Fuzzy Multi-Criteria Based Decision Support System for Supplier Selection in Textile Industry

S.M. Aqil Burney, Syed Mubashir Ali

Abstract
It has been recognized that supplier selection is one of the fundamental operations in supply chain. Over the past few decades, industries as well as academia has focused on optimization of product cost and providing improved services to the clients by optimizing supply chain management. There needs to be an efficient supplier selection method in order to achieve this goal. The supplier selection is a multiple criteria decision making problem which involves numerous factors including both quantitative and qualitative data. This study applies fuzzy analytic hierarchy process (F-AHP) approach for supplier selection in a textile industry in Pakistan. Criteria for supplier selection were identified by having informal interview with the purchase manager of a textile manufacturing company for paper cone supplier selection. Criteria identified and considered for supplier selection were price & cost, quality, services, delivery time & payment terms. Later, ranking of suppliers have been done to select the best supplier and discussed research implications.

Key words: Soft computing, supply chain management, multiple criteria decision making, Pakistan textile industry.

1. Introduction
Supplier selection has received a lot of attention both by academic researchers as well as practitioners because of its significance in achieving successful supply chain management [1], [2]. In order to achieve sustainability and efficient performance for any organization, evaluation and selection of a suitable supplier is one of the most vital components of supply chain management [3]–[5]. Particularly for manufacturing industry, one of the critical success factor for achieving reduced purchasing / manufacturing cost, improved customer satisfaction and increased competitive advantage is selecting the right supplier [6]. According to [7], procurement of goods constitutes the major standalone cost for any organization. It has been recognized that more than 60% of organization’s sales revenue is being spent on purchased items [8], [9].

Supplier selection is a complex decision making process [10], consisting of multiple objectives and conflicting criteria that needs to be taken into consideration and evaluated accordingly [11], [12]. It is a strategic decision taken by organizations as a result of the identification and evaluation of potential suppliers with the intention to have contract with them for organizational needs [13]. There has been a variety of approaches being utilized to evaluate and select potential suppliers using multiple criteria decision making (MCDM) techniques [14]–[17]. These techniques belong to diverse fields including but not limited to operations research, soft computing and decision theory [18].

The next section will review the existing literature for supplier selection techniques. Section 3 briefly explains the fuzzy-AHP approach. Section 4 will apply fuzzy-AHP for supplier selection in a textile manufacturing company in Pakistan. Section 5 will discuss limitations of this research. The last section will highlight future research directions and will conclude this paper.

2. Literature Review
According to [18], the process of identification, evaluation and contracting with the suppliers by the purchaser is referred to as supplier selection. Another study [19] looked for and discussed various criteria that can be used to evaluate suppliers and how important it is in selecting and retaining good suppliers. The criteria identified in this study were generalized and not according to any specific organization type or industry. Another research proposed multiple criteria decision analysis method for the problem of supplier selection [20]. The research focused on the various factors that affect supplier selection decision process and the relation between each factor.

A researcher from turkey divided the criteria for supplier selection under 4 main categories namely supplier, product performance, service performance and cost which were also further divided into sub criteria. However their research was based on the interview of the manager purchase in a white good manufacturing company in Turkey [21]. In [22], researchers proposed voting analytic hierarchy process method for evaluating and selection supplier. The proposed approach utilized ranking of votes instead of paired comparison to determine the weights for ranking of potential suppliers.

Jain et.al utilized fuzzy AHP and TOPSIS method for supplier evaluation and selection in an automotive industry in India [10]. Another study from the same...
researcher reviewed various issues related to selection of a suitable supplier as well as the relationship between supplier and buyer. Supplier related issues in a dynamic supply chain [23]. Another research [24] also viewed the supplier selection issue as a MCDM problem. They implemented a hybrid fuzzy AHP and fuzzy TOPSIS methods for selecting appropriate supplier for customized equipment. They also discussed about the other possible and applicable MCDM techniques that can be used in for supplier selection.

From the above literature review, it is evident that supplier selection is clearly a multi-criteria decision making problem. The next section will discuss about the methodology of the research study.

3. Materials & Methods

Fuzzy logic is used to make conclusions that are based on uncertain, imprecise, vague and missing value information [25]–[28]. Fuzzy logic was first proposed by Zadeh [29], [30]. AHP was developed by Saaty and fuzzy AHP or F-AHP integrates the fuzzy logic with AHP in order to make the decision support system tolerant to imprecise and uncertain [31]–[33]. AHP has been widely used to solve multiple criteria decision making (MCDM) problems [34]. It assigns priorities to various decision criteria by performing pair wise comparison between alternatives [35]. In a generic AHP model, first level denotes the goal; the criteria and sub-criteria (if any) are in the third and fourth levels respectively and the fourth level contains the alternatives [36], [37].

![Generalized structure of AHP](image)

In F-AHP, linguistic variables represented by triangular fuzzy numbers are being utilized to perform pair-wise comparison among the criteria and alternatives themselves [8], [36], [39]. This is achieved by constructing a fuzzy judgment matrix [40]. Laarhoven and Pedcrycz [41] were one of the first researchers to integrate fuzzy logic into AHP. They introduced the triangular membership function to be used in F-AHP for pair-wise comparison [8]. Buckley introduced a new method to compute fuzzy weights and specifically utilized triangular membership functions [42]. Other researchers such as Chang [43] and Samvedi et-al [40] also introduced new methods to use triangular membership functions in pair-wise comparisons.

This study utilizes the method described by Buckley and uses triangular fuzzy membership function to calculate relative weights of criteria as well as alternatives. Reason for using triangular membership function is that while interviewing the case company which is discussed in the next section, all the approximate values for each criterion as described by the purchasing staff was around a single value instead of any standard or a range of values. Following are the steps to be performed:

**Step 1:** Comparing criteria and alternatives using linguistic variables shown in table 1.

<table>
<thead>
<tr>
<th>Linguistic Variables</th>
<th>Saaty Value</th>
<th>Fuzzy Triangular Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equally Important</td>
<td>1</td>
<td>(1, 1, 1)</td>
</tr>
<tr>
<td>Slightly Important</td>
<td>3</td>
<td>(2, 3, 4)</td>
</tr>
<tr>
<td>Strongly Important</td>
<td>5</td>
<td>(4, 5, 6)</td>
</tr>
<tr>
<td>Very Strongly Important</td>
<td>7</td>
<td>(6, 7, 8)</td>
</tr>
<tr>
<td>Extremely Important</td>
<td>9</td>
<td>(9, 9, 9)</td>
</tr>
</tbody>
</table>

As we can see from table 1; the linguistic terms are mapped to triangular fuzzy numbers. Suppose if the expert suggests that “Criterion 1 (Cr1) is strongly important than criterion 2 (Cr2)”, then it will take (4, 5, 6) fuzzy triangular value. On the other hand, while constructing pair-wise matrix, comparison of Cr2 to Cr1 will have fuzzy triangular value (1/6, 1/5, 1/4).

The sample pair-wise comparison matrix “A” is shown is equation 1. Here $d_{ij}$ indicates the comparison of $i^{th}$ criterion with $j^{th}$ criterion using fuzzy triangular values as mentioned in table 1. For the above example of Cr1 is strongly important than Cr2, $d_{12}$ value represent this comparison and will have be equal to; $d_{12} = (4, 5, 6)$.

$$A = \begin{bmatrix} d_{11} & d_{12} & \cdots & d_{1k} \\ d_{21} & d_{22} & \cdots & d_{2k} \\ \vdots & \vdots & \ddots & \vdots \\ d_{n1} & d_{n2} & \cdots & d_{nk} \end{bmatrix}$$

(1)

**Step 2:** The geometric mean of fuzzy comparison values are calculated for each criterion which is shown in equation 2.

$$r_i = \left(\prod_{j=1}^{n} d_{ij}\right)^{1/n}; \ i = 1, 2, \ldots, n$$

(2)

**Step 3:** Find the vector summation of each $r_i$. Then find the reciprocal of summation vector and replace the fuzzy triangular value to make it in an increasing order. Then find the fuzzy weight of each criterion $i$ ($w_i$) by multiplying each $r_i$ with this reverse vector.
\[ w_t = r_t \times (r_1 + r_2 + \ldots + r_n)^{-1} = (lw_t, mw_t, uw_t) \] (3)

**Step 4:** In this step, defuzzification of fuzzy weights by utilizing centroid method is being carried out via applying equation 4.

\[ M_i = \frac{lw_i + mw_i + uw_i}{3} \] (4)

**Step 5:** \( M_i \) is a non fuzzy member which needs to be normalized using equation 5.

\[ M_i = \frac{lw_i + mw_i + uw_i}{\sum_{i=1}^{n} M_i} \] (5)

After finding the normalized weights of all the criteria and the alternatives, the score or rank of each alternative is calculated by multiplying each alternative weight with the related criteria. The alternative with the highest score is ranked 1st and can be selected by the decision maker. This methodology has been applied for supplier selection is a textile industry using a real case study which is discussed in the next section.

### 4. Application of F-Ahp in Textile Industry

This research applied F-AHP methodology in a XYZ textile manufacturing company in Pakistan which produces denim fabric and cotton yarn. The company is the largest manufacturer of denim in Asia. The company’s name and the alternative suppliers’ names are kept confidential on the request of the company. Paper cone, one of the most frequently used raw materials used in yarn manufacturing industry was taken into account for its supplier selection with respect to 5 criteria and 3 alternative suppliers. The overall goal and hierarchy of the supplier selection criteria and alternatives with respect to the case company is shown in Figure 2. The weight needs to be calculated for both the criteria and alternatives; therefore both the parts will be analyzed one by one.

![Fig. 2 AHP hierarchy for XYZ Textile Company](image)

To identify and finalize the criteria, and then to evaluate the alternative suppliers, an interview was being conducted with the purchasing manager of the XYZ textile company. According to the company’s preferences, pairwise comparison matrix was formed shown in table 2.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Price &amp; Cost</th>
<th>Quality</th>
<th>Services</th>
<th>Delivery Time</th>
<th>Payment Terms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price &amp; Cost</td>
<td>(1, 1, 1)</td>
<td>(6, 7, 8)</td>
<td>(1/6, 1/5, 1/4)</td>
<td>(1/8, 1/7, 1/6)</td>
<td>(1/8, 1/7, 1/6)</td>
</tr>
<tr>
<td>Quality</td>
<td>(4, 5, 6)</td>
<td>(1, 1, 1)</td>
<td>(1/6, 1/5, 1/4)</td>
<td>(4, 5, 6)</td>
<td>(4, 5, 6)</td>
</tr>
<tr>
<td>Services</td>
<td>(6, 7, 8)</td>
<td>(1/6, 1/5, 1/4)</td>
<td>(1/4, 1/3, 1/2)</td>
<td>(1, 1, 1)</td>
<td>(6, 7, 8)</td>
</tr>
<tr>
<td>Delivery Time</td>
<td>(6, 7, 8)</td>
<td>(1/6, 1/5, 1/4)</td>
<td>(1/9, 1/9, 1/9)</td>
<td>(1/8, 1/7, 1/6)</td>
<td>(1, 1, 1)</td>
</tr>
</tbody>
</table>

After creating pair-wise matrix, the geometric mean of fuzzy comparison values of each criterion is being calculated using equation 2. For example, \( r_t \) geometric mean of fuzzy comparison value of “price & cost” criterion is calculated as shown below:

\[
r_t = \left( \prod_{j=1}^{n} d_{ij} \right)^{1/n} = \left[ (1 \times 1/6 \times 1 \times 1/8 \times 1/8)^{1/5} ; (1 \times 1/5 \times 1 \times 1/7 \times 1/7)^{1/5} ; (1 \times 1/4 \times 1 \times 1/6 \times 1/6)^{1/5} \right] = [0.30; 0.33; 0.37]
\]

Table 3 shows all the geometric means of fuzzy comparison values for each criterion. Additionally it shows the total as well as reverse values. The last row of table 3 has been modified as fuzzy triangular number needs to be in ascending order.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>( r_t )</th>
<th>( r_t )</th>
<th>( r_t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price &amp; Cost</td>
<td>0.30</td>
<td>0.33</td>
<td>0.37</td>
</tr>
<tr>
<td>Quality</td>
<td>1.03</td>
<td>1.06</td>
<td>1.19</td>
</tr>
<tr>
<td>Services</td>
<td>1.25</td>
<td>1.40</td>
<td>1.55</td>
</tr>
<tr>
<td>Delivery Time</td>
<td>1.08</td>
<td>1.27</td>
<td>1.52</td>
</tr>
<tr>
<td>Payment Terms</td>
<td>0.43</td>
<td>0.47</td>
<td>0.52</td>
</tr>
<tr>
<td>Total</td>
<td>6.09</td>
<td>7.09</td>
<td>8.15</td>
</tr>
<tr>
<td>Reverse (Power of -1)</td>
<td>0.16</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>Increasing Order</td>
<td>0.12</td>
<td>0.14</td>
<td>0.16</td>
</tr>
</tbody>
</table>

In the next step, the fuzzy weight ‘Price & Cost’ \( w_t \) criterion is calculated using equation 3 as follows:

\[ w_t = [(0.30*0.12); (0.33*0.14); (0.37*0.16)] = [0.037; 0.047; 0.059] \]
Similarly the fuzzy weights for all criteria are calculated and are shown in table 4.

Table 4: Relative fuzzy weights for each criterion

<table>
<thead>
<tr>
<th>Criteria</th>
<th>( w_i )</th>
<th>( \frac{w_i}{\sum w_i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price &amp; Cost</td>
<td>0.047</td>
<td>0.074</td>
</tr>
<tr>
<td>Quality</td>
<td>0.314</td>
<td>0.438</td>
</tr>
<tr>
<td>Services</td>
<td>0.083</td>
<td>0.12</td>
</tr>
<tr>
<td>Delivery</td>
<td>0.183</td>
<td>0.248</td>
</tr>
<tr>
<td>Payment Terms</td>
<td>0.051</td>
<td>0.083</td>
</tr>
</tbody>
</table>

After calculating the fuzzy weights of each criterion, the relative non-fuzzy weight needs to be calculated by averaging the fuzzy numbers for each individual criterion which is then used to calculate the normalized weights for each criterion and is shown in table 5.

Table 5: Average and normalized non-fuzzy weights for each criterion

<table>
<thead>
<tr>
<th>Criteria</th>
<th>( w_i )</th>
<th>( \frac{w_i}{\sum w_i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price &amp; Cost</td>
<td>0.047</td>
<td>0.074</td>
</tr>
<tr>
<td>Quality</td>
<td>0.314</td>
<td>0.438</td>
</tr>
<tr>
<td>Services</td>
<td>0.083</td>
<td>0.12</td>
</tr>
<tr>
<td>Delivery</td>
<td>0.183</td>
<td>0.248</td>
</tr>
<tr>
<td>Payment Terms</td>
<td>0.051</td>
<td>0.083</td>
</tr>
</tbody>
</table>

After calculating the normalized non-fuzzy relative weights for each criterion, the alternatives are to be compared pair-wise with respect to each individual criterion using the same above mentioned methodology. Table 6 shows the pair wise comparison matrix with respect to ‘Price & Cost’ criterion.

Table 6: Comparison matrix for alternatives with respect to ‘Price & Cost’ Criterion

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>Supplier A</th>
<th>Supplier B</th>
<th>Supplier C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price &amp; Cost</td>
<td>((1, 1, 1))</td>
<td>((1/4, 1/3, 1/2))</td>
<td>((2, 3, 4))</td>
</tr>
<tr>
<td>Quality</td>
<td>((2, 3, 4))</td>
<td>((1, 1, 1))</td>
<td>((6, 7, 8))</td>
</tr>
<tr>
<td>Services</td>
<td>((1/4, 1/3, 1/2))</td>
<td>((1/8, 1/7, 1/6))</td>
<td>((1, 1, 1))</td>
</tr>
<tr>
<td>Delivery</td>
<td>((1, 1, 1))</td>
<td>((1, 1, 1))</td>
<td>((1, 1, 1))</td>
</tr>
</tbody>
</table>

Using the same previous methodology used for individual criterion, the fuzzy geometric mean \( r_i \) and relative fuzzy weights of alternatives with respect to each criterion \( w_i \) is shown in table 7 and 8 respectively.

Table 7: Geometric means for alternatives with respect to ‘Price & Cost’ Criterion

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>( r_i )</th>
<th>( r_i )</th>
<th>( r_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>0.79</td>
<td>1.00</td>
<td>1.26</td>
</tr>
<tr>
<td>Supplier B</td>
<td>2.29</td>
<td>2.76</td>
<td>3.17</td>
</tr>
<tr>
<td>Supplier C</td>
<td>0.31</td>
<td>0.36</td>
<td>0.44</td>
</tr>
<tr>
<td>Total</td>
<td>3.40</td>
<td>4.12</td>
<td>4.87</td>
</tr>
<tr>
<td>Reverse</td>
<td>0.29</td>
<td>0.24</td>
<td>0.21</td>
</tr>
<tr>
<td>Increasing</td>
<td>0.01</td>
<td>0.24</td>
<td>0.29</td>
</tr>
</tbody>
</table>

Table 8: Fuzzy weights for alternatives with respect to ‘Price & Cost’ Criterion

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>( w_i )</th>
<th>( w_i )</th>
<th>( w_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>0.167</td>
<td>0.240</td>
<td>0.365</td>
</tr>
<tr>
<td>Supplier B</td>
<td>0.481</td>
<td>0.662</td>
<td>0.921</td>
</tr>
<tr>
<td>Supplier C</td>
<td>0.086</td>
<td>0.087</td>
<td>0.127</td>
</tr>
</tbody>
</table>

Later, the average and normalized non-fuzzy weights are being calculated using centroid method which is shown in table 9.

Table 9: Average and normalized non-fuzzy weights for each alternative with respect to ‘Price & Cost’ Criterion

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>( Mi )</th>
<th>( Ni )</th>
<th>( w_i )</th>
<th>( \frac{w_i}{\sum w_i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>0.258</td>
<td>0.124</td>
<td>0.149</td>
<td>0.216</td>
</tr>
<tr>
<td>Supplier B</td>
<td>0.688</td>
<td>0.662</td>
<td>0.072</td>
<td>0.055</td>
</tr>
<tr>
<td>Supplier C</td>
<td>0.099</td>
<td>0.090</td>
<td>0.643</td>
<td>0.174</td>
</tr>
</tbody>
</table>

The similar methodology is being employed to calculate the non-fuzzy normalized weights of each alternative with respect to all criterions and is being shown in table 10.

Table 10: Average and normalized weights for each alternative with respect to each criterion

<table>
<thead>
<tr>
<th>Alternatives</th>
<th>( Mi )</th>
<th>( Ni )</th>
<th>( w_i )</th>
<th>( \frac{w_i}{\sum w_i} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>0.248</td>
<td>0.072</td>
<td>0.066</td>
<td>0.093</td>
</tr>
<tr>
<td>Supplier B</td>
<td>0.662</td>
<td>0.072</td>
<td>0.066</td>
<td>0.093</td>
</tr>
<tr>
<td>Supplier C</td>
<td>0.090</td>
<td>0.090</td>
<td>0.643</td>
<td>0.174</td>
</tr>
</tbody>
</table>

By using the data in table 5 and table 10, ranking of alternative suppliers is presented in table 11. It can be observed that for the case company, the best supplier who ranked first is Supplier B.

Table 11: Individual score for each alternative with respect to each criterion

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Score of Alternatives with respect to each criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price &amp; Cost</td>
<td>Supplier A 0.248 Supplier B 0.662 Supplier C 0.090</td>
</tr>
<tr>
<td>Quality</td>
<td>Supplier A 0.063 Supplier B 0.220 Supplier C 0.090</td>
</tr>
<tr>
<td>Services</td>
<td>Supplier A 0.257 Supplier B 0.072 Supplier C 0.043</td>
</tr>
<tr>
<td>Delivery</td>
<td>Supplier A 0.771 Supplier B 0.055 Supplier C 0.174</td>
</tr>
<tr>
<td>Payment Terms</td>
<td>Supplier A 2.043 Supplier B 1.282 Supplier C 1.676</td>
</tr>
</tbody>
</table>

Table 12: Ranking of Alternative Suppliers

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Weight</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier A</td>
<td>0.296</td>
<td>1</td>
</tr>
<tr>
<td>Supplier B</td>
<td>0.372</td>
<td>2</td>
</tr>
<tr>
<td>Supplier C</td>
<td>0.332</td>
<td>3</td>
</tr>
</tbody>
</table>

5. Research Limitations

There are a number of limitations in this research study. Firstly, the data for conducting this study was gathered from one organization belonging to a textile industry. Secondly, the researchers have used fuzzy triangular numbers instead of other fuzzy membership functions. There is a possibility that using trapezoidal or some other membership function to fuzzify the Saaty scale of AHP might have ranked the suppliers differently. Lastly, the
case company used only five basic criteria and no sub-criteria which if used may have differently ranked the suppliers.

6. Conclusion

Supplier selection is a critical task in supply chain management. It can greatly impact an organizational business performance by minimizing demand and supply gap as well as optimizing cost thus resulting in increased customer satisfaction. This research proposed a method for selecting the best supplier for any textile industry in Pakistan using a real case study as an example. This research has done three novel contributions. First, AHP has been applied in textile industry in Pakistan for supplier selection which will gives confidence to the decision makers and procurement managers within this industry to perform decision making with confidence. Second, by incorporating fuzzy soft computing technique in AHP analysis enabled the decision maker to deal with vagueness, imprecision and linguistic chaos while performing pair-wise comparison. Lastly, this research can become a simple decision making tool and a starting point for other textile companies for their supplier selection needs.

References


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