SUPPLIER SELECTION UNDER PURCHASING AND TRANSPORTATION CONDITIONS

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Abstract: Little attention is given in the literature to the transportation impact on the supplier selection decision. In this paper, we propose a mixed nonlinear programming model to simultaneously determine the optimal number of suppliers to employ and the order quantities to allocate to them, taking into account the transportation. The objective of the model is to minimize the total cost, which includes purchasing, transportation, ordering and inventory costs subject to suppliers, buyer and transportation constraints. The model is solved several times, evaluating various scenarios. Each scenario depends on the shipment type used between the suppliers and the buyer.

Keywords: Nonlinear programming, transportation, Supplier evaluation, Inventory.

1. INTRODUCTION

Supplier selection and transportation are among the principal levers of the supply chain optimization. On one hand, the cost of the purchases constitutes more than 50% of the total cost of the product (Weber et al., 1991) and on other hand, the transportation cost accounts a large part of the total logistic costs and impacts the inventory system of the firm.

The studies in the supplier selection problem were interested in the determination of supplier selection criteria, the tools to evaluate the supplier's performance and the choice between sole and multiple sourcing. The research in that area indicate that splitting an order among several vendors promotes competitive bidding, reduces the risk of supplier nonperformance and can offer savings in inventory costs (Goffin et al., 1997; Sedarage et al., 1999). However, very few contributions highlight, in an explicit way, the impact of transportation on this selection. This is a great limitation because splitting orders across multiple suppliers will lead to smaller transportation quantities which will likely imply larger transportation cost. Moreover, transportation and inventory elements are highly interrelated and contribute most to the total cost of logistics: costs incurred in the suppliers while the product waits to be shipped, costs represented by the product in transit and costs incurred in the buyer while the product waits to be used. Finally, transportation has a direct impact on the lead-time, which affects the firm's total cycle time.

The purpose of this paper is to study the impact of transportation on the supplier selection problem and the order quantity allocations among them in a multiple sourcing network. A mixed nonlinear programming model to solve this problem is developed. The model considers a single product, which is purchased over a planning horizon.

The paper is organized as follows. Section 2 presents the background to the supplier selection problem and cites the relevant literature in that area. Some work relating to multi-sourcing and transportation are also presented in this section. Section 3 describes the mathematical form of the proposed model. Section 4 reports the results of computational experiments made using Matlab software. The last section contains concluding remarks.

2. BACKGROUND

Supplier selection decision is a complex process involving various criteria such as procurement cost, product quality, delivery performance, etc. Dickson (1966) has identified 23 different criteria by which purchasing managers have selected suppliers in various procurement environments. The problem is how to select suppliers that perform satisfactorily on the desired criteria. Weber et al. (1991) have compiled 74 articles published since 1966 in this area and found that vendor selection is a multicriteron decision. They also showed that supplier evaluation approaches might be grouped into three categories, which are: linear weighting models, mathematical programming models and statistical/probabilistic approaches. However, this study identified very few articles that have proposed mathematical programming techniques to analyze supplier selection decisions. In the last few years, other approaches appeared in the literature. We can mention: interpretive structural modeling (Mondal and Deshmukh, 1994), expert system (Vokurka et al., 1996), data envelopment analysis (Weber, 1996; Liu et al., 2000), goal programming (Weber et al., 2000), integrated approach (Çebi et Bayraktar, 2003), etc.

In these various approaches, the criteria relating to transportation like shipment cost, in-transit time and location of supplier are only considered implicitly in the supplier selection process. The most important articles that have addressed the problem of multi-sourcing, in particular dual sourcing and transportation are those of Hong and Hayya (1992), who have discussed reducing lot size in the JIT purchasing environment with multiple vendors. A non-linear programming problem is formulated and the objective function is to minimize the aggregate ordering and holding costs under delivered cost and quality constraints. For multiple sourcing, the model gives the optimal selection of suppliers and the size of the split orders whereas, for the single sourcing, it determines the optimal number of deliveries. More recently, Tyworth and Ruiz-Torres (2000) investigate the role of transportation in the sole versus dual sourcing decision. They present a model, which minimize the sum of purchasing, ordering, storage and transportation costs. No constraints are defined in the model. They demonstrated that dual supplier sourcing could yield savings under some conditions on supplier price, annual demand, lead-time performance and line-haul distance.

In these researches, stocks in the entire transport network (suppliers, in-transit and buyer) are not clarified and the constraints related to transportation are not considered. In our analysis, we expand the inventory system focus on a board perspective that includes suppliers, in-transit and buyer inventories.

3. MODEL FORMULATION

In a multiple sourcing network, a buyer must make a choice among several suppliers and decide of the order quantities to split among them. The model proposed considers the criteria, which take into account transportation, namely: total product cost and lead-time. The objective is to minimize the total cost, which includes purchasing, ordering, transportation and inventory costs. Lead-time is formulated as a constraint. The other constraints of the problem are the lead-time required and production capacity of each supplier, lead-time imposed by the buyer and the type shipment. Moreover, the buyer's demand is constant.

The notation used in this paper is given below:

n: number of suppliers,
D: buyer demand per unit time,
Q: ordered quantity to all suppliers in each period,
Q_i: ordered quantity to i^{th} supplier in each period,
A_i: ordering cost of i^{th} supplier per order,
P_i: purchase price of i^{th} supplier,
C_i: production capacity of i^{th} supplier,
l_i: lead-time required for i^{th} supplier,
T_i: average transit time between the i^{th} supplier and the buyer,
L: lead-time imposed by the buyer,
r: holding rate
Cf_i: fixed shipping cost between the i^{th} supplier and the buyer,
Cv_i: variable shipping cost between the i^{th} supplier and the buyer.

The decision variables for the model are:

$$X_i : \text{percent of Q assigned to } i^{th} \text{ supplier}$$

$$Y_i = \begin{cases} 1 \text{ if } X_i \succ 0 \ (i^{th} \text{ supplier is selected}) \\ 0 \text{ if } X_i = 0 \end{cases}$$

In a general case, as the demand is constant and X_i is the percent of Q assigned to the i^{th} supplier, it can be stated that

$$Q = \sum_{i=1}^{n} Q_i$$

$$Q_i = X_i Q \qquad i = 1, 2, ..., n$$

$$0 \le X_i \le 1 \qquad i = 1, 2, ..., n$$

$$\sum_{i=1}^{n} X_i = 1$$

In addition, D/Q is the number of periods during the time considered. The objective function has the following form:

$$TC = \sum_{i=1}^{n} \begin{bmatrix} DX_i P_i + (D/Q)(Cf_i Y_i + QX_i Cv_i) \\ +(D/Q)A_i Y_i + rDX_i P_i (T_i + X_i Q/D) \end{bmatrix} \quad (1)$$

The first term in this function is the total purchasing cost. The second term represents the total transportation cost. The third term is the total ordering cost. A_i is restricted to traditional (non-transportation) ordering and inspection cost elements. The last term in the function is the total inventory cost. In a transportation network, inventory cost equals the sum of an in-transit inventory cost, an inventory cost incurred while loads are waiting to be shipped from each supplier and an inventory cost incurred while loads are waiting to be used by the buyer. That supposes that each supplier produce items at a constant rate and the production planning is synchronized with that of transport. The average time required to i^{th} supplier to produce a shipment of size Q_i is Q_i/D. Each item in the load waits on average half of this time before being shipped $Q_i/2D$. After arriving, each item waits on average $Q_i/2D$ before being used. Thus, the average time spend by an item from i^{th} supplier to buyer is: $Q_i/D + T_i$

As Q is the optimum order quantity, it can be calculated by using the derivation of TC:

$$\frac{\partial TC}{\partial Q} = 0 \Rightarrow Q = \sqrt{(D\sum_{i=1}^{n} Y_i(A_i + Cf_i))/(r\sum_{i=1}^{n} P_i X_i^2)}$$

By substituting for Q in expression (1), the final model is:

$$\text{Min } (TC) = \sum_{i=1}^{n} DX_i(P_i + rP_iT_i + Cv_i)$$
$$+ 2\sqrt{Dr(\sum_{i=1}^{n} Y_i(A_i + Cf_i))(\sum_{i=1}^{n} P_i X_i^2)}$$

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$$\begin{cases} X_i D \le C_i & i = 1,2,...,n \quad (2) \\ \sum_{i=1}^{n} l_i X_i \le L & (3) \\ \sum_{i=1}^{n} X_i = 1 & (4) \\ \varepsilon Y_i \le X_i \le Y_i & i = 1,2,...,n \quad (5) \\ 0 \le X_i \le 1 & i = 1,2,...,n \quad (6) \\ Y_i = 0,1 & i = 1,2,...,n \quad (7) \end{cases}$$

Constraint (2) represents the capacity restriction for each supplier. Constraint (3) is an aggregate performance measure for delivery for all suppliers. Constraint (4) indicates that demand is placed with the set of n suppliers. Constraint (5) requires that an order is placed with a supplier if only he is selected. ε is a positive number, slightly greater than zero. Constraint (6) enforces the non-negativity restriction on the decision variables X_i. Constraint (7) imposes binary requirements on the decision variables Y_i.

The next section presents a numerical example to evaluate the model. All results presented are generated on a personal Compaq computer (Intel Pentium IV, 2.40 GHz) using Matlab version 6.5, a high-performance language that offers the optimization Toolbox as *fmincon* that perform minimization on general nonlinear functions.

4. MODEL VALIDATION

In this section, a study of the performance of the model is first presented by representing the CPU time in function of the number of suppliers and then, a case study of three suppliers is illustrated under two situation. The first situation examines the case where all suppliers offer the same purchase price. In the second situation, the third supplier, who is far from the buyer, offers a purchase price lower than the other suppliers.

In this numerical example, two types of shipment are used: a truckload (TL) and a less than truckload (LTL), which are characterized respectively by the variable shipping cost 0 and 0.05 and the fixed shipping cost 1.32\$/mile and 0.15\$/mile. The demand of the buyer is 1000 per week, r=20%, the maximum accepted lead-time is 2 days, the ordering cost is 10\$. In these experiments, we take ε = 0.01 and the supplier's capacities are supposed limited.

Table 1 below contains other information on the suppliers, according to whether they use TL or LTL.

Table 1 : Suppliers' information

		Supplier 1	Supplier 2	Supplier 3
Capacity		700	800	900
Distance to buyer (miles)		100	150	200
Lead time (days)	LTL	1.4	2.1	2.8
	TL	0.6	0.9	1.1
Transit time (weeks)	LTL	0.14	0.21	0.29
	TL	0.06	0.09	0.11

4.1 Performance of the model

Table 2 gives the CPU time, which includes the generation, compilation and execution times in seconds, to provide an optimal solution for each value of n.

Table 2. Computational time in CPU seconds

n	CPU (seconds)
2	0.94
3	1.58
4	1.70
5	4.48
6	22.19
7	63.92
8	196.26
9	538.66
10	1827.61

This time appears to grow exponentially in the number of suppliers, especially from value 7 of n. In this case, CPU time varies from 1 minute for n=7 to 30 minutes for n=10. This increase is attributed to the combinations of binary variables Y_i (2^n). But we can conclude that our model can be solved in a rather reasonable amount of time.

4.2 Situation 1

Assume that all suppliers offer a purchase price of 10$. The model is computing under five scenarios, each depending upon a shipment type used by each supplier, as follows:

- Scenario 1: each supplier uses a LTL,
- Scenario 2: each supplier uses a TL,
- Scenario 3: supplier 1 uses a TL while suppliers 2 and 3 use LTL each one,
- Scenario 4: supplier 2 uses a TL while suppliers 1 and 3 use LTL each one,
- Scenario 5: supplier 3 uses a TL while suppliers 1 and 2 use LTL each one.

Table 3 below gives the optimum solutions for each scenario:

Table 3 . Optimum solutions for each scenario

scenario	1	2	3	4	5
X1	0.55	0.51	0.04	0.61	0.55
X2	0.45	0.49	0.84	0	0.45
X3	0	0	0.12	0.39	0
Q	339	837	320	355	339
In transit inventory cost	171	75	214	199	171
Transportatio n cost	163	394	215	179	163
Inventory cost of buyer	86	209	115	93	86
Total cost	556 4	591 2	572 2	562 0	556 4

From these results, we can deduce the following remarks:

The main objective of the buyer is to select suppliers according to cost criterion. Thus, the buyer will choose suppliers 1 and 2 for scenarios 1, 2 and 5. For scenario 3, the choice will relate to all the suppliers. Finally, for scénario 4, the buyer will choose suppliers 1 and 3. The supplier selection depends well on transport.

The minimum of all the total costs is reached for scenarios 1 and 5 and therefore is the optimum solution. It's better for buyer to choose suppliers 1 and 2. In both scenarios, suppliers use a LTL transportation mode, which gives a minimum transportation cost of 163$. The optimum order allocations assigned to each supplier are respectively, in proportion 0.55 and 0.45. The optimum order quantity is 339 and the order quantities, which should be purchased from suppliers, respectively are 186 and 153 for each of the two periods because there are D/Q (=2.95) periods. At the 3rd period, the buyer may order 186 to supplier 1 and 136 to supplier 2 to satisfy the demand (see fig. 1).

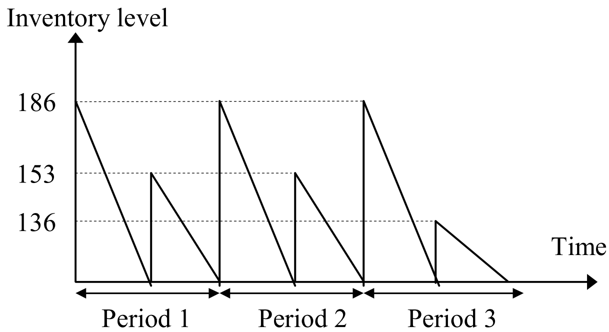

Fig.1 Inventory level of the buyer

The in-transit inventory cost is less for selected suppliers if they use TL each one than LTL. Indeed, a TL is faster and thus the products remain less long in the road. However, the transportation cost of TL is higher than that of LTL. Conversely, the inventory cost of buyer is minimum for scenarios 1 and 5 whereas it's significant for scenario 4, then for scenario 3 and more significant for scenario 2. The use of a TL implies that the products arrive quickly to the buyer and its stock is maximum.

4.3 Situation 2

Assume that supplier 3 offers a purchase price P_3 lower than the other suppliers. The computation of the model indicate that :

- If P_3 varies from 1$ to 3$, the buyer has to select suppliers 1 and 3 for scenarios 1, 2, 3 and 5 and suppliers 2 and 3 for scenario 4.
- For P_3 =4$, the selection will relate to supliers 1 and 3.

In these two cases, supplier 3 is selected. This situation reflects the majority of the real cases where the purchaser buys to the distant suppliers as the case of international sourcing. These suppliers offer low purchase prices, thus compensating for the high costs of transport.

An example of computational results for are shown in table 4 below:

Table 4 . Optimum solutions for each scenarion and the assuption of $P_3 = 3$

scenario	1	2	3	4	5
X1	0.57	0.1	0.36	0	0.1
X2	0	0	0	0.42	0
X3	0.43	0.9	0.64	0.58	0.9
Q	388	916	698	810	777
Transportation cost	168	432	265	311	365
Inventory cost of buyer	85	227	131	153	193
Total cost	4687	4174	4415	4623	4049

These results indicate that the total cost is less important than in the first situation. Moreover, if the buyer chooses scenario 5, which gives the minimum of all the total costs, the significant part of the quantity (90%) will be ordered to supplier 3 who offers a low purchase price even if the total transportation cost is higher.

5. CONCLUSION

Supplier selection is one of the most important activities of purchasing managers in which many criteria like cost, delivery, etc., should be considered in selecting the best suppliers.

This paper introduced a mixed nonlinear programming model that simultaneously determines the optimal set of suppliers to employ and order quantities to place among them, taking into account the transportation.

The computational results of the model also show that the value of the product is very important in the procurement process. Indeed, although the transportation cost is important, the firms source from the distant suppliers, who offer low purchase prices. It is the case of international procurement, especially from developing countries.

The model offers decision makers a variety of scenarios on which the buyer can select the suppliers. These scenarios depend on the transportation mode used to carry the products bought from the suppliers to the buyer with an aim of minimizing the total product cost.

6. REFERENCES

Çebi, F., and D. Bayraktar (2003). An integrated approach for supplier selection. *Logistics Information Management*, **16,** 6, 395-400.

Dickson, G. W. (1966). An analysis of vendor selection systems and decisions. *Journal of Purchasing*, **2**, 1, 5-17.

Goffin, K., Szwejczewski, M. and C. New (1997). Managing suppliers: when fewer can mean more. *International Journal of physical Distribution & Logistics Management*, **27**, 7, 422-436

Hong, J. D. and J. C. Hayya (1992). Just-In-Time purchasing: Single or multiple sourcing? *International Journal of Production Economics*, **27**, 175-181.

Liu, J., Ding, F. Y. Ding and V. Lall (2000). Using data envelopment analysis to compare suppliers for supplier selection and performance improvement. *Supply Chain Management: An International Journal*, **5**, 3, 143-150.

Mondal, A. and S. G. Deshmukh (1994). Vendor selection using Interpretive Structural modeling (ISM). *International Journal of Operations & Production Management*, **14**, 6, 52-59.

Sedarage, D., Fujiwara, O. and H. T. Luong. (1999). Determining optimal splitting and reorder level for N-supplier inventory systems. *European Journal of Operational Research*, **116**, 389-404.

Tyworth, J. E. and A. Ruiz-Torres (2000). Transportation' role in the sole-versus dual sourcing decision. *International Journal of Physical Distribution & Logistics Management*, **30**, 2, 128-144.

Vokurka, R. J., Choobineh, J. and L. Vadi (1996). A prototype expert system for the evaluation and selection of potential suppliers. *International Journal of Operations & Production Management*, **16**, 12, 106-127.

Weber, C. A., Current, J. and W. C. Benton (1991). Vendor selection criteria and methods. *European Journal of Operational Research*, **50**, 2-18.

Weber, C. A (1996). A data envelopment analysis approach to measuring vendor performance. *Supply Chain Management*, **1**, 1, 28-39.

Weber, C. A., Current, J. and A. Desai (2000). An optimization approach to determining the number of vendors to employ. *Supply Chain Management: An International Journal*, **5**, 2, 90-98.