



# Integrated scheduling of a multi-product multi-factory manufacturing system with maritime transport limits



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## ABSTRACT

This paper studies a practical multi-factory job allocation and scheduling problem involving inland and maritime transport limits. A new heuristic called Due-date Based Cut-off rule (DBC) is developed to improve the computational efficiency of both exact and genetic algorithms (GA). Except the application of DBC, this proposed GA is guided by a novel fuzzy controller aimed at eliminating the drawbacks other GAs have when dealing with multi-factory models. The tests of the solution quality and computational efficiency for this GA are carried out. The numerical experiments demonstrate the value of the proposed approach in this practical global supply chain.

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## 1. Introduction

With the growing trend of globalization, increasing number of factories have shifted from the centralized to decentralized production network for the purpose of better production quality and customer satisfaction. The multi-factory scheduling problems that have attracted much attention and achieved rapid development for two decades are applicable in many industries such as the automotive companies, food and chemical process industries, steel corporations and electric power generating industries.

Quick responses indicate high customer service level. It generally contributes to more customer orders. Therefore, delivery lead time become a much more significant factor for consideration during the decision making in supply chain. In order to achieve shorter delivery lead time, more shipments with shorter shipping times may have to be used, which will cause more distribution cost. Meanwhile, the production scheduling will also be affected by the distribution scheduling so that more production cost may be induced. Therefore, optimizing the trade-off between the customer service levels and operating cost is a main goal of the integrated production and distribution model.

Many researchers have studied single-factory production and distribution scheduling problems so as to realize quick responses to customers at minimum cost. In multi-factory manufacturing systems, production and distribution scheduling problems are much more complicated because they have to make job allocations to machines in the factories with different geographic locations and operating parameters, so as to utilize the maximum resources.

In this paper, the inter-relationship of the job allocation, production scheduling, storage management, and determination of transportation policy is studied. A set of given jobs are firstly processed in the factories and our main task for this stage is

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to allocate each job to one production line located in one of the factories and to determine the processing sequence of each job in each production line. After completion of production, the finished goods will be stored in the warehouse waiting for distribution. For distribution stage, an inland-maritime transport is considered. Different transportation delays are considered for the inland trips. Additionally, more variation and limits exist for maritime shipments, i.e. fixed departure terminals and times, limited shipments and shipping lead time based freights. The freights perform the rule that shipments with shorter shipping lead times cause much more money. It is much more reasonable and realistic than most existing studies where transportation is always assumed to be available and unlimited, or its delivery time and cost required are simplified to be identical for the distribution. For distribution scheduling, the maritime shipment assignment of each job and the departure times of the inland trips from warehouses are determined.

This paper studies a new and practical approach for multi-factory job allocation and production–distribution scheduling problems in which inland distance–dependent transportation lead time and maritime transport limits and variations are taken into consideration. The objective is to minimize the total operating costs, i.e., cost of production, storage, distribution and penalty. This study is not only an extension to the parallel-structured multi-factory scheduling problems but also to the coordinated production–distribution scheduling problems. A pure mathematical approach is proposed by a mixed-integer programming (MIP). A new heuristic called due-date based cutoff rule (DBC) is exploited to achieve computational efficiency by reducing the feasible region without removing optimal solutions. Moreover, a hybrid 2-level fuzzy guided genetic algorithm (H2LFGGA) is developed for more practical and large-scale problems. In this GA, a new mutation operation that is based on a novel fuzzy controller is introduced. Both workload and busy conditions between production lines are devised in this fuzzy controller. According to the knowledge of the authors, no research to date addresses this model.

This paper is divided into the following sections. Section 2 is a literature review. Section 3 describes the problem background and details of the MIP, DBC formulation and H2LFGGA. Section 4 presents the details of numerical experiments. Section 5 discusses the results of the proposed Multi-factory Integrated Production and Distribution model (MIPD) for small-scale problems as well as the solution quality and computational efficiency of DBC and H2LFGGA. Section 6 is the conclusions.

## 2. Literature review

Due to the increasing trend of globalization, researchers and industrialists have paid attention to multi-factory scheduling problems since 1990s (Behnamian and Ghomi, 2014). In a multi-factory production scheduling model, the factories can be structured in parallel or in series. A parallel structure model means each factory can produce the finished goods with the same quality which can be supplied to the customers directly (Timpe and Kallrath, 2000; Chan et al., 2005a, 2006; Chung et al., 2009a; De Giovanni and Pezzella, 2010), while a series structure model means the finished items from one factory become raw materials or components of another factory for further production. The finished goods will be delivered to customers by the end of production in the last factory in series (Chung et al., 2009b, 2010; Ruifeng and Subramaniam, 2011; Karimi and Davoudpour, 2015).

For multi-factory or multi-site scheduling problems in parallel-structure, it usually involves jobs (orders) allocations to the factories and production sequence in each factory. The popular objective for the parallel-structured multi-factory models in very recent studies is minimization of makespan (Behnamian and Fatemi Ghomi, 2013; Lin et al., 2013; Ziaee, 2014; Naderi and Ruiz, 2014a,b; Xiong et al., 2014). They focused on the production scheduling without transportation constraints. Behnamian and Fatemi Ghomi (2013) modeled each factory with parallel identical machines. A genetic algorithm with new encoding scheme and local search was developed to find near-optimal solution. Lin et al. (2013) proposed a modified iterated greedy algorithm for a distributed permutation flow-shop scheduling problem which was simpler and more efficient. A similar problem was solved by Naderi and Ruiz (2014a) by a scatter search algorithm which was seldom explored for flow-shop setting. While Ziaee (2014) solved a parallel structured scheduling problem in job-shop setting by a fast heuristic algorithm. In the same year, Naderi and Azab (2014b) proposed a similar distributed job-shop scheduling problem. Two mixed integer linear programming models were proposed for small-scale problems. The new proposed greedy heuristic was able to find optimal solutions for small-scale problems efficiently.

Other optimization criteria were also explored. A distributed parallel factories scheduling problem with transshipment lead time in which each factory had different objective (i.e., processing cost minimization and profit maximization) was recently discussed and solved by a hybrid variable neighborhood search/taboo search algorithm (Behnamian, 2013). A hybrid GA with reduced variable neighborhood search was developed to minimize a weighted sum of makespan and mean completion time for a two-stage assembly scheduling problem (Xiong and Xing, 2014).

The coordinated production and distribution problems have developed for more than 2 decades (Chandra and Fisher, 1994). In order to stay competitive in the market, companies hope to keep operating cost low while improving the customer service level. With the fast development of logistics, they have got opportunities to realize it by integration of production and distribution planning (Thomas and Griffin, 1996). Danese and Bortolotti (2014) recently verified that only entire supply chain integration makes notable benefit for the company rather than partial integrated activities. The majority of existing literature for integrated production–distribution problems were modeled in single-factory production network. Besides the traditional consideration of transport constraints (Chen and Pundoor, 2009), some researchers discussed more details about the

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