The Impact of Transportation Network on the Supplier Selection

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Abstract: Supplier selection decision is largely studied in the literature but little attention is given to the transportation aspect in this decision. In this paper, a multi-objective programming model, based on lexicographic method, is proposed to simultaneously determine the optimal number of suppliers to employ and the order quantities to allocate to them, taking into account the transportation policies. The product bought from supplier can be shipped directly or via consolidation terminal to the buyer. The objectives to minimize in the model are total logistics cost and lead-time, under suppliers, buyer and transportation constraints. A comprehensive example is provided to illustrate the model.

Keywords: Multiobjective optimisation, nonlinear programming, supplier performance, decision making, transportation.

1. INTRODUCTION
Supplier selection and transportation organization are among the main levers of the supply chain optimization. The costs of raw materials and components account for 40 to 60% of production costs for most US manufacturers (Wadhwa and Ravindran, 2007), while the transportation cost accounts a large part of the total logistic costs and impacts the inventory system of the firm.

Most of previous studies on supplier selection decision are interested in the selection of either criteria, methods used to evaluate the supplier’s performance, and choice sole versus multiple sourcing strategy. This paper also caters these issues but shows the impact of transport on this decision. Indeed, in the case of a multiple sourcing network, splitting orders across multiple suppliers will lead to smaller transportation quantities which will likely imply larger total cost of logistics, namely costs incurred in the suppliers elements are highly interrelated and contribute mostly to the total cost of logistics, namely 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. In addition, transport has a direct impact on the lead-time. Finally, transport takes a great place in the current context of durable development.

The remainder of this paper is organized as follows. Section 2 presents relevant literature on the supplier selection problem. In section 3, the mathematical model is described. Section 4 presents the solution methodology used. Section 5 reports the results of computational experiments. The last section contains concluding remarks.

2. LITERATURE REVIEW
Supplier selection and evaluation is one of the most critical activities in purchasing process. This evaluation process is complex because it involves various conflicting criteria such as cost, quality, delivery, etc. Dickson (1966) was the first one to address this issue and 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. Based on a review of 74 papers published since 1966, Weber et al. (1993) have found that vendor selection is a multicriteria decision making. They also showed that supplier evaluation approaches might be grouped into three categories, which are: linear weighting methods, mathematical programming models, and statistical/probabilistic approaches. In the last years, other methods in various research contexts such as supply chain design/management, agile manufacturing, and dynamic alliances appeared in the literature. For instance: Expert system (Yigin et al., 2007), DEA (Liu et al., 2000), multi-objective programming (Talluri and Narasimhan, 2003; Aguezzoul and Ladet, 2007; Amid and Ghodspour, 2009), data-mining methods (Ni et al., 2007), hybrid approach (Tseng et al., 2006; Selvkli et al., 2007; Demirtas and Üstün, 2008), etc. An analysis of these methods can be found in (De Boer et al., 2001; Aguezzoul and Ladet, 2006; Ho et al., 2010).

In these various approaches, the criteria relating to transportation like shipment cost, in-transit time, geographrical location of supplier, etc. are considered in the supplier selection process only in an implicit manner. Moreover, the in-transit stock in the entire transport network linking buyer to suppliers is not evaluated. The only works to our knowledge that have considered the problem of multi-sourcing taking transportation into account are those of Aguezzoul (2005) and Aguezzoul & Ladet (2007). They proposed a multiobjective model that minimizes simultaneously total product cost and lead-time.
criteria. The weighted sum of distances from the goals is used to solve the model.

In this paper, we consider this work using the lexicographic method to solve it. The lexicographic method is used for the first time by Arunkumar et al. (2006) in the case of selection of suppliers, even if transport is not taken into account in their model. At the end, a comparison of results with those obtained by the weighted sum of distances from the goals will be presented.

3. MODEL DEVELOPMENT

In this paper, we consider total cost and lead-time as the relevant criteria to minimize simultaneously for the selection of the most viable suppliers in the supply chain management area. We choose these criteria because they are used in the literature and are related to transport. Total cost includes purchasing, ordering, transportation and inventory costs while suppliers’ capacity and buyer’s demand are formulated as constraints. The following notation and formulations to model this problem are used as suggested in Aguezzoul (2005) and Aguezzoul and Ladet (2007):

\[ n: \text{number of suppliers,} \]
\[ D: \text{buyer demand per unit time, assumed constant,} \]
\[ Q: \text{ordered quantity to all suppliers in each period,} \]
\[ Q_i: \text{ordered quantity to } i^{th} \text{ supplier in each period,} \]
\[ A_i: \text{ordering cost of } i^{th} \text{ supplier per order in each period,} \]
\[ P_i: \text{purchase price of } i^{th} \text{ supplier,} \]
\[ C_i: \text{production capacity of } i^{th} \text{ supplier,} \]
\[ T_i: \text{average transit time between the } i^{th} \text{ supplier and the buyer,} \]
\[ l_i: \text{lead-time required for } i^{th} \text{ supplier,} \]
\[ l_i: \text{lead-time imposed by the buyer,} \]
\[ r: \text{Inventory holding cost rate,} \]
\[ d_i: \text{distance between the } i^{th} \text{ supplier and the buyer,} \]
\[ C_f: \text{shipping cost per distance between the } i^{th} \text{ supplier and the buyer,} \]
\[ C_V: \text{shipping cost per load between the } i^{th} \text{ supplier and the buyer.} \]

The decision variables for the model are:
\[ X_i: \text{fraction of } Q \text{ assigned to } i^{th} \text{ supplier} \]
\[ Y_i = \begin{cases} 
1 & \text{if } X_i > 0 \ (i^{th} \text{ supplier is selected}) \\
0 & \text{if } X_i = 0
\end{cases} \]

In addition, \( D/Q \) is the number of periods during the time considered. The total cost has the following form:

\[
TC = \sum_{i=1}^{n} [DX_iP_i] + [(D/Q)(d_iC_fY_i + QX_iC_V_i)] \\
+ \sum_{i=1}^{n} [(D/Q)A_iY_i] + [rDX_iP_i(T_i + X_iQ/D)] 
\]  

- The first term in this function is the total purchasing cost. \( XD \) is the part of demand to assign to \( i^{th} \) supplier,
- The second term represents the total transportation cost. \( C_f \) is a fixed shipping cost which is independent of a load and includes cost of stop and cost per unit distance. \( C_v \) is a cost per load and it’s independent of the distance covered,
- 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, total inventory includes in-transit inventory, loads that are waiting to be shipped from each supplier, and loads that 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 \( Q \) is \( Q/D \). Each item in the load waits on average half of this time before being shipped \( Q/2D \). After arriving, each item waits on average \( Q/2D \) before being used. Thus, the average time spend by an item from \( i^{th} \) supplier to buyer is: \( Q/D + T_i \)

Here, we use the Economic Order Quantity (EOQ) model which is widely used to calculate the optimal lot size to reduce the total logistics cost. EOQ is the value that cancels the derivation of TC:

\[
EOQ = \sqrt{\frac{D\sum_{i=1}^{n} Y_i(A_i + d_iC_f)}{r\sum_{i=1}^{n} P_iX_i^2}}
\]

Thus, by replacing \( Q \) by \( EOQ \) in (1a), the final expression of the total cost is:

\[
TC = \sum_{i=1}^{n} DX_i(P_i + rP_iT_i + C_V_i) \\
+ 2\sqrt{\frac{(D\sum_{i=1}^{n} Y_i(A_i + d_iC_f))(\sum_{i=1}^{n} P_iX_i^2)}} 
\]  

An appropriate aggregate performance measure for delivery to the buyer is given by the expression (1b). This expression is given by several authors (Chaudhry et al., 1993; Jayaraman et al., 1999) and must be less than the lead-time imposed by the buyer. This implies that the long lead-time of one supplier is compensated by the sort lead-time of other suppliers.

\[
LT = \sum_{i=1}^{n} l_iX_i 
\]

The mathematical formulation of the nonlinear multi-objective program model is given as follows:
4. SOLUTION METHODOLOGY

The multi-objective programming is often used to find a compromised solution, which simultaneously satisfy a number of design criteria. Most methods of solving multi-objective programs use the weighted sum for its simplicity. In our case, the lexicographic method is used. It’s a method that optimizes one of the original objectives, subject to constraints on other objectives; that gives a better visibility for the purchasing manager to frame a constraint for subsequent objectives. This step-by-step process first generates an objective value based on constraints discussed in model. Then, the objective function is added as another constraint for the next objective function based on the value found in the previous step. The value is relaxed in the decision of the purchase manager and the company policy. The experimentation is continued until the final objective considered is reached.

In the lexicographic method, the designer ranks the objectives in order of importance. The optimum solution is then found by minimizing the objective functions, starting with the most important and proceeding according to the order of importance of the objectives.

In our model, total cost (TC) and leadtime (LT) are the two objectives to simultaneously minimize. Thus, the lexicographic method is used twice: The first one, noted Lexico1, estimated that total cost is a priority with respect to total cost. The same previous steps are used in inverting total cost and leadtime.

5. NUMERICAL EXAMPLE

5.1 Problem Data

In this section, we present a case study of three suppliers, denoted S1, S2 and S3, who have capacities limited. Two types of shipment are used: a TruckLoad (TL) and a Less than TruckLoad (LTL), characterized respectively by the shipping cost per load of 0€ and 0.05€ and the shipping cost per distance of 1.32€/mile and 0.15€/mile. The demand of the buyer is 1000 per week, r=20%, the maximum accepted lead-time is 3 days, the ordering and the purchasing costs are respectively 10€ and 5€. The capacities of the three suppliers are respectively 900, 800 and 700 when their distances to buyer are respectively 100, 150 and 200 miles. In these experiments, we take ε = 0.001 by supposing that 0.1% is the minimum percentage of the demand that the buyer will order to a supplier.

The model is then computed under eight scenarios, each depending upon on direct or indirect delivery between each supplier and buyer. TL is used in the case of direct delivery, while LTL is used in indirect delivery (through a terminal):

- Scenario 1: Each supplier uses a TL,
- Scenario 2: S1 uses a LTL while S2 and S3 each use TL,
- Scenario 3: S2 uses a LTL while S1 and S3 each use TL,
- Scenario 4: S3 uses a LTL while S1 and S2 each use TL,
- Scenario 5: S1 and S2 each use LTL while S3 uses TL,
- Scenario 6: S1 and S3 each uses LTL while S2 uses TL,
- Scenario 7: S2 and S3 each uses LTL while S1 uses TL,
- Scenario 8: Each supplier uses a LTL.

An illustration of the problem is given in figure 1 below:

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Min Z = (TC, LT)                                                    (1)                        
S. T  

\[
\begin{align*}
X_i \leq C_i & \quad i = 1, n \quad (2) \\
\sum_{i=1}^{n} Y_i X_i \leq L_u & \quad (3) \\
\sum_{i=1}^{n} X_i = 1 & \quad (4) \\
\varepsilon Y_i \leq X_i \leq Y_i & \quad i = 1, n \quad (5) \\
Y_i = 0,1 & \quad i = 1, n \quad (6)
\end{align*}
\]

Equation (1) represents the two objectives (TC, LT) to minimize simultaneously and whose expressions are given by (1a) and (1b). 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. Constraints (5) requires that an order be placed with a supplier if only he is selected; ε is a positive number, slightly greater than zero. Constraint (6) imposes binary requirements on the decision variables Y_i.

The solution of the problem is obtained as \( X_i^* \) and \( LT^* = LT(X_i^*) \).

The second one, noted Lexico2, estimated that leadtime is a priority with respect to total cost. The same previous steps are used in inverting total cost and leadtime.

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Fig 1. Structure of distribution network
5.2 Computational Results

The results presented in table 1 below are generated with the use of Matlab 6.1. It gathers the results of lexicographic method and those of the weighted sum of distances from the goals (Aguezoul, 2005; Aguezzoul and Ladet, 2007). The weight values reported here correspond to cost criterion while those of leadtime are subtracted from 1.

Table 1. Computational results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Selected supplier</th>
<th>% of order quantities</th>
<th>Selected supplier</th>
<th>% of order quantities</th>
<th>Selected supplier</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>S1, S2</td>
<td>X1 = 0.51 X2 = 0.49</td>
<td>S2, S3</td>
<td>X2 = 0.30 X1 = 0.70</td>
<td>S2, S3</td>
<td>0 to 0.6</td>
</tr>
<tr>
<td>2</td>
<td>S1, S2</td>
<td>X1 = 0.46 X2 = 0.54</td>
<td>S1, S3</td>
<td>X1 = 0.56 X2 = 0.46</td>
<td>S1, S3</td>
<td>0 to 0.5</td>
</tr>
<tr>
<td>3</td>
<td>S1, S2</td>
<td>X1 = 0.59 X2 = 0.41</td>
<td>S1, S2</td>
<td>X1 = 0.53 X2 = 0.47</td>
<td>S1, S2</td>
<td>0 to 1</td>
</tr>
<tr>
<td>4</td>
<td>S1, S3</td>
<td>X1 = 0.62 X3 = 0.38</td>
<td>S1, S3</td>
<td>X1 = 0.68 X2 = 0.32</td>
<td>S1, S3</td>
<td>0 to 1</td>
</tr>
<tr>
<td>5</td>
<td>S1, S2</td>
<td>X1 = 0.55 X2 = 0.45</td>
<td>S1, S3</td>
<td>X1 = 0.55 X2 = 0.45</td>
<td>S1, S3</td>
<td>0 to 0.4</td>
</tr>
<tr>
<td>6</td>
<td>S1, S3</td>
<td>X1 = 0.61 X3 = 0.35</td>
<td>S1, S2</td>
<td>X1 = 0.77 X2 = 0.23</td>
<td>S1, S2</td>
<td>0 to 0.1</td>
</tr>
<tr>
<td>7</td>
<td>S2, S3</td>
<td>X2 = 0.55 X3 = 0.45</td>
<td>S1, S2</td>
<td>X1 = 0.54 X2 = 0.46</td>
<td>S1, S2</td>
<td>0 to 0.9</td>
</tr>
<tr>
<td>8</td>
<td>S1, S2</td>
<td>X1 = 0.55 X2 = 0.45</td>
<td>S1, S2</td>
<td>X1 = 0.90 X2 = 0.10</td>
<td>S1, S2</td>
<td>0 to 1</td>
</tr>
</tbody>
</table>

From these results, we can deduce the following remarks:

- This table gives the number of supplier to choose according to the transport policy used,
- According to the priority given to total cost or leadtime, the lexicographic method determine the number of suppliers to choose, the order quantities to allocate to them, and transport policy to consider. For example, in considering the case of Lexico1, where preference is given initially at cost, scenario 1 allows to choose suppliers S1 and S2. The optimum order allocations assigned to each supplier are respectively, in proportion 0.51 and 0.49. Similarly, in the case of Lexico2, where preference is given initially at leadtime, scenario 3 allows to choose these suppliers,
- The same results are found with weighted sum of distances from the goals, except in the case of scenario 6. Indeed, the 3 vendors are selected where the weight varies from 0.2 to 0.6 while in the lexicographic method, they are never all selected.
- However, preference to be given to a particular criterion is not evaluated by defined values of these weights. Thus, for scenario 2, suppliers S1 and S3 are chosen with a weight that varies from 0 to 0.5, while they are selected in scenario 6 with a weight that varies from 0.7 to 1. As for the order quantities to allocate to each supplier selected, they depend on the weights associated with the criteria. For example, in scenario 1, when the weight is 0.9, the percentages of the order quantities to be given to each supplier S1 and S2 are respectively 0.50 and 0.50. These percentages become 0.47 and 0.53 if the weight is 0.7.

6. CONCLUSION

Supplier selection is one of the most critical activities of purchasing management in a supply chain. A review of literature on that field shows that there has been very little work that comprehensively examines the role of the transportation in this selection.

In this paper, a nonlinear multiobjective programming approach, based on lexicographic method, is developed to simultaneously select the appropriate suppliers to employ and determine the order quantities to allocate to them, taking into account the type of delivery, direct or through a logistic site (a platform or warehouse).

The proposed model offers decision makers a variety of scenarios on which they can select the suppliers. These scenarios depend on the transportation policies used to carry
the products bought from the suppliers to the buyer with an aim of simultaneously minimizing total product cost and leadtime. Moreover, it is more interesting because its subjectively avoids assigning the weights associated with criteria, as it is in the case of the weighted sum method. Finally, it allows making sensitivity analysis by varying the main parameters of the model such as purchasing price, distance between buyer and suppliers, and buyer demand.

One of the prospects for this work is to integrate the case where goods can be transshipped between more than one terminal (intermodal freight transport). In this case, the goods undergo at least three changes of the means of transport between their origin and their destination. For example, in a road-rail combined transport, a shipment is first transported by truck to a terminal. There it is transshipped from truck to train. The train takes care of the terminal to terminal transport. At the other end of the transport chain, the shipment is transshipped from train to truck and delivered by truck to the receiver.

It is also interesting to incorporate the external cost of transport, which is linked to air pollution, noise, congestion, accidents, etc., in the current context of growing sustainably.

REFERENCES


