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A knowledge-based approach for multi-factory production systems

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A R T I C L E I N F O

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A B S T R A C T

This paper investigates scheduling of jobs with deadlines across a serial multi-factory supply chain which involves minimizing sum of total tardiness and total transportation costs. Jobs can be transported among factories and can be delivered to the customer in batches which have limited capacity. The aim of this optimization problem is threefold: (1) determining the number of batches, (2) assigning jobs to batches, and (3) scheduling the batches production and delivery in each factory. The proposed problem formulated as a mixed-integer linear program. Then the model's performance is analyzed and evaluated through two examples. Moreover, a knowledge-based imperialistic competitive algorithm (KBICA) is also presented to find an approximate optimum solution for the problem. Computational experiments of the proposed problem investigate the efficiency of the method through different sizes of the test problems.

1. Introduction

Nowadays quick changes and variations in production environments, invoke researchers and industrialists to consider multi-factory production systems. This system enables firms to increase their competitiveness and responsiveness in the global markets. These companies should work in a coordinated manner in order to vouch for a reliable flow of goods, services and information. So they are altering from single-factory production to multi-factory production environments. Thus, many of the production firms are converting to global chains which contains several factories or manufacturing sites such as supplier, production shops and also outsourcing units [1].

The significance of distributed scheduling problem in a multi-factory production network has been one of the hottest topics in recent years [2]. As there are number of factories along the supply chain, the scheduling activities are more complex than the traditional single-factory scheduling problems [3]. Many of the researchers and industrialists are interested in this issue in recent years. [4] stated that independent manufacturing firms are transforming to dependent manufacturing factories to become capable of competitive advantages in economic environment. In a multi-factory production system, factories may be structured in parallel, series or network. In the serial structure, the finished goods of a factory delivered to the downstream factory as a raw material and at last delivered to the customer as its order. If consecutive factories are located in different geographical places, transportation time and costs would be considered. Serial multi-factory supply chains involve high complexity due to collaborative interrelation among factories. Production of the downstream factories is affected by material shortage in the upstream factories and on the other hand production of upstream factories is affected by stopping the production in the downstream factories because of inventory accumulation. Thus, production and transportation between upstream and downstream factories should be synchronized in order to decrease inventory cost and also to avoid risk of stock out for a factory [5]. 6] applied the constraint satisfaction approach for the case study of integrated production and transportation scheduling in the serial multi-site manufacturing environment. [7] investigated a problem which considers sequencing, lot-sizing and scheduling of several products which are being manufactured through several firms in a serial-type supply chain. They implemented a time-varying lot-sizing policy for problem formulation and also solved it by a three-phase heuristic.

In the parallel structure, multiple factories which are able to produce various types of products are positioned in a parallel structure [8–18]. Network structure is a combination of serial and parallel structure. [19] studied the multi-factory scheduling problem. In this study factories are structured as network. They considered a capacity constraint, precedent relationship and production lines with parallel machines. They presented a modified genetic algorithm to minimize the completion time. As mentioned above, due to transporting goods among factories these systems are incorporated with transportation cost. Thus coordinating production and transportation in such systems is of special importance.

[20] introduced an approach for the first time that allots number of jobs to several batches each of which would be

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Nomenclature

Indices

f, m	Factory
j	Job
h	Batch

Parameters

F	Number of factories
n	Number of jobs to be processed
d_j	Due date of job j
B	Capacity of each vehicle (maximum number of the jobs in a batch)
p_j^f	Processing time of job j in the factory f
τ^f	The Transportation time between factory f and $f+1$
M	Big number
η	The cost of tardiness
β	The cost of delivery

Decision variables

σ_{jh}	Equal to 1 if job j is positioned in batch h, and 0 otherwise
Δ_h	Equal to 1 if there is any job in batch h, and 0 otherwise
C_h^f	The completion time of batch h in the factory f
A_h^f	The arrival time of batch h in the factory f
T_j	Tardiness of job j

delivered to the customers as a single shipment in a single machine scheduling problem. All jobs which are transported at the same time by the transportation vehicle are considered as a batch. The problem of scheduling and batch delivery to a customer with the aim of minimizing the summation of the total weighted flow time and delivery cost on a single machine is considered by [21]. [22,23] have also minimized the summation of the total flow time and delivery cost considering multiple customers with zero and non-zero ready time. An integrated due date assignment and single machine production and batch delivery scheduling problem for make-to-order production system is addressed by [24]. [25] considered an scheduling problem in which jobs should be processed on a single machine with fixed unavailability interval and then delivered in batches to the customers. They presented a fully polynomial time approximation scheme (FPTAS) to minimize the sum of total flow time and batch delivery cost. [26] modeled a supply chain which should produce and deliver jobs as a single machine scheduling problem and proposed a heuristic to minimize the sum of weighted flow time and the batch delivery costs. Scheduling a set of jobs on a single machine with specific release times was investigated by [27] for minimizing the costs of maximum tardiness plus delivery. In their study, batch delivery of jobs to a customer or another machine is also considered where a particular delivery cost is assumed for each batch. They developed a mixed-integer programming (MIP) model and a branch and bound algorithm based on the LP relaxation of the MIP model. Batch delivery of jobs is also considered in another single-machine due window assignment and scheduling problem by [28]. Polynomial-time solution procedures are developed to minimize the total cost of the system which is obtained from earliness of delivery, job holding, start time of due window, size of due window, number of delivery batches and tardiness penalty. [29] considered a single machine scheduling production system in which two agents compete on processing their own jobs. Jobs of the same agent are allowed to be delivered at the same time. They presented a MILP model and a pseudo-polynomial dynamic programming algorithm to minimize the objective function of one agent, while keeping the objective function value of the other agent below or at a given value.

[30] considered serial multi-factory environment where the batch delivery of jobs is allowed. A branch and bound method for the serial multi-factory supply chain scheduling problem is proposed for minimizing the summation of jobs transportation costs and tardiness costs. Since this problem belongs to NP-hard class, exact methods are not able to find the solution in a reasonable time. Thus efficient algorithms are required to solve this problem in reasonable computational time. In recent years, combinatorial optimization problems are successfully solved by heuristics and metaheuristics.

As this is a new field of study, there is little literature for this problem's solutions. We implement a novel population-based evolutionary algorithm for this problem based on Imperialistic Competitive Algorithm (ICA). ICA was first presented by [31] for optimizing the continuous problems. This algorithm is inspired by social-political imperialistic competition mechanism. As it can be implemented simply, it has been applied on different optimization problems. There is large literature for using ICA in different field of studies, but some of studies in scheduling are: [32–40]. It can be claimed that ICA is an important metaheuristic algorithm with some prominent properties; it has indeed some inherent drawbacks like other well-known metaheuristics. Furthermore, the importance of ICA is obvious from its emergence; the research and application of ICA is exponentially increasing every year [41]. So we are motivated to utilize ICA for this problem.

From [42], one of the most significant weaknesses of the evolutionary algorithms is their high dependence on operators with random nature. Thus many researchers tried to enhance these algorithms via integrating it with other strategies. One of the strategies that have been more concentrated on is the learning strategy. For instance, [43–45] make relation among learning and evolutionary algorithms. In this study, the best solutions of the previous iterations are inspected for extracting useful information as *'knowledge'* for guiding the search procedure which would lead to improve the performance of ICA. This is implemented in the algorithm by representing the achieved knowledge as artificial imperialists. This knowledge is utilized in the assimilation strategy of ICA. One of the distinctive features of our presented method from the traditional ICA, is the using of resistant strategy which simulates the colony's opposing against its imperialist. The other real world character of the imperialist that is included in this algorithm is imperialist's reinforcement that shows each imperialist's trying for enhancing its own power and is implemented based on the artificial imperialist concept too.

Since during the last decades, GA has become one of the most well-known metaheuristics and is widely used in many combinatorial optimization problems including machine scheduling [46], we check the performance of the proposed algorithm, via comparing with the adapted classical ICA and GA for this problem.

So, in this study, we investigate the serial multi-factory scheduling problem with batch delivery for minimizing sum of total tardiness cost and total transportation cost. In spite of the difficulty of the scheduling problems, if the number of batches is