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Application of fuzzy optimization to a supply chain network design: A case study of an edible vegetable oils manufacturer

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ABSTRACT

This study applies fuzzy sets to integrate the supply chain network of an edible vegetable oils manufacturer. The proposed fuzzy multi-objective linear programming model attempts to simultaneously minimize the total transportation costs. The first part of the total transportation costs is between suppliers and silos; and rest one is between manufacturer and warehouses. The approach incorporates all operating realities and actual flow patterns at production/distribution network with reference to demands of warehouses, capacities of tin and pet packaging lines. The model has been formulated as a multi objective linear programming model where data are modeled by triangular fuzzy numbers. Finally, the developed fuzzy model is applied for the case study, compiled the results and discussed.

1. Introduction

Having an efficient and effective supply chain network provides a marketing area for enterprises in the global business environment. Determining positions and counting of actors, amount of product flow between and decreasing transportation costs are handled as a network design problem in supply chain management (SCM). In recent years, commercial and academic interests in SCM have increased remarkably. In the studies, importance and need of items that comprise the supply chain are highlighted to provide customer satisfaction and to obtain competitive advantage in process between raw material suppliers and end customers. Today, on the one hand, enterprises are expanding their own supply chain networks; on the other hand, they have to solve the problems of communication and long response time. However, it seems quite difficult to do it successfully for these companies owing to their huge and extremely complicated logistics networks, though they usually have imminent desire to cut down their logistics cost [1].

In this field, numerous researches are conducted. Pyke and Cohen [2] developed a mathematical programming model by using stochastic sub-models to design an integrated supply chain that involves manufacturers, warehouses and retailers. The model minimizes the total cost under a service level constraint and determines the economic re-order interval and replenishment batch sizes. Özdamar and Yazgaç [3] developed a distribution/production system, which involves a manufacturer center and its warehouses. The proposed model minimizes the total costs such as inventory and transportation costs under production capacity and inventory equilibrium constraints. Petrovic et al. [4] modeled supply chain behaviors under fuzzy constraints. They use simulation techniques to examine the dynamic and performance of the whole supply chain. Their model showed that uncertain customer demands and deliveries play a big role about behaviors. Paksoy [5] developed a mixed-integer linear programming to design a multi-echelon supply chain network under material requirement constraints.

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The model considers sub-components (bill of materials), multi products and choice of distribution centers to be opened or not. Lin et al. [1] compared flexible supply chains and traditional supply chains with a hybrid genetic algorithm and mentioned advantages of flexible ones. The existence of flexible supply chains makes the problem much more difficult by traditional optimization methods. They formulate this problem as location-allocation model, and propose an effective hybrid genetic algorithm to solve this problem. Moreover, numerical analysis of a case study is carried out to show the effectiveness of the proposed approach. You and Grossmann [6] addressed the optimization of supply chain design and planning under responsive criterion and economic criterion with the presence of demand uncertainty. By using a probabilistic model for stock-out, the expected lead time is proposed as the quantitative measure of supply chain responsiveness. Gumus et al. [7] developed a mixed-integer linear programming model and proposed a neuro-fuzzy method for designing and optimizing the multi-echelon supply chain network of a multinational company in alcohol-free beverage sector. Chinese and Meneghetti [8] developed a mixed-integer linear programming model for designing of forest bio-fuel supply chains. They considered a real-life problem of supplying a bio-energy plant with forest fuel and determined the optimal configuration of the supply chain. Because of the difficulties to formulate mathematical models in designing production–distribution networks owing to lack of certainty, long time periods and complexity of networks, they developed and used a decision-support system to be very helpful especially for the global optimization of the supply chains. Schütz et al. [9] presented a supply chain design problem modeled as a sequence of splitting and combining processes. They formulated the problem as a two-stage stochastic program. The first-stage decisions are strategic location decisions, whereas the second stage consists of operational decisions. The objective is to minimize the sum of investment costs and expected costs of operating the supply chain. Ahumada and Villalobos [10] reviewed the main contributions in the field of production and distribution planning for agri-foods based on agricultural crops. Through their analysis of the current state of the research, they diagnosed some of the future requirements for modeling the supply chain of agri-foods.

In most real-world SCM problems, environment coefficients and model parameters are frequently imprecise/fuzzy because some information is incomplete and/or unavailable over the planning. Conventional linear programming (LP) and special solution algorithms cannot solve all fuzzy SCM problems. Fuzzy set theory was developed by Zadeh [11], since then fuzzy set theory has been applied to the fields of operations research (linear programming, non-linear programming, multiple criteria decision making and so on), management science, artificial intelligence/expert system, statistics and many other fields. To formulate the fuzzy/imprecise numbers, membership functions could be used. Traditional mathematical programming techniques, obviously, cannot solve all fuzzy programming problems. In practice, input data are usually fuzzy/imprecise because of incomplete or non-obtainable information and knowledge. Because of this, precise mathematics is not sufficient to model a complex system. For solving decision making problem and fuzzy linear programming problem, various models are developed. In the last two decades, multiple objective decision making techniques have been applied to solve practical problem, such as academic planning, production and manufacturing planning, location, logistics, financial planning, portfolio selection, and so on [12,13].

Liang [14] developed an interactive fuzzy multi-objective linear programming method for solving the fuzzy multi objective transportation problems with piecewise linear membership function. The model considered multi-product and multi-time period production/distribution planning decisions problems with fuzzy objectives. The proposed model attempts to simultaneously minimize total costs and total delivery time in relation to inventory levels, available machine capacity and labor levels at each source, and forecast demand and available warehouse space at each destination and total budget. The decision maker (DM) computes the value in each cost category by considering the time value of money in the proposed model, which is appropriate for practical application to the problem in a supply chain. Liang [15] developed a fuzzy multi-objective linear programming model with piecewise linear membership function to solve integrated multi-product and multi-time period production/distribution planning decisions problems with fuzzy objectives. The proposed fuzzy model provides a systematic framework that facilitates fuzzy decision-making process, enabling the DM to interactively adjust the search direction during the solution procedure to obtain a DM's preferred satisfactory solution. Liang and Cheng [16] applied fuzzy sets to multi-objective manufacturing/distribution planning decision problems with multi-product and multi-time period in supply chains by considering time value of money for each of the operating categories. Peidro et al. [17,18] proposed a new mathematical programming model for supply chain planning under supply, process and demand uncertainty. The model has been formulated as a fuzzy mixed integer linear programming model where data are ill-known and modeled by triangular fuzzy numbers. Hu and Fang [19] solved the problem of fuzzy inequalities linear membership function by employing the concepts of constraint subrogation and maximum entropy, and it shows that a system of fuzzy inequalities with piecewise linear membership functions can be converted to a one-constraint nonlinear programming problem. An augmented Lagrangean algorithm is applied to solve the resulting problem. Xu and Zhai [20] considered a two-stage supply chain coordination problem under fuzzy demand constraints. They investigated the optimization of the vertically integrated two-stage supply chain under perfect coordination and contrast with the non-coordination in case of the fuzzy demand. They proved that the maximum expected supply chain profit in a coordination situation is greater than the total profit in a non-coordination situation.

In this study, a fuzzy multi objective linear programming (FMOLP) model under fuzzy material requirement constraints are developed and optimized for production/distribution network of an edible vegetable oil manufacturer. The remainder of this study is organized as follows. In the second section, the proposed model is explained with its parameters and decision variables. In the third section, little information about the oils company and its whole process are given and then the