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Co-scheduling of lock and water–land transshipment for ships passing the dam

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ABSTRACT

In this paper, we take the water–land transshipment as new efficient way to share the pressure of the lock for ships passing a dam. A co-scheduling model of a single lock and different kinds of water–land transshipment docks mixed transportation system for ships passing a dam is established. The model is divided into two layers, in which the outer layer refers to the decision of the ships between the lock mode and the water–land transshipment mode. The inner layer concerns the lock scheduling for ships which choose to pass the dam through lock and the berth scheduling for the others that select the water–land transshipment mode. A genetic operators based artificial bee colony (GB-ABC) algorithm is utilized to optimize the combinatorial problem in the outer layer. The berth scheduling sub-problem in the inner layer is identified as the identical parallel machine scheduling problem which is solved by first-come-first-served (FCFS) strategy. The lock scheduling sub-problem is solved by a method which takes into account both fairness of the ships and efficiency of the lock. The experiments show that an appropriate coordination between the lock and the water–land transshipment docks can help to decrease the waiting time of the ships and relief the congestion of the water traffic around the dam especially when the throughput capacity of the lock is insufficient.

1. Introduction

Water transport as one of the most important means of transportation is famous for its advantages in big capacity and low cost. And reasonable navigation management is the indispensable condition for keeping the water transportation safe and smooth. As we known, dams are always built for flood control, irrigation and improving the navigation condition of the inland waterway. However, the water level difference resulted from the building of dams also becomes an obstruction for ship navigation. As a consequence, how to manage the ships for passing dams efficiently turns into an important problem for navigation management [1].

The already exist researches related to management for ships passing the dams almost focus on the lock scheduling. The lock as a facility of the dam use the lock chamber to keep the water at a navigable level so that to transfer a ship from one side of a dam to another side. How to transfer the ships in a rapid and effective way is one of the most important issues of lock scheduling. Lock scheduling problem with multiple parallel chambers was introduced by Verstichel et al. [1–5]. The authors divided the lock scheduling problem into three interrelated sub-problems: ship placement, chamber assignment and lockage operation scheduling. And different approaches were proposed to solve the lock scheduling problem, which were also tested by the system with real lock and ship data in Albertkanaal. In Refs. [1,2], authors considered the problem as the identical parallel machine scheduling problem with sequence dependent setup times and release dates and presented a corresponding mathematical model. Different stochastic meta heuristic algorithms were presented to optimize the minimum objective which was weighted by the total waiting time of the ships and the maximum waiting time of the ships. By combining the chamber assignment and lockage operation scheduling into a master problem and using the ship placement as a sub problem, the exact Combinatorial Benders' approach was used to solve the lock scheduling problem [3]. Instead of considering the three sub-problems as separately and using interaction between them to achieve solutions in Refs. [1–3], Verstichel et al. [4] took the sub-problems as an integral and established a mixed integer linear programming (MILP) model for the lock scheduling problem. The branch and bound algorithm was utilized to solve the integrated MILP model and exact solutions were obtained. Compared to the stochastic solutions in each calculation obtained in Refs.

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[1,2] by the meta heuristic algorithms, the results achieved by the exact approaches in Refs. [3,4] were certain. However, the calculation time of the exact approaches increased exponentially as the dimension of the problem raised. Verstichel et al. [5] took the ship placement as an independent problem and tested the merits of exact and heuristic methods for placing ships in a single type of chamber. 29 series connected locks which extend 600 miles in the Upper Mississippi River (UMR) were studied in Refs. [6–11]. On that river, barges were joined together into tows for transport, which needed to be transferred by single chamber locks that were often smaller than the tow itself. The tow was split into different groups of barges and these groups were transferred one at a time, and were then rejoined for the next phase of their travel. Refs. [6–10] proposed different congestion solving strategies for increasing the throughput of the locks and a simulation tool was built for validating the strategies [6–10]. In addition, optimal sequencing of the tows after a disruption at a lock on the UMR was presented in Ref. [11]. Other cases such as the locks in Three Gorges dam and Gezhouba dam had also been researched aiming at relieving the pressure of navigation resulted from insufficient throughput of the locks [12–15]. The lock at Three Gorges dam consists of two identical five-step chambers and each for single direction, while the Gezhouba lock was composed of three independently operated parallel chambers. Zhang et al. [12] established a mixed-integer nonlinear programming model of static co-scheduling of the locks in both of the dams, where the lock scheduling problem was separated into two layers: the optimization of lockage number and direction of the lockages in the outer layer and the start time of the lockages in the inner layer. Then a modified simulated annealing algorithm was combined with heuristic adjustment strategies for solving the lock scheduling problem. But the merit of the solution was too depends on the outer layer optimization, which could not be guaranteed by the heuristic adjustment strategies. Other methods for static co-scheduling of Three Gorges and Gezhouba dam such as series queuing network [13] and co-evolutionary strategy [14] had also been proved feasible. Considering the dynamic factors such as the arriving time of the ships might be changed during a long scheduling period, a model of dynamic rolling horizon procedure was proposed [15]. During the scheduling procedure, an original long period static scheduling problem was separated into several short-term scheduling problems and rescheduling strategy was utilized to response to the dynamic variation. Thus, the dimension of the short-term scheduling was small and exact methods such as branch and bound algorithm could be used to solve the problem.

As a whole, the researches related to the lock scheduling almost concern the problem that how to arrange the locks to transfer ships safely and effectively. However, the throughput capacity of some locks becomes insufficient as the rapid development of waterway transportation, which stands out during the transport peak season and when the weather condition is bad [8,16]. Therefore, it is necessary to explore new ideas for relieving the bottleneck restrictions of the navigation result from the lock. On that basis, this paper takes a new mode of transportation into consideration. That is water–land transshipment. The water–land transshipment mode means the goods or the passengers carried by ships are unloaded on the docks which are located in front of the lock, then the goods or passengers pass the dam by land transport. And the unloaded ships which supposed to pass the dam can leave in other directions so that these ships can avoid passing the lock. By this way, the goods and passengers on the ships are shunted into two ways. A part of the goods and passengers pass the dam through the lock and the other part of the goods and passengers are unloaded from the ships and pass the dam by land transport. Therefore, the throughput pressure of the lock can be greatly alleviated and the congestion situation around the dam can be relieved. This is a lock and water–land transshipment mixed co-scheduling problem and choose an appropriate mode for each ship is the main problem. Previous relevant researches have mainly focused on lock scheduling problem, while the already published academic papers about the lock and water–land transshipment mixed co-scheduling problem are very little. Thus, we attempted to establish a co-scheduling model of a mixed transportation system for ships passing a dam, which is composed of a single lock chamber and several water–land transshipment docks, and present appropriate approaches for dealing with the model. The co-scheduling of the mixed transportation problem can be divided into two layers in which the outer layer decides the mode for ships. That is to pass the dam through the lock or unload the goods by water–land transshipment. The inner layer concerns the lock scheduling and berth scheduling on basis of the decision result obtained at the outer layer.

Taking the whole ships applied for passing the dam as the research objects, the mode decision of the outer layer is a combinational optimization problem. However, there are still no exact approaches can achieve the optimal solution in polynomial time for high dimension combinational optimization problem [17]. In order to find appropriate method for this problem, many researches have been done and the satisfactory results have been achieved. One of the most important achievements is the application of many heuristic algorithms in solving combinational optimization problems. For example, non-dominated sorting genetic algorithm II, discrete particle swarm optimization and gravitation search algorithm have been successfully applied for solving many optimization problems in engineering field, such as PID controller design [18], feature selection [19], short-term hydrothermal scheduling [20], unit commitment [21,22], and so on.

In recent years, a new optimization method known as artificial bee colony (ABC) algorithm proposed by Karaboga [23] has become a candidate for optimization application due to its flexibility and efficiency, which is inspired by the foraging behavior of colony. ABC algorithm has been verified with high performance in solving different optimization problems, such as power flow optimization [24] and load economic dispatch [25] in power system, and so on. However, application of ABC algorithm in combinatorial optimization problem is still limited. The major obstacle of successfully applying ABC algorithm to combinatorial problem is due to its continuous nature. To remedy this drawback, different binary artificial bee colony algorithms have been proposed by Kashan et al. [26] and Ozturk et al. [27] etc. And the performance of the algorithms has been proved good in terms of solving classical testing problems such as travelling salesman problem.

Motivated by these studies, this paper has made an attempt to utilize the recently proposed genetic operation based artificial bee colony (GB-ABC) algorithm to optimize the mode decision in the outer layer of the mixed transport co-scheduling problem. From a scheduling point of view, a chamber can be seen as a machine and a lockage can be considered as a job, where each job can be processed on the machine. Therefore, the lock scheduling problem in the inner layer can be identified as the single machine scheduling problem with unit processing times and release dates. In order to schedule the lockage, ships must be assigned to them first. And that can be simplified as a two-dimensional bin-packing problem. In this paper, we use the width sorting based fast dispatch algorithm to deal with the bin-packing problem and the first-come-first-served (FCFS) strategy for the lockage scheduling. As for the berth scheduling of a certain kind of berth in the inner layer, it can be identified as the parallel machine scheduling problem, where a ship can be regarded as a job and a berth can be considered as a machine. Here, the FCFS strategy is used to handle the berth scheduling problem. Finally, the problem is tested based on the lock and ship data from the waterway traffic on the Three Gorges Project in China.

A co-scheduling model of the lock and water–land transshipment mixed transport system is presented in Section 2. Section