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Optimizing a bi-objective multi-product multi-period three echelon supply chain network with warehouse reliability

Seyed Hamid Reza Pasandideh [a,1], Seyed Taghi Akhavan Niaki [b,*], Kobra Asadi [a,1]

[a] Department of Industrial Engineering, Faculty of Engineering, Kharazmi University, Theran, Iran
[b] Department of Industrial Engineering, Sharif University of Technology, Tehran, Iran

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ABSTRACT

Bi-objective optimization of a multi-product multi-period three-echelon supply chain network consisting of manufacturing plants, distribution centers (DCs) each with uncertain services, and customer nodes is aimed in this paper. The two objectives are minimization of the total cost while maximizing the average number of products dispatched to customers. The decision variables are: (1) the number and the locations of reliable DCs in the network, (2) the optimum number of items produced by plants, (3) the optimum quantity of transported products, (4) the optimum inventory of products at DCs and plants, and (5) the optimum shortage quantity of the customer nodes. The problem is first formulated into the framework of a constrained bi-objective mixed integer linear programming model. Then, to solve the problem using the GAMS software, six multi-objective decision-making (MODM) methods are investigated in order to select the best in terms of total supply chain cost, total expected number of products dispatched to customers, and their required CPU time, simultaneously. At the end, some numerical illustrations are provided to show the applicability of the proposed methodology.

1. Introduction

Supply chain (SC) management has been considered as one of the most important activities in several organizations. In the classical SC problem, the goal has been to send products from one layer to another in order to supply demands such that sum of the fixed and current cost is minimized. However, intricacy involved in mutual relations between various components together with risks and uncertainties throughout the chain have turned the SC decision-making a challenging problem, where newer goals are propound. The uncertainties in supply chain network are divided into three fields based on the supplier layer (stochastic disorder in the facilities' function), the receiver layer, and in the middle layers. Murthy, Solem, and Roren (2004) pointed out that at the strategic decision-making level, the uncertainty to locate facilities in a SC is the most important and difficult issue to consider. If a facility at the distribution layer is not able to service the lowest layers of the chain (due to reasons such as natural events, terrorist attacks, change in owners, labor mistake, weather conditions, etc.), the reallocation of customers to other active distributers changes the topology of the supply chain network (SCN) and hence increases the distributer's costs significantly (Shen, Zhan, & Zhang 2010). The problem of locating facilities at the distributer level of SCs when facilities are subject to random failures is called the "reliable facility location problems (RFLP)." In addition to traditional goals of the RFLP with fixed costs, the objective in this problem is to minimize the mean of failure cost (Snyder & Daskin, 2005).

In this paper, a multi-periodic three-echelon SC consisting of manufacturing plants that produce several products, distribution centers (DCs) that receive the products and stores them in order to satisfy customers' demands, and customer nodes as final recipients of the products is considered, in which the distribution (warehouse) facility is subject to random failure. The goal is to determine the number and the locations of reliable warehouses in the network, the optimum number of items produced by plants, the optimum quantity of products to be dispatched from plants to DCs and from DCs to customer nodes, the optimum inventory of products at DCs and plants, and the optimum shortage quantity of the customer nodes. The problem has two conflicting objectives. The first is to minimize the total chain cost and the second is to maximize the average total number of products dispatched to customers. The problem is first formulated into a bi-objective mixed-integer linear programming model. Then, six multi-objective decision-making (MODM) methods are employed to solve the problem using the

* Corresponding author. Tel.: +98 21 66165740; fax: +98 21 66022702.
E-mail addresses: shr_pasandideh@khu.ac.ir (S.H.R. Pasandideh), niaki@sharif.edu (S.T.A. Niaki), asadi_kb@yahoo.com (K. Asadi).
[1] Tel.: +98 (21) 88830891; fax: +98 (21) 88329213.

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GAMS software (Hwang & Masud, 1979). The performances of these methods are compared in terms of both the solution quality and the CPU time required, in an attempt to select the best.

Note that while the uncertainty involved in distribution facilities of SC networks has not been considered in most of relevant works, this paper aims to provide a framework to address it by assuming that the distribution facility is subject to random failures due to natural events, terrorist attacks, weather condition, and so on. Moreover, different methods are suggested to model two conflicting objectives in this research. These methods reflect different expectations and willing of decision makers.

The structure of the remainder of this paper is organized as follows. In the next section, relevant current studies found in the literature are reviewed. Section 3 describes the problem modeling and provides the mathematical model. Section 4 proposes the solution methods. Section 5 contains numerical illustration to demonstrate the application of the proposed methodology and to assess its performance. Section 6 concludes with the main findings and future research.

2. Literature review

In most of the designs developed for SC networks, there is a single objective to either minimize the costs or maximize the profit. For example, Gebennini, Gamberini, and Manzini (2009) suggested a three-stage production–distribution system to minimize the related costs. Their method formulates a dynamic location–allocation problem by controlling customer service level and optimizing safety stock. Amiri (2006) developed a model for a supply chain problem to obtain the best strategic decisions on locating production plants and distribution warehouses in order to dispatch the products from plants to customers with the goal of minimizing the total costs of the distribution network. However, in addition to cost minimization or profit maximization, satisfying customers' demands has a homologous importance. As such, some researchers worked on simultaneous optimization of more than one objective such as maximizing customer service level and minimizing total related costs. In this regard, Azaron, Brown, Tarim, and Modarres (2008) investigated a three-echelon supply chain network with uncertain cost parameters. They proposed a tri-objective stochastic programming approach to minimize the sum of the current and the expected future costs along with the minimization of the variance of the total costs and unreliability involved to hold a specified budget. Liang (2008) examined a fuzzy multi-objective linear programming (FMOLP) model with piecewise linear membership function that would seek to minimize the total related fuzzy costs and total delivery times at an integrated multi-product multi-period production/distribution planning decision (PDPD) problem.

In an attempt to unify cooperative and competitive scenarios, Zamarripa, Aguirre, Méndez, and Espũna (2012) considered two different supply chains each consisting of three stages to simultaneously minimize system costs and accumulated delivery time from different production echelons to the storage centers. They utilized the game theory to decide which scenarios to be selected. Shankar, Basavarajappa, Chen, and Kadadevaramath (2013) investigated a single-product four-echelon supply chain network to optimize two objectives synchronously; first, to minimize the transportation cost resulted from different facility locations, second to maximize customer demands. James (2014) proposed a Bayesian approach in a real-world supply chain with fuzzy parameters. This paper describes the structure of a Bayesian network and determines a posterior probability distribution for backorders using a stochastic simulation based on Markov blankets. Jaipuria and Mahapatra (2014) proposed a methodology based on forecasting the demand under uncertain environment of a supply chain. In this study, an integrated approach of discrete wavelet transforms (DWT) and artificial neural network (ANN) is proposed to forecast the demand. Their model was tested with demand data collected from three different manufacturing firms. Ramanathan (2014) studied several supply chain management initiatives such as vendor-managed inventory, continuous replenishment, and collaborative planning forecasting and replenishment (CPFR) that have been previously proposed in the literature to improve the performance of supply chains. In this research, collaborative performance measurement acts as a testing tool to identify helping environment to collaborate by pinpointing areas requiring improvements before initializing collaboration.

Beside multi-objective optimizations of SC problems, a number of research works were performed under uncertain environments. As mentioned, there are three types of uncertainties that influence strategic, tactical, and operational design issues. In the operational design, Georgiadis, Tsiakis, Longinidis, and Sofioglou (2011) considered a four-echelon supply chain network under uncertainties in time and demand. These uncertainties were found according to a number of scenarios that were possible to take place at the life-time of the network. Mirzapour Al-e-Hashem, Malekly, and Aryanezhad (2011) considered a three-echelon multi-product multi-period SC problem that would face with uncertainties in cost parameters and demands. They developed a multi-objective robust optimization model in which the first objective function would try to minimize total attached costs of the network and the second would minimize the total maximum amount of shortages for middle customers. Cardona-Valdés, Álvarez, and Ozdemir (2011) proposed a two-echelon supply chain design to minimize total costs and total service time, coincidentally. In this research, a stochastic optimization model was developed for uncertain demand shown by a number of scenarios. Besides, Pishvaee, Jolai, and Razmi (2009) extended a stochastic programming model for an integrated forward/reverse logistics network design under uncertainty. First, they developed an efficient deterministic mixed-integer linear programming (MILP) model to avoid the sub-optimality caused by the separate design of the forward and reverse networks. Then, they proposed a stochastic counterpart of the proposed MILP model using a scenario-based stochastic approach.

None of the above-mentioned research works considers uncertainty involved in distribution facilities of SC networks. Therefore, in this research, while an objective function is defined to minimize total costs, another objective function is developed to maximize sum of the expected number of products dispatched. In other words, not only a minimum total cost is aimed, but also more reliable warehouse facilities are found to minimize digression of the customers' demands. Moreover, different methods are suggested to model the bi-objective optimization problem at hand.

In the next section, the problem is mathematically formulated.

3. Problem modeling

In this section, nomenclatures, the problem, and the assumptions required to model the problem are introduced before the mathematical formulation.

3.1. Nomenclatures

The notations including indices, parameters, and decision variables are: