Journal of Southeast University (English Edition) Vol. 24, No. 1, pp. 104 – 109 Mar. 2008 ISSN 1003—7985

Supplier selection and order splitting modeling in the presence of supplier capacity and resilience

Yu Haisheng Zhao Lindu

(School of Economics and Management, Southeast University, Nanjing 210096, China)

Abstract: To solve the problem of a supplier's failure to deliver thus impacting supply chain system performance in the supply chain operating process, a model of supplier selection and order splitting in the context of a multiple sourcing setting is proposed. First, by the analysis of the elements of expected total costs of the buyer firm, namely, expected loss costs, resilience effort costs, supplier maintenance costs, and cycle purchase costs, the expected total costs function is obtained. And then, the effects of supplier characters on the supplier selection and order splitting decision-making are investigated by numerical examples. The results show that the maximum delivery capacity, the probability of failure to deliver and the resilience parameters are crucial elements in determining which suppliers should be selected and how to do order splitting between suppliers. Finally, current analyses focus only on the expected total costs of the buyer firm but ignore the suppliers' costs; thus, it is more interesting to examine the supplier decisions from both parties' points of view.

Key words: supplier selection; order splitting; capacity; resilience

It can be observed that the relationships between suppliers and immediate buyer firms have evolved from previously fragmented, scattered links to today's integrated, interdependent supply chain network. Although such changes have led to numerous benefits in efficiency and productivity, they can result in severe problems that cannot be ignored, and one such problem is a supplier's failure to deliver what has been witnessed by the entire business world in the past few years. Every buyer firm needs a successful supplier program, especially since purchasing typically is the largest component of costs for many products and then supplier failures can disrupt operations, delay the completion or cause the cancellation of customer orders. The use of order splitting during an order cycle seems to have received much attention recently considering supply chain risks and disruptions. For example, Kelle and Miller provided analytical and numerical results for the optimal rate of order splitting if the objective is to minimize the out-of-stock risk[1].

In this paper, we consider a two-stage supply chain that contains one buyer firm and multiple suppliers. Facing the market demand, the buyer firm purchases raw materials from the suppliers, adds some value to the product, and sells it to the customers. Every supplier has the capacity constraints to deliver raw materials to buyer firms, and it has the resilience effort to increase its output in the event of the failure of other suppliers[2]. The goal of the model is to minimize the expected total costs of buyer firms.

The motivation of this paper comes from two research fields, supplier selection and order splitting. With the development of just-in-time (JIT) production and total-quality-management (TQM), it is often suggested that a buyer firm use a single supplier in order to build a long-term supplier relationship to improve service quality. However, using multiple suppliers is still very popular in practice considering the risk of supplier failure to deliver. Qi studied an integrated decision-making model for a supply chain system where a manufacturer faced a price-sensitive and multiple capacitated supplier[2]. The goal is to maximize total profits by determining an optimal selling price, order splitting and at the same time acquiring enough supplying capacity. Berger et al. presented a supplier's decision-making model using a decision tree approach considering supply chain catastrophic and unique events risk[3]. The expected cost function is obtained and the optimal number of suppliers is determined. Ruiz-Torres et al. reported a decision-making model that optimizes the allocation of demands across a set of suppliers by considering the expected losses due to supplier's failure to deliver, the purchasing costs, and the costs of maintaining a set of suppliers[4].

The importance of reliable supply is increasing with global sourcing and JIT production. If a single, reliable supplier is not available, the order can be split among the vendors until a reliable supplier emerges. Extending the models of Berger et al. and Ruiz-Torres et al., we address the problem: how many suppliers are preferable and how do we deal with order splitting if the objective of the decision is to minimize the expected total costs under supplier capacity and resilience circumstances?

1 Literature Review

There are numerous papers in the research on supplier selection or order splitting, but these two issues are often studied separately. Supplier selection is a decision-making problem. While some researchers emphasize strategic decision making[5], the majority treat it as an optimization problem. Different solution methodologies have been proposed, ranging from linear programming[6] to non-linear programming[7].

The stream of research on order splitting follows two major tracks. The first focuses on statistical theory and methods for estimating the effects of splitting on the distribution of effective lead times and, in turn, on safety stock holding costs and shortage costs[1]. The second track concentrates on economic analysis, or more specifically, on developing long run average cost models to assess the performance of split models in relation to non-split models under common condi-

Received 2007-09-30.

Biographies: Yu Haisheng (1978—), male, graduate; Zhao Lindu (corresponding author), male, doctor, professor, ldzhao@seu.edu.cn.

Foundation items: The National Key Technology R&D Program of China during the 11th Five-Year Plan Period (No. 2006BAH02A06), the National Natural Science Foundation of China (No. 70671021).

Citation: Yu Haisheng, Zhao Lindu. Supplier selection and order splitting modeling in the presence of supplier capacity and resilience[J]. Journal of Southeast University (English Edition), 2008, 24(1): 104 − 109.

tions[7-8].

There are only a few papers in the research on supplier selection and order splitting[9-10]. Tyworth and Ruiz-Torres expanded the Ramasesh model by investigating the effects of transportation costs on the sourcing decision. Kawtummachai and van Hop addressed the problem of allocating a percentage of the demand across a set of suppliers in order to minimize total purchasing costs, while maintaining a specified service level. They considered multiple products, where each can be sourced from several suppliers and each supplier sells the product at a unique price and has its own on time delivery percentage. Kawtummachai and van Hop proposed an order allocation algorithm and tested it using historical data.

The works most related to our model were done by Berger et al. and Ruiz-Torres et al. [3-4]. Berger et al. studied the problem of the supplier decision-making model using a decision tree approach considering supply chain catastrophic and unique events risk. Ruiz-Torres et al. studied a decision-making model that optimizes the allocation of demands across a set of suppliers by considering the expected losses due to supplier failure to deliver, the purchasing costs, and the costs of maintaining a set of suppliers. Our model also looks like a supplier selection and order splitting problem. The new features in our model are considering supplier capacity and resilience under circumstances of the risk of a supplier's failure to deliver.

2 Proposed Model

In this paper, we consider a supplier selection and order splitting decision problem faced by a manufacturer (a buyer). Let N represent the set of suppliers: $N = \{1, 2, \ldots, n\}$, where n is the total number of possible suppliers. And every supplier has not only the capacity constraints but also resilience effort to increase its output in the event of the failure of other suppliers. In the presence of the possible supplier failure risk, how should the manufacturer make the supplier decision-making? This problem under study is typical in today's supply chains.

2.1 Assumptions and notations

In this paper, we focus on the issue of supplier selection and order splitting considering supplier capacity and resilience where the buying firm has the total cycle order size Q. To simplify the analysis and concentrate on the focus issue, we first assume that the total cycle order size Q is stationary. Random demand is discussed thereafter based on approximations. Furthermore, the model assumes that the buying firm places its replenishment order of a single product to every supplier in the same time.

The following summarizes the notations used in this paper. Some of the definitions are deferred until they are used. c is the raw materials baseline cost per unit; a_i is the proportion of the total cycle order size Q allocated to supplier i, where $\sum_{i \in N} a_i = 1$; C_i is the maximum delivery capacity to the buying firm of supplier i during a supply cycle, $C_i \leqslant Q$; p_i is the probability that supplier i fails to deliver during a supply cycle; r_i is the resilience parameter that relates to the ability of supplier i to increase its output in the event of the failure of other suppliers; c_l is the expected financial loss per unit not acquired; c_r is the resilience cost of a supplier's effort to make capacity available for the buying firm per unit.

2.2 Expected total costs functions

The impact of expected total costs functions on the supplier selection and order splitting modeling was proposed by Berger et al. They considered the expected total costs related to the loss of all suppliers failing to deliver and the costs of maintaining these supplies. They took into account the probability of a mega event that shuts down all suppliers, P, and the probability that supplier i fails to deliver during a cycle, p_i. Given that their results and those of Ruiz-Torres and Mahmoodi demonstrated that P has no effect on supplier selection and order splitting at reasonable levels of the variable, the mega event probability is not considered in this study. And Ruiz-Torres and Mahmoodi presented further the research results about supplier allocation considering delivery failure, maintenance and supplier cycle costs.

The focus of the model presented in this paper is to determine supplier selection and order splitting of the demand across a set of suppliers. Furthermore, the proposed model accounts for expected total costs of a buyer firm based on capacity constraints and resilience efforts. So given that a resilience parameter r_i to supplier i and its proportion of the total cycle order size Q allocated is a_i, its maximum delivery capacity to the buyer firm during a supply cycle is C_i. Based on this condition, the maximum supply proportion for supplier i during a cycle with partial delivery failure (and where supplier i does not fail) is modeled as $\min[C_i/Q, a_i^{r_i}]$, where $C_i \leqslant Q$ and r_i can take on values between 0 and 1.

A value of $r_i = 0$ indicates that supplier i can supply the maximum capacity during any cycle. This represents that suppliers are significantly underutilized and/or hold a large amount of inventory. On the other hand, a value of $r_i = 1$ indicates that supplier i cannot supply more than its original proportion of the total cycle order size Q. This represents that supplier i cannot supply additional units to satisfy new requirements; i. e., supplier i has not the resilience ability to deal with the emergency requirements of other supplier delivery failures. In summary, r_i values close to 0 indicate high output resilience, while r_i values close to 1 indicate low output resilience. Note that the model differs from the Berger et al. model and the Ruiz-Torres and Mahmoodi model. Their models implied that when $r_i = 0$, for all i in N, as long as one supplier does not fail, the single operating supplier can change its production for that cycle so it can supply 100% of the required demand. However, in our model, every supplier in N has not only the resilience effort but also capacity constraints in the event of the failure of other suppliers. So the single operating supplier cannot change its production for that cycle to supply 100% of the required demand.

Obviously, the expected total costs can be expressed as the summation of the expected loss costs, the resilience effort costs, the supplier maintenance costs, and the cycle purchase costs.

The supplier maintenance costs can be divided into two components during a supply cycle as follows:

$$C_{\mathrm{SM}}(M) = O + mI \tag{1}$$

where O represents the fixed cost elements that do not change with the number of suppliers, such as the preparation of specifications and request for bids, the bid evaluations, the contract documents, the letters of credit. The component mI captures the aggregate incremental costs of splitting orders, including shipping, receiving, handling, and inspection.

The supplier expected loss costs during a supply cycle are then dependent on the suppliers that fail, and by consequence, the maximum supply capacity of those that do not fail. Therefore, what the buyer firm receives during a supply cycle is

$$\min\left[1, \sum_E \min[C_i/Q, a_i^{r_i}]\right]$$

where E is the set of suppliers that do not fail during a supply cycle. The expected financial loss given set E is modeled by

$$\left(1 - \min\left[1, \sum_E \min[C_i/Q, a_i^{r_i}]\right]\right)c_1 Q \quad (2)$$

By considering the probability that supplier i fails to deliver during a supply cycle, we can determine the expected loss costs given a set of suppliers.

Let M represent a subset of suppliers from N and $C_{\mathrm{EL}}(M)$ represent the expected loss costs from set M. Let m represent the number of suppliers in set M. If $m=1$ with $M=\{i\}$, the expected loss is determined as

$$C_{\mathrm{EL}}(i) = p_i c_1 Q \quad (3)$$

If the number of suppliers in set $M=\{i,j\}$ equals two, the expected loss costs are

$$C_{\mathrm{EL}}(i,j) = (p_i p_j + p_i(1-p_j)(1-\min[C_j/Q, a_j^{r_j}]) + p_j(1-p_i)(1-\min[C_i/Q, a_i^{r_i}]))c_1 Q \quad (4)$$

As m increases, so does the number of terms that must be included in the calculation of the expected loss costs for set M. When $m=3$, the expected loss costs for $M=\{i,j,k\}$ are

$$\begin{aligned} C_{\mathrm{EL}}(i,j,k) = {} & (p_i p_j p_k + p_i p_j(1-p_k)(1-\min[C_k/Q, a_k^{r_k}]) + \\ & p_i p_k(1-p_j)(1-\min[C_j/Q, a_j^{r_j}]) + \\ & p_j p_k(1-p_i)(1-\min[C_i/Q, a_i^{r_i}]) + \\ & p_i(1-p_j)(1-p_k)(1-\min[1, \min[C_j/Q, a_j^{r_j}] + \\ & \min[C_k/Q, a_k^{r_k}]]) + p_j(1-p_i)(1-p_k)\cdot \\ & (1-\min[1, \min[C_i/Q, a_i^{r_i}] + \min[C_k/Q, a_k^{r_k}]]) + \\ & p_k(1-p_j)(1-p_i)(1-\min[1, \min[C_j/Q, a_j^{r_j}] + \\ & \min[C_i/Q, a_i^{r_i}]]))c_1 Q \end{aligned} \quad (5)$$

The $C_{\mathrm{EL}}(M)$ calculations for $m>3$ can be performed accordingly.

The supplier resilience effort costs during a supply cycle rest with the difference between the original proportion and the maximum supply proportion. Let $C_{\mathrm{RE}}(M)$ represent the supplier resilience effort costs from set M. If $m=1$ with $M=\{i\}$, the resilience effort costs are zero when supplier i has not produced the effort. If $m=2$ with $M=\{i,j\}$, the resilience effort costs are

$$C_{\mathrm{RE}}(i,j) = (p_i(1-p_j)(\min[C_j/Q, a_j^{r_j}] - a_j) + p_j(1-p_i)(\min[C_i/Q, a_i^{r_i}] - a_i))c_{\mathrm{r}} Q \quad (6)$$

When $m=3$, the resilience effort costs for $M=\{i,j,k\}$ are

$$\begin{aligned} C_{\mathrm{RE}}(i,j,k) = {} & (p_i p_j(1-p_k)(\min[C_k/Q, a_k^{r_k}] - a_k) + \\ & p_i p_k(1-p_j)(\min[C_j/Q, a_j^{r_j}] - a_j) + \\ & p_k p_j(1-p_i)(\min[C_i/Q, a_i^{r_i}] - a_i) + \\ & p_i(1-p_j)(1-p_k)(\min[1, \min[C_j/Q, a_j^{r_j}] + \\ & \min[C_k/Q, a_k^{r_k}]] - a_j - a_k) + p_j(1-p_i)(1-p_k)\cdot \\ & (\min[1, \min[C_i/Q, a_i^{r_i}] + \min[C_k/Q, a_k^{r_k}]] - a_i - a_k) + \\ & p_k(1-p_j)(1-p_i)(\min[1, \min[C_j/Q, a_j^{r_j}] + \\ & \min[C_i/Q, a_i^{r_i}]] - a_j - a_i))c_{\mathrm{r}} Q \end{aligned} \quad (7)$$

The cycle purchase costs $C_{\mathrm{CP}}(M)$ are based on the total order size per cycle and the raw materials baseline price.

$$C_{\mathrm{CP}}(M) = Qc\min\left[1, \sum_E \min[C_i/Q, a_i^{r_i}]\right] \quad (8)$$

So the expected total costs $C_{\mathrm{ET}}(M)$ are the sum of the expected loss costs, the resilience effort costs, the supplier maintenance costs, and the cycle purchase costs. For a given set of suppliers M, the expected total costs are determined as

$$C_{\mathrm{ET}}(M) = C_{\mathrm{SM}}(M) + C_{\mathrm{EL}}(M) + C_{\mathrm{RE}}(M) + C_{\mathrm{CP}}(M) \quad (9)$$

3 Model Analyses

The preceding section has obtained the expected total costs model including three components, namely the expected loss costs, the resilience effort costs and the supplier maintenance costs. However, the buyer firm is interested in knowing the conditions under which suppliers are selected and the details of order splitting. Thus, we analyze the expected total costs model to obtain the best decision-making according to the differences between homogeneous and heterogeneous suppliers.

To reduce the size of the search space, the supplier order splitting is allowed in increments of 10%[10]. The expected total costs model is coded in Excel in combination with Matlab 7.0 for application. Clearly, the best decision-making depends on the parameters of the maximum delivery capacity C_i, the probability of failure to deliver p_i, the resilience parameter r_i and the cost c_1, c_{r}.

3.1 Homogeneous suppliers

Homogeneous suppliers have the same maximum delivery capacity C_i, the same probability of failure to deliver p_i, the same resilience parameter r_i and the same cost c_1, c_{r}.

Raw material cost per unit is assumed as 1. Tab. 1 presents the optimal number of suppliers and the optimal scheme of order splitting for each experimental condition. Based on the homogeneous supplier, the capacity is no constraints. When $r_i > 0$, the optimal solution is to evenly split the order size across the selected number of suppliers, therefore in the case of two suppliers, the order splitting is {50%, 50%}(marking {50, 50} in Tab. 1, the same below). However, with three suppliers the order splitting is {30%, 30%, 40%} given the 10% increment; this is the same as {40%, 30%, 30%} or {30%, 40%, 30%}. When $r_i = 0$, the order splitting across the homogeneous suppliers does not change the expected total costs; therefore, the order splitting presented in Tab. 1 is just one of the possible results. For example, if the optimal solution is three suppliers, all order splitting allocations to three suppliers result in the same expected total costs(e. g. , the expected total costs with {30% , 30% , 40% }are the same as the expected total costs with {10% , 40% , 50% }) .

Some of the observed effects are intuitive: higher expected financial loss per unit due to failure and the resilience cost of a supplier's effort leads to multiple sourcing, whereas, single sourcing is selected. As the resilience parameter r_i changes from 0 to 1, the optimal number of suppliers is increasing. It shows that the degree of effort of supplier resilience is in positive correlation with the optimal number of suppliers. So the buyer firm should select high resilience suppliers into its supply base. Tab. 1 also demonstrates that the probability that a supplier fails to deliver during a supply cycle is in positive correlation with the optimal number of suppliers.

Tab. 1 Results for homogeneous suppliers

c_l	c_r	r_i	p_i(the optimal of number of suppliers)			p_i(the optimal scheme of order splitting)		
			0. 001	0. 01	0. 1	0. 001	0. 01	0. 1
1	1	0	1	1	1	{1 0 0}	{1 0 0}	{1 0 0}
		0. 3	1	1	1	{1 0 0}	{1 0 0}	{1 0 0}
		0. 6	1	1	1	{1 0 0}	{1 0 0}	{1 0 0}
		1. 0	1	1	1	{1 0 0}	{1 0 0}	{1 0 0}
	5	0	1	1	1	{1 0 0}	{1 0 0}	{1 0 0}
		0. 3	1	1	2	{1 0 0}	{1 0 0}	{50, 50}
		0. 6	1	1	3	{1 0 0}	{1 0 0}	{30, 40, 40}
		1. 0	1	1	3	{1 0 0}	{1 0 0}	{30, 40, 40}
	10	0	1	2	2	{1 0 0}	{50, 50}	{50, 50}
		0. 3	1	2	3	{1 0 0}	{50, 50}	{30, 40, 40}
		0. 6	1	1	3	{1 0 0}	{1 0 0}	{30, 40, 40}
		1. 0	1	1	5	{1 0 0}	{1 0 0}	{20, 20, 20, 20, 20}
5	1	0	1	1	2	{1 0 0}	{1 0 0}	{50, 50}
		0. 3	1	1	2	{1 0 0}	{1 0 0}	{50, 50}
		0. 6	1	1	2	{1 0 0}	{1 0 0}	{50, 50}
		1. 0	1	1	1	{1 0 0}	{1 0 0}	{1 0 0}
	5	0	1	2	2	{1 0 0}	{50, 50}	{50, 50}
		0. 3	1	2	3	{1 0 0}	{50, 50}	{30, 30, 40}
		0. 6	1	3	4	{1 0 0}	{30, 30, 40}	{20, 20, 30, 30}
		1. 0	1	1	6	{1 0 0}	{1 0 0}	{10, 10, 20, 20, 20, 20}
	10	0	2	2	3	{50, 50}	{50, 50}	{30, 30, 40}
		0. 3	1	3	3	{1 0 0}	{30, 30, 40}	{30, 30, 40}
		0. 6	1	4	5	{1 0 0}	{20, 20, 30, 30}	{20, 20, 20, 20, 20}
		1. 0	1	2	7	{1 0 0}	{50, 50}	{10, 10, 10, 10, 20, 20, 20}
10	1	0	1	2	2	{1 0 0}	{50, 50}	{50, 50}
		0. 3	1	2	3	{1 0 0}	{50, 50}	{30, 40, 40}
		0. 6	1	1	3	{1 0 0}	{1 0 0}	{30, 40, 40}
		1. 0	1	1	1	{1 0 0}	{1 0 0}	{1 0 0}
	5	0	2	2	3	{50, 50}	{50, 50}	{30, 30, 40}
		0. 3	2	3	4	{50, 50}	{30, 30, 40}	{20, 20, 30, 30}
		0. 6	1	3	5	{1 0 0}	{30, 30, 40}	{20, 20, 20, 20, 20}
		1. 0	1	2	7	{1 0 0}	{50, 50}	{10, 10, 10, 10, 20, 20, 20}
	10	0	2	3	3	{50, 50}	{30, 30, 40}	{30, 30, 40}
		0. 3	2	3	5	{50, 50}	{30, 30, 40}	{20, 20, 20, 20, 20}
		0. 6	3	5	7	{30, 30, 40}	{20, 20, 20, 20, 20}	{10, 10, 10, 10, 20, 20, 20}
		1. 0	1	3	8	{1 0 0}	{30, 30, 40}	{10, 10, 10, 10, 10, 10, 20, 20}

3. 2 Heterogeneous suppliers

For heterogeneous suppliers, the parameters of the maximum delivery capacity, resilience ability and the failure probabilities to deliver during a supply cycle are unequal. Tab. 2 presents the specific parameters used in these sets.

Tab. 3 presents the optimal number of suppliers and the optimal scheme of order splitting for each experimental condition about the heterogeneous supplier. Obviously, higher expected financial loss per unit due to failure and the resilience costs of a supplier's effort leads to multiple sourcing which is the same as the situation of homogeneous suppliers. And the difference is that the proportion of single sourcing increases, which is contrary to the homogeneous suppliers for the sake of supplier capacity constraints. The proportion of single sourcing changes from 50% of homogeneous supplier to 33% of heterogeneous supplier for supplier capacity constraints. And another observed effect is that supplier 3 rarely comes forth in the optimal suppliers set since its capacity is lower than that of the others.

Tab. 2 Heterogeneous supplier set parameters

Supplier i	C_i	r_i			p_i		
		HRS	MRS	LRS	HRL	MRL	LRL
1	0.8	0.30	0.60	0.90	0.001	0.010	0.050
2	0.7	0.28	0.56	0.86	0.002	0.014	0.057
3	0.6	0.24	0.52	0.83	0.004	0.019	0.061
4	1.0	0.21	0.48	0.78	0.005	0.023	0.069
5	1.0	0.19	0.43	0.72	0.006	0.029	0.074
6	0.8	0.12	0.40	0.69	0.008	0.036	0.081
7	0.7	0.09	0.37	0.65	0.009	0.045	0.093
8	0.9	0	0.30	0.60	0.010	0.050	0.100

Notes: HRS means high resilience ; MRS means medium resilience; LRS means low resilience; HRL means high reliability; MRL means medium reliability; LRL means low reliability.

Tab. 3 Results for heterogeneous suppliers

c_l	c_r	r_i	p_i(the detail of suppliers)			p_i(the optimal scheme of order splitting)		
			HRL	MRL	LRL	HRL	MRL	LRL
1	1	HRS	{4}	{4}	{4}	{1 0 0}	{1 0 0}	{1 0 0}
		MRS	{4}	{4}	{4}	{1 0 0}	{1 0 0}	{1 0 0}
		LRS	{4}	{4}	{4}	{1 0 0}	{1 0 0}	{1 0 0}
	5	HRS	{4}	{4}	{1, 2}	{1 0 0}	{1 0 0}	{60, 40}
		MRS	{4}	{1, 2}	{1, 4}	{1 0 0}	{60, 40}	{80, 20}
		LRS	{4}	{1, 4}	{1, 2, 3}	{1 0 0}	{80, 20}	{40, 30, 30}
	10	HRS	{4}	{1, 2}	{1, 2, 3}	{1 0 0}	{50, 50}	{40, 30, 30}
		MRS	{4}	{1, 2}	{1, 2, 4}	{1 0 0}	{60, 40}	{40, 30, 30}
		LRS	{4}	{1, 2, 4}	{1, 2, 4, 5}	{1 0 0}	{40, 30, 30}	{30, 30, 20, 20}
5	1	HRS	{4}	{4}	{4}	{1 0 0}	{1 0 0}	{1 0 0}
		MRS	{4}	{1, 2}	{1, 4}	{1 0 0}	{60, 40}	{80, 20}
		LRS	{4}	{1, 4}	{1, 2, 4}	{1 0 0}	{80, 20}	{40, 30, 30}
	5	HRS	{4}	{1, 2}	{1, 2, 3}	{1 0 0}	{60, 40}	{40, 30, 30}
		MRS	{1, 2}	{1, 2, 4}	{1, 2, 4, 5}	{60, 40}	{40, 30, 30}	{30, 30, 20, 20}
		LRS	{1, 2}	{1, 2, 3}	{1, 2, 4, 5, 8}	{60, 40}	{40, 30, 30}	{40, 30, 10, 10, 10}
	10	HRS	{4}	{1, 2}	{1, 2, 4}	{1 0 0}	{60, 40}	{40, 30, 30}
		MRS	{1, 4}	{1, 4, 5}	{1, 2, 4, 5, 6}	{60, 40}	{40, 30, 30}	{30, 30, 20, 10, 10}
		LRS	{1, 4, 5}	{1, 2, 4, 5}	{1, 2, 4, 5, 6, 8}	{40, 30, 30}	{30, 30, 20, 20}	{30, 20, 20, 10, 10, 10}
10	1	HRS	{4}	{1, 4}	{1, 2, 3}	{1 0 0}	{50, 50}	{40, 30, 30}
		MRS	{4}	{1, 2, 4}	{1, 2, 4, 6}	{1 0 0}	{50, 30, 20}	{40, 30, 20, 10}
		LRS	{4}	{1, 2, 4}	{1, 2, 4, 5}	{1 0 0}	{40, 30, 30}	{30, 30, 20, 20}
	5	HRS	{4}	{1, 2}	{1, 2, 4}	{1 0 0}	{60, 40}	{40, 30, 30}
		MRS	{1, 4}	{1, 2, 4}	{1, 2, 4, 5}	{80, 20}	{50, 30, 20}	{30, 30, 20, 20}
		LRS	{1, 4}	{1, 4, 5}	{1, 2, 4, 5, 6, 8}	{60, 40}	{40, 30, 30}	{30, 20, 20, 10, 10, 10}
	10	HRS	{1, 4}	{1, 2}	{1, 2, 4}	{90, 10}	{50, 50}	{40, 30, 30}
		MRS	{1, 4}	{1, 2, 4, 6}	{1, 2, 4, 5, 6}	{60, 40}	{40, 20, 20, 20}	{30, 30, 20, 10, 10}
		LRS	{1, 4, 5}	{1, 2, 4, 5, 7}	{1, 2, 4, 5, 6, 7, 8}	{40, 30, 30}	{50, 50}	{30, 20, 10, 10, 10, 10, 10}

4 Conclusion

This research presents a supplier selection and order splitting model under the circumstances of supplier failure to deliver. Especially, the supplier capacity and resilience is the focus in the model. By the analysis of elements of the expected total costs of a buyer firm, namely, the expected loss costs, the resilience effort costs, the supplier maintenance costs, and the cycle purchase costs, the expected total costs function is obtained. We have identified the parameters of the maximum delivery capacity C_i, the probability of failure to deliver p_i, resilience parameter r_i and the cost c_l and c_r are crucial elements to confirm which supplier should be selected and how to do order splitting between the suppliers.

This research is potentially valuable in helping managers and decision-makers choose the most profitable sourcing strategies in the presence of the risk of supply chain disruptions. However, it is necessary to point out a number of limitations of this research. First, the total cycle order size Q is assumed to be stationary; to make the model more realistic, factors such as the time, the product lifetime, and the disruption duration can be added to the model and the total cycle order size Q should be dynamic. Secondly, lead time risks by order splitting should be considered. Finally, current analyses focus only on the buyer firm's expected total costs but ignore the suppliers' costs; thus, it would be more interesting to examine the supplier decisions from both parties' points of view.

References

[1] Kelle P, Miller P A. Stockout risk and order splitting [J]. *International Journal of Production Economics*, 2001, **71**(1/2/3): 407 - 415.
[2] Qi Xiongtong. Order splitting with multiple capacitated suppliers [J]. *European Journal of Operational Research*, 2007, **178**(2): 421 - 432.
[3] Berger P D, Gerstenfeld A, Zeng A Z. How many suppliers are best? A decision-analysis approach [J]. *Omega*, 2004, **32**(1): 9 - 15.
[4] Ruiz-Torres A J, Mahmoodi F. The optimal number of suppliers considering the costs of individual supplier failures [J]. *Omega*, 2006, **35**(1): 104 - 115.
[5] Davidrajuh R. Modeling and implementation of supplier selection procedures for E-commerce initiatives [J]. *Industrial Management and Data Systems*, 2003, **103**(1): 28 - 38.
[6] Ustun Ozden, Demirtas Ezgi Aktar. An integrated multi-objective decision making process for supplier selection and order allocation [J]. *Omega*, 2008, **36**(1): 76 - 90.
[7] Ghodsypour S H, O'Brien C. The total cost of logistics in supplier selection, under conditions of multiple sourcing, multiple criteria and capacity constraint [J]. *International Journal of Production Economics*, 2001, **73**(1): 15 - 27.
[8] Ryu S W, Lee K K. A stochastic inventory model of dual sourced supply chain with lead-time reduction [J]. *International Journal of Production Economics*, 2003, **81/82**: 513 - 527.
[9] Tyworth J E, Ruiz-Torres A. Transportation's role in the sole versus dual-sourcing decisions [J]. *International Journal of Physical Distribution and Logistics Management*, 2000, **30**(2): 128 - 136.
[10] Kawtummachai R, van Hop N. Order allocation in multiple-supplier environment [J]. *International Journal of Production Economics*, 2005, **93/94**: 231 - 238.

考虑容量和弹性的供应商选择和批量分解模型

于海生　　赵林度

(东南大学经济管理学院,南京 210096)

摘要:为了解决供应链运作流程中供应商交付失败风险影响供应链绩效问题,提出了多源采购环境下供应商选择和批量分解模型.首先阐述了供应商具有容量限制和弹性能力情形下,买方期望总成本包括期望损失成本、弹性努力成本、供应商维持成本和周期采购成本,并给出了相应的数学描述.其次研究了供应商特征对供应商选择和批量分解决策的影响,给出了相应的数值仿真.结果显示,供应商最大交付能力、交付失败概率和弹性能力是影响决策的关键因素.最后指出当前研究焦点仅是买方期望总成而本而忽略了供应商成本,应该综合考虑供应链系统双方成本.

关键词:供应商选择;批量分解;容量;弹性

中图分类号:O225