TRANSPORTATION COST IN THE MULTIPLE SUPPLIER SELECTION MODEL

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ABSTRACT

Supplier selection aims at determining two common decisions, namely, which suppliers should be selected and how much of any particular order should be allocated among them. To do so, involves a number of criteria, factors and conditions. One missing gap is the effect of transportation cost and its relationship to others, especially, inventory cost. This paper aims to formulate a model that includes transportation cost, in order to examine its effects on decisions. The objective function is total cost comprising purchasing, transportation, and inventory cost affected by different arrivals from each supplier. From computational results, it can be found that transportation cost has a significant impact on the decision solution. Also, it has to be traded off with inventory cost in order to determine the optimal order quantity, as these are in conflict. Moreover, total cost from the model is lower than a model that excludes transportation cost. However, there may be some factors that have been insufficiently addressed in supplier selection. These factors may include components of transportation cost that have been ignored and the exclusion of multiple objectives. These are challenging topics for future research.

Keywords: supplier selection, transportation cost, inventory cost
1. INTRODUCTION

It is the responsibility of a buyer’s purchasing department to select suppliers for particular inventory and to allocate orders. For an order, they must decide which suppliers to select and the proportion allocated to each. The buyer may allocate the order to either a single supplier or to multiple suppliers. A single supplier must be able to meet all conditions—such as capacity, quality and delivery time—without qualification.

With multiple suppliers, on the other hand, the order is split among them. Splitting may be necessary, when only the whole order cannot be handled by a single supplier, because none is capable of meeting all conditions on the order. There are also distinct advantages in order splitting. To hedge against or avoid uncertainties, the buyer can spread risk. By choosing multiple suppliers with different lead times, the buyer can stagger deliveries with the benefit of reducing the amount of stock held in store.

To select suppliers, a number of criteria can be applied to evaluate them. Dickson (1966), in a very often cited article based on a survey of 273 purchasing agents, concludes that there are 23 criteria to consider in supplier selection problems. Three significant ones are cost, quality and delivery performance. Weber, Current and Benton (1991) later reviewed 74 articles based on Dickson’s 23 criteria and found that the net price, delivery and quality are the three most popular criteria applied in supplier selection decisions. Also, the net price has extremely important comparing to the others.

According to the literature review by Ghodsypour and O’Brien (2001), most articles deal with the cost criterion, but limited to net price. They thereby exclude other significant costs, i.e., transportation, ordering and shortage. To compensate for this shortcoming, they developed a supplier selection model that aggregated price, ordering, and inventory cost. It includes the capacity constraints of the suppliers and buyers’ limitations regarding budget, quality etc. They contend that the total cost in their model includes transportation, inspection, ordering and storage costs. While the objective function explicitly includes ordering and storage costs, transportation and inspection costs seem to be subsumed into the price. This model therefore cannot consider the effects of costs of various transportation modes and strategies.

Other papers that apply the three significant criteria identified by Dickson (see above) include, inter alia, Aissaoui et al (2007), Hong et al (2005), Kumar et al (2006), Liao and Rittscher (2007a, b), Liu and Hai (2005), Narasimhan et al (2006), Pi and Low (2006), Vipul et al. (2004) and Xia and Wu (2007). These papers take total cost as a dominant criterion. However, they focus on purchasing and inventory cost, solely. They disregard transportation cost: a significant contributor to total cost as explained by Aguezzoul and Ladet (2007), Thomas and Tyworth (2006), and Tyworth and Ruiz-Torres (2000). Few papers examine transportation cost. Some significant articles are by Tyworth and Ruiz-Torres (2000), Kren and Wang (2005) and Aguezzoul and Ladet (2007).

Tyworth and Ruiz-Torres (2000) studied the effects of transportation on single and dual supplier selection. Their model minimizes total cost comprised of transportation, annual holding, ordering, and shortage costs. Transportation cost is as function of total weight and minimum weight of delivered product.

Kreng and Wang (2005) proposed a model in which transportation cost is included in total cost for selecting the single best supplier. Here, transportation cost is a function of delivery time for different modes of transport. Using the model, they calculated total cost for two suppliers. In determining minimum cost, they used fixed costs for direct labour, equipment and manufacturing time, while varying transportation cost. The effects of the fixed costs (seemly arbitrarily set), constraints and optimization techniques are not discussed.
In studying multiple-supplier selection, Aguezzoul and Ladet (2007) included transportation cost within total cost. Transportation cost was based on two factors: distance between suppliers and the buyer; whether or not, the trucks are fully laden. Applying multiobjective programming, they minimised a weighted function of lead-time and total cost, which includes transportation cost. Varying the types of shipment, they found that selection of supplier depended upon the relative weights, as there is conflict between minimization of lead-time and total cost.

The above papers do not consider the effect of delivery time on the level of inventory. They also neglect the correlation between inventory and transportation cost. This is critical, as higher transportation cost normally accompanies shorter lead-time (faster delivery), and vice versa. However, higher transportation cost can allow the buyer to reduce inventory, with consequential reduction in holding cost. In this respect, suppliers who can minimize both costs are at an advantage. This relationship is of prime importance in our research.

We present a multiple-supplier selection model that includes transportation cost. Our Base model concerns unequal-order splitting, capacity limitation and different lead-times from each supplier for delivery. The objective of the model is the minimization of total cost, comprising purchasing (Prc), transportation (Trs) and inventory (Inv) costs.

The remainder of this paper is structured as follows:

- The Base model is presented, focusing on assumptions, notation and calculation of inventory level
- A numerical example and the optimizing procedure are described
- Results of the Base model are drawn and discussed. These are compared to the results for another model that neglects transportation cost (herein called the EOQ model).
- Finally, overall conclusions are drawn.

2. THE MODEL FORMULATIONS

This section covers the formulation of the Base model. It embraces the assumptions, parameters, decision variables and notation, inventory level of unequal order splitting, and objective function and constraint formulations.

2.1. Assumptions of the Model

Various assumptions are defined below to place bounds on the system; otherwise the model would be extremely complicated and impossible to formulate:
- The demand is known and constant over time
- Only one item is considered
- The product price quoted by each supplier can differ
- Each supplier has limited capacities
- Orders of the buyer are placed simultaneously to all selected suppliers
- Product price is not a function of order quantity
- Lead time for delivery is known and constant
- In-transit holding cost is not considered
- No limited capacity for transportation of each supplier
- No limitation condition on budgeting
- No shortages are allowed

2.2. Notation

Index:

\[ i \quad = \quad \text{The index indicator for suppliers, } i = 1, \ldots, n \]
**Parameters:**

- $Q$ = order quantities allocate to all selected suppliers in each period
- $P_i$ = unit product price from supplier $i$
- $A_i$ = ordering cost for placing each order to supplier $i$
- $h$ = holding rate
- $T$ = replenishment period
- $I_{avg}$ = average inventory level
- $D$ = annual demand which is known and constant
- $d$ = daily demand rate which is constant per unit time
- $l_i$ = delivery lead time from supplier $i$
- $F_i$ = fixed transportation cost charged by supplier $i$
- $V_i$ = variable transportation cost from supplier $i$ (cost rate multiply by total weight)
- $c_i$ = capacity of supplier $i$
- $R$ = reorder point
- $C_{total}$ = total cost

**Decision variables**

- $X_i$ = fraction of total order quantities assigned to supplier $i$ \([0, 1]\)
- $\lambda_i$ = 1 if $X_i \neq 0$ (supplier $i$ is selected)
- = 0 otherwise

### 2.3. Inventory Level of the Unequal Order Splitting Problem

Figure 1, below, illustrates inventory level pattern of this paper. From that figure, for single supplier selection, when inventory level is depleted to reorder point ($R$), the whole order is placed to such supplier. After the order arrived, the stock level is replenished instantaneously to the $Q$ level. The stock is consumed at a constant rate. When inventory decreases to the reorder point, another order is placed. The process repeats over the planning horizon.

Contrastingly, for the multiple supplier selection, each supplier may have different lead-times for delivery and the order may be unequally split among them. Such circumstances cause order deliveries to be staggered: that is, the split order is delivered at different time from each supplier. As a result, the inventory level changes from $Q$ to $Q_i$ ($i = 1 \text{ to } n$), shown.
as solid line in Figure 1. When the inventory level is depleted to reorder point, the whole order quantity is unequally split and placed simultaneously to all selected suppliers. Therefore, the average inventory level holding for this case has to be revised and recalculated as described below.

The average inventory level \( I_{avg} \) can be calculated from summation of each trapezoid area of each arrival order quantity \( Q_i \), the whole area under the solid line, and then divided by replenishment period \( T \). That is,

\[
I_{avg} = \frac{I_1 + I_2 + \cdots + I_{n+1}}{T}; \quad T = \frac{Q}{d}
\]  

(1)

For simplicity’s sake, it can be calculated from the average of whole area under the inventory curve minus the average inventory reduction (shaded area).

\[
\text{Inventory reduction} = \frac{dQ_1 (l_2 - l_1) + dQ_2 (l_3 - l_1) + \cdots + dQ_n (l_n - l_1)}{Q}
\]  

(2)

That is, average inventory level for multiple suppliers can be stated as below.

\[
I_{avg} = \left( R - d \left( \arg \min l_i \lambda_i \right) + \sum_{i=1}^{n} \frac{X_i Q}{2} \right) - \left( \frac{dQ_2 (l_2 - l_1)}{Q} + \frac{dQ_3 (l_3 - l_1)}{Q} + \cdots + \frac{dQ_n (l_n - l_1)}{Q} \right)
\]  

(3)

From such equation, it is formulated as sequence arrival of supplier 1 to \( n \). In fact, arrival of suppliers is not always as that pattern, but rather whichever supplier who has the shortest lead time is arrived first, followed by the second shortest lead time supplier, and then the next shortest lead time supplier come until the last supplier. Therefore, the \( I_{avg} \) equation can be re-written and adjusted to a short form as the following equation.

\[
I_{avg} = \left( R - d \left( \arg \min l_i \lambda_i \right) + \sum_{i=1}^{n} \frac{X_i Q}{2} \right) - \sum_{i=1}^{n} \frac{dX_i (l_i - \arg \min l_i \lambda_i)}{2}
\]  

(4)

2.4. Objective Function and Constraints Formulations

The objective function for this paper is to minimized total cost which can be defined as:

\[
\text{Min } Z = \sum_{i=1}^{n} \left( \frac{DF_i \lambda_i}{Q} + DV_i X_i \right) + \sum_{i=1}^{n} DP_i X_i + \frac{D}{Q} \sum_{i=1}^{n} \lambda_i + \sum_{i=1}^{n} hP_i I_{avg}
\]  

(5)

The first term is the transportation cost \( (Trs) \), which includes fixed plus variable cost. In this paper, fixed cost is charged per time of delivery, while variable cost is quoted by the total weight of delivered products. The second term is purchasing cost \( (Prc) \) which is calculated from product price of each supplier. The last two terms are inventory cost \( (Inv) \) which equals to ordering and holding cost, respectively. The model is optimized subject to the following constraints.

\[
Q X_i \leq c_i, \quad \forall i
\]  

(6)

\[
\sum_{i=1}^{n} Q X_i \geq Q; \quad \sum_{i=1}^{n} X_i = 1
\]  

(7)
\[ R - d \left( \arg \min l_i \lambda_i \right) \geq 0 \]  
(8)

**All variables are non-negative and c, d, D, Q, R are integer**  
(9)

The first constraint is set to ensure that the order quantity split among suppliers cannot exceed the capacity of each supplier. The second constraint assures that the summation of all deliveries cover the total demand of the buyer. The next constraint avoids shortage. The final constraint ensures that the values of all variables are non-negative, and that some must be integer.

\[ Q \] that minimizes total cost \((C_{\text{total}})\) is found by equating the derivative of \(C_{\text{total}}\) with respect to \(Q\) to zero:

\[
\frac{\partial (C_{\text{total}})}{\partial Q} = -\sum_{i=1}^{n} \frac{DF_i \lambda_i}{Q^2} - \sum_{i=1}^{n} \frac{DA_i \lambda_i}{Q^2} + \frac{1}{2} \sum_{i=1}^{n} hP_i X_i = 0
\]

(10)

Hence,

\[ Q = \sqrt{\frac{2D \sum_{i=1}^{n} (A_i + F_i) \lambda_i}{hP_i X_i}} \]  
(11)

3. **A NUMERICAL EXAMPLE**

A simple numerical example can demonstrate the impact of transportation cost on supplier selection. The intention is to be simple and transparent, while demonstrating how transportation cost affects multiple supplier selection. Therefore, only three suppliers are considered. Using transportation costs from Tyworth and Ruiz (2000), which is a significant study of transportation cost in supplier selection, we assume that each supplier quotes the product price at $5, $6 and $7, respectively, and each has a limited capacity of 700 units. The annual demand of the buyer is 2,880 units and demand rate is 80 units per day. The ordering cost, including inspection, is $15 for every supplier, while the holding rate is set at 20%. The buyer can receive the order from supplier 1, 2 and 3 at 6, 4, and 5 days, respectively. Fixed transportation cost is charged at the same rate of $100 for all suppliers. Whereas variable costs, taken from Tyworth and Ruiz (2000), for each supplier are based on the total weight of product, each unit of product assigned at 5 pounds, shown in Table 1 below.

<table>
<thead>
<tr>
<th>Supplier 1</th>
<th>Supplier 2</th>
<th>Supplier 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (lbs)</td>
<td>Cost ($/cwt\text{*})</td>
<td>Weight (lbs)</td>
</tr>
<tr>
<td>1 - 456</td>
<td>42.28</td>
<td>1 - 396</td>
</tr>
<tr>
<td>457 - 830</td>
<td>38.62</td>
<td>397 - 802</td>
</tr>
<tr>
<td>831 - 1,529</td>
<td>32.10</td>
<td>803 - 1,767</td>
</tr>
<tr>
<td>1,530 - 3,508</td>
<td>24.55</td>
<td>1,768 - 3,985</td>
</tr>
</tbody>
</table>

* The cwt is a hundredweight unit (1 cwt = 100 pounds)

4. **ROUTINE FOR SOLVING THE PROBLEM**

The mathematical model in this paper is mixed-integer, which requires some decision variables to be integers. Some factors and conditions are in conflict. In addition, full search is used to assure an optimal solution. The optimal routine has the following steps:

**Step 1:** Generate combination of \(X_i\) by varied \(X_i\) from 0 to 1 step at 0.01 with a condition that summation of \(X_i\) for each combination has to be less than or equals to 1.
Step 2: In each combination, substitute the value of all parameters and variables in objective functions and constraints to determine optimal order quantity \( (Q) \), and then \( Q_i \) is calculated from multiply \( Q \) by \( X_i \).

Step 3: Comparing quantity order allocated to each supplier \( (Q) \) to its limited capacity, if such \( Q_i \) is over capacity limitation, the program will return infeasible computation: IC, then completed process for that combination. Otherwise, move to the next step.

Step 4: All required values are calculated and then kept the results to be compared to each other. Such values are \( C_{\text{total}} \), \( Prc \), \( Inv \) and \( Trs \) which are calculated by substituted all relevant values to each relevant equation.

Step 5: Repeated step 1 to 4 until completed all combinations of \( X_i \) then go to step 6.

Step 6: Compare all feasible solutions from all combinations of \( X_i \), and then reflect the optimal results, mentioned in Step 4, before printing outputs to file or showing at monitor.

5. RESULTS

The solution for minimization of total cost splits the order quantity of 1,110 units, such that supplier 1 has 699 units and supplier 2 has 411 units. The minimum total cost of $21,517.04 included purchasing cost of $15,465.60, inventory cost of $1,076.64 and transportation cost of $4,974.80.

In examining correlations between inventory and transportation cost, some feasible solutions are shown in Table 2. These relationships are plotted in Figure 2.

![Table 2. Some Feasible Solutions of Transportation and Inventory Cost](image)

<table>
<thead>
<tr>
<th>Combinations</th>
<th>( X_1 )</th>
<th>( X_2 )</th>
<th>( X_3 )</th>
<th>( Q )</th>
<th>( Trs )</th>
<th>( Inv )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.01</td>
<td>0.48</td>
<td>0.51</td>
<td>1,236</td>
<td>7,031.65</td>
<td>2,178.45</td>
</tr>
<tr>
<td>2</td>
<td>0.01</td>
<td>0.49</td>
<td>0.50</td>
<td>1,237</td>
<td>7,025.03</td>
<td>2,181.97</td>
</tr>
<tr>
<td>3</td>
<td>0.01</td>
<td>0.50</td>
<td>0.49</td>
<td>1,238</td>
<td>7,018.42</td>
<td>2,185.48</td>
</tr>
<tr>
<td>4</td>
<td>0.01</td>
<td>0.51</td>
<td>0.48</td>
<td>1,239</td>
<td>7,011.81</td>
<td>2,192.60</td>
</tr>
<tr>
<td>5</td>
<td>0.01</td>
<td>0.52</td>
<td>0.47</td>
<td>1,240</td>
<td>7,005.20</td>
<td>2,196.12</td>
</tr>
</tbody>
</table>

![Figure 2. Correlations between \( Trs \) and \( Inv \)](image)

Table 2 shows that transportation and inventory cost are in opposite directions. Transportation cost continuously increases from $7,031.65 to $7,005.20, while inventory cost
reduce from $2,178.45 to $2,196.12, as the optimal order quantity \( Q \) increases. This is possibly because the small order quantity causes inventory holding to be low. However, as it forces the buyer to place orders more frequently, transportation cost will be higher. Conversely, larger quantity can lead to transportation cost reduction but it causes higher inventory level, resulting in higher inventory cost.

To examine effects of transportation cost on supplier selection, the results of the Base model are compared to those of the model that overlooks transportation, i.e., the EOQ model. The formulation and routine for the solving the problem for the EOQ model are similar to the Base model excluding transportation cost. The optimal order quantity for the EOQ model is 293 units, which was allocated solely to supplier 1. The associated inventory cost is $294.44, which contributes to the total cost of $14,694.44.

The comparisons of results from both models are demonstrated in Table 3 below. The order quantity from the EOQ model is smaller and the total cost (in the highlighted column). This is also lower than the Base model. This is because EOQ model is balanced between holding and ordering cost.

Table 3. Some Feasible Results of Trs and C total from Both Models

<table>
<thead>
<tr>
<th>X_1</th>
<th>X_2</th>
<th>X_3</th>
<th>Q</th>
<th>C_{total(no-Trs)}</th>
<th>Trs_{EOQ}</th>
<th>C_{total}</th>
<th>C_{total}*</th>
<th>Q</th>
<th>Trs</th>
<th>C_{total}</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05</td>
<td>0.48</td>
<td>0.47</td>
<td>449</td>
<td>19,422.64</td>
<td>9,095.94</td>
<td>28,518.58</td>
<td></td>
<td>1.244</td>
<td>7,005.55</td>
<td>27,672.93</td>
</tr>
<tr>
<td>0.49</td>
<td>0.35</td>
<td>0.16</td>
<td>478</td>
<td>17,133.53</td>
<td>8,264.76</td>
<td>25,398.29</td>
<td></td>
<td>1.323</td>
<td>5,717.89</td>
<td>24,197.45</td>
</tr>
<tr>
<td>0.54</td>
<td>0.00</td>
<td>0.46</td>
<td>382</td>
<td>17,630.98</td>
<td>7,526.16</td>
<td>25,157.14</td>
<td></td>
<td>1.057</td>
<td>5,502.97</td>
<td>23,798.31</td>
</tr>
<tr>
<td>0.64</td>
<td>0.00</td>
<td>0.36</td>
<td>388</td>
<td>17,039.48</td>
<td>7,728.57</td>
<td>24,768.05</td>
<td></td>
<td>1.076</td>
<td>5,184.04</td>
<td>22,906.74</td>
</tr>
</tbody>
</table>

* total cost of the EOQ model included transportation cost

The EOQ model does not include transportation cost in determining order quantity. However, transportation cost cannot be avoided; in practice, it must be included in total costing. Therefore, when transportation cost is calculated based on the order quantity of the EOQ model, the results are shown as Trs_{EOQ} column in Table 3 above. When comparing transportation cost and total cost when transportation cost is included, Trs and C total of the Base model are clearly lower than those from the EOQ model. The Base model provides saving in costs of up to 7.5%.

The effects of inventory on transportation cost were shown above to significantly affect total cost. Variations in holding rate affect inventory cost. Therefore, the effects of inventory cost were studied in relation to supplier selection, using holding rates of 20%, 50% and 100%.
Figure 3. Correlation of $Q$, $Inv$ and $Trs$ When $h$ is Varied

Figure 3 shows that the order quantity decreases, while inventory and transportation costs increase, as the holding rate increases. When the holding rate changes from 20% (0.2) to 100% (1.0), it causes the order quantity dropped from 1,269 to 567 units, by 55% approximately. Yet, there is an increase in inventory and transportation cost: almost 90% and more than 30%, respectively. When the holding rate increases, the holding cost is greater. Hence, the order quantity has to be smaller to reduce holding cost. Nevertheless, small orders force more frequent ordering and delivery, thereby increasing inventory and transportation cost.

6. CONCLUSION

In this paper, we showed that if transportation cost is ignored, then supplier selection decision focuses only on inventory cost. However, by comparing results from the Base and $EOQ$ models, we demonstrated that transportation cost affects supplier selection. In particular, when transportation cost is considered in decisions, the buyer has to balance between inventory and transportation cost. As they affect each other, they should be considered simultaneously and not, separately and independently. By including transportation cost, we found that the buyer’s selection of suppliers and the splitting of order quantities would be different to that determined by merely considering inventory cost. Furthermore, the total cost was found to be less if both costs are included.

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