Abstract

In this paper, a two-phase methodology is proposed. In the first phase the initial list of suppliers is shortened to a manageable one that is afterward fed to a second phase. The second phase uses a Multi-Objective Programming model (MOP) to select the best suppliers listed in the newly generated list and allocate the demand quantities among them. The model considers multiple criteria aspect. The quantities allocated to each supplier could fulfill the demand constraints, the limitation of order quantities, purchasing budget, number of suppliers selected, price discount, and lead time. The proposed methodology was tested in a real world case in pharmaceutical industry. The output showed applicability and efficiency of use due to flexibility in dealing with different criteria, and ability to efficiently and objectively choose among a large number of suppliers.

Keywords:
Supply chain, Supplier selection, Order allocation, Multi-objective Programming

1. INTRODUCTION AND REVIEW

Industrial corporations are led to adopt the supply chain management (SCM) philosophy to cope with market challenges [1]. Managing the purchasing task in the supply chain has been a challenge in the last decade for many corporations [2]. One of the most important processes of the purchasing function is the supplier selection [3]. Identification and evaluation of an appropriate supplier ensures that a firm will receive high-quality materials at a reasonable price, deliver the right quantities at the right time, and provide excellent services in order to satisfy customers’ demands [4]. The selection process would be simple if only one criterion was used in the decision making. However in many situations, a number of criteria must simultaneously be taken into account. Although the decision criteria for supplier selection may vary from one company to another [5], cost, quality, and delivery were known as the most common criteria in supplier selection [6]. Thirteen criteria pertaining to supplier selection process was considered from the perspective of different researchers. Namely they are: (1) Cost criteria, those include unit cost, ordering cost, transportation cost, duties and taxes, warranty cost, total delivery cost, payment terms, price discount [5-18]. (2) Quality criteria, including defective percentage at incoming material, defective percentage at production line, defective percentage from final customer, quality certificate (ISO 9000), quality system, continuous improvement, ability to solve quality problems [1, 5-15, 17-22]. (3) Delivery criteria that studied order fulfillment rate, percentage of late delivery, lead time, location, mode of transportation, delivery with packaging standards, delivery in good condition [1, 5-22]. (4) Service criteria comprising after-sales support, warranty support, repair and maintenance service, service response time [1, 5-12, 17, 20-22]. (5) Flexibility/responsiveness criteria consisting of flexibility in changing order volume, order due date, order mix, urgent delivery, and product variety [1, 5-10, 13-19, 21, 22]. (6) Personnel capability criteria expressed by labor overall skills and labor experience. [7, 19, 20] (7) Machines capability criteria divided into production capacity and manufacturing technology used. [1, 6-8, 12, 19, 20, 22] (8) Manufacturing capability criteria including development of process technology and manufacturing planning capability [7, 19, 20]. (9) Technical capability criteria considering R&D capability and design capabilities [1, 12, 18, 22]. (10) Financial capability criteria split into financial condition and stability, last year profit [6-8, 12, 17, 20, 21]. (11) Supplier profile criteria expressed by supplier position in industry, years in business working, market share, sales trend, business references.
past experience, trust [1, 6-8, 19, 20, 22]. (12) degree of cooperation criteria that considered the communication system, the information share, the long-term relationship, the support in value engineering, the cost reduction planning, the involvement in formulating new product or developing the current products [1, 6, 7, 9, 10, 12, 17, 18, 22] and finally (13) Environmental criteria where ISO14000 was considered and also waste management[8]. Supplier selection approaches could be classified according to the number of suppliers that will be selected. In single supplier selection, Analytic hierarchy process (AHP) is the most popular approach used [23, 24]. AHP was applied in different cases for supplier selection [7-10, 19, 25]. In addition, AHP has been combined with other methods such as Grey relational analysis [11, 12, 21]. For multiple supplier selection, mathematical programming approach has been used especially Multi-Objective mathematical Programming (MOP). Dahel [13], Arunkumar et al [14], and Wadhwa and Ravindran [15] presented an MOP model to deal with the supplier selection problem. It must be noted that using purely mathematical methods needs consideration of qualitative factors which can be handled via AHP. This combination method was implemented in different research papers [1, 5, 16-18, 22]. This paper is organized as follows: section 1 is an introduction and a review. In section 2 the proposed methodology is presented. Section 3 presents a case study. Section 4 discusses the sensitivity of the model to the changes and the conclusion is presented in section 5.

2. PROPOSED METHODOLOGY
The proposed two-phase methodology solves the supplier selection problem in case of multi-item, multiple sourcing, and with multiple criteria in quantity discount environment. In the first phase, the methodology screens the initial list of company’s suppliers and reduces it to a small manageable one. In phase 2, the final suppliers are selected from the pre-selected ones and the demand is allocated among them.

2.1. PHASE 1: SUPPLIER PRE-SELECTION
The pre-selection phase consists of three steps. Firstly, criteria for pre-selection are determined according to the company activities and preferences. Secondly, suppliers are sorted using $L_p$ Metric suggested by Mendoza et al [5]. One of the most commonly used $L_p$ metrics is the $L_2$ metric ($p=2$), which measures the Euclidean distance between two vectors. The sorting of suppliers is done by calculating the $L_2$ metric between the ideal solution and each vector representing the supplier’s rating against the pre-selection criteria. The following steps are summarizing $L_p$ metric procedure:

- Specify the ideal value ($H_j$) for each criterion $j$. The ideal value represents the best value attainable of each criterion $j$ from the list of potential suppliers.
- Use the $L_2$ metric to measure the closeness of rating vector with respect to the ideal supplier vector.

The $L_2$ metric for supplier $k$ is given by $L_2(k) = \sqrt{\sum_j |H_j - Y_{jk}|^2}$, where $H_j$ is the ideal value for criterion $j$ and $Y_{jk}$ is the $j$th criterion value of supplier $k$.

- Suppliers with the smallest $L_2$ value are ranked first, followed by the next smallest $L_2$ value etc. Thirdly a shortlist of suppliers is formed from a number of the top ranked ones. This shortlist helps decision maker to efficiently collect detailed data about shortlisted suppliers with minimal efforts in the next phase.

2.2. PHASE 2: SUPPLIER SELECTION AND ORDER ALLOCATION PHASE
In this phase, the MOP model is devised to assist the decision maker in choosing the most favorable suppliers according to pre-specified objectives and to allocate orders among them.

2.2.1. MODEL ASSUMPTIONS
The model assumes a single-time period, a known demand of each item and the demand is considered to be sufficient to satisfy the market over the planning horizon, an ordering cost for each supplier that does not depend on variety and quantity of items involved. When a supplier offers quantity discount, each range of discount offered by the supplier is regarded as an additional supplier with the same quality and delivery performance.
2.2.2. NOTATIONS USED IN MODEL

Model Indices

- \( i \): ordered item \( i = 1, 2, \ldots, I \);
- \( j \): supplier \( j = 1, 2, \ldots, J \);
- \( k \): discount interval \( k = 1, 2, \ldots, K \).

Model Parameters

- \( q_{ijk} \): Average defect ratio of ordered item \( i \) from supplier \( j \) in discount interval \( k \) (%).
- \( d_{ijk} \): Average delivery delay of ordered item \( i \) from supplier \( j \) in discount interval \( k \) (%).
- \( p_{ijk} \): Price of ordered item \( i \) from supplier \( j \) in discount interval \( k \) (LE).
- \( t_{ijk} \): Unit transportation cost of ordered item \( i \) from supplier \( j \) in discount interval \( k \) (LE).
- \( r_{ijk} \): Ordering cost of item \( i \) from supplier \( j \) in discount interval \( k \) (LE/order).
- \( SC_{ijk} \): Supplier score of item \( i \) from supplier \( j \) in discount interval \( k \).
- \( D_i \): Demand for ordered item \( i \) (Stock-keeping unit SKU).
- \( Q_{ijk \text{ min}} \): Minimum order quantity from supplier \( j \) for item \( i \) in discount interval \( k \) (SKU).
- \( Q_{ijk \text{ max}} \): Maximum order quantity from supplier \( j \) for item \( i \) in discount interval \( k \) (SKU).
- \( n_i \): Minimum number of supplier to be selected for ordered item \( i \).
- \( B_i \): Total budget allocated for supplying each item \( i \) (LE).
- \( l_{ijk} \): Lead time of supplier \( j \) to supply item \( i \) in discount interval \( k \) (days).
- \( L_i \): Maximum allowable lead time for item \( i \) (days).

Model Decision Variables

The proposed model aims to decide which suppliers should be selected and how much order quantity to be allocated to each selected supplier.

- \( X_{ij k} \): Amount of ordered item \( i \) from supplier \( j \) in discount interval \( k \). (SKU-Stock keeping unit)
- \( Y_{ijk} \): Represents binary variable which indicate if supplier is selected or not.
  - \( Y_{ijk} = 1 \) if supplier \( j \) is chosen for ordered item \( i \) in discount interval \( k \).
  - \( Y_{ijk} = 0 \) otherwise.

2.2.3. MODEL OBJECTIVE FUNCTIONS

The MOP model consists of four objectives:

- \( Z_1 \): Total cost of purchasing objective (minimizing total purchasing cost including unit price of ordered item, transportation cost and ordering cost).
- \( Z_2 \): Delivery objective, minimizing total delivery delay of ordered items.
- \( Z_3 \): Quality objective, minimizing total amount of defect, scrap or rejected ordered quantity.
- \( Z_4 \): Total value of purchase objective: Maximizing total value of purchasing. This objective helps decision maker in incorporating qualitative criteria in the supplier selection process. Suppliers are evaluated against these criteria with aid of Analytical hierarchy process (AHP). Saaty’s systematic procedure is followed [24]. The result of AHP is used as the coefficient of this objective function.

\[
\begin{align*}
\text{Min } Z_1 &= \sum_i \sum_j \sum_k \beta_{ijk} \cdot X_{ijk} + \sum_i \sum_j \sum_k t_{ijk} \cdot X_{ijk} + \sum_i \sum_j \sum_k r_{ijk} \cdot Y_{ijk} \\
\text{Min } Z_2 &= \sum_i \sum_j \sum_k d_{ijk} \cdot X_{ijk} \\
\text{Min } Z_3 &= \sum_i \sum_j \sum_k q_{ijk} \cdot X_{ijk} \\
\text{Max } Z_4 &= \sum_i \sum_j \sum_k SC_{ijk} \cdot X_{ijk}
\end{align*}
\]

2.2.4. MODEL CONSTRAINTS

The MOP model constraints are classified into supplier constraints and manufacturer constraints.

**Supplier Constraints:**

1. Minimum order quantity \( X_{ijk} \geq Q_{ijk \text{ min}} \cdot Y_{ijk} \)
2. Maximum order quantity \( X_{ijk} \leq Q_{ijk \text{ max}} \cdot Y_{ijk} \)
3. Lead time \( l_{ijk} \cdot Y_{ijk} \leq L_i \)

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Manufacturer Constraints:
1. Production demand \( \sum_j \sum_k X_{ijk} (1-q_{ijk}) = D_i \) \( \forall i \)
2. Minimum number of suppliers \( \sum_j \sum_k Y_{ijk} \geq n_i \) \( \forall i \)
3. Purchasing budget \( \sum_j \sum_k p_{ijk} X_{ijk} + \sum_j \sum_k t_{ijk} X_{ijk} + \sum_j \sum k r_{ijk} Y_{ijk} \leq B \) \( \forall i \)
4. Discount interval constraint \( \sum_k Y_{ijk} \leq 1 \) \( \forall i,j \)
5. Non-negativity, integer constraint \( X_{ijk} \geq 0 \) and integer \( \forall i,j,k \)
6. Binary constraints. \( Y_{ijk} = 0 \) or \( 1 \) \( \forall i,j,k \)

3. MODEL TESTING AND REAL CASE APPLICATION
After testing the proposed methodology a real case study from pharmaceutical industry is investigated. Data is shown in table 1.

Table 1: Purchasing item and supplier codes

<table>
<thead>
<tr>
<th>Product</th>
<th>Purchased item</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>First product</td>
<td>First purchased item</td>
<td>Supplier A</td>
</tr>
<tr>
<td></td>
<td>(P1T1)</td>
<td>Supplier B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supplier C</td>
</tr>
<tr>
<td>Second product</td>
<td>Second purchased item</td>
<td>Supplier D</td>
</tr>
<tr>
<td></td>
<td>(P2T1)</td>
<td>Supplier E</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Third product</td>
<td>First purchased item</td>
<td>Supplier F</td>
</tr>
<tr>
<td></td>
<td>(P3T1)</td>
<td>Supplier G</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Second purchased item</td>
<td>Supplier H</td>
</tr>
<tr>
<td></td>
<td>(P3T2)</td>
<td>Supplier I</td>
</tr>
</tbody>
</table>

Phase 1: Supplier pre-selection
Based on the company own regulations, the company has pre-selected the suppliers to compete in the next phase as shown in the previous table.

Phase 2: Supplier selection and order allocation
In this phase, the company needs to determine which suppliers to be selected and how the demand will be allocated among them. The MOP model was solved using preemptive goal programming (PGP). The solution of the PGP model is shown in table 2 and the order allocation in table 3.

Table 2: PGP model results

<table>
<thead>
<tr>
<th>Preemptive goals</th>
<th>Target value</th>
<th>Actual achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>10,836.79</td>
<td>10,836.79</td>
</tr>
<tr>
<td>Quality</td>
<td>642,698.4</td>
<td>644,896.1</td>
</tr>
<tr>
<td>Total value of purchase</td>
<td>156,714.1</td>
<td>155,378.3</td>
</tr>
</tbody>
</table>

4. FLEXIBILITY OF THE MODEL AND MANAGERIAL CONSIDERATIONS

4.1. OBJECTIVES PRIORITY STRUCTURE
Four scenarios for the criteria priority measure the sensitivity of the decision taken when a different priority structure is devised. The first scenario (1) quality, cost, TVP, corresponds to the priority structure originally defined by the decision maker the following three scenarios are defined in the same structure. Results are shown in table 3.

4.2. CHANGE IN DEMAND
The effect of 10% and 20% increase in the production demand have been tested on the model performance. The model could allow acceptable solution for 10% increase but provided infeasible solution for the 20% increase indicating that the allocated budget have to be increased.

Table 3: Order allocation for different priority structure

<table>
<thead>
<tr>
<th>Ordered item</th>
<th>Supplier</th>
<th>Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Quality, cost, TVP</td>
<td>(2) Quality, TVP, Cost</td>
<td>(3) Cost, Quality, TVP</td>
</tr>
</tbody>
</table>
5. CONCLUSION

A two-phase methodology has been proposed for tackling the supplier selection problem in case of multi-item, and multi-supplier in quantity discount environment. The first phase helps in shortening the initial list of suppliers. The second phase uses a multi-objective programming model (MOP) to determine the orders allocation considering demand fulfillment, limitation of order quantities, purchasing budget, number of suppliers selected, price discount, and lead time. Prioritizing the used objectives, enables the management to reflect different strategies in the purchasing activities and to analyze trade-offs among multiple objectives.

REFERENCES