Optimal supplier number of a supply chain company under stochastic demand

Chen Liu¹, Wei Shan²* and Jing Yu³

¹Business School, University of Shanghai for Science and Technology, Shanghai 200093, China.
²School of Economics and Management, Beijing University of Aeronautics and Astronautics, Beijing 100191, China.
³Department of Political Science, East China Normal University, Shanghai 200241, China.

Accepted 26 October, 2011

This paper seeks to provide academic researches with a better understanding about the determination of supplier number to control supply chain risk. By introducing multi-supplier strategy and some assumptions of the suppliers, a supply chain model based on traditional newsvendor model is proposed. This model considers both supply risk and demand risk. A nonlinear integer programming model is built to determine an optimal supplier number of this supply chain, and the risks under this model are analyzed. Simulations are also made to test this model under different market demand distribution. This paper presents a supplier number determination model which can maximize expected profit of a supply chain company under supply risk and demand risk (stochastic demand).

Key words: Supply chain, supply chain risk, risk analysis, stochastic demand.

INTRODUCTION

As performance of modern enterprises rely heavily on their supply chain, competitions between them have become those of supply chain. All members on the chain are closely related with each other, which mean any broken links could be a deathblow to the chain as a whole. Such broken links could not only be resulted from failure of reputation and operation of a company but also from unexpected factors like natural disasters, terrorism, war, sickness, etc (Chopra and Sodhi, 2004). Well-known examples include the fire in New Mexico on March 17, 2000, which caused damage of millions of microchips and a sharp decline of market share of Ericsson in mobile phone. Another example is Ford who had to close down some factories due to the September 11 Terrorist Attacks. Besides broken risk, supply chains have to face with another risk stemmed from the stochastic demands at the same time.

This research studies method of selecting an optimal supplier number to maximize the expected revenue of a supply chain company under supplier failure risk and stochastic demands. The results are valuable in reducing supply chain risk including supplier failure risk and demands risk. In order to consider these two kinds of supply chain risk, a multi-supplier model was proposed. This model is based on traditional newsvendor model, in which optimal stock quantity is displaced by optimal supplier number. Theoretical analysis and simulation show that, in this model, the risk of supply shortage will close to zero and the stock quantity will close to expected market demand under sufficient supplier.

This paper is organized as follows; brief literature review on related fields containing supply chain risk control, supplier selection, and newsvendor model, etc; background and some assumptions of the model; model and risk analysis; example and simulations; conclusions, managerial implications and directions for future work.

LITERATURE REVIEW

As supply failure accounts for a large proportion of supply chain risks, it has been taken as one of the most important research areas of supply chain risk management. Cranfield Management School studied the risk factors of supply chain in their research project “Supply Chain Vulnerability”, and perceived supply risk as one of the six risk factors (Peck, 2005). Sheffi (2001) studied the impact of international terrorism on supply
chain, and pointed out that terrorism can cause delay or unavailability of materials from suppliers, and thus, leading to a supply shortage which would paralyze activities of a company. Hallikas et al. (2004) studied the process of risk management in supplier networks. He divided the risks in supplier network into four categories:

1) Too low or inappropriate demand
2) Problems in fulfilling customer deliveries
3) Cost management and pricing
4) Weaknesses in resources, development and flexibility.

In this research, Hallikas et al. (2004) also advanced a semi-quantitative method to assess supplier network risks. He divided risk impacts into five ranks, as well as risk probability. Then, he showed them in a risk diagram. By doing this, the most important risk gets the most important concern, and this method illustrated that the effective way to reduce supply network risks is to reduce the combination of risk probability and risk impact.

Supply risks include all the vulnerability in the logistic process from supplier to a company. But the most important factor is the reliability of suppliers. Reliable suppliers can significantly reduce supply risk, and supplier selection therefore becomes an important research area of supply chain risk management. Ting and Cho (2008) took supplier selection as a multi-criteria decision problem. They used analysis hierarchy process (AHP) to assess suppliers and built a multi-objective linear programming model to calculate optimal order quantity of the suppliers. Sevki et al. (2008) proposed a new approach called “analytical hierarchy process weighted fuzzy linear programming model (AHP-FLP)” for supplier selection. They found that AHP-FLP method is better than the AHP method for supplier selection with respect to restricted supplier selection criteria. Besides these researches, Taguchi loss functions (Ordoobadi, 2009) and data envelopment analysis (DEA) (Liu et al., 2000) were also used to study supplier assessment and selection problems.

Such researches on supplier selection mainly focused on supplier assessment. However, supplier number is also an important factor of supply risks. The problem whether to choose single sourcing strategy or multiple sourcing strategy has been studied using different methods (Hong and Hayya, 1992; Ghodsypour and O'Brien, 2001). Multiple sourcing strategies may cause longer management time and higher operation cost, and result in supply delay and production plan disruption. And companies, at the same time, have to bear additional costs such as technology, professional knowledge, quality control and transportation. Therefore, traditional management theories like “Just in time” emphasize on simplifying supply chain and reducing management complexity with a view to reducing costs,. From the perspective of the total cost of sourcing, it is supposed that a small number of suppliers be selected and long-term partnerships be established (Bakos and Brynjolfsson, 1993). But in the light of risk aversion, companies should source from as many suppliers as possible. Smeltzer and Siferd (1998) point out that reducing supplier number will lead to higher supply risk, especially risk of disruption when there is single one supplier and when an earthquake, war or terrorist attack happens. In addition to reducing supply risk, multi-sourcing can also reduce the purchaser’s dependency on product quality, price and delivery, and help them obtain cheap but high-quality service due to the competition of suppliers. Investigation of Johnson (2001) on American toy industry shows that producers adopt multi-sourcing strategy and placing order to suppliers in various countries in Southeast Asia so as to avoid supply risk brought by foreign exchange fluctuation, natural disasters, political upheaval, etc.

Considering both risk aversion and cost reduction, selection of an optimal supplier number becomes extremely important for a company. Berger et al. (2004) built a decision-making process using decision tree. They considered two kinds of risk events, that is, “super-events” impacting many/all suppliers and “unique events” impacting only one supplier. In the decision process, they assumed that either all suppliers are down or not all suppliers are down. Ruiz-Torres and Mahmoodi (2005) improved Berger’s model and proposed 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 and when it is not equal. In their model, partial failure of single supplier is considered.

These models consider only the risk on the supplying side. As a matter of fact, however, companies have to face with risks lying in stochastic demand. Newsvendor model provides a prototype to catch the demand risk. An optimal level of stock is determined in this model to estimate demand and maximize profit. Studies on this model mainly concentrated on price strategy and inventory strategy. Lin and Kroll (1997) investigated a single-item newsvendor model considering two types of quantity discount strategy. Their model “maximizes the expected profit subject to a constraint that the probability of achieving a target profit level is no less than a predetermined risk level”. Other related researches on newsvendor model include changing of model’s objective function (Kogan and Lou, 2003), constraint condition (Cherkikh, 2000), model parameters and decision variables (Dana and Petruzzi, 2001), etc. Heuristic algorithms (Erlebacher, 2000), iterative algorithms (Abdel-Malek and Areratchakul, 2007), and convex programming theory (Niederhoff, 2007) were used to solve the models. Newsvendor model is a type of single-stage supply chain model, and does not consider factors of supplier. The model in this research combines supplier selection theory with newsvendor mode, and considers both supply risk and demand risk in determining optimal
supplier number.

PROBLEM DESCRIPTION AND ASSUMPTIONS

Structure and risks of the supply chain

Figure 1 shows the supply chain structure of a company denoted by A. Suppose that company A sells only one kind of good, which is denoted by G. A can select one or more suppliers to meet market demand. The market demand of G is r, which is a stochastic variable. The distribution of r can be obtained through market forecasting. Quantity of supplier in the market is limited, as well as that of their maximum supply. It can be concluded from Figure 1 that there are two kinds of risks: supply risk and demand risk.

Supply risks from supplier include delivery delay, shortage, quality defects, location error, etc. These risks may come from supplier, such as workers’ operational errors, mismanagement, equipment failures and even deliberate default. They may also originate from external environment, like natural disasters, political turmoil, economic crisis and accidental administrative interference or judicial punishment. Supply failure always causes chain reaction considering other factors of the supply chain, like capital and information flows. Two strategies can be used to control supply risks. First is to decrease the risk of single supplier by selecting strong and credible supplier. Supplier selection and appraisal have been studied by many researchers (Liu et al., 2000; Sevkli et al., 2008; Ting and Cho, 2008; Ordoobadi, 2009). Second is the multi-supplier strategy, which is favorable in that the supply shortfall can be made up by working suppliers, and the risk impact can be decreased thereby. It is obvious that more suppliers would result in less supply risk. But the cost of management and coordination of multi-supplier strategy is much higher than that of single-supplier strategy. Purchase cost may also be higher as the order quantity is split. If suppliers adopt quantity discount strategy, multi-supplier would mean higher purchase price. Therefore, decision makers of a company must balance supply risk and supplier cost when determining the number of supplier.

Demand risk of supply chain comes from the uncertainty of market demand. As the ultimate purpose of a supply chain is to fulfill the need of customers, every company on the supply chain must forecast the demand to make a perfect production plan. Nevertheless, forecast does not always coincide with the real demand. This discrepancy results in oversupply or shortage which can cause lots of cost. Many scholars call this kind of uncertainty demand risk and regard it as a very important risk factor on supply chain (Harland et al., 2003; Tang, 2006). The aim of research on supply chain system under demand risk is to decrease the disruption of demand uncertainty and get an optimal stock quantity.

Parameters of the model

Based on former description and assumptions, a nonlinear integer programming can be built to determine an optimal supplier number, which enables a company to gain maximum return under lower risks. Variables used in this model are as follows:

a) n is the supplier number of company A;

b) r is market demand of G to company A;

c) f(r) is probability distribution of the market demand. It can be determined by market forecasting based on history data and operation experience. It follows

\[ F(r) = \sum_{v=0}^{\infty} f(v) \] under discrete r, and

\[ F(r) = \int_{0}^{r} f(x)dx \] under continuous r. In both discrete and continuous condition, \( F(\infty) = 1 \);

d) \( X \) is maximum number of supplier in the market;

e) \( s_i \) is the maximum supply of supplier i, where \( i \leq n \). \( s_i = s \) means that all suppliers have the same maximum supply s;

f) \( p_i \) is the probability of failure, or risk, of supplier i. \( p_i = p \) if all single supplier have the same failure risk;

g) \( v \) is the purchase price from suppliers. As all suppliers adopt quantity discount strategy, \( v \) is a piecewise function as

\[ v(q) = \begin{cases} v_1 & 0 < q < q_1 \\ \vdots \\ v_i & q_{i-1} \leq q < q_i \\ \vdots \end{cases} \]

where \( q \) and \( q_i \) are purchase quantity from a supplier, and \( v > v_1 \);

h) \( e \) is the sale price, and \( e > v_1 \);

i) \( g(n) \) is the management cost of n suppliers. It also includes fixed procurement costs, and it is an increasing function about n;

j) \( k(f) \) is the shortage cost, and \( f \) is the stockout quantity. It is also an increasing function.

Assumptions

In real supply chains, interactions including logistics,
information flow and capital flow are complex among a company and its suppliers and are all concerned with supply risk. Further more, risk factors are diverse in different companies, wherefore the model of risk forecasting and assessment are very complex. As a result, the following assumptions are made to simplify the model without losing its practical significance.

1) Suppliers are homogeneous and independent of each other: The homogeneity of suppliers means that they are the same for a demand-side company. All suppliers have the same risk and maximum supply, which are denoted by \( p \) and \( s \) respectively in this model, and adopt the same quantity discount strategy. Due to the homogeneity, a company always purchases the same quantity of goods from its suppliers.

   The independence of suppliers means that the risk probability of them is independent. Failure of a supplier does not affect others.

2) Supply of a supplier is either total success or total failure: This assumption means that the order would be canceled if a supplier becomes failure. And this order would be equally apportioned to other normally functioning suppliers.

3) A company can not change supplier within a short time: This assumption keeps the supplier number relatively steady.

4) Supply chain is agile enough, and the company has a credible contractual relationship with all its suppliers: This assumption ensures that a company's purchase quantity would not exceed market demand. A company can interact with suppliers effectively if the supply chain is agile enough. Moreover, with the credible contractual relationship, oversupply risk can be kept to an insignificant level.

5) Management cost and shortage cost: Management cost of \( n \) suppliers is \( g(n) \), where \( n \) is the number of supplier. And \( g(n) \) is an increase function about \( n \). Larger number of suppliers brings higher management complexity, and results in greater cost. To calculate easily, fixed procurement cost is included in \( g(n) \). From the fourth assumption, it can be concluded that demand risk is equal to the stockout probability. Then we assume that the shortage cost is \( k(l) \), where \( l \) is the shortage quantity. As the limited supply quantity of suppliers, demand risk is correlated to the number of supplier. As a result, a company must balance risks and supplier cost so as to maximize its revenue.

Based on these assumptions, the traditional newsvendor model is changed into a new model which considers both demand risk and supply risk. The company has to determine an optimal supplier number instead of an optimal stock quantity.

**Supply chain contracts in assumptions**

As the model is simplified based on former assumptions, this section analyzes the feasibility of these assumptions. It is mainly about contracts between a company and its suppliers. And, in fact, two contracts, quantity discount contract and quantity flexibility contract, are hided in the assumptions.

Supply chain contract is the clause between supply chain members. It contains some incentives to optimize and coordinate the whole supply chain. Some important supply chain contracts include buy back contract (Padmanabhan and Png, 1995), quantity flexibility contract (Eppen and Iyer, 1997), wholesale price contract (Lariviere and Porteus, 2001), revenue sharing contract (Dana and Spier, 2001), quantity discount contract (Cachon and Lariviere, 2001), etc.

Quantity discount contract is always used for encouraging companies to increase its purchase quantity. Suppliers would give a company different discount according to its purchase quantity. That is to say, multi-supplier strategy could split purchase quantity and the company thus gets a relatively small discount. This is a kind of cost of multi-supplier strategy.

The fourth assumption ensures that a company does not have to deal with oversupply risk, and it simplifies the risk control model. Although, this assumption is not true in real supply chain, a delicate quantity flexibility contract can be used to decrease the oversupply risk to a negligible level. In a quantity flexibility contract, a company place and order before sales period, and determine final order quantity after getting the exact market demand. This paper mainly focuses on the determination of optimal supplier number to avoid supply chain risk. Hence, the supply chain contract will be studied in further work.

**MODEL AND RISK ANALYSIS**

**The model to balance the risk level and risk control cost**

The ultimate purpose of supply chain risk control is to maximize the profit of the company. In this part, an integer programming model which considers supply risk and demand risk is built to maximize expected profit of a company. This model could find an optimal supply number to balance the risk and cost of risk control.

Firstly, two random events are given for the sake of following analysis.

1) \( N \) is the event that the company selects \( n \) suppliers;
2) \( \{i\} \) is the event that \( i \) suppliers function normally.

As the independent assumption of suppliers, following conditional probability can be got.

\[
P(I \mid N) = C^n_i (1 - p)^i \ p^{n-i}. \tag{1}\]
Then, the probability that supply could meet market demand when the company selects \( n \) suppliers and \( i \) of them function normally is:

\[
P(r \leq i \cdot s | I, N) = P(I | N) \cdot F(i \cdot s).
\]  
\(2\)

Then, the stockout probability is

\[
P(r > i \cdot s | I, N) = P(I | N) \cdot \left[1 - F(i \cdot s)\right].
\]  
\(3\)

The cost of multi-supplier strategy includes two parts. First is the opportunity cost caused by quantity discount policy of suppliers. As all suppliers are homogeneous, it can be known that the order quantities to all normally functioning suppliers are equal. Therefore, the discount is determined by \( v(\cdot) \) and \( i \). Another is the management cost, which is \( g(n) \).

If supply could meets market demand, the sale quantity is \( r \), and profit of the company is:

\[
R_1 = r \cdot (e - v(r/i))
\]  
\(4\)

When supply can not meets market demand, the sale quantity is \( i \cdot s \), which is the maximum supply of all successful suppliers. Under this circumstance, the company also has to pay the shortage cost, and its profit is

\[
R_2 = i \cdot s \cdot \left(e - v(s)\right) - k(r - i \cdot s)
\]  
\(5\)

Then, if the company selects \( n \) suppliers, its profit can be calculated by:

\[
R(n) = \sum_{i=0}^{n} \left[ P(r \leq i \cdot s | N, I) R_1 \right] + \left[ P(r \leq i \cdot s | N, I) R_2 \right] - g(n)
\]  
\(6\)

The number of suppliers in a market is always limited. And it is ever supposed that the maximum number of supplier in the market is \( X \). So, the risk control model of supplier number under stochastic demands is:

\[
\max R(n), \quad \text{s.t.} \begin{cases} 0 \leq n \leq X \\ n \in \mathbb{Z} \end{cases}
\]  
\(7\)

This model is a nonlinear integral program model and it has a complex object function. So, it is very difficult to get an analytical solution. Yet, it is relatively easy to use intelligence algorithm like genetic algorithm (GA) to get a numerical solution. On the other hand, it does not have to get an analytical solution both in the following analysis of this paper and in the application of this model by a supply chain company. In fact, a company always makes selection among few suppliers, and its decision-making is always limited within several integers. So, trial method is enough for a company to get an optimal supplier number using this model.

**Risks of the model**

This area analyzes risks of the afore-mentioned model. The purpose of risk control is to meet the market demand well, and then bring more profit to a company. In this case, this model synthesizes supply risk and demands risk into stockout probability, in which total supply of normally functioning suppliers can not meet market demand. Therefore, risk of this model is analyzed from two aspects, stockout probability and the company’s actual supply quantity.

When the company selects \( n \) suppliers, the probability that supply could meet market demand is:

\[
P(N) = \sum_{i=0}^{n} P(r \leq i \cdot s | I, N)
\]  
\(8\)

\[
= \sum_{i=0}^{n} P(I | N) \cdot F(i \cdot s)
\]

Then, the stockout risk when the company selects \( n \) suppliers is:

\[
P_r = 1 - P(N),
\]  
\(9\)

When the company selects \( n \) suppliers, the expected number of successful supplier is \( n \cdot p \), and expected maximum supply quantity is \( n \cdot p \cdot s \). Larger supplier number can make the company meet a larger expansion of market demand, and get a larger \( P(N) \). If \( n \) is large enough, the stockout risk \( P_r \) would tend to zero.

The company’s expected actual supply quantity when it selects \( n \) suppliers and \( i \) of them supply successfully is:

\[
S_E^i = \sum_{r=0}^{\infty} r \cdot f(r) + \sum_{r=i+1}^{\infty} f(r)
\]  
\(10\)

So, the expected actual supply quantity of \( n \) suppliers can be obtained as:

\[
S_E(n) = \sum_{i=0}^{n} P(I | N) S_E^i
\]  
\(11\)

Like the analysis of stockout risk, if \( n \) is large enough, the company can get sufficient goods to meet market demand. With the credible contractual relationship of a company and its suppliers, the risk of oversupply can be avoided. Therefore, sufficiently large supplier number can make expected actual supply quantity of the company close to expected market demand. But, following proof
shows that expected actual supply quantity is always less than expected market demand.

Firstly, let

\[
T = S(n) - \sum_{i=0}^{\infty} rf(r)
\]

and following proofs shows that \( T < 0 \).

As \( \sum_{i=0}^{\infty} P(J \mid N) = 1 \), expected market demand then can be represented as:

\[
\sum_{i=0}^{\infty} rf(r) = \sum_{i=0}^{n} P(J \mid N) \sum_{i=0}^{\infty} rf(r)
\]

Then, it can be obtained that

\[
T = \sum_{i=0}^{\infty} P(J \mid N) S_{K}^{i} - \sum_{i=0}^{\infty} rf(r)
\]

\[
= \sum_{i=0}^{n} P(J \mid N) \left[ S_{K}^{i} - rf(r) \right]
\]

\[
= \sum_{i=0}^{n} P(J \mid N) \left[ \sum_{r=i+1}^{\infty} (i \cdot s - r) f(r) \right] < 0
\]

\( \text{(13)} \)

\( \text{(14)} \)

EXAMPLE AND SIMULATIONS

In this area, the risk control model is tested by an example. Simulation results include the changing of company’s expected profit, risk, expected actual supply quantity along supplier numbers. The relationships of company’s maximum profit and other parameters, including maximum supply quantity of a single supplier, shortage cost and management cost, are also given.

The following are the parameters of this example:

1) All suppliers adopt following quantity discount strategy:

\[
V(q) = \begin{cases} 
10 & 0 < q < 5 \\
9 & 5 \leq q < 10 \\
8 & 10 \leq q < 15 \\
7 & 15 \leq q
\end{cases}
\]

2) Supply risk of a single supplier, \( p = 0.1 \);
3) Management cost, \( g(n) = 10n \);
4) Shortage cost, \( k(l) = 5l \);
5) Company’s sale price, \( e = 15 \);
6) Maximum supply quantity of a single supplier, \( s = 20 \).

Three kinds of market demand distribution are analyzed in the example, including

1) Discrete uniform distribution \( f(r) = 0.01, 0 \leq r \leq 99, r \in N \)
2) Normal distribution \( f(x) = N(50.50, \sqrt{3}) \);
3) Poisson distribution \( f(x) = P(\lambda = 50) \).

It should be noticed that these three distributions have equal mathematical expectation, and variances of discrete uniform distribution and normal distribution are also equal.

Figure 2(a) shows that, under these three distributions, company’s profits increase at first and then decrease. As expectation and variances of both discrete uniform distribution and normal distribution are equal, the two profit lines are almost overlapped. Figure 2 b and c show that if the company has enough suppliers, the risk would approach zero rapidly, and the expected actual supply quantity would be close to expected market demand.

Under all these three distributions, maximum profit of the company is a positive correlation with maximum supply quantity of single supplier, and a negative correlation with optimal supplier number (Table 1). To
avoid shortage cost, the company must select more suppliers. So, shortage cost is a negative correlation with profit and a positive correlation with optimal supplier number (Table 2). The relations of management cost and maximum profit, as well as optimal supplier number, are shown in Table 3. Higher management cost causes the company to select fewer suppliers, and it even adopts single-supplier strategy.

**CONCLUSIONS**

A model has been presented to help decision makers to determine an optimal supplier number. The model aims at answering this basic question: assuming that the market demand of goods follows a kind of stochastic distribution, how should the firm find an optimal supplier number to minimize supply risk and demand risk to a right level? On the basis of the literatures on supply chain risk control and newsvendor model, a new model which considers both supply risk and demand risk (shortage risk) is devised. By balancing the cost of suppliers and benefit of risk control, an optimal supplier number can be determined to maximize the expected profit of a supply chain company. To examine validity of our model, some simulations of an example have been made. These simulations consider three kind of demands distribution: discrete uniform distribution, normal distribution and poisson distribution. Results show that our model can effectively find a proper supplier number to balance multi-supplier management cost and risk control level. The main advantages related to our findings are summarized as follows:

1) Our model synthesizes supply risk and demand risk. The company only needs to consider whether its suppliers can meet market demand.
2) Supply chain company can decrease these risks to an appropriate level by determining only one parameter: supplier number.
3) This model limits the ability of suppliers. All suppliers have an upper limit of supply quantity. This is more
Table 3. Influence of management cost (MCost) of company’s maximum profit (MaxP) and optimal supplier number (OSN) under different demand distribution.

<table>
<thead>
<tr>
<th>MCost</th>
<th>Discrete uniform distribution</th>
<th>Normal distribution</th>
<th>Poisson distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MaxP</td>
<td>OSN</td>
<td>MaxP</td>
</tr>
<tr>
<td>10</td>
<td>292.9</td>
<td>6</td>
<td>290.5</td>
</tr>
<tr>
<td>20</td>
<td>242.9</td>
<td>6</td>
<td>240.5</td>
</tr>
<tr>
<td>30</td>
<td>194.7</td>
<td>5</td>
<td>199.2</td>
</tr>
<tr>
<td>40</td>
<td>154.7</td>
<td>5</td>
<td>159.2</td>
</tr>
<tr>
<td>50</td>
<td>114.7</td>
<td>5</td>
<td>119.2</td>
</tr>
<tr>
<td>60</td>
<td>74.7</td>
<td>5</td>
<td>79.2</td>
</tr>
<tr>
<td>70</td>
<td>34.7</td>
<td>5</td>
<td>45.7</td>
</tr>
<tr>
<td>80</td>
<td>1.6</td>
<td>4</td>
<td>15.7</td>
</tr>
<tr>
<td>90</td>
<td>-247.5</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>100</td>
<td>-247.5</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

consistent with real supply chain as it is also a source of supply risk.

4) Our model extends the research of newsvendor model as it can be taken as a special newsvendor model which includes several risky suppliers.

Implementation of the proposed models to determine an optimal supplier number requires assessment of supplier risk and market demand distribution. So, this model can be integrated with other interrelated method and embedded in the decision support system of a company. This integrated method can provide the company an immediate and efficient method to select proper suppliers.

DIRECTIONS FOR FUTURE RESEARCH

However, current study has some limitations for further research. Firstly, it has not considered the risk of oversupply. To get a state of low oversupply risk, a proper contract must be found in further research. Secondly, this model supposes that all the suppliers have the same risk and maximum supply quantity. But this is not real in real supply chain. Further research can combine this model and other supplier selection model to determine how many and which suppliers can bring supply chain company maximum profit. Further more, our model has another implied assumption, where the company is a small one and cannot influence sales price. Further research can adopt an oligopoly market model to consider the company’s influence on sales price.

REFERENCES


ACKNOWLEDGEMENTS

The authors are very grateful for the insightful comments and suggestions of the anonymous reviewers, the editor and editorial assistant Franklyn Monyei, which have helped to significantly improve this article. Furthermore, this research was supported by the National Natural Science Foundation of China (No. 70901023), the Research Fund for the Doctoral Program of Higher Education of China (No. 20101102120024), the Humanity and Social Science Foundation of Ministry of Education of China (No. 11YJC660057, No. 12YJCZH126), Aviation Science Fund (No. 2010ZG51073), and the Fundamental Research Funds for the Central Universities.


