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Toward an integrated modeling approach for production and delivery operations in flow shop system: Trade-off between direct and routing delivery methods

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ABSTRACT

In this paper, the joint scheduling of production and delivery operations as both pivotal and important operations in the manufacturing system are studied with an integrated vision. Two distinct problems which depend on the delivery method are considered. In first problem, the integrated M-flow shop production and delivery with direct method is introduced. In second problem, scheduling of M-flow shop and delivery with Routing Decision Method is investigated. The purpose is to minimize the total cost which includes sum of the production and delivery cost. The problems are formulated mathematically, and then an improved imperialist competitive algorithm (I-ICA) is proposed to solve the problems. In order to achieve robust results, parameters of the I-ICA are set by means of the Taguchi method. In the computational study, four appropriate test problem sets are generated randomly. At the end, capability of algorithm, effectiveness of the proposed integrated models and efficient delivery method are evaluated through a computational experiment.

1. Introduction

Due to the market globalization, implementation of the integration approaches among various operations in a supply chain has become one of the fundamental decisions for the manufacturers to gain more benefits and competitive advantages. Most of the production scheduling literature assume job sequencing without attention to the delivery concept or by assuming delivery after production hieratically and separately. There are only a few researchers who have considered the joint optimization of machine scheduling and job delivery in which the completion time is defined as the time when a job is delivered to the final customers. In the joint scheduling of production and delivery operations, after receiving orders from the customers, the production center processes these orders on the machines and then delivers the finished orders to the customers' locations by vehicles. In aforementioned integration approach, there is no storage for finished products. This means that the finished products are immediately delivered to the relevant customers.

The idea of integrated scheduling of production and delivery operations was first proposed by Potts [1]. He was studied a single machine scheduling problem with dissimilar delivery and release times. After that, Matsuo [2] and Hall and Shmoys [3] considered a similar problem. Herrmann and Lee [4], Yuan [5], Chen [6], Cheng et al. [7] have evaluated that products are delivered after being processed, by infinite delivery capacity via enough number of vehicles. Yang [8] proposed a model similar to the one studied by Cheng et al. [7], but with given delivery dates. Hall and Potts [9] suggested a variety of scheduling and delivery problems within a supply chain and minimized the total production and delivery cost. They firstly study the cost of system in their paper. Constraints against both transportation capacity and transportation time were studied by Lee and Chen [10]. After that, Hall and Potts [11] studied a variety of single machine scheduling problems with the objective of minimizing the overall production and delivery cost. Chang and Lee [12] further studied this problem, in which each job requires different physical space for delivery and minimize the total costs. This paper is one of the most important paper in this literature that is referred by many researchers. Li et al. [13] developed a single-machine scheduling model that incorporates routing decisions of a delivery vehicle which serves to customers at different locations. He et al. [14], Zhong et al. [15] and Su et al. [16] reviewed the problem of Chang and Lee [12] and made improved algorithms. Chang and Lee [17] considered a more general two stages scheduling problem where in the second stage of transportation, there are

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multiple transportation modes to select with multiple destinations. Liu and Lu [18] proposed the single machine scheduling problem with release times and job delivery to minimize the make-span. In most of the mentioned researches, delivery was conducted by the direct method in the integrated single machine production and delivery scheduling.

Woeginger [19] considered a scheduling problem on parallel machines without considering release dates and proposed a heuristic method with worst-case analysis. Wang and Cheng [20] studied a parallel machine scheduling to integrate scheduling with delivery. Chen and Vairaktarakis [21]extended the problem to more destinations and to an infinite number of vehicles with a threshold on loading capacity limited to a maximum number of jobs. Single machine as well as parallel machine scheduling problems are addressed in their research. According to Su et al. [16], jobs are processed by two parallel machines and delivered to a customer with the objective of minimizing the make-span. Lu et al. [22] further considered a similar problem like [18] research, on an unbounded parallel batch machine. Ullrich [23] integrated the production and outbound distribution scheduling in order to minimize total tardiness. Wan and Zhang [24] investigated a coordinated scheduling problem on the parallel identical machines with job delivery. Moreover, Lee [25] proposed the coordinated scheduling of production and delivery issues, where jobs are processed on a single machine without preemption and then delivered to a customer. It was assumed that the delivery cost depends on the time period for delivery, but does not depend on individual jobs. Integrated production and delivery scheduling on a serial batch machine to minimize the make-span is proposed by Lu et al. [26].

2-machine flow shop scheduling with transportation constraints was suggested by Yuan et al. [27] to minimize makes-pan. Pan et al. [28] focused on a class of 2-machine flow shop problem in which jobs should be delivered to the customers by vehicles after production stages.

As can be seen, all the reviewed papers have just studied the integration approach of production and delivery operations in single machine, parallel machine(s) and at the end, in two-flow shop environments. To the best of our knowledge, there is no study in the literature that introduced integration approach for production in M-flow shop system and delivery. While the M −machine flow shop scheduling problem (PFSSP) is a well-known class of scheduling problem with many applications in any manufacturing systems rather than single machine and parallel machine(s).

In this study, two new mathematical models are developed for the joint scheduling of production and delivery problems. In both proposed models, a PFSSP is assumed for production system, and two distinct delivery methods which called direct method and delivery with routing decisions, are assumed for the delivery system in two different models. Indeed, in proposed integration approach, not only production decision variables are determined for jobs on each machine, but also delivery decision variables of routes and vehicles are determined for achieving minimum total cost.

After developing the mathematical model, ICA algorithm is used for solving both proposed models as capable as met-heuristic algorithm. To enhance the performance of selected algorithm, some new policies are defined and added to explore and exploit the solution space in algorithms' different steps and for the final used algorithm which is called improved ICA (I-ICA) in this study. To examine the capability of I-ICA, four well-known benchmark sets with different problem size from flow shop scheduling problem literature are used. Then, to enhance the performance of the I-ICA, the algorithm parameter setting phase is implemented by means of Taguchi method. The results of I-ICA are firstly compared with some other algorithms in flow shop literature that show good performance of it.

Furthermore, in order to investigate the value of the proposed integration approach and comparing the delivery methods by developed models, random data sets are needed. For this purpose, four standard benchmarks are used as the data sets for production scheduling part of the integrated models (two sets from Taillards' data, Carliers' data and Reeves' data sets) and delivery data is generated randomly for each production benchmarks by exploring VRP benchmarks.

For evaluating the value of the proposed integration approach, total cost of system is used as a performance measure which is defined as sum of the production total cost and delivery total costs. In order to investigate the effectiveness of integration approach, the total cost of hierarchical and integrated approach is compared for direct delivery method and delivery with routing decision separately. Obtained results confirm the adequate performance of integrated models. Also, by comparing the integrated results for two different delivery methods, the statistical analysis results show acceptable performance of delivery with routing method.

The reminder of the paper is structured as follows. Section 2 introduces the problems, develops two mathematical models. Section 3 presents an improved solution algorithm based on ICA. The computational study and simulation results are provided in Section 4. Section 5 contains the conclusions and some directions for future research.

2. Mathematical modeling

2.1. General problems description

The M-flow shop scheduling problem (MFSSP) consists of scheduling n different jobs $\{J_1, J_2, \ldots, J_n\}$ with predefined processing times that must be processed on m different machines $\{M_1, M_2, \ldots, M_m\}$ in which the same order of jobs is performed on all m machines. Each of n jobs should be sequentially performed on m machines. In addition, a $n \times m$ matrix (P_{gh}) represents the processing times of h'$^{\text{th}}$ operation of g'$^{\text{th}}$ order. Each job should be processed on at most one machine and each machine would handle at most one job at any time. The objective of MPFSS is to find an optimal sequence for all jobs that is the same for each machine so that one or more predefined objective functions are optimized. We also consider such a problem in this paper for the production phase. In most industrial applications, final products should be immediately delivered to the final customer after the production process. Two proposed models in this section describe this situation.

In the first proposed model, it is assumed that the products after the production process have no need to wait and they are left to the customer's location by means of one vehicle. This delivery method is called direct delivery method. Integrated model of the MFSSP and direct delivery method for distribution phase is developed in first proposed model. In this model, not only starting and completion times of the orders in each production machines should be calculated, but also the time of each vehicle departs from center and time of the receiving orders to relevant customers for minimizing the total cost as an objective function. Thus, in first problem, the customers' orders initially should be processed on machines in the determined optimal production sequence and then, each order must be departed from shop center by one vehicle. Then, each order reaches to its customer by the relevant vehicle.

In second new model, the MFSSP part of the integrated model is the same as first proposed model described above. Integration model of the MFSSP and delivery with routing decision is developed in second model. In addition to the production decision variables, the time of each vehicle departs from center, the route of each vehicle and time of receiving orders to the relevant customers should be calculated for minimizing the total cost as the objective function