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# On the fair optimization of cost and customer service level in a supply chain under disruption risks

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A B S T R A C T

This paper presents a new decision-making problem of a fair optimization with respect to the two equally important conflicting objective functions: cost and customer service level, in the presence of supply chain disruption risks. Given a set of customer orders for products, the decision maker needs to select suppliers of parts required to complete the orders, allocate the demand for parts among the selected suppliers, and schedule the orders over the planning horizon, to equitably optimize expected cost and expected customer service level. The supplies of parts are subject to independent random local and regional disruptions. The fair decision-making aims at achieving the normalized expected cost and customer service level values as much close to each other as possible. The obtained combinatorial stochastic optimization problem is formulated as a stochastic mixed integer program with the ordered weighted averaging aggregation of the two conflicting objective functions. Numerical examples and computational results, in particular comparison with the weighted-sum aggregation of the two objective functions are presented and some managerial insights are reported. The findings indicate that for the minimum cost objective the cheapest supplier is usually selected, and for the maximum service level objective a subset of most reliable and most expensive suppliers is usually chosen, whereas the equitably efficient supply portfolio usually combines the most reliable and the cheapest suppliers. While the minimum cost objective function leads to the largest expected unfulfilled demand and the expected production schedule for the maximum service level follows the customer demand with the smallest expected unfulfilled demand, the equitably efficient solution ensures a reasonable value of expected unfulfilled demand.



## 1. Introduction

In global supply chain networks the optimization of material flows subject to unexpected disruption events, focuses on a variety of different optimality criteria. The most commonly used criteria for a global supply chain performance are minimization of cost and maximization of customer service level that measures the percentage of customer demand satisfied on time. The above two performance metrics are in conflict and, in addition, the decision makers often do not have preference to any objective, i.e., the two objectives are equally important. Then, an equitably efficient solution should be generated, in which the two normalized objective function values are as much close to each other as possible. Such kind of solutions can be generated by applying the lexicographic minimax method, as a special case of the ordered weighted averaging aggregation, e.g., Kostreva et al. [1], Ogryczak et al. [2]. The lexicographic minimax problem can be transferred to a lexicographic minimization problem and recently Liu and Papageorgiou [3] developed an approach to transfer the lexicographic minimax problem to a minimization optimization problem, instead of a lexicographic minimization problem, which needs to solve a sequence of optimization problems iteratively. The recent approach, however, is restricted to some special cases of a multiple objective problem (Liu et al. [4]).

The selection of part suppliers and allocation of order quantities under disruption risks may particularly help to optimize performance of a global supply chain network in the presence of unexpected disaster events (e.g., Park et al. [5], Fujimoto and Park [6], Schmitt and Singh [7]). Nevertheless, the research on supplier selection under disruption risks is limited, (e.g., Simangunsong et al. [8]). For example, Berger et al. [9], Berger and Zeng [10], Ruiz-Torres and Mahmoodi [11], Yu et al. [12] and Zeng and Xia [13] considered the impacts of supply disruption risks on the choice between single, dual and multiple sourcing strategies.

The literature on supply chain risk management indicates that the stochastic programming methodology has been successfully applied in a risk management related decision-making (e.g., [14,15]). In particular, stochastic mixed integer programming (stochastic MIP) is

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an appropriate tool for supply chain optimization under disruption risks due to its ability to handle uncertainty by probabilistic scenarios of disaster events as well as their outcomes. Stochastic programming allows for exact mathematical modeling approaches and optimization algorithms to be applied and the optimal solutions with respect to multiple relevant objective functions to be achieved. While the primary purpose of supply chain risk management is to avoid lower tail performances, stochastic MIP allows both the risk-neutral, average performance as well as the risk-averse, worst-case performance of a supply chain network to be optimized. For example, Li and Zabinsky [16] developed a two-stage stochastic programming model and a chance-constrained programming model to determine a minimal set of suppliers and optimal order quantities. Both models include several objectives and strive to balance a small number of suppliers with the risk of not being able to meet demand. The stochastic programming model is scenario-based and uses penalty coefficients whereas the chance-constrained programming model assumes a probability distribution and constrains the probability of not meeting demand. Hammami et al. [17] proposed a scenario-based stochastic model for supplier selection in the presence of uncertain fluctuations of currency exchange rates and price discounts. Using a portfolio approach and the percentile measures of risk, Value-at-Risk (VaR) and Conditional Value-at-Risk (CVaR), Sawik [18–20] considered supplier selection and order quantity allocation in the presence of supply chain disruption risks. In particular in [19,20] a resilient supply portfolio was considered with fortified suppliers that are capable of supplying parts in the face of disruption events and with emergency [19] or regular [20] inventory pre-positioned at the fortified suppliers. The emergency inventory is used to compensate for the loss of capacity of the other suppliers, unprotected and hit by disruptions, while the regular inventory can be fully used under each disruption scenario to fulfill regular orders placed on the protected suppliers.

Most works on supply chains optimization focus on coordinating the flows of supply and demand over a supply chain network to minimize the inventory, transportation and shortage costs. However, the equitable optimization with respect to equally important conflicting objective functions (e.g., [3]) and under disruption risks is rarely considered as well as the associated coordinated scheduling of the disrupted material flows. Lei et al. [21] considered an integrated production, inventory and distribution routing problem involving heterogeneous transporters with non-instantaneous traveling times and many capacitated customer demand centers. A mixed integer programming (MIP) approach combined with a heuristic routing algorithm was proposed to coordinate the production, inventory and transportation operations. Bard and Nananukul [22] developed a MIP model and a reactive tabu search-based algorithm for a transportation scheduling problem that included a single production facility, a set of customers with time-varying demand and a fleet of vehicles. Wang and Lei [23] considered the problem of operations scheduling for a capacitated multi-echelon shipping network with delivery deadlines, where semi-finished goods are shipped from suppliers to customers through processing centers, with the objective of minimizing the shipping and penalty cost. The three polynomial-time solvable cases of this problem were reported: with identical order quantities; with designated suppliers; and with divisible customer order sizes. Sajadieh et al. [24] considered an integrated production-inventory model for a three-stage supply chain involving multiple suppliers, multiple manufacturers and multiple retailers, with stochastic lead times to retailers.

The major contribution of this paper is that it proposes a stochastic MIP model for the integrated selection of supply portfolio and scheduling of customer orders in a global supply chain under disruption risks to equitably optimize expected cost and expected customer service level. The supplies of parts are subject to independent random local and regional disruptions. The cost includes the cost of ordering, purchasing and shortage of parts, while the customer service level is a performance measure independent on any cost parameters, defined as the fraction of customer orders or customer demand, filled on or before their due dates. The equitable decision-making aims at achieving the normalized expected cost and customer service level values as much close to each other as possible. In order to obtain an equitably efficient solution to the combinatorial stochastic optimization problem, the ordered weighted averaging aggregation of the two conflicting objective functions is applied, e.g., Yager [25]. The stochastic MIP model proposed is based on the stochastic optimization approach presented in Sawik [26–28] for the integrated supplier selection, order quantity allocation and customer orders scheduling under disruption risks, where the problem objective was either to minimize expected cost or expected worst-case cost or to maximize expected service level or expected worst-case service level. In [26], the risk-neutral and the risk-averse solutions that minimize, respectively expected cost and expected worst-case cost were found for a single or multiple sourcing of different part types. The supplies were subject to independent random local disruptions of each supplier individually and to global disruptions of all suppliers simultaneously. The idea presented in [26] was further enhanced in [27] for the customer service level objective function and a single or dual sourcing strategy for a single critical part type. The suppliers were assumed to be located in two different geographic regions: in the producer's region (domestic suppliers) and outside the producer's region (foreign suppliers) and the supplies were subject to independent random local disruptions of each supplier individually and to regional disruptions of all suppliers in the same region simultaneously. Finally, the results achieved in [27] were enhanced in [28] for the risk-averse, single and multiple sourcing strategies under multi-regional disruption scenarios. Given a set of customer orders for products, the decision maker needs to decide which single supplier or which subset of suppliers to select for purchasing parts required to complete the customer orders and how to schedule the orders over the planning horizon, to mitigate the impact of disruption risks. The suppliers are located in different geographic regions and the supplies are subject to different types of disruptions: to random local disruptions of each supplier individually, to random regional disruptions of all suppliers in the same region simultaneously and to random global disruptions of all suppliers simultaneously. The problem objective was either to minimize the expected worst-case cost of ordering and purchasing of parts plus penalty cost of delayed and unfulfilled customer orders due to the parts shortages or to maximize the expected worst-case customer service level, i.e., the expected worst-case fraction of customer orders satisfied on time. In this paper, the two risk-neutral conflicting criteria: expected cost and expected customer service level are fairly optimized to achieve an equitably efficient supply portfolio and production schedule in the presence of supply chain disruption risks. The two alternative customer service level measures are compared: the expected fraction of satisfied on time customer orders or customer demand. The equitably efficient solutions obtained for the ordered weighted averaging aggregation of the two conflicting objective functions are compared with non-dominated solutions obtained using the weighted-sum aggregation approach.

The paper is organized as follows. The description of the integrated selection of supply portfolio and scheduling of customer orders with multiple suppliers subject to independent local and regional disruptions is presented in Section 2. The stochastic mixed integer programs for equitably efficient optimization of expected cost and expected customer service level are developed in Section 3. Numerical examples and some computational results, in particular comparison with the weighted-sum