Journal of Purchasing & Supply Management 23 (2017) 211–220

Contents lists available at ScienceDirect

Journal of Purchasing & Supply Management

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

A fuzzy multi-objective programming approach for determination of resilient supply portfolio under supply failure risks

Shyh-hwang Lee

Graduate School of Business and Administration, Shu-Te University of Science and Technology, Kaohsiung City, Taiwan (R.O.C.)

A R T I C L E I N F O

Keywords:
Resilient supply portfolio
Supplier order allocation
Supply failure risk
Emergency capacity
Fuzzy multi-objective programming

A B S T R A C T

The main contribution of this paper is to develop a new decision tool that interprets strategies for determination of resilient supply portfolio under supply failure risks. The strategic decisions include the allocation of emergency capacities to be pre-positioned at backup suppliers, the output of which can be increased in the event of mitigating a shortage caused by another supplier's failure. The model contains three objective functions – minimising the total cost, minimising the net rejected items and minimising the net late deliveries – while satisfying capacity and minimum order quantity requirement constraints. A weighted additive fuzzy multi-objective model is proposed to simultaneously consider the imprecision of information and the relative importance of objectives for determining the allocation of order quantity and emergency capacity to each supplier. The application of the proposed model is illustrated using an example case of global supply chains with different supplier characteristics.

1. Introduction

The purchasing function and associated decisions are a managerial priority. The cost of component parts in most companies constitutes up to 70% of the total cost (Holweg et al., 2011). In such circumstances, the purchasing department can play a key role in cost reduction. Supplier selection, especially in the area of assigning orders among appropriate suppliers, is one of the most important functions of purchasing management (Tempelmeier, 2002; Aissaoui et al., 2007). In order to optimally allocate the buyer's total demand among selected suppliers, different purchasing criteria are considered. Traditionally, studies on the supplier selection and order allocation (SS & OA) problem have expatiated on cost, quality and delivery time. However, modern supply chains are exposed to the increasing supply failure risks of unexpected natural or man-made disasters such as earthquakes, fires, floods, volcanic eruptions, hurricanes, transport accidents or equipment breakdowns, labour strikes, economic crisis or bankruptcy, deliberate sabotage or terrorist attack (Heckmann et al., 2015). Supply failure risk can be defined as “the probability that supply of an item will be affected because of problems at the supplier's end and the resulting costs as its impact” (Zsidisin, 2003; Sarkar and Mohapatra, 2009). Generally speaking, supply failure risk can be divided into two risk categories: operational and disruption (Tang, 2006; Torabi et al., 2015). Operational risks refer to those inherent uncertainties that inevitably exist in supply systems. These include, but are not limited to, supply uncertainty due to poor quality, environmental problems, operational inflexibility or difficulties (Torabi et al., 2015). Disruption risks refer to the major disruptions caused by unexpected natural or man-made disasters such as earthquakes, floods, volcanic eruptions, hurricanes, transport accidents, deliberate sabotage or terrorist attacks (Heckmann et al., 2015).

Most firms have reported that their supply chains are vulnerable to supply failures with large unanticipated consequences of seemingly contained incidents (Harland et al., 2003). For example, the recent earthquake and tsunami in Japan severely affected global electronics production and led to extended business disruptions for the automotive industry. In October 2011, the catastrophic floods in Thailand, where almost 1000 electronics factories were concentrated, caused business disruption in global supply chains and resulted in an estimated US$20 billion in losses (The World Bank, 2011). These disruptions are detrimental to businesses from the lost productivity and revenue standpoint. In a 2011 survey by The World Economic Forum (2011), more than 90% of respondents, almost 400 executives across 10 major industries, indicated that supply chain and transport risk management has become a greater priority in their organisations. Therefore, providing a resilient supply portfolio to protect the buyer from shortages and disruption in the supply chain is all the more critical. Resilience can be defined as “the adaptive capability of a firm to survive, adapt, and grow in the face of change and uncertainty” (Fiksel, 2006). Resilient supply portfolio, for purchasing and supply management, refers to a resilient portfolio of suppliers with flexible capability of supplying parts in the face of disruption events due to supply failure

E-mail address: shlee@stu.edu.tw.

http://dx.doi.org/10.1016/j.pursup.2017.01.003
Received 6 May 2016; Received in revised form 23 December 2016; Accepted 10 January 2017
Available online 30 January 2017
1478-4092/

– this includes, for instance, the pre-positioned emergency output capacities at backup suppliers for crucial operations or business functions in the events (Sawik, 2013; Torabi et al., 2015).

The unanticipated consequences of supply failures and their impacts on companies' performance have vividly demonstrated the recent need for changes regarding traditional strategies (Snyder et al., 2005). This motivated researchers and practitioners to increasingly explore how companies can overcome impacts arising from sudden and unforeseen events by means of resilient practices (Zsidisin and Wagner, 2010; Carvalho et al., 2012; Sawik, 2013; Pereira et al., 2014; Torabi et al., 2015). In this context, we review the most relevant published works addressing the SS & OA problem under supply failure risks and accounting for resilient supply chains, specifically as they use common mitigation strategies in the supply side of a supply chain for improving supply chain resilience. It is remarked that research on the SS & OA problem under supply failure risks has not been well-explored in the recent area of “resilience”. In particular, the research on quantitative approaches for building a resilient portfolio of suppliers with the consideration of proactive strategies is very limited in the current literature (Sawik, 2013). It addresses an important research gap in purchasing and supply management, especially those addressing the SS & OA problem under supply failure risk. Hence, the development of a managerial decision tool that helps procurement managers better select the supply base to cope with supply failures more effectively is considered the incentive and motivation of conducting this work.

This paper aims to develop a new decision model that considers contracting with backup suppliers a portion of allocation remaining capacity to build a resilient supply portfolio under supply failure risks. Contracting with backup suppliers is one of the important approaches aiming to ameliorate supply failure risk (Torabi et al., 2015). A portion of allocation remaining capacity can be pre-positioned at backup suppliers. The capacity of the supplier that does not fail remains unchanged under a disruption event, and the pre-positioned emergency capacity output can be used to replace non-delivered parts from failed suppliers hit by disruptions in the event.

The central question of this research is how to build a fortification (protection against supply failure) model, considering such resilient practices, that aids the decisions as to which supplier to select for parts delivery and how to allocate order quantities among the selected suppliers, and which of the selected suppliers to protect against disruptions and how to allocate emergency capacity among the backup suppliers. For a real-life supplier selection, decision makers need to specify multiple objectives with different weights and to deal with the problem of uncertainty related to the objectives. To this end, a weighted additive fuzzy multi-objective model, which has been widely used in multi-objective supplier selection problems (Amid et al., 2009; Yücel and Guneri, 2011; Shaw et al., 2012), is proposed to simultaneously consider the imprecision of information and the relative importance of objectives for determining a resilient supply portfolio against supply failures. The model accounts for the uncertainty of critical data, such as some costs being difficult to measure, and with net rejected items and net late deliveries being considered as vague goals.

To the best of our knowledge, this paper is the first in the literature to quantitatively account for protection decisions on contracting with backup suppliers' emergency capacities against supply failure in the SS & OA problem. A number of theoretical and practical implications are concluded as a result of this study. Likewise, for these implications, the light shed on the issues underpinning the development of a resilient supply portfolio from a procurement perspective can also be considered a contribution to the purchasing and supply management literature as well as its practice. The remainder of this paper is organised as follows: Section 2 provides a review of the related literature. Section 3 includes the problem description and model development. A weighted additive fuzzy programming approach is developed in Section 4. An application case and sensitivity analysis is presented in Section 5. Finally, conclusions are made in the last section.

2. Literature review

A large number of studies are available in the literature on SS & OA problems. Here, a review of the relevant literature is presented below in two distinct but related research streams: supplier order allocation under supply failure risk and resilient supply chain.

2.1. Order allocation under supply failure risk

The SS & OA problem has been a focus of research since 1950. Aissaoui et al. (2007) present a literature review that covers the entire purchasing process, focusses on the final SS & OA stage, and addresses a strong need for a systematic approach to purchasing decision-making, especially in the area of assigning orders among appropriate suppliers. As the risk of supply disruption is increasingly important for a purchasing company, researchers have also made a lot of efforts to handle this problem (Shin et al., 2000; Berger and Zeng, 2006; Yu et al., 2009). A variety of models have been proposed to support decision-making regarding the allocation of demand across the suppliers for strategic components. We concentrate mainly on works addressing the SS & OA problem under supply failure risk and employing computational models. Basically, published works can be divided into two groups – single objective and multiple objective – and are validated by different quantitative and analytical methods (i.e. mathematical, optimisation and simulation modelling efforts).

Single-objective programming methods aim at minimising total procurement costs. Some of the main works dealing with this issue are reviewed in this study. For instance, Federgruen and Yang (2008) analysed a planning model for a firm that needs to cover uncertain demand and supply risks for a given item by procuring supplies from multiple sources. Each source faces a random yield factor with a general probability distribution. Two approximations were developed for the shortfall probability, on the basis of which the aggregate order and its allocation among the suppliers are determined. Xanthopoulos et al. (2012) developed generic single-period inventory models for both risk-neutral and risk-averse decision makers to capture the trade-off between inventory policies and supply disruption risks in managing uncertainties and risks in dual-sourcing supply chains. Meena and Sarmah (2013) developed a mixed integer non-linear programming model for order allocation by a manufacturer/buyer among multiple suppliers under supply disruption risks, while aiming to minimise the total cost by considering different capacities, failure probabilities and quantity discounts for each supplier.

In the above-mentioned single-objective programming models, only one criterion is considered as an objective function, and the other relevant criteria such as quality and lead time are modelled as constraints. To overcome these limitations, some researchers suggest the use of multi-objective programming methods, which were first introduced by Weber and Current (1993) for supplier selection. Many authors assert that this alternative allows the various criteria to be evaluated in their natural units of measurement and has several advantages over single-objective analysis (Aissaoui et al., 2007). For example, Azaron et al. (2008) develop a multi-objective stochastic programming approach for supply chain design under uncertainty. Three objective functions are considered in the traditional supply chain design problem: minimising the sum of current investment costs and the expected future expansion costs, minimising the variance of the total cost, and minimising the financial risk. To decide on supplier selection, Wu et al. (2010) propose a fuzzy multi-objective programming model that takes risk factors into consideration. Possibility multi-objective programming models are obtained by applying possibility measures of fuzzy events to fuzzy multi-objective programming models. Shaw et al. (2012) present an integrated approach for supplier selection and quota allocation, addressing the carbon emission issue, using fuzzy-AHP and fuzzy multi-objective linear programming.