Expert Systems with Applications 42 (2015) 6237–6254

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Fuzzy multi-objective model for supplier selection and order allocation in reverse logistics systems under supply and demand uncertainty

Kamran S. Moghaddam

Department of Information Systems and Decision Sciences, Craig School of Business, California State University-Fresno, Fresno, CA 93740, USA

ARTICLE INFO

Article history:
Available online 19 February 2015

Keywords:
Reverse logistics systems
Supplier selection
Order allocation
Fuzzy multi-objective optimization
Fuzzy goal programming

ABSTRACT

In this research, we develop a fuzzy multi-objective mathematical model to identify and rank the candidate suppliers and find the optimal number of new and refurbished parts and final products in a reverse logistics network configuration. This modeling approach captures the inherent uncertainty in customers' demand, suppliers' capacity, and percentage of returned products as well as existence of conflicting objectives in reverse logistics systems. The objective functions in this study are defined as total profit, total defective parts, total late delivered parts, and economic risk factors associated with the candidate suppliers whereas the uncertainties are treated in a fuzzy environment. In order to avoid the subjective weighting from decision makers when solving the multi-objective model, a Monte Carlo simulation integrated with fuzzy goal programming is developed to determine the entire set of Pareto-optimal solutions of the proposed model. The effectiveness of the mathematical model and the proposed solution method in obtaining Pareto-optimal solutions is demonstrated in a numerical example from a real case study.

1. Introduction

The increasing trend in outsourcing of raw materials, unfinished/semi-finished parts, and final products and services has been enforcing companies to give more attention to outsourcing operations and their related decisions (Aissaoui, Haouari, & Hassini, 2007). With the pressure of global competition, companies strive to achieve excellence in delivering high quality and low cost products and services to their customers by improving the efficiency of their supply chain system to gain competitive advantages. Supply chain management deals with suppliers, manufacturers, distribution centers, and retailers to ensure the efficient flow of raw materials, work-in-process inventory, finished products, sales information, and funds among different parties to maximize total supply chain surplus (Chopra & Meindl, 2013). A growth in supply chain surplus increases the size of the total share and allows contributing organizations of the supply chain to make more profit. One of the important decisions that impact the company's performance as well as the entire supply chain competitiveness is supplier selection and order allocation to the selected suppliers.

Reverse logistics stands for all operations related to reuse of products and materials. It is the process of planning, implementing, and controlling the flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics (Fleischmann et al., 1997; Hawks, 2006). Logistics generally deals with events that bring final product towards the customer but in the case of reverse logistics the final product goes at least one step back in the supply chain. For instance, goods move from the customer to the distributor or to the manufacturer (Rengel & Seydl, 2002). In addition to identifying the candidate suppliers and allocate optimal orders to them, reverse logistics systems may include reuse, resale, repair, refurbishing, remanufacturing, and recycling operations. In the remanufacturing process, returned products are disassembled and then usable parts are collected, cleaned, refurbished, and transmitted to part inventory. In the next stage the new products are manufactured from the refurbished and new parts (Kim, Song, & Jeong, 2006). In most supply chains the purchasing function is a prominent task for most companies because the purchasing costs account for more than 50% of all companies' internal expenses (Aissaoui et al., 2007). In reverse logistics, new parts are purchased from external suppliers and used parts are obtained from used or returned products. Not only the cost of purchase is important but also other criteria of suppliers' performance play a vital role. For example, late

E-mail address: kmoghaddam@csufresno.edu

http://dx.doi.org/10.1016/j.eswa.2015.02.010
0957-4174/

delivery can negatively affect the production schedule and increases the final costs significantly. Hence, suppliers should be assessed based on several conflicting criteria and purchasing cost is only one of them. Supplier evaluation and selection problem is a multi-criteria decision making problem that includes both quantitative and qualitative factors such as total cost, on-time delivery, quality, customer satisfaction level, etc. The problem can be decomposed into two interrelated sub-problems:

(1) Which supplier(s) should be selected?
(2) How much/many should be purchased from each selected supplier?

Weber and Current (1993) declared this pair of decisions as the supplier selection problem. In addition to cost related factors in supplier evaluation and selection when reducing the number of suppliers, companies will encounter the risk of not having sufficient raw materials to meet their fluctuating demand. These risks might be caused by natural disasters or man-made actions (Li & Zabinsky, 2011). Environmental aspects and regulations are the other group of characteristics that should be considered in sustainable reverse logistics configurations. Recycling, clean technology, pollution reduction capacity, and environmental costs are examples of environmental aspects to be taken into account. It is observed that conservation of environment is becoming one of the designated goals in designing and operating sustainable reverse logistics systems (Amin & Zhang, 2012).

In this research, we extend the work of Amin and Zhang (2012), Arikan (2013) and Shaw, Shankara, Yadava, and Thakurb (2012) and develop a general reverse logistics network that includes suppliers, manufacturing/refurbishing sites, and disassembly facilities. The manufacturer uses new parts purchased from suppliers and refurbished parts from returned products to manufacture new products that are in demand by the customers. The main decisions of this system are the optimal set of candidate suppliers and refurbishing strategies along with the optimal number of products and parts to be positioned in each stage of the network. Since some important parameters of this system are associated with uncertainty the problem is formulated as a fuzzy multi-objective mathematical model in which the objective functions are total profit to be maximized, total number of defective parts purchased from suppliers to be minimized, total number of late delivered parts to be minimized, and economic risk factors of the candidate suppliers to be minimized. In order to avoid the subjective weighting from decision makers when solving the multi-objective model, a Monte Carlo simulation algorithm integrated with fuzzy goal programming is developed to determine the entire set of Pareto-optimal solutions (*aka* non-dominated solutions) of the proposed model.

The remainder of this paper is structured as follows: Section 2 reviews the current literature on network configuration in reverse logistics and also different decision models used in supplier evaluation and order allocation. Section 3 demonstrates formulation of the problem as a fuzzy multi-objective optimization model. Section 4 develops the solution methodology in which Monte Carlo simulation is integrated with fuzzy goal programming to find the Pareto-optimal solutions of the proposed multi-objective model. Section 5 details the computational results for a global manufacturing company as a sample problem and provides guidelines for the sourcing and refurbishing decisions. Section 6 concludes the paper by pointing out the benefits of inclusion of the fuzzy parameters and multiple objectives in the modeling approach and provides direction for future research and expansions.

2. Literature review

2.1. Network configuration in reverse logistics systems

Network design is one of the main research venues in reverse logistics systems and the majority of researchers apply facility location models to formulate such networks. However, there are few studies in which supplier selection techniques have been utilized during reverse logistics configuration. Fleischmann et al. (1997) reviewed and categorized reverse logistics networks and closed-loop supply chain systems literature into three main categories; distribution planning, inventory planning, and production planning. Melo, Nickel, and Saldanha-da-Gama (2009) examined the application of facility location models in supply chain management and segmented the literature of reverse logistics to closed-loop supply chains and recovery networks. Kim et al. (2006) developed a mathematical model to determine the quantity of parts and products in manufacturing and refurbishing facilities and the number of parts to be purchased from a single supplier while maximizing production cost savings. A mixed integer nonlinear programming model was formulated by Ko and Evans (2007) in order to model multi-period, two-echelon, multi-commodity, and capacitated network design problem with simultaneous forward and reverse flows of parts and products. Pati, Vrat, and Kumar (2008) proposed a goal programming model to determine the facility location, route, and flow of different types of recyclable wastepaper in a multi-product, multi-echelon and multi-facility decision making context. Lee, Gen, and Rhee (2009) formulated a mathematical model for a general closed-loop supply chain network and used genetic algorithm to solve the model. A mathematical model to maximize the profit of a remanufacturing system was presented by Shi, Zhang, and Sha (2011) and Amin and Zhang (2012) examined a general closed-loop supply chain network containing manufacturer, disassembly, refurbishing, and disposal sites and proposed a two-phase integrated model to select suppliers and refurbishing sites and to allocate number of parts and products to the network. In an another study, Amin and Zhang (2013) expanded their previous work by developing three-stage model that included evaluation, network configuration, and order allocation using fuzzy set theory. A multi-objective linear programming model is developed by Arikan (2013) to model and solve multiple sourcing supplier selection problem. The author defined three objective functions as minimization of costs, maximization of quality, and maximization of on-time delivery.

2.2. Decision models for supplier evaluation and selection

2.2.1. Mathematical programming methods

Narasimhan, Talluri, and Mahapatra (2006) formulated a mathematical model that effectively incorporated different types of products with different ranges of life cycles for optimally selecting suppliers and supplier bids. Ravindran, Bilsel, Wadhwa, and Yangc (2010) modeled the risk-adjusted supplier selection problem as a multi-criteria optimization problem and solved it in two phases. In their formulation, price, lead-time, risk of disruption due to natural event, and risk of quality were explicitly considered as four conflicting objectives to be minimized simultaneously. Li and Zabinsky (2011) developed a two-stage stochastic programming (SP) model and a chance-constrained programming (CCP) model to determine a minimal set of suppliers and optimal order quantities with consideration of business volume discounts. Two multi-objective mixed integer nonlinear models were developed for multi-period lot-sizing