

Supplier selection under the risk of supply disruptions

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Abstract

This paper studies a supplier selection problem under the risk of supply disruptions. In this paper, we have developed an analytical model to determine the optimal number of supplier considering the risk of supplier failure due to the catastrophic events disruption. A simple algorithm is designed here to find the optimal solution and a numerical study is carried out to check the performance of the algorithm. This study contributes to the literature towards supplier selection under supply disruption risks by considering different capacity and failure probability for each supplier.

Keywords: Supply base, supplier selection, disruptions risk, optimal number of suppliers

1. Introduction

Supplier selection is one of the critical issues for most of the purchasing managers, as companies are trying to integrate their supply chains in order to reduce costs, shorten production lead times, increase quality and improve relationships with suppliers. Recently, due to the pressure of cost reduction and development of various logistics theories and practices, like just-in-time philosophy, lean production etc., the trend of supply base reduction has been increased. Choi and Krause [1] have defined supply base as a group of suppliers from which manufacturer purchases parts, materials, and services. The reduction of supply base promotes cost-effectiveness, higher quality of coordination, improved delivery performance, and a desire for continuous improvement and innovation ([2]). However, reduced supply base increases the supply risks for buying organization ([3–4]). A well known example regarding the drawback of single sourcing or reduced supply base is the fire at Ericsson supplier (Philips microchip) plant in Albuquerque, New Mexico, in 2000, led Ericsson to a loss of about 400 million Euros. Recently, supply disruption risks have been started receiving attention from the managers and researchers. One of the reasons for this growing attention is the spate of recent high-profile catastrophic events disruption, such as 9/11, the hurricanes Katrina, Rita in 2005, the Asian tsunami in 2004. The widespread disruptions are cited in the literature ([4–8, 12]).

According to India Business Continuity Survey report [9], more than half of the respondents (out of 131 respondents from 95 organizations) have reported that at least one significant business disruption organizations have faced in year 2008, and the average number of significant disruptions per organization have increased to 1.8 compared to 1.6 in year 2007. The survey also mentioned that the average loss per disruption in 2008 has increased significantly to Rs. 20.5 Crores compared to Rs. 7.7 Crores in 2007, which is an increase of nearly 200%. Tomlin [10] has suggested sourcing as one the efficient strategy to cope with risks of supply disruption. Though the dual sourcing or multiple sourcing are more reliable for purchasing organization, however, these strategies may increase the management cost which includes cost of managing a supplier contract, and monitoring the quality. Therefore in today's competitive and unstable environment, the task before buying firms is to find the optimal number of supplier to balance between supplier management cost and supply risks cost in order to minimize the total cost. So far there is limited research pertaining to sourcing decision under risks of supply disruption. In this study, we aim to extend the work of [11] by relaxing the assumptions of equal capacity, failure probability for all suppliers for determining the optimal number of suppliers to minimize the total cost considering risks of catastrophic events disruption.

The paper is organized as follows. The development of analytical model is provided in section 2. The solution algorithm and results of the study are given in Section 3. The numerical illustration and sensitivity analysis are provided in section 4 and 5 respectively. Section 6 discusses the conclusions and future scopes of the study.

2. Model Development

Supplier selection is generally carried out in two stages. First stage deals with pre-qualification of suppliers and in second stage, the final supplier selection is done. Our focus is on second stage. After qualification stage, only limited suppliers remain in supply base. In this paper, we assume that a set of supplier is already selected based on the different criteria. We have considered a single period, single item and two stage supply chain involving single manufacturer and n number of suppliers.

2.1 Notations and Assumptions

The following notations and assumptions are used throughout this paper to develop the proposed models.

Assumptions

In the development of the model, we have considered the following assumptions.

- i. The demand of manufacturer is deterministic over a period.
- ii. Manufacturer demand is split equally between suppliers.
- iii. Number of potential suppliers is known.
- iv. Management cost has a linear relationship with the number of suppliers.
- v. Each supplier has different capacity.
- vi. The unique events failure probability is different for all potential suppliers.

Notations

D	Total demand of manufacturer over a cycle	Q_i	Capacity of supplier(s) who fail ($i=1, 2, 3, \dots, r$)
a	Purchasing cost (monetary/unit)	Q_j	Capacity of supplier(s) who don't fail ($j=1, 2, 3, \dots, S$)
b	Management cost (mu/supplier)	P^*	Probability of occurrence of super-event that would fail all suppliers
n	Number of potential suppliers ($n=1, 2, 3, \dots, N$)	U_z	Probability of occurrence of unique-event that down a single supplier ($z=1, 2, 3, \dots, k$)
y^*	Optimal number of suppliers	K_j	Compensation of suppliers that don't fail. where, $K_j = \left(Q_j - \frac{D}{n} \right)$
C_L	Loss per not received unit (mu)	$A(ni)$	Set of suppliers who fail, $A(ni) = \{(A(n1)), (A(n2)), \dots, (A(nr))\}$ where, $A(n1)$ is set of any one supplier who fail $A(n2)$ is the set of any two suppliers who fail
Q_z	Capacity of individual supplier ($z=1, 2, 3, \dots, k$)	$B(mj)$	Set of suppliers who don't fail $B(mj) = \{(B(m1)), (B(m2)), \dots, (B(mS))\}$ where $B(m1)$ is the set of not failed suppliers, when there is one out of n suppliers fail
Q_n	Total capacity of all suppliers	l_1	Loss associated with one supplier failure (mu)
		l_2	Loss associated with two suppliers failure (mu)

2.2 Purchasing and Management Costs

The management cost includes the cost of managing a supplier contract, and monitoring the quality etc. The purchasing and managing cost of n number of suppliers is denoted by $PC(n)$.

$$PC(n) = a + b(n) \quad (1)$$

2.3 Supplier Failure Cost

Supplier failure cost is the expected loss face by the manufacturer when a supplier(s) fails to supply the negotiated or allocated demand due to the occurrence of catastrophic events disruptions. In this paper, we have considered two types of catastrophic events namely, super-event and unique-events. Occurrence of a super-event downs all

suppliers, whereas the occurrence of unique-event downs a single supplier. When all suppliers fail to supply due to occurrence of super-event then the expected total loss to manufacture is $(Q_n \times P^*)$. Yand and Qian [11] have assumed equal capacity and failure probability for all suppliers. In this study, we have relaxed these assumptions and considered different capacity and failure probability for each supplier. We show below, how the occurrence of unique event causing individual suppliers to fail. For showing the same we assume $n = 3$. When the probability of super-event is zero then possible outcomes of supplier failure due to unique-event probability are given in Table 1.

Table 1: Possible outcomes of suppliers failure for $n=3$

Suppliers failure scenario	Outcome
Probability of zero supplier failure out of three suppliers	$(1 - P^*)P[0, 3]$
Probability of one supplier failure out of three suppliers	$(1 - P^*)P[1, 3]$
Probability of two suppliers failure out of three suppliers	$(1 - P^*)P[2, 3]$
Probability of all three suppliers failure	$P^* + (1 - P^*)P[3, 3]$

We introduce an indicative function $I_{[x]}$, if x holds then 1, otherwise equal 0. We have assumed that the surplus of supplier(s) who don't fail can compensate the unmet order quantity of the failed supplier(s). We have considered a case where each supplier has different capacity Q_z and unique failure probability U_z . Suppose D is the total demand of manufacturer and there are n potential suppliers available then according to our assumption, the total demand is equally split between potential suppliers. The amount of order quantity allocate to each suppliers is $\frac{D}{n}$,

so each supplier that do not fail has the ability of $\left(\sum_{i \in A(ni)} Q_i - \sum_{j \in B(mj)} K_j \right)$ to support the manufacturer. The total

failure cost is the expected loss associated with the failure of supplier due to occurrence of super-event and unique-events. We denote the expected supplier failure cost by $ESFc$. Therefore, expected suppliers failure cost is equal to

$$\begin{aligned}
 E S F c = & C_L \left[(Q_n \times P^*) + (1 - P^*) \left\{ \right. \right. \\
 & \left(I_{\left(\sum_{i \in A(ni)} Q_i - \sum_{j \in B(mj)} K_j \right) > 0} \times \left(\sum_{i \in A(ni)}^{A(n1)} Q_i - \sum_{j \in B(mj)}^{B(m1)} K_j \right) \times \left(\sum_{i \in A(ni)} \left(\frac{A(n1)}{U_i} \times \prod_{j \in B(mj)} (1 - U_j) \right) \right) \right) \\
 & + \left(I_{\left(\sum_{i \in A(ni)} Q_i - \sum_{j \in B(mj)} K_j \right) > 0} \times \left(\sum_{i \in A(ni)}^{A(n2)} Q_i - \sum_{j \in B(mj)}^{B(m2)} K_j \right) \times \left(\sum_{i \in A(ni)} \left(\frac{A(n2)}{U_i} \times \prod_{j \in B(mj)} (1 - U_j) \right) \right) \right) \\
 & + \dots + \left(I_{\left(\sum_{i \in A(ni)} Q_i \right) > 0} \times \left(\sum_{i \in A(ni)}^{A(nr)} Q_i \right) \times \left(\prod_{i \in A(ni)}^{A(nr)} U_i \right) \right) \left. \right\} \left. \right]
 \end{aligned} \tag{2}$$

where, $i \neq j$

2.4 Expected Total Cost

The total cost of manufacturer consists of three costs namely: purchasing cost, supplier management cost and supplier failure cost. We get the following expression for expected total cost (ETC) per period.

$$E T C (n) = P C (n) + E S F c \tag{3}$$

Using equation (1), (2) and (3), we get the following expected total cost per period for manufacturer

$$\begin{aligned}
ETC(n) = & a + b(n) + C_L \left[(Q_n \times P^*) + (1 - P^*) \left\{ \right. \right. \\
& \left(I \left(\sum_{i \in A(n)} Q_i - \sum_{j \in B(m)} K_j \right) > 0 \right) \times \left(\sum_{i \in A(n)} Q_i - \sum_{j \in B(m)} K_j \right) \times \left(\sum_{i \in A(n)} \left(\frac{A(n)}{U_i} \times \prod_{j \in B(m)} (1 - U_j) \right) \right) \\
& + \left(I \left(\sum_{i \in A(n)} Q_i - \sum_{j \in B(m)} K_j \right) > 0 \right) \times \left(\sum_{i \in A(n)} Q_i - \sum_{j \in B(m)} K_j \right) \times \left(\sum_{i \in A(n)} \left(\frac{A(n)}{U_i} \times \prod_{j \in B(m)} (1 - U_j) \right) \right) \\
& + \dots + \left(I \left(\sum_{i \in A(n)} Q_i \right) > 0 \right) \times \left(\sum_{i \in A(n)} Q_i \right) \times \left(\sum_{i \in A(n)} U_i \right) \left. \right\} \right]
\end{aligned} \tag{4}$$

where, $i \neq j$

3. Solution Algorithm

The past studies have used decision tree approach to solve the problem. But in our case, incorporation of new elements like different capacity and failure probability for all suppliers has made the problem more complex. Because of too many alternatives, the solution for this problem is too cumbersome to handle with decision tree. Therefore, we develop an efficient algorithm to determine the optimal number of suppliers in order to minimize the expected total cost under the risks of supplier failure due to catastrophic events disruption.

3.1 Step Wise Solution Procedure

Step 1: For $n=1$, check $\left(Q_z - \frac{D}{n} \right)$ to find eligible suppliers from the potential suppliers list.

Step 2: Calculate ETC for all eligible suppliers and select the supplier with minimum ETC.

Step 3: To reduce the ETC, increase the value of n to $(n+1)$, and check $\left(Q_z - \frac{D}{n} \right)$ to find new eligible suppliers from the potential suppliers.

Step 4: Calculate ETC for all the combinations of $(n+1)$ eligible suppliers and select suppliers' combination with minimum ETC.

Step 5: Check, if $(b / (l_1 - l_2)) > 1$ or $(b / (l_1 - l_2)) < 0$, then stop, and $(n+1) - 1$ value will be optimal number of suppliers. Else go to next step.

Step 6: Repeat step 3 to 5.

4. Numerical Illustration

This section presents the numerical study of determining the optimal number of suppliers by using proposed solution algorithm. We consider following parameter values for the numerical study. Total demand of the manufacturer D is 100 Units; purchasing cost of raw material a is 500 monetary; management cost per supplier b is 5 monetary; per unit loss due to supplier failure $C_L = 5$ monetary and the probability of occurrence of super event P^* is 0.01. We assume that 7 potential suppliers are pre-qualified on the basis of different criteria. The capacity and unique events probabilities for each supplier are given in Table 2.

Table 2: Capacity and unique-events probability of each supplier

Suppliers	Supplier capacity (units)	Unique-events probability
S1	110	0.50
S2	105	0.40
S3	95	0.30
S4	90	0.25
S5	80	0.20
S6	70	0.15
S7	60	0.10

4.1 Computational Results for Finding the Optimal Number of Suppliers

In this section, we determine the optimal number of suppliers by following the proposed solution algorithm discussed in last section.

CASE 1: Suppose manufacturer select one supplier from available potential suppliers.

- Check for $\left(Q_z - \frac{D}{n}\right)$ condition, to find eligible supplier(s)
- Capacities of 110 and 105 units are eligible suppliers
- Calculate ETC for each supplier and select the supplier with minimum ETC

There are only two eligible suppliers; therefore manufactures can choose any of the suppliers. The value of ETC for 105 units capacity supplier is less than the 110 units capacity supplier. Therefore, the capacity of 105 units is an efficient supplier.

CASE 2: When manufacturer select two suppliers from available seven potential suppliers

- Check for $\left(Q_z - \frac{D}{n}\right)$ condition, to find eligible supplier(s)
- Capacities of 110, 105, 80, 70, 60, 95, and 90 units are eligible suppliers
- Calculate ETC for each eligible supplier and select the combination of two suppliers that has minimum ETC

The combinations of selecting any two out of the seven eligible suppliers are 21. The value of ETC is 583.07 for capacity of 60 and 70 units suppliers and that is minimum as compared to other supplier combinations. Therefore, the set of 60 and 70 units capacity suppliers is an efficient combination. According to algorithm, we calculate $(b / (l_1 - l_2))$. Here the value of $(b / (l_1 - l_2))$ is equal to 0.039. This value is not more than 1 and less than 0 therefore, we go to next step.

CASE 3: When manufacturer select three suppliers from available seven potential suppliers

- Check for $\left(Q_z - \frac{D}{n}\right)$ condition, to find eligible supplier(s)
- Capacities of 110, 105, 80, 70, 60, 95, and 90 units are eligible suppliers
- Calculate ETC for each eligible supplier and select the combination of three suppliers that has minimum ETC

There are total 35 combinations of selecting any three suppliers from seven eligible suppliers. The minimum value of ETC is 571.37 for the capacity of 60, 70 and 80 units suppliers. Therefore the set of 60, 70 and 80 units suppliers is an efficient combination. Similar to last case we calculated the value of $(b / (l_1 - l_2))$ and that is equal to 0.299. This value is not exceeding 1 and not less than 0 therefore, we go to next step.

CASE 4: When manufacturer select four suppliers from available potential suppliers.

- Check for $\left(Q_z - \frac{D}{n}\right)$ condition, to find eligible supplier(s)
- Capacities of 110, 105, 80, 70, 60, 95, and 90 units are eligible suppliers
- Calculate ETC for each eligible supplier and select the combination of four suppliers that has minimum ETC

The combinations of selecting any four suppliers out of seven eligible suppliers are 35. The combination of 60, 70, 80 and 90 units capacity suppliers is having minimum ETC value i.e. 588.87, as compared to other suppliers combinations. Therefore, set of 60, 70, 80 and 90 units capacity suppliers is the efficient combination. Similar to last case, we calculated the value of $(b / (l_1 - l_2))$. In this case, the value of $(b / (l_1 - l_2))$ is less than 0 (i.e. - 0.399), therefore, we stop here. Following the 5th step of the algorithm, the optimal numbers of suppliers is 3. Therefore, the capacities of 60, 70 and 80 units are the efficient suppliers among the available supplier for minimizing the total expected cost.

5. Sensitivity Analysis

The sensitivity analysis is performed to see the effect of two different parameters namely; (i) super event probability and (ii) supplier management cost on the optimal solution.

- (i) **Sensitivity analysis of super event probability:** The sensitivity analysis is performed by varying the value of P^* while keeping other parameters value constant at their base value. As shown in Table 3 the value of P^* is

varied from 0.01 to 0.60. The results show that the value of P^* doesn't have substantial effect on y^* i.e. the optimal number of suppliers. Therefore, utilizing more number of supplier is not worthy under high risks of super event.

Table 3: Sensitivity analysis of value of P^*

P^*	y^*
0.01	3
0.02	3
0.07	2
0.10	2
0.30	2
0.40	1

Table 4: Sensitivity analysis of b

b	y^*
5	3
12	3
35	2
55	2
85	2
90	1

- (ii) **Sensitivity analysis of supplier management cost:** The value of b is varied keeping values of other parameters constant to perform the sensitivity as shown in Table 4. The results show that with the increasing value of b the value of optimal number of suppliers (y^*) decreases.

6. Conclusions and future works

In this work, we have studied the problem of supplier selection in the presence of supply disruption risks. In previous studies, the capacity and failure probability was considered equal for all the suppliers. Here, we have relaxed these assumptions. The incorporation of new elements like different capacity, failure probability and compensation has made the problem more complex. So the solution alternatives become too cumbersome to handle with decision tree. Therefore, we have developed an efficient algorithm to find the optimal solution. This study can be extended by relaxing the assumptions used in this work. The manufacturer demand assumed deterministic over a period, therefore it will be interesting to consider stochastic demand of manufacturer over a period. The another assumption that we made in this paper is equal allocation of manufacturer demand among suppliers, therefore development of a model considering uneven split of the demand between suppliers to determine the optimal number of suppliers under risk of supply disruption will be other extension to this work.

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