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Integrated supply chain planning under uncertainty using an improved stochastic approach

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ABSTRACT

This paper proposes an integrated model and a modified solution method for solving supply chain network design problems under uncertainty. The stochastic supply chain network design model is provided as a two-stage stochastic program where the two stages in the decision-making process correspond to the strategic and tactical decisions. The uncertainties are mostly found in the tactical stage because most tactical parameters are not fully known when the strategic decisions have to be made. The main uncertain parameters are the operational costs, the customer demand and capacity of the facilities. In the improved solution method, the sample average approximation technique is integrated with the accelerated Benders' decomposition approach to improvement of the mixed integer linear programming solution phase. The surrogate constraints method will be utilized to acceleration of the decomposition algorithm. A computational study on randomly generated data sets is presented to highlight the efficiency of the proposed solution method. The computational results show that the modified sample average approximation method effectively expedites the computational procedure in comparison with the original approach.

1. Introduction

A supply chain is a network of suppliers, manufacturing plants, warehouses, and distribution channels organized to acquire raw materials, convert these raw materials to finished products, and distribute thee products to customers. In a supply chain, the flow of goods between a supplier and customer passes through several stages, and each stage may consist of many facilities (see [1–4]). A generic supply chain network is depicted in Fig. 1.

The planning of a supply chain network involves making decisions to cope with long-term (strategic planning), medium-term (tactical planning) as well as short-term (operational planning) issues. These decisions can be classified into three categories according to their importance and the length of the planning horizon considered as the following:

- the number, location and capacity of manufacturing plants and warehouses,
- the supplier selection, product range assignment as well as distribution channel and transportation mode selection,
- the flows of materials in the network.

The supply chain network design (SCND) problem consists of making the above-mentioned decisions to satisfy customer demands while minimizing the sum of strategic, and tactical/operational costs. Because the importance of the interactions

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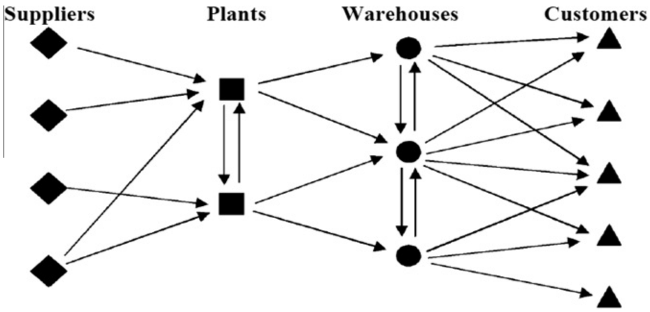

Fig. 1. A generic supply chain network.

between these decisions, important benefits can be obtained by treating the network as a whole and considering its various components simultaneously. The SCND decisions are costly and difficult to reverse, and their impact spans a long time horizon. The customer demand, the operational costs, and the capacity of the facilities may be highly uncertain. This has made the development of models for SCND under uncertainty a high priority for researchers in stochastic optimization communities.

The two-stage nature of SCND problems has made these problems very attractive to researchers exploring approaches to decision making under uncertainty. A large number of these approaches have been applied to SCND problems. The sample average approximation (SAA) technique is a solution method for stochastic optimization problems with large numbers of scenarios. A key difficulty in solving the stochastic program is in evaluating the expectation in the objective. This approach approximates the expected objective value utilizing Monte Carlo simulation. The idea of this technique is to solve the approximation instead of the true values and to generate a sample of the stochastic parameters to construct the approximation.

In this paper, the provided mathematical formulation by Mohammadi Bidhandi et al. [5] has been developed to present a two-stage stochastic model for SCND problems under uncertainty. The first stage consists of the deciding the configuration decisions, and the second stage consists of processing/transporting products from suppliers to customers with uncertainty in the operational costs, the customer demand, and the capacity of the facilities. In the modified solution method, the SAA technique has been improved by integrating with an accelerated Benders' decomposition algorithm. The contribution of this paper is to introduce an integrated and flexible formulation of the SCND for the stochastic, multi-commodity, single-period context, and describe an improved solution method for solving the problem efficiently.

2. Literature review

The most recent comprehensive review for facility location and supply chain management demonstrated that most of the literature deals with deterministic models when compared with stochastic ones (approximately 82% against 18%) [6]. Uncertainty is one of the most challenging but important problems in the practical analysis of SCND performance. However, the literature in the background of SCND under uncertainty is still scarce. Because of the difficulty in solving stochastic SCND problems, research on more complex multi-echelon models under uncertainty has only begun to appear in the literature in the past decade. Many of these models may be viewed as stochastic extensions of the seminal model by Geoffrion and Graves [7]. Although, the majority of papers in the literature on integrated SCND problems are for the deterministic environment, recent research in SCND problems under uncertainty is increasing significantly.

The SCND models under demand uncertainty have received significant attention in the literature. Many researchers have considered customer demand as the single uncertain parameter in their model (see [8–17]). The body of literature related to these models is extensive. Interested readers could refer to the excellent reviews regarding: approaches for optimization under uncertainty applied in facility location problems [18], systematic consideration of uncertainty within supply chain optimization problems for the process industries [19], and SCND problems under uncertainty and the available models proposed to support the design process [20].

Some articles include several stochastic components simultaneously. Sabri and Beamon [21] incorporated production, delivery, and demand uncertainty in their model. Louveaux and Peeters [22] have studied the uncapacitated facility location problem as a two-stage stochastic program with uncertainty on demand, selling prices, production and transportation costs.

Cheung and Powell [23] considered the distribution problem with uncertain demands as a two-stage stochastic program. In their model, they incorporated one stochastic parameter, which is customer demand. They suggested a network recourse decomposition method to solve the problem efficiently. However, the authors did not investigate sensitivity of the solution to the characteristics of the demand process as well as the other parameters, such as holding cost and the opportunity cost of lost sales.

Gutierrez et al. [24] addressed uncapacitated network design problem under input data uncertainty. The modeling framework is a standard MILP formulation with an objective to minimize total cost including strategic and flow costs. They have developed the algorithms based on the Benders' decomposition methodology to find robust network designs.