in the yard, by coordinating the yard cranes with the working lines. To fully utilize the YCs and to overcome the workload imbalance among blocks, a YC may have to move from one block to another or from one yard zone to another. The allocation and the movement of YCs among blocks or yard zones is called YC scheduling herein. Since moving a YC from one yard zone to another takes a long time, the need for such movement should be eliminated. Since one YC cannot move through another, the possibility of YC–YC collisions must be taken into consideration.

2.3. Coordinated relationship between storage subsystem and YC scheduling subsystem

The storage subsystem and the YC scheduling subsystem perform important functions at a container terminal. A poor storage plan may result in the wastage of loading/unloading resources, and unreasonable allocation of loading/unloading resources may also cause a delay of vessels. Under such circumstances, every independent subsystem has difficultly in following the coordination plan. Accordingly, coordinating the two subsystems and sharing information between them is very important. Based on the above analysis, an optimization model of a yard system at a container terminal is developed based on the multidisciplinary variable coupling design optimization method. In this method, two mathematic model are established to represent storage subsystem and YC scheduling subsystem respectively and a coordinating controller is responsible for optimizing the whole yard system by the sharing of information between the storage subsystem and the YC scheduling subsystem.

3. Coordinated model of yard system

In solving the coordinated planning problem of a container yard, the effective use of yard resources and integrating the storage plan with the YC scheduling plan can globally optimize the yard system through the sharing of information. The sharing of information causes each subsystem to understand the goals of all subsystems, and enables each subsystem to be optimized in a manner that does not detrimentally affect another subsystem. The sharing of information among subsystems is dynamic, and so may cause non-linearities, time-variability and imbalance in multi-system coordination.

Owing to the complexity of the coordinated planning problem of a container yard, finding the global optimum using a traditional optimization method is difficult. This work develops a coordination planning method that is based on a genetic algorithm, employing the number of YCs and the initial position of each to code the genes. Although genetic algorithms have been used to solve particular systems used in container terminals in some studies, these studies have focused on the separate subsystems but not the overall system. In the problem of coordinated planning, the optimal solution for any subsystem is not the global optimum of the whole system. However, the coordinated model that is proposed in this paper can solve the global problem effectively.

3.1. Assumptions and framework of coordinated model of yard system

Assumptions of the model are presented as follows:

(1) The unloading and loading jobs of each working line of each vessel are known.
(2) The number of YCs and their initial positions are decision variables.
(3) The objective of the storage subsystem is to minimize the sum of distance moved by the YTs, and that of the YC scheduling subsystem is to minimize the maximum operating time.
(4) Different types of containers can be stored in a single block.
(5) To reduce the complexity of the problem, re-handling is neglected.

The framework of coordinated model of yard system are presented as follows:

The framework of the coordinated model of a container yard, presented in Fig. 1, is composed a storage subsystem and a YC