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The fuzzy multi-objective distribution planner for a green meat supply chain

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A R T I C L E I N F O

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A B S T R A C T

It is often a complex task for developing a product distribution plan of a supply chain (SC) network and a supportive decision tool can be useful for easing the role of decision-making. On the other hand, it has been increasingly becoming a demand to design a supply chain network considering the environmental impact as a new dimension as required by authorities in many countries. This paper describes a development of a product distribution planner for a three-echelon green meat supply chain (MSC) design in terms of issues including numbers and locations of facilities that should be opened in association with the product quantity flows. These issues were formulated into a fuzzy multi-objective programming model (FMOPM) with an aim to minimize the total cost of transportation and implementation, the amount of CO_2 emissions in transportation and the distribution time of products from farms to abattoirs and from abattoirs to retailers, and maximize the average delivery rate in satisfying product quantity as requested by abattoirs and retailers. To optimize the four objectives simultaneously, three solution methods were investigated and used; which are the LP-metrics method, the ε-constraint method and the goal programming method. The best solution was determined using the Max-Min method by comparing the obtained Pareto solutions. A case study was examined based on the developed model that demonstrates its applicability in making an optimal product distribution plan in trade-offs among the four objectives.

1. Introduction

The global demand for food may be doubled by 2050, this makes food supply chains (FSC) as one of the key sectors in economy (Accorsi et al., 16,2016; Mattevi and Jones, 2016; Fritz and Schiefer, 2009). Thus, a robust design of food supply chain network is essential for a success to survive in an increasingly competitive market. This involves a strategic decision in a determination of location and allocation of relevant facilities and a tactical decision in quantity flow of products travelling throughout the supply chain network.

Today, environmental issues are equally important and should be taken into account when designing a supply chain network. Besides, in today's competitive economy, many parameters such as cost and potential market demand can vary. Thus, in recent years, issues of uncertainty (such as varying costs and demands) need also to be taken into account when design a supply chain network (Fattahi et al., 2015; Davis, 1993). A number of researchers applied fuzzy multi-objective optimization methods to tackle the randomness in input data of supply chain networks (Wang and Hsu, 2010; Qin and Ji, 2010; Gholamiana et al., 2015). In recent years, the concern of food safety is a big issue and customers demand more transparency for real time information on food they purchase in food stores. One of solutions on this is to implement RFID-based supply chain networks using an RFID system which, however, is subject to an additional cost in investments that should be considered in FSC.

In this paper, a fuzzy multi-objective optimization model for tackling a distribution planning problem for a meat supply chain network under multiple uncertainties (e.g. costs, demand and capacity levels of related facilities) was developed. The model was used aiming to minimize the total transportation and implementation cost, the amount of CO_2 emissions in transportation, the distribution time of products from farms to retailers, and maximize the average delivery rate in satisfying product quantity as requested by abattoirs and retailers.

The rest of this article proceeds as follows: Section 2 is dedicated to a review of literature. Section 3 presents the model development including the problem description, notations and model formulation, followed by an optimization strategy thoroughly presented in Section 4. Section 5 shows implementation and evaluation of the developed model. Finally, conclusions are given in Section 6.

2. Literature review

This section presents some prior research studies in the relevant

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field of multi-objective optimization in food supply chains, fuzzy multi-objective optimization in supply chains and multi-objective optimization in green supply chains.

2.1. Multi-objective optimization in food supply chains

There are a few publications in research using multi-objective optimization in the context of FSC management. Rong et al. (2011) developed a mixed integer linear programming model for solving a production and distribution planning problem of a food supply chain. Paksoy et al. (2012) developed a fuzzy multi objective linear programming model for talking an optimization problem of a production distribution network of an edible vegetable oil manufacturer. Sahar et al. (2014) proposed a multi-objective optimization model of a two-layer dairy supply chain aimed at minimizing the amount of CO_2 emissions for transportation and the total cost for the product distribution. Similar studies were published by Robinson and Wilcox (2008) and Pagell and Wu (2009). Teimoury et al. (2013) developed a multi-objective model which was used for identifying the best import quota policy of a supply chain providing fruits and vegetables. García-Flores et al. (2014) developed a mathematical optimization model aimed at determining an allocation of the optimal location of cattle rest sites and the optimal flow from breeding farms to ports, abattoirs and sale-yards. Bortolini et al. (2016) proposed a three-objective distribution planner to tackle the tactical optimization issue of a fresh food distribution network. The optimization objectives were to minimize operating cost, carbon footprint and delivery time; the research work, however, did not consider other costs and the effect of uncertainty that may occur.

2.2. Fuzzy multi-objective optimization in supply chains

A number of studies focused on the provision of fuzzy programming techniques in the context of solving supply chain network design and distribution problems (Wang and Hsu, 2010; Qin and Ji, 2010; Gholamiana et al., 2015). Vidal and Goetschalckx (1997) and Snyder (2006) reviewed supply chain distribution planning issues in data uncertainty. Petrovic et al. (1998) employed a fuzzy approach applied into a simulation model of a supply chain. The approach was developed to assist in decision making on operational supply chain control in an uncertain environment. The objective was to obtain a compromise between maximization of profit and maximization of service level. Shih (1999) addressed the cement transportation planning issue using fuzzy linear programming approaches. Sakawa et al. (2001) developed a fuzzy mathematical programming model used for minimizing costs of production and transportation of products in a manufacturer. The model aimed at handling the obscure estimation of parameters for the capacities of the factories and the demands in the regions. Liu and Kao (2004) proposed a method to obtain the membership function of the total transport cost as a fuzzy objective value where the cost coefficients and the supply and demand quantities are considered as imprecise parameters. Wang and Shu (2005) investigated a fuzzy decision strategy that helps tackle the issue of uncertainties of a supply chain. Liang (2006) formulated an interactive fuzzy multi-objective linear programming model to solve fuzzy multi-objective transportation problems. The model objectives were minimizing the total distribution cost and the total delivery time. Wang and Shu (2007) developed a possibilistic model used for the supply chain network design that a genetic algorithm was applied to seek a near-optimal solution. Aliev et al. (2007) presented a fuzzy integrated multi-period and multi-product production and distribution model of a supply chain network. The model was formulated in terms of fuzzy programming and the solution was provided by a genetic algorithm. Selim et al. (2008) formulated a multi-objective linear programming model aimed at determining the optimum facility location and allocation and the optimum capacity levels of a warehouses that satisfies product quantity requested by retailers. Torabi and Hassini (2008) provided a supply chain master planning model, which consists of multiple suppliers, one manufacturer and multiple distribution centers. The model was formulated as a multi-objective possibilistic mixed integer linear programming model considering the imprecise nature of market demands, cost/time coefficients and capacity levels. Peidro et al. (2009) proposed a fuzzy mono-objective mixed-integer linear programming model used for a supply chain tactical planning in which the total cost was to be minimized. Zarandi et al. (2011) used the interactive fuzzy goal programming method in order to solve the network design optimization problem of a closed-loop supply chain. Liu and Papageorgiou (2013) addressed issues in production, distribution and capacity planning of a global supply chain and developed a multi-objective mixed-integer linear programming approach in opimization of the total cost, the flow time and the loss of sales as three objectives. Özceylan and Paksoy (2013) employed a fuzzy multi-objective linear programming method for solving fuzzy bi-objective reverse logistics network design problems. Two objectives were considered including minimization of the total cost and the total delivery time of the system simultaneously. Özceylan and Paksoy (2014) examined strategic and tactical problems for a closed-loop supply chain (CLSC) network and a fuzzy multi-objective mixed-integer non-linear programming model was proposed to tackle these optimization issues.

2.3. Multi-objective optimization in green supply chains

In recent years, the research in supply chains has been growing. Paksoy et al. (2012) provided a fuzzy multi-objective model for helping design a green closed-loop supply chain network by minimizing all the transportation costs and the amount of total CO_2 emissions. Pishvaee and Razmi (2012) proposed a multi-objective fuzzy mathematical programming model for designing a supply chain network towards the optimization of two objectives, which are minimization of the total cost and the environmental impact of wastes. Kannan et al. (2013) proposed an approach to rank and select the best green suppliers of a supply chain according to economic and environmental criteria allocating the optimum order quantities among them. The proposed approach is a combination of the fuzzy multi-attribute utility theory and multi-objective programming. Harris et al. (2014) proposed a multi-objective optimization approach for solving a facility location–allocation problem of a supply chain network where financial costs and CO_2 emissions are considered as objectives. Talaei et al. (2015) presented a bi-objective facility location-allocation model for a closed loop supply chain network design using a robust and fuzzy programming approache to investigate the effects of uncertainties of the variable costs and the demand rate on the network.

The literature review showed that several studies applied the fuzzy optimization approach to supply chains network design. To the best of our knowledge, limited or no study applied the fuzzy optimization approach in the context of green FSCs considering (i) multiple uncertainties in the input data such as costs, demand and capacity levels and (ii) strategic and tactical design decisions.

The main contributions of this article can be summarized as follows:

- It presents a development of a fuzzy multi-objective programming model of a three-echelon green meat supply chain. The model can be used as a product distribution planner in supporting strategic and tactical design decisions.
- The work considers the optimization of four key objectives for a successful FSC including minimization of total transportation and implementation cost, minimization of CO_2 emissions in transportation, maximization of the average delivery rate and minimization of