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# Integrated supply, production and distribution scheduling under disruption risks ☆

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ABSTRACT

This paper presents a bi-objective stochastic mixed integer programming approach for a joint selection of suppliers and scheduling of production and distribution in a multi-echelon supply chain subject to local and regional disruption risks. Two conflicting problem objectives are minimization of cost and maximization of service level. The three shipping methods are considered for distribution of products: batch shipping with a single shipment of different customer orders, batch shipping with multiple shipments of different customer orders and individual shipping of each customer order immediately after its completion. The stochastic combinatorial optimization problem is formulated as a time-indexed mixed integer program with the weighted-sum aggregation of the two objective functions. The supply portfolio is determined by binary selection and fractional allocation variables while time-indexed assignment variables determine the production and distribution schedules. The problem formulation incorporates supply–production, production–distribution and supply–distribution coordinating constraints to efficiently coordinate supply, production and distribution schedules. Numerical examples modelled after an electronics supply chain and computational results are presented and some managerial insights are reported. The findings indicate that for all shipping methods, the service-oriented supply portfolio is more diversified than the cost-oriented portfolio and the more cost-oriented decision-making, the more delayed the expected supply, production and distribution schedules.



## 1. Introduction

The key operational functions in a supply chain are supply, production and distribution operations. To achieve a high performance of supply chain, it is crucial to integrate these three functions and jointly schedule them in a coordinated manner. The joint decision-making might particularly prove its usefulness in the presence of supply chain disruption risks, e.g., Gurnani et al. [1]. For example, in customer-driven supply chains, where customer orders are executed immediately or shortly after arrival of material supplies and the ordered products are delivered to customers immediately or shortly after their completion, the impact of disruption risks can be best mitigated when an integrated decision-making is applied. At the same time, the integrated decision-making allows reaching various conflicting objectives, such as reduction in total cost and increase in service level. However, the research on the integrated decision-making in the presence of supply chain disruption risks is nearly unreported, e.g., Ivanov et al. [2]. The purpose of this paper is to study the integrated decision-making to simultaneously select suppliers of parts and schedule production and delivery of finished products to customers in a supply chain under disruption risks.

A common tool for supply chain optimization under disruption risks is stochastic mixed integer programming (stochastic MIP), e.g., Heckmann et al. [3]. Stochastic MIP is an exact mathematical modelling approach that allows for the inclusion of uncertainty by probabilistic scenarios of disruption events and for finding the optimal solutions with respect to multiple objective functions. In this paper the stochastic MIP formulation and the supply portfolio approach proposed in Sawik [4–8] are enhanced for the integrated decision-making. In addition to supplier selection, order quantity allocation and scheduling of customer orders, distribution of finished products to customers is simultaneously considered with different shipping methods to optimize the trade-off between cost and service level. The three different shipping methods will be modelled and compared for the distribution of products: batch shipping with a single shipment of different customer orders, batch shipping with multiple shipments of different customer orders and individual shipping of each customer order immediately after its completion. The stochastic MIP approach will be illustrated by numerical examples modelled after an electronics supply chain and some managerial insights will be reported.

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The remainder of this paper is organized as follows. The integrated supply–production–distribution scheduling literature, as well as supply disruption management literature is reviewed in the next section. The description of the integrated selection of supply portfolio and scheduling of production and distribution of finished products in a supply chain subject to independent local and regional disruptions is presented in Section 3. The stochastic mixed integer programs for a joint scheduling of supply, production and distribution with single batch, multiple batch or individual shipping to customers, to optimize the trade-off between expected cost and expected service level are developed in Section 4. Numerical examples and some computational results are provided in Section 5, and final conclusions are made in the last section.

## 2. Literature review

There is a growing body of literature on deterministic models on integrated production–distribution planning and scheduling, however, without the supply operations, which are mostly considered separately, e.g., Erenguc et al. [9]. For example, Li et al. [10] investigated an integrated scheduling of assembly and multi-destination air-transportation in a consumer electronics supply chain. The problem was divided into two sub-problems. The air transportation allocation was formulated and solved using a MIP approach, and two heuristics were proposed for the assembly scheduling problem. Lei et al. [11] studied an integrated production, inventory and distribution routing problem and proposed a MIP approach combined with a heuristic routing algorithm to coordinate the production, inventory and transportation operations.

A comprehensive review and classification of existing deterministic models that integrate production and outbound distribution operations at the detailed scheduling level was presented in Chen [12]. The variety of models were classified by shipping and delivery methods. In particular, models with individual and immediate delivery of each order and models with batch delivery and routing of orders to different customers delivered together in the same shipment were considered. Such models attempt to optimize detailed order-by-order production and delivery scheduling jointly by taking into account relevant revenues, costs, and customer service levels at the individual order level.

In a more recent work on deterministic approaches, Cakici et al. [13] proposed a MIP approach for multi-objective scheduling of customer orders in an integrated production and distribution system. The problem objective was to optimize the trade-off between total weighted tardiness as a service level measure and total distribution costs. Bilgen and Celebi [14] applied a hybrid simulation and MIP approach to the integrated production scheduling and distribution planning in dairy supply chain and the model obtains the optimal production plan with the delivery plan. Liu and Papageorgiou [15] developed a multi-objective MIP approach to address production, distribution and capacity planning of global supply chains considering cost, responsiveness and customer service level simultaneously to achieve an equitably efficient or Pareto optimal solution. Lee and Fu [16] considered joint production and delivery lot sizing for a make-to-order producer–buyer supply chain with transportation cost. An integrated production and distribution scheduling problem in a make-to-order supply chain with limited production and distribution capacity was considered by Viergutz and Knust [17]. The problem consists in finding a selection of customers to be supplied such that the total satisfied demand is maximized.

In a related research, Ivanov and Sokolov [18] and Ivanov et al. [19] developed supply chain dynamic models. In the former paper they proposed a new dynamic model for co-ordinated scheduling of interlinked processes in a supply chain under a process modernization, represented as a special case of the scheduling problem with dynamically distributed jobs. In the latter work, an integrated multi-stage scheduling and routing problem with alternative machines at each supply chain stage and non-preemptive operations was considered. A dynamic decomposition of the problem on the basis of optimal program control was proposed, and the solution was based on a combined application of discrete and continuous optimization.

There are also some reported studies on joint supplier selection and production and distribution planning. Sawik [20] compared a monolithic and a hierarchical approach to multi-objective, integrated supply chain scheduling. A decomposition of the complex multi-objective production, manufacturing and supply scheduling into a hierarchy of much simpler decision-making problems was proposed and simple MIP formulations were provided. The objective functions integrated both the total cost and the customer service level and the scheduling was combined with the selection of part suppliers for each customer order and due date setting for some orders. In Cui [21] a MIP model was proposed for joint optimization problem of production planning and supplier selection. The objective was to maximize the manufacturers total profit subject to various operating constraints of the supply chain. Sarrafha et al. [22] considered a multi-period supply chain network design and logistic decision-making that encompassed procurement of raw materials from suppliers, production of finished product at factories, distribution of finished product to retailers via distribution centers, and the storage of raw materials and end product at factories and distribution centers. A bi-objective mixed integer non-linear programming model and a heuristic solution procedure were proposed. Gao et al. [23] developed a MIP formulation and a heuristic with a guaranteed worst-case bound for integrated production and distribution problem in which orders are processed and delivered in batches with limited vehicle capacity. Cheng at al. [24] considered an integrated scheduling of production and distribution to minimize total cost of production and distribution for the manufacturer. A MIP model was developed and an improved ant colony method was proposed to solve the production scheduling and the First-Fit-Decreasing heuristic used in the bin-packing problem, for the distribution scheduling.

While deterministic models mainly focus on the integration of production and distribution operations, supply chain risk management focuses on supplier selection and quantity allocation to determine appropriate mitigation and contingency strategies under supply disruption risks, e.g., Ruiz-Torres and Mahmoodi [25], Hou et al. [26], Ruiz-Torres et al. [27], Meena et al. [28], Zeng and Xia [29], Heese [30], Qi et al. [31], Torabi et al. [32], Merzifonluoglu [33], He and Hongyan [34].

Sawik [4–8] proposed a new stochastic MIP formulation and a supply portfolio approach to integrated supplier selection, order quantity allocation and customer orders scheduling under supply disruption risks. In Sawik [4], the risk-neutral and the risk-averse solutions (e.g., [33,35]) that minimize, respectively expected cost and expected worst-case cost were found for a single or multiple sourcing of different part types. Then, the approach was further enhanced in Sawik [5] for the service level objective function and a single or dual sourcing of a single critical part type. Single and multiple sourcing strategies under multi-regional disruption scenarios were investigated in Sawik [6]. In Sawik [7] a robust decision-making was studied to reach an equitably efficient average and worst-case performance of a supply chain under disruption risks. Finally, in Sawik [8] a fair optimization of expected cost and expected service level under supply disruption risks was