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Scheduling of loading and unloading operations in a multi stations transshipment terminal with release date and inventory constraints

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ABSTRACT

In this paper, we study a transshipment scheduling problem with multiple identical loading/unloading stations and release date and inventory constraints. This problem is similar to the parallel machine scheduling problem where the makespan is to be minimized, which is an NP-hard problem in the scheduling theory. We formulate the problem as an integer linear programming model, which is solvable only for small-size instances by CPLEX solver in reasonable times. Also, we develop two constructive heuristic solution approaches, namely parallel and serial schedule generation schemes. We also develop three metaheuristic methods based on genetic algorithm, particle swarm optimization and cuckoo optimization algorithm. The developed solution methods have been compared using computational studies based upon 870 randomly generated test instances. The experimental results show that the parallel schedule generation scheme outperforms the serial one and the cuckoo optimization algorithm shows the best performance among the developed metaheuristic methods.

1. Introduction

In this article, we consider a cross docking system containing multiple dock doors, which can process one inbound or outbound truck at a time, which is an extension of Briskorn, Choi, Lee, Leung, and Pinedo (2010). It is assumed that the given set of dock doors are equipped similarly and have identical factors for loading and unloading activities, such as capacity and processing speed. Moreover, only one type of product is considered and the loading and unloading operations are distinguished by the inventory modification they made. In this regard, we separate the operations into two classes, positive and negative, so that positive operations represent unloading activities which increase the inventory level, and the negative ones account for loading activities that lead to a decrease in the inventory level. Each loading/unloading operation is executed by a specific vehicle, which has arrived at the terminal at a certain point in the time, named release date, and requires a predetermined processing time. Also, preemption of operations is not allowed, i.e. once docked, a truck must be fully loaded or unloaded before its departure. Furthermore, a limited storage space is also supposed to exist inside the transshipment terminal where an initial inventory is held. Additionally, we assume that the inventory level is immediately decreased by the time a loading operation starts, whereas the modification made by an unloading operation is applied by the time it is completed.

Regarding the aforementioned parameters to be integers, this problem can be viewed as a parallel machine scheduling problem with inventory constraints. In other words, dock doors are supposed to act as production machines and loading/unloading operations are considered as the jobs to be processed. Since the objective is to minimize the makespan, according to the three field notation introduced by Graham, Lawler, Lenstra, and Kan (1979) this problem can be represented as $Pm|r_j, inv|C_{max}$.

Due to the increasing amount of attention paid to cross docking scheduling in recent years, there is an extensive literature dealing with this research area. Boysen and Fliedner (2010) and Van Belle, Valckenaers, and Cattrysse (2012) present an extensive overview in this direction and provide recent surveys of the scheduling systems in cross docking platforms. Briskorn et al. (2010) focus on single machine scheduling subject to inventory constraints, where all jobs are available at the beginning of the time horizon and they either increase or decrease the inventory level according to their type, so that it remains nonnegative at each time. The authors relax the capacity restrictions and determine the computational complexity of the problem for several cases with different objectives

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such as minimization of total weighted completion time and the number of tardy jobs, and prove the strongly NP-hardness of the general versions. The problem of scheduling the trucks in a cross dock with a single dock door is also considered in Vahdani and Zandieh (2010). The authors apply five metaheuristic algorithms for such a problem to minimize the total operation times in the facility. In Briskorn, Jaehn, and Pesch (2013), the authors develop exact methods for tackling the single machine problem subject to inventory constraints, where the objective is to minimize the total weighted completion time. They also assume that all jobs are available at the beginning and the inventory's capacity is unlimited. Briskorn and Leung (2013) consider the similar problem to find a schedule such that the maximum lateness among all jobs is minimized, and present four branch and bound algorithms.

Introducing a basic model for scheduling trucks at cross docking terminals with multiple dock doors, Boysen, Fliedner, and Scholl (2010) assume that the terminal has two gates and model it as a two machine scheduling problem. They also show that minimizing the makespan is strongly NP-hard even if all processing times are equal. Madani-Isfahani, Tavakkoli-Moghaddam, and Naderi (2014) discusses about a truck scheduling problem in a multiple cross docks, where two types of delay times are considered and the objective is to minimize the total operation time or maximize the throughput of the cross docking system. In the problem proposed by Alpan, Bauchau, Larbi, and Penz (2008), cross docking with multiple doors and temporary storage is considered. To determine the optimal truck sequence such that the total cost is minimized, the authors develop a bounded dynamic programming. Alpan, Ladier, Larbi, and Penz (2011a) and Alpan, Larbi, and Penz (2011b) also study a cross dock scheduling problem for serving outbound trucks at multiple stack doors. They assume that the arrival sequence of inbound trailers is fixed and consider a First-Come-First-Served (FCFS) policy to assign the order of incoming trucks.

The contributions of this article are threefold: (1) we introduce $Pm|r_j, inv|C_{max}$ and formulate it as a linear integer programming model; (2) we develop two schedule generation schemes named as parallel and serial to create feasible solutions for the problem; and (3) we develop three metaheuristic algorithms to improve the created solutions by the parallel and serial schedule generation schemes.

The remainder of this paper is organized as follows. Section 2 deals with modeling the problem as a linear integer programming and solution methods are sketched in Section 3. Section 4 is devoted to the computational study and evaluation of the developed algorithms. Finally, conclusions and future research directions are presented in Section 5.

2. Problem statement and modeling

We assume that the transshipment terminal has a set M of $|M|$ identical docks, considered as identical parallel production machines. It is also assumed that one product type is handled. Set of loading and unloading operations is denoted by J, considered as the set of jobs in the corresponding parallel machine scheduling problem. This set is separated into two subsets, J^+ and J^-, so that J^+ consists of unloading operations (positive jobs) and J^- accounts for loading ones (negative jobs). Each job $j = 1, \ldots, |J|$ has a processing time p_j and is processed with a single truck that arrives at a specific release date shown by r_j. Considering a storage space with a given capacity IC, it is assumed that its initial inventory level is I^{ini}, and δ_j defines the inventory modification made when job $j = 1, \ldots, |J|$ is processed. This parameter takes a positive value for unloading operations and a negative amount for the loading ones. It should be mentioned that any reduction in inventory level is applied immediately by starting a loading operation and the increase made by an unloading operation is done when it is completely processed. Clearly, inbound and outbound shipments quantity must be taken into account so that the inventory level remains nonnegative and does not exceed its capacity at each point of time.

Table 1 summarizes the parameters and decision variables required to formulate the problem as a mathematical model.

Regarding the above notations, the formulation of this problem reads as follows.

$$Min\ C_{max} \tag{1}$$

subject to

$$C_{max} \geqslant \sum_{t=1}^{|T|}\sum_{i=1}^{|M|} tX_{jit}; \quad \forall j \in J \tag{2}$$

$$\sum_{t=1}^{|T|}\sum_{i=1}^{|M|} X_{jit} = 1; \quad \forall j \in J \tag{3}$$

$$\sum_{\tau=t-p_j+1}^{t}\sum_{\forall j' \in J\setminus\{j\}} X_{j'i\tau} \leqslant B(1 - X_{jit}); \quad \forall i \in M; \quad \forall j \in J; \quad \forall t \in T \tag{4}$$

$$\sum_{j=1}^{|J|}\sum_{\tau=max(t+1,r_j+p_j)}^{min\{|T|,t+p_j\}}\sum_{i=1}^{|M|} X_{ji\tau} \leqslant |M|; \quad \forall t \in T \tag{5}$$

$$\sum_{t=1}^{|T|}\sum_{i=1}^{|M|} tX_{jit} - p_j \geqslant r_j; \quad \forall j \in J \tag{6}$$

$$I_t = I_{t-1} + \sum_{j\in J^+}\sum_{i=1}^{|M|}\delta_j X_{jit} + \sum_{j\in J^-}\sum_{i=1}^{|M|}\delta_j X_{j,i,t+p_j}; \quad \forall t \in \{1, \ldots, |T|\} \tag{7}$$

$$I_0 = I^{ini} + \sum_{j\in J^-}\sum_{i=1}^{|M|}\delta_j X_{ji,p_j}; \tag{8}$$

$$I_t \leqslant IC; \quad \forall t \in T \tag{9}$$

$$X_{jit} \in \{0, 1\}; \quad \forall j \in J; \quad \forall t \in T \tag{10}$$

$$I_t \in \mathbb{Z}^+; \quad \forall t \in T \tag{11}$$

The objective function (1) minimizes the makespan, which is set greater than or equal to the completion time of the last job in

Table 1
Description of parameters and variables.

Parameters	Definitions
$M : \{1, 2, \ldots, \|M\|\}$	Set of machines with index i
$\|M\|$	Total number of machines
$J : \{1, 2, \ldots, \|J\|\}$	Set of jobs with index j
$\|J\|$	Total number of jobs
$T : \{0, \ldots, \|T\|\}$	Set of times with index t
$\|T\|$	An upper bound for the completion time of all jobs
IC	Capacity of storage space
I^{ini}	Initial inventory level
p_j	Processing time of job j
r_j	Release date of job j
Variables	Definitions
X_{jit}	Binary variable that takes the value of 1 if processing of job j is completed on machine i at time instant t and takes 0, otherwise
I_t	Inventory level of transshipment terminal at time instant t