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Omega 35 (2007) 104 – 115

omega
The International Journal of Management Science

www.elsevier.com/locate/omega

The optimal number of suppliers considering the costs of individual supplier failures ☆

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Received 7 February 2005; accepted 26 April 2005
Available online 29 June 2005

Abstract

This paper utilizes the decision tree approach to determine the optimal number of suppliers in the presence of supplier failure risks. Previous proposed models have considered only two states of nature: all suppliers fail to deliver and not all suppliers fail to deliver. In practice, however, there is clearly a partial loss associated with the failure of any individual supplier. We present models that allow a more realistic decision-making process by taking into consideration the independent risks of individual supplier failures when the probability of failure for each of the suppliers is equal as well as the case where the probability of failure from each of the suppliers is not equal. We also consider various levels of supplier failure probability and possible procurement or operating cost savings gained from using less reliable suppliers. The results indicate that when suppliers are highly reliable, sole sourcing is the lowest cost approach under all experimental conditions. However, as the suppliers become less reliable, additional suppliers may be required to obtain the lowest cost. Finally, it was shown that only in the extreme conditions of unreliable suppliers, high loss to operational cost per supplier, and low ability to mitigate the failure from a partial set of suppliers, having a large number of suppliers is an effective strategy.
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Keywords: Supply chain management; Sourcing; Purchasing; Risk analysis

1. Introduction

The importance of supplier decisions continues to grow as corporations emphasize outsourcing and supply chain partnerships, and commit a growing percentage of their fortunes to their suppliers [1]. Furthermore, as a result of the widespread adoption of "lean" practices, typically smaller amounts of safety stock is carried, resulting in lost production capability in case of supplier delivery disruptions. Such disruptions could not only occur due to supplier failure, but also from a variety of other factors such as natural disasters, war, terrorism, outbreak of diseases, and logistical factors [2–5].

The problem of supplier selection and the associated decision of the number of suppliers to have has been tackled by multiple researchers (e.g., [6–9]). These decisions consider cost and risk factors including all areas of logistics such as transportation, inventory management, and customer service [10].

This paper presents an extension to the models proposed by Berger et al. [11] which consider risk associated with the number of suppliers to have. The risks considered in Berger et al. [11] include catastrophic *super* events, which affect all suppliers, as well as *unique* events which affect a

☆ This paper was processed by Associate Editor RD Metters

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doi:10.1016/j.omega.2005.04.005

single supplier. The unique events might include fire, hurricane, flood, bankruptcy, local strike, etc. The costs considered are the operational cost of dealing with the suppliers and the loss cost of all suppliers not being able to deliver. To jointly consider the risk and cost associated with using multiple suppliers or a single supplier, they modeled the decision-making process using a decision tree. For each decision tree choice, they considered only two states of nature: all suppliers are down and not all suppliers are down.

In this paper, we consider the partial costs resulting from having some of the suppliers down. This is done by dividing the loss of all suppliers down as to have a partial cost of one supplier down, two suppliers down, up to having all suppliers down, as described in Section 3. This allows a more realistic decision-making process by taking into consideration the independent risks of individual supplier failures. We also consider various levels of supplier failure probability and possible purchase or operating cost savings gained from using riskier suppliers. Finally, we examine a variety of cases aimed at understanding supplier risk versus total cost behavior.

The paper is organized as follows; Section 2 briefly presents the original model presented by Berger et al. [11]. We refer to this model as the BGZ model hereafter. Section 3 proposes an extension to this model that considers the financial loss related to the failure of any of the suppliers when the probability of failure for each of the suppliers is equal. We also propose a second extension that considers the financial loss of any of the suppliers where the probability of failure from each of the suppliers is not equal. Section 4 compares the BGZ and the proposed models by conducting a sensitivity analysis in order to better understand the effect of the input parameters on the optimal number of suppliers. Finally, Section 5 discusses the conclusions and managerial implications and provides directions for future work.

2. The BGZ model

During a supply cycle the probability of a *super* event that results in all suppliers down is P^*, and the probability of having supplier j down is U_j. Assuming that U_k is independent of U_j for $k \neq j$, and U_j and P^* are independent events, the probability that supplier j cannot deliver during the supply cycle is $P^*+(1-P^*)U_j$. If there is a single supplier the probability of this supplier being down is $P^*+(1-P^*)U_1$ while if there are two suppliers, the probability that both will be unable to deliver is $P^*+(1-P^*)U_1U_2$.

When all n suppliers are down, the financial loss to the decision making company is given by L, and the cost of operating n suppliers is given by $C(n)$. Based on the BGZ assumption that $C(n) = a + bn$, we define the Expected Supplier Costs (ESC) as

$$\mathrm{ESC}_{\mathrm{BGZ}} = C(n) = a + bn.$$

Furthermore, given the unique probability of down is about the same for each supplier (i.e., $U_1 = U_2 = \cdots = U_n = U$), and that there are only two states of nature: *all suppliers down* and *not all suppliers are down*, the following Expected Loss Costs (ELC) for the BGZ model are defined as

$$\mathrm{ELC}_{\mathrm{BGZ}}(n) = L(P^* + (1-P^*)U^n).$$

Therefore a loss is incurred when a *super* event occurs with a probability of P^*, and if all suppliers are down (and no *super* event) with a probability of $(1-P^*)U^n$. Finally, the Expected Total Cost (ETC) is determined by

$$\mathrm{ETC}_{\mathrm{BGZ}}(n) = \mathrm{ESC}_{\mathrm{BGZ}} + \mathrm{ELC}_{\mathrm{BGZ}}.$$

3. Partial loss per supplier down model

In practice there is clearly a partial loss associated with the failure from any of the suppliers, unless as assumed in the BGZ model, the other suppliers that are "not down" can make up the shortfall at no extra cost. Thus, we propose that the loss from all suppliers down, L, be divided into $A_{[1,n]}, A_{[2,n]} \ldots A_{[n,n]}$, where $A_{[1,n]}$ represents the partial loss associated with the first supplier who fails, while $A_{[2,n]}$ relates to the additional loss associated with the second supplier who fails, etc. We propose that the sum of all partial losses be equal to the loss of all suppliers down, therefore

$$L = \sum_{j=1\ldots n} A_{[j,n]}.$$

Let $Z_{[j,n]}$ be defined as the cumulative loss when j of the n suppliers fail:

$$Z_{[j,n]} = \sum_{j=1\ldots j} A_{[j,n]}, \quad \text{thus } Z_{[n,n]} = L.$$

To model the partial losses of individual supplier failures we must consider the probability of supplier failures under multiple states of nature or outcomes. There are $n+1$ possible outcomes. For example, in the case the number of suppliers (n) is 2, the three possible outcomes are all suppliers down, one supplier down, and none of the suppliers down. Let $P_{[j,n]}$ represent the probability that j of the n suppliers fail to deliver not considering the *super* event probability. Using this notation, the ELC function for the BGZ model is represented by

$$\mathrm{ELC}_{\mathrm{BGZ}}(n) = L(P^* + (1-P^*)P_{[n,n]}).$$

The ELC for the partial loss per supplier down formulation ($\mathrm{ELC}_{\mathrm{PLSD}}$) is:

$$\mathrm{ELC}_{\mathrm{PLSD}}(n) = LP^* + (1-P^*)(Z_{[1,n]}P_{[1,n]} + \cdots + Z_{[n-1,n]}P_{[n-1,n]} + LP_{[n,n]})$$

Clearly, when $n=1$, $\mathrm{ELC}_{\mathrm{BGZ}} = \mathrm{ELC}_{\mathrm{PLSD}}$. However, when $n>1$, $\mathrm{ELC}_{\mathrm{PLSD}}(n) > \mathrm{ELC}_{\mathrm{BGZ}}(n)$.

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