Expert Systems with Applications 41 (2014) 2851–2858

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

Block transportation scheduling under delivery restriction in shipyard using meta-heuristic algorithms

Cheol Min Joo [a], Byung Soo Kim [b,*]

[a] Department of Industrial and Management Engineering, Dongseo University, Busan 617-716, Republic of Korea
[b] Department of Industrial and Management Engineering, Incheon National University, 12-1 Songdo-dong, Yeonsu-gu, Incheon 406-772, Republic of Korea

ARTICLE INFO

Keywords:
Transporter scheduling
Shipyard
Meta-heuristics

ABSTRACT

Special vehicles called transporters are used to deliver heavy blocks from one plant to another in shipyards. Because of the limitation on the number of transporters, the scheduling of transporters is important for maintaining the overall production schedule of the blocks. This paper considers a scheduling problem of block transportation under a delivery restriction to determine when and by which transporter each block is delivered from its source plant to its destination plant. The objective of the problem is to minimize the penalty times that can cause delays in the overall block production schedule. A mathematical model for the optimal solution is derived, and two meta-heuristic algorithms based on a genetic algorithm (GA) and a self-evolution algorithm (SEA) are proposed. The performance of the algorithms is evaluated with several randomly generated experimental examples.

1. Introduction

Shipbuilding characterizes typical heavy industries that normally operate under a build-to-order strategy to produce large structures characterized by complex configurations, long makespan, and advanced manufacturing technology. Because the body of a whole ship is massive, it is split into a large number of units called *blocks*, with various shapes and weights. The blocks undergo a series of operations, which include pre-outfitting, painting, assembly, fitting-out, and pre-erection, as work in process before the ship is erected in the dock. The processing of the blocks is performed at several plants scattered in a shipyard, and the special vehicles called *transporters* are used to deliver the heavy blocks from one plant to another. There are various types of transporters, and each block can only be delivered by some of the transporters, because the blocks differ in characteristics such as weight, shape, and volume, etc.

In order to construct a ship by the delivery date, all processing of blocks should be accurately performed according to the schedule. To maintain the overall production schedule of the blocks, the transporters should be able to deliver blocks to processing plants at the scheduled times. Thus, the scheduling of transporters is important, because delays in moving blocks among processing plants can in turn cause delays in the overall production schedule. The source plant, ready time for pick-up, destination plant, due time for delivery, and available set of transporters are determined for each block according to the schedule for the processing of the blocks. Furthermore, the loading time, unloading time, and moving time of each block are determined according to the characteristics of the block and the available transporters. Each transporter delivers one block at a time. The blocks are available to be picked up after specific ready times and expected to be delivered before specific due times. There are two penalty times that can cause delays in moving blocks and should be reduced; namely *delay time* and *tardy time*. Delay time is incurred when a block is picked up after its ready time, and this can cause a delay in the production schedule because of the space occupied in the source plant. Tardy time is incurred when a block is delivered after its due time, and this directly delays the production schedule of the destination plant. Thus, the objective in the transporter scheduling problem is to determine when and by which transporter each block should be delivered from its source plant to its destination plant in order to minimize the delay times and tardy times.

The transporter scheduling problem is similar to a multiple traveling salesman problem with time windows (m-TSPTW) that consists of finding routes for all m salesmen, who all start and finish at the depot, such that each intermediate node is visited exactly once within a specified time window and the total cost of visiting all the nodes is minimized. Laporte and Osman (1995), Crainic and Laporte (1998), and Chao (2002) surveyed well-known TSPs, m-TSPs, and general vehicle routing problems. Calvo (2000) presented a heuristic algorithm based on a greedy insertion method for TSPTWs. Wang and Regan (2002) described an iterative solution technique in which explicit time constraints are replaced by binary flow variables for an m-TSPTW. Jula, Dessouky, Ioannou, and Chas-

* Corresponding author. Tel.: +82 32 835 8482; fax: +82 32 835 0777.
E-mail address: bskim@incheon.ac.kr (B.S. Kim).

0957-4174/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.eswa.2013.10.020

siakos (2005) proposed an asymmetric m-TSPTW with special constraints to model the container movements by trucks in the hinterlands of seaports. To solve the problem, they implemented an exact two-phase algorithm based on dynamic programming as well as a modified genetic algorithm. Zhang, Yun, and Moon (2009) proposed an m-TSPTW to model a container truck transportation problem with multiple depots, two types of customers and one terminal. A cluster method and a reactive tabu-search (RTS) algorithm were developed to solve the problem. Zhang, Yun, and Kopfer (2010) extended the setting of Zhang et al. (2009) by considering more than one terminal. A window-partition-based (WPB) method inspired by Wang and Regan (2002) was used as the solution approach. Sterzik and Kopfer (2013) proposed a tabu-search algorithm for the inland container transportation problem to control the movement of full and empty containers among a number of terminals, depots, and customers in a hinterland.

The transporter scheduling problem for delivering blocks in shipyards considered in this paper has characteristics distinct from that of the m-TSPTW because of the production processes and the delivery restriction of the blocks. Fig. 1 depicts an example of routes for two transporters *T1* and *T2*. Transporter *T1* sequentially visits plants 3, 4, 1, 4, and 2 to deliver blocks *B1*, *B6*, and *B3*. This transporter can start delivering block *B1* from its source (Plant 4) to its destination (Plant 1) after its ready time. It travels empty from Plant 4 to Plant 1, because the destination plant of block *B1* and the source plant of block *B6* are different. Similarly, transporter *T2* sequentially visits plants 5, 7, 4, 3, 6, and 7 to deliver blocks *B2*, *B5*, and *B4*.

Only a few studies have been reported on research related to transporter scheduling for shipyards, even though it is possible to increase the productivity of a shipyard and decrease the building cost of a ship through efficient transporter operation (Roh & Cha, 2011). Joo, Lee, Koo, and Lee (2006) first studied the scheduling of single-type transporters for block transportation in shipyards. They proposed a heuristic algorithm to minimize the total weighted logistic times of blocks delivered by transporters. Park and Seo (2013) also studied the scheduling of single-type transporters for block transportation in shipyards. They proposed a greedy randomized adaptive search procedure (GRASP) algorithm to maximize the workload balance among transporters under the time constraint that all assembly blocks should be transported within a predetermined time. Roh and Cha (2011) expanded the block transportation scheduling problem of Joo et al. (2006) to include multi-type transporters having different deadweight. Their objective was to minimize the travel distance without loading of and interference between the transporters while satisfying the constraints on the allowable transportation weights of the transporters. Kim and Joo (2012) considered a similar block transportation scheduling problem to minimize the total weighted logistics time, including delay times, and tardy times, and empty transporter travel times, for heterogeneous transporters having different deadweight.

In this paper, we expand the block transportation scheduling problem of Roh and Cha (2011) and Kim and Joo (2012) by generalizing the block delivery restriction on the multi-type transporter. Each block can or cannot be delivered by a transporter according to the various characteristics of the block. The available set of transporters for each block is assumed to be predetermined. We derive a mixed integer programming (MIP) model and propose effective meta-heuristic approaches for the block transportation scheduling problem. The chief objective of meta-heuristic approaches for the block transportation scheduling problem with a block delivery restriction is to avoid the occurrence of infeasible solutions during operations. Roh and Cha (2011) and Kim and Joo (2012) used an ant colony optimization algorithm (ACO) to avoid infeasible solutions. Roh and Cha (2011) proposed a two-steps hybrid meta-heuristic algorithm. In their algorithm, the blocks to be moved by each transporter are determined by the ACO in the first step and the sequence of blocks for each transporter is determined by the genetic algorithm (GA) in the second step. However, their two-steps hybrid meta-heuristic algorithm has a disadvantage in finding good solutions, because it preemptively determines the allocation and sequence. Kim and Joo (2012) proposed an ACO with random selection (ACO_RS) to determine the blocks assigned to each transporter and the sequence of blocks for each transporter simultaneously. Their ACO_RS is a good alternative for obtaining good solutions, but the computation time increase significantly as the number of blocks and transporters increases. To improve the effectiveness and efficiency of the solution process, we propose two meta-heuristic algorithms based on the GA and the self-evolution algorithm (SEA) for simultaneously assigning blocks to available transporters and sequencing blocks for each transporter. The SEA, which is a technique similar to the GA, was first introduced by Joo and Kim (2012) who also demonstrated its performance. Both algorithms are designed with a dispatching rule to avoid the occurrence of infeasible solutions caused by the block delivery restriction.

The remainder of this paper is organized as follows. Section 2 derives a mathematical model for finding the optimal solution. Section 3 proposes two meta-heuristic algorithms based on the GA and the SEA, respectively. Section 4 evaluates the performance of the meta-heuristic algorithms through computational experiments. Finally, a summary and remarks on further research are provided in Section 5.

2. Mathematical model

In this section, we derive a mathematical model that minimizes the total weighted sum of delay times and tardy times under the

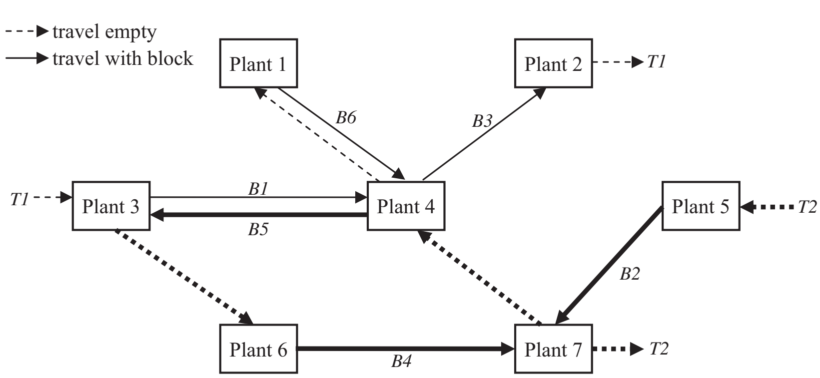

Fig. 1. Example of transporters routing.