Transportation Research Part E 48 (2012) 919–936

Contents lists available at SciVerse ScienceDirect

Transportation Research Part E

journal homepage: www.elsevier.com/locate/tre

# Stochastic programming approach to re-designing a warehouse network under uncertainty

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ARTICLE INFO

*Article history:*
Received 17 June 2011
Received in revised form 14 November 2011
Accepted 5 April 2012

*Keywords:*
Warehouse network re-design
Sample average approximation
Benders decomposition
Uncertainty modeling

ABSTRACT

The warehouse network re-design problem includes integrating or eliminating existing warehouses and establishing new sites. In this paper, we incorporate variability in product demand and operational costs with a two-stage stochastic modeling approach. We use the Sample Average Approximation (SAA) approach together with Benders decomposition to provide a solution method. Our results indicate not only that the stochastic solution is an improvement over the deterministic solution but also that the solutions' differences grow with increasing uncertainty. The stochastic solutions show more robustness than the deterministic solutions. The computational results show that a change in the type of probability distribution of the stochastic parameters does not significantly affect the value of the stochastic solutions.



## 1. Introduction

A supply chain is a system of suppliers, manufacturers, distributors, retailers and customers. In this system, materials move from suppliers to customers, and information flows in both directions (Geoffrion and Powers, 1995). Different types of facilities in the supply chain network are organized such that this system acquires row materials, converts them to finished products and finally delivers them to customers. The structure of this network significantly impacts the performance of operational activities, such as the production and distribution of products. Hence, the total cost of the finished product, which incorporates the production and distribution costs (Delaney, 1991), is affected by this supply chain property. Ballou (1999) claimed that an efficient network structure is a comparative advantage for multinational logistic networks. The primary design of a supply chain network consists of the numbers, location and capacity decisions for the facilities and the quantity of materials that flows between them (Amiri, 2006). A supply chain network re-design includes the relocation, capacity expansion or reduction decisions for existing facilities, as well as the numbers, location and capacity decisions for new facilities. This process can result in the elimination (phase out), transfer or consolidation of existing facilities. Indeed, a re-design project includes network design activities for both new and old facilities. Two factors distinguish between a primary design and a re-design project for a supply chain network. The first aspect is the state of the existing facilities (i.e., the number, location and capacity level of the facilities) that affect potential new sites. Furthermore, every change in the network state (phase out, capacity transfer, etc.) needs substantial capital investment and has a long-lasting effect on the efficiency of the supply chain activities. Second, a re-design project should be implemented gradually such that changing the state of existing facilities does not disrupt the typical activities of the supply chain, e.g., serving demands. Hence, a re-design is more complex compared with a primary design of a supply chain network.

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http://dx.doi.org/10.1016/j.tre.2012.04.005

In an operating supply chain, re-design projects in the warehouses layer are more common than in other types of facilities and have many advantages. Ballou (1999) reported that, out of 200 logistic networks, 65% of them will re-design their warehouse networks. Consolidation and phase-out activities in the warehouse network can save transportation, inventory and warehousing costs (Melachrinoudis et al., 2005). The integration of warehouses or distribution centers can reduce the shortage in serving demands (e.g., Bordley et al., 1999). We found many mathematical formulations that can be considered a re-design model in the supply chain network design literature. However, the majority of them did not explicitly consider the cost effects of change in the setting of existing facilities. Hence, to put aside this type of study because it is outside of our scope, we limit the literature with two assumptions:

1. Relocation decisions, such as the opening and closing of facilities, must be considered simultaneously. Furthermore, closing existing facilities must have a cost or cost saving effect in the objective function. Bidhandi et al. (2009) addressed the design of a supply chain network using location decisions in multi-layers. However, the cost or cost savings effect was not considered, although the state of facilities was modeled by binary variables, and the zero state was interpreted as the phase-out of the existing facility.
2. Re-design decisions are strategic and do not return to end of the planning horizon. In the model of Aghezzaf (2005), warehouses are periodically opened and closed. Indeed, re-designing decisions are not assumed to be strategic decisions.

Despite the many advantages that a supply chain network re-design can produce, the literature on this issue is very rare. In the following paragraph, we review the studies that explicitly address re-design decisions in a supply chain network with a mathematical programming approach.

Melachrinoudis and Min (2000) proposed a multi-objective model to relocate a single facility. Capacity can be transferred from a source facility to a destination. However, the extension or reduction of the total network capacity is not considered, nor is uncertainty. Finally, a resulting mixed integer linear program (MILP) was solved using commercial software. Melo et al. (2005) proposed a fairly comprehensive model in this scope. The strategic re-design decisions are not confined to a single layer or facility. The capacity of the facilities can be partially transferred, as an integer or in continuous manner, to another one. The total network capacity can be extended or reduced. Another property is the consideration of budget limitation on re-design decisions. Again, the uncertainty has not been considered. Unfortunately, the authors did not suggest a solution procedure for their MIP model. Melachrinoudis and Min (2007) addressed a warehouse network re-design problem. The strategic re-design decisions consist of the phase-out, capacity transfer or consolidation of existing warehouses and establishing new sites. The relocation decisions are considered simultaneously for multi-facilities. There is a limitation on the distance between the warehouse and the customer. Hence, re-design decisions must be made so as not to disrupt the ability to meet the customer's demands. The capacity could be totally transferred. By phasing out warehouses, the total network capacity could be reduced. However, the total capacity expansion was not considered. In addition to multi-sourcing, the single sourcing situation is modeled without considering uncertainty. Finally, the authors solved this MILP model by partially relaxing the allocation integer variables combined with rounding procedures.

An important issue that has not been addressed in this scope is the uncertainty in the data. As mentioned earlier, re-design decisions are strategic and require substantial capital investment. Additionally, these decisions have a great impact on the operational activities and, thus, on the total unit cost of the products. For these reasons, network re-design decisions must maintain their optimality or near optimality over the lifetime of the supply chain. However, we cannot expect all parameters, such as demand or operational costs, to remain constant over long periods of time.

Thus, it is clear that the uncertainty in operational parameters is an unavoidable aspect of re-design projects. Indeed, implementing strategic decisions without considering the uncertainty assumptions can produce high risk. Our aim is to model a re-design project such that the strategic decisions remain optimal or near optimal in a changing environment. Furthermore, we want to consider the behavior of the total cost of the deterministic solutions under the uncertainty situation. We use a two-stage stochastic programming approach to incorporate the uncertainty by assuming that the behavior of the operational parameters consisting of product demands and operational costs are known in terms of probability distributions. Each stochastic parameter has an independent probability distribution.

The main contributions of this study are as follows:

- This paper extends the deterministic warehouse network re-design model to consider uncertainty. Our study reveals the huge gap between the resulting costs from two approaches (deterministic approach *versus* stochastic approach).
- An efficient algorithm provided base on Sample Average Approximation in combining with accelerated Benders decomposition and other heuristic methods.

The remainder of this paper is organized as follows: In the next section, we propose a two-stage stochastic model for the re-design of a warehouse network based on a previously developed deterministic model. In Section 3, we describe the solution method. Section 4 presents experimental results generated using random test problems. Finally, we discuss our conclusions in Section 5.