A Study to Compare Relative Importance of Criteria for Supplier Evaluation in e-Procurement

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Abstract

Purchasing is the primary point of contact with most supply-chain partners and thus extremely crucial for the performance of the supply chain specifically and in overall for the firm. Understanding how the various criteria for evaluating suppliers play a role is crucial for a better understanding of the dynamics of the supply chain. This study attempts to find out the relative importance of the various criteria in the decision making process for supplier selection in e-procurement using a multi-response fuzzy analytic hierarchy process. The objective of the study was to capture the dynamics of these criteria in the Indian manufacturing industries.

1. Introduction

Purchasing is the primary point of contact with most supply-chain partners and thus extremely crucial. At the strategic level, the firm must define the corporate, manufacturing and sourcing strategies and identify the products and services that should be acquired from outside. At the operational level, all the procurement activities, such as to review suppliers, to identify opportunities and to develop and implement product or service agreements, should be developed and controlled. Thus the decisions taken at the purchasing stage has a great impact on the overall supply-chain and production planning processes and on the overall performance of the firm. Thus it is extremely crucial to understand how the dynamics for supplier selection are affected.

India, being very crucial in this wake of economic growth, and being predicted as one of the bigger players to have a key role in the future growth of many other economies, the study has been done to understand the relative importance of the few common criteria across all manufacturing companies in the Indian context, for supplier evaluation in the prequalification stage.

2. Literature review

2.1 Supplier selection

Supplier selection studies have dated back to as early as 1960s. Few of the more referred papers of that era due to their classical contribution are those by Busch[5] (1962), Dickson[10] (1966), Hakansson[12] et al. (1975) and Dempsey[9] (1978). These studies established the importance of quality of products and delivery are important factors for supplier selection. Traditional methodologies of the supplier selection process in research literature include the cost-ratio method, the categorical method, weighted-point evaluations, mathematical programming models and statistical or probabilistic approaches. One of the more cited conceptual papers in supplier selection literature is that of by Weber[36] et al. (1991) and they develop an interpretive structural model (ISM) to show the inter-relationship of different criteria and...
their levels of importance in the vendor selection process. Their study reveals that “attitude”, “willingness for business” and “after sales service” are also important factors for supplier selection.

In contrast with the abundant literature dealing with various domestic supplier selection problems, analytical studies on international supplier selection were virtually absent in previous studies. The adaptation of the e-procurement systems leads to sourcing of raw materials globally. Min[23] (1994) introduced 7 selection criteria such as “financial terms”, “quality assurance”, “perceived risks”, “service performance”, “buyer–supplier partnerships”, “cultural and communicational barriers” and “trade restrictions” and thus addressed the geographically dispersed suppliers, increasingly getting important, with the advent of the e-procurement scenario.

Among recent studies, Petroni[26] et al. (2000) suggested that criteria such as “management capabilities”; “production facilities and capacity”; “technological capabilities”; “financial position”; “experience”; “geographical location”; “profitability”; “quality” and “delivery compliance”; to address integration capabilities of viable suppliers, and thus provide an updated framework of criteria in the era of integrated supply chain management, which seems more apt in the wake of e-procurement. Bottani[3] et al. (2005) advanced their work and incorporated electronic transaction capabilities as another key criterion consisting of electronic catalogue management, electronic order management, electronic financial management and supplier e-skills into the supplier selection framework. This was done with a strong focus to study supplier selection in the e-procurement scenario.


2.2 The fuzzy analytic hierarchy process

The Analytic Hierarchy Process (AHP) is a general theory of measurement. Proposed by Saaty[29] (1980), it has been extensively used in the domain of multi criteria decision making. It is used to derive ratio scales from both discrete and continuous paired comparisons in multilevel hierarchic structures. These comparisons may be taken from actual measurements or from a fundamental scale that reflects the relative strength of preferences and feelings. The AHP checks for departure from consistency and the measurement of this departure, and with dependence within and between the groups

The analytic hierarchy process first decomposes the decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. In this paper, a modification of the analytic hierarchy process has been made, by incorporating fuzzy set theory in the same. The original analytic hierarchy process was developed for a single crisp response from a single respondent. However in the given problem scenario, since there are multiple criteria comparisons between which need to be done, the technique needed to accommodate the human vagueness of thoughts which may arise from such comparisons. Responses with so many binary comparisons could make the respondent slightly less confident about their relative importance, which the modified technique would take care of. Also the a single response would not be representative of the actual scenario for the manufacturing industries. This is why again the original technique had to be modified to accommodate multiple responses to capture the relative importance of criteria for supplier selection in manufacturing industries.

To deal with vagueness of human thought, Zadeh[41] (1965) first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. In his paper, Zadeh introduced a theory whose objects, fuzzy sets, are sets with boundaries that are not precise. The membership in a fuzzy set is not a matter of absolute belongingness or absolute non-belongingness, but rather a degree of belongingness. The significance of Zadeh's study was that it challenged not only probability theory as the sole agent for uncertainty, but the very foundations upon which probability theory is based: Aristotelian two-valued logic. When A is a fuzzy set and x is a relevant object, the proposition "x is a member of A" is not necessarily either true or false, as required by two-valued logic, but it may be true only to some degree, the degree to which x is actually a member of A.

The fuzzy AHP technique can be viewed as an advanced analytical method developed from the traditional AHP using both fuzzy set theory and the AHP. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision makers judgments, fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgments of decision makers in conventional AHP approaches as was established by Bouyssou[4] et al.(2000). So, many researchers (Boender[1] et al., 1989; Laarhoven[18] et al., 1983; Buckley, 1985; Chang[6], 1996; Lootsma[20], 1997; Ribeiro[27], 1996) who have studied the fuzzy AHP which is the extension of Saaty’s theory, have provided evidence that fuzzy AHP shows relatively more sufficient description of these kind of decision making processes compared to the traditional AHP methods. Yu[40] (2002) employed the property of goal programming to solve group decision making fuzzy AHP problem. Weck[37] et al. (1997) evaluated alternative production cycles using fuzzy AHP. Sheu[32] (2004) presented fuzzy-based approach to identify global logistics strategies. Kulak[19] et al. (2005) used fuzzy AHP for multi-criteria selection among transportation companies. Kuo[17] et al. (2002) integrated fuzzy AHP and artificial neural network for selecting convenience store location. Cheng[7] (1996) proposed a new algorithm for evaluating naval tactical missile systems by the fuzzy AHP based on grade value of membership function. Zhu[43] et al. (1999) made a discussion on the extent analysis method and applications of fuzzy AHP. These studies demonstrate the applicability of the fuzzy analytic hierarchy process for multi criteria decision making problems.

In complex systems, the experiences and judgments of humans are represented by linguistic and vague patterns. Therefore, a much better representation of these linguistics can be developed as quantitative data using fuzzy set theory. On the other hand, the AHP method is mainly used in nearly crisp (non-fuzzy) decision applications and creates and deals with a very unbalanced scale of judgment. Therefore, the AHP method does not take into account the uncertainty associated with the mapping. The AHP’s subjective judgment, selection and preference of decision-makers have great influence on the success of the method. The conventional AHP still cannot reflect the human thinking style. Avoiding these risks on performance, the fuzzy AHP, a fuzzy extension of AHP, was developed to solve the hierarchical fuzzy problems.

This paper presents a technique that uses fuzzy set theory to improve and modify the performance of analytic hierarchy process for multiple responses multiple criteria decision making. Fuzzy set modeling has been used as a method for describing the characteristics of a system using fuzzy inference rules as was described by Takagi[33] et al., (1985).

3. Research gap and contribution

There has been a lot of literature which attempts to choose suppliers by using analytic hierarchy process and other techniques to compare between
their capabilities amongst the multiple criteria used to evaluate supplier capabilities for their selection. However all such studies are done at the firm level and results could vary across firms even in the same industry, and will vary across industries. All such significant studies attempted to understand the requirements at the firm level and that too often at a product category level by comparing amongst a few suppliers and their capabilities for that product category. These studies then attempted to identify the best or the top few suppliers using the technique for the given product category for the firm. Also other studies in decision support attempted to propose a technique to rank few suppliers or choose the best suppliers. Similarly empirical studies have attempted to identify the criteria for supplier selection and to develop the scale for their evaluation after doing an industry level analysis.

There has been no significant attempt in recent literature to make an estimate of what is the relative importance of these criteria for supplier selection, across multiple manufacturing industries. This study addresses this gap and tries to estimate this precisely with a very unique approach using multi-response fuzzy analytic hierarchy process across 41 firms.

The findings of this study would be of significant insight to suppliers and thus they would be in a position to understand their overall expectations better from their customers. Also the findings of this study would enable the procurement managers get an idea of the requirements and preferences across other industries, and if that is significantly different from that of their firm, subsequently analyze what creates this difference in their firm. This will also enable relatively inexperienced procurement manager to re-evaluate and then to focus on criteria which would require them to pay more importance to, than they do so at the time.

4. Proposed fuzzy AHP

The new proposed methodology differs from Saaty’s classical technique in that it takes multiple responses from different decision makers, and maps those linguistic responses quantitatively using fuzzy set theory, to generate the relative importance of criteria in a multi-criteria decision making problem. The multiple responses from multiple persons ensure that if the relative importance of criteria needs to be studied, multiple responses of the decision makers needs to be factored in to get a representative understanding of the problem domain. For the same, a fuzzy modification of the Saaty’s scale for accepting the responses has been proposed.

For going forward with the proposed technique, only those responses have been accepted which have passed the consistency check as per Saaty’s analytic hierarchy process. The scale chosen for making the binary comparison of criteria described below.

<table>
<thead>
<tr>
<th>Definition</th>
<th>Rating on Saaty’s scale</th>
<th>Proposed Fuzzy set for the same</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal importance</td>
<td>1</td>
<td>~1</td>
</tr>
<tr>
<td>Moderate importance</td>
<td>3</td>
<td>~3</td>
</tr>
<tr>
<td>Strong importance</td>
<td>5</td>
<td>~5</td>
</tr>
<tr>
<td>Very strong importance</td>
<td>7</td>
<td>~7</td>
</tr>
<tr>
<td>Extreme importance</td>
<td>9</td>
<td>~9</td>
</tr>
</tbody>
</table>

Here a triangular fuzzification function has been chosen to receive responses instead of the usual Saaty’s response. The triangular function has been taken it is argued that there is equal probability of the response of the next level as is to the response of the previous level, when a slightly vague linguistic comparison is made by a respondent. Linear change in the comparison levels has been assumed. A sample response of \([\sim n]\) on the proposed fuzzy scale will have a value of \([(n-2, 0.25), (n, 0.50), (n+2, 0.25)]\), where \((x, \mu)\) is such that ‘\(x\)’ is the element of the fuzzy set and ‘\(\mu\)’ is the degree of belongingness of the response to the element.

Here, the entropy of response is being maximized for the central element by maximizing Shanon’s function for the central element:

\[S(\mu) = \mu \ln \mu - (1-\mu) \ln (1-\mu).\]

Since the entropy of the central element is maximum at \(\mu = 0.50\), the rest is equally distribute between the previous and the next level of relative importance.

Also, the two extreme fuzzy sets (\(~1\) and \(~9\)) for comparison of extreme responses have been kept at the same level, i.e. at \((1, 1, 1)\) and \((9, 9, 9)\). The reason for keeping them at the same level is that it is assumed that these extreme end points will be selected by the respondent if the relative importance of the criteria are very clearly exactly equal or extremely high importance as compared to the other criteria and there is no doubt about it. It is argued that if there were any vagueness regarding this judgment,
the intermediate points would have been chosen, i.e. ~3 or ~7, respectively. It is being argued that the very clarity on their importance makes one choose the extreme points on the scale while making the comparative judgments.

The pictorial representation of the scale for accepting the responses is as follows:

![Figure 1: Triangular fuzzy sets for responses](image)

In this methodology, “n” decision makers or respondents are to be asked to make binary comparison between all the criteria of the Multi-Criteria Decision Making (MCDM) problem multiple times. So, eventually, we obtain a set of fuzzy sets as follows for each pair of criteria after making binary linguistic comparison from the “n” respondents:

\[(a_{11}, a_{21}, a_{31}), (a_{12}, a_{22}, a_{32}), \ldots (a_{1n}, a_{2n}, a_{3n})\]

For each of the “n” fuzzy sets, the following operation is performed to get the new fuzzy set:

\[\left(\frac{1}{n}.(a_{11} + a_{12} + \ldots a_{1n}), \frac{1}{n}.(a_{21} + a_{22} + \ldots a_{2n}), \ldots \frac{1}{n}.(a_{31} + a_{32} + \ldots a_{3n})\right) = X_{ij}\]

This essentially brings out the mean of the distribution of fuzzy numbers for the set of responses obtained. Taking the mean of the responses ensures that the method is more sensitive to variation in the responses.

This fuzzy set would be denoted as \(X_{ij}\) for the given pair of criteria, “i” and “j” where \(X_{ij}\) is of the form \([b_{ij1}, b_{ij2}, b_{ij3}]\). Then the relative importance table would be created as follows:

### Table 2: Initial response table

<table>
<thead>
<tr>
<th>criteria</th>
<th>1</th>
<th>2</th>
<th>-</th>
<th>-</th>
<th>(n_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(X_{1,1})</td>
<td>(X_{1,2})</td>
<td>-</td>
<td>-</td>
<td>(X_{1,ni})</td>
</tr>
<tr>
<td>2</td>
<td>(X_{2,1})</td>
<td>(X_{2,2})</td>
<td>-</td>
<td>-</td>
<td>(X_{2,ni})</td>
</tr>
<tr>
<td>3</td>
<td>(X_{3,1})</td>
<td>(X_{3,2})</td>
<td>-</td>
<td>-</td>
<td>(X_{3,ni})</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

The \(X_{ij}\) variables in the table indicate the relative importance of criteria “i” with respect to criteria “j” in the upper triangular matrix, the leading diagonal values all being 1, and the lower triangular matrix having the inverse values of the relative importance of criteria “i” with respect to criteria “j”.

The inverse of \([b_{ij1}, b_{ij2}, b_{ij3}]\) would be calculated as follows:

\[\left[b_{ij1}, b_{ij2}, b_{ij3}\right]^{-1} = \left[1/b_{ij1}, 1/b_{ij2}, 1/b_{ij3}\right]\]

Let both inverses and initial \(X_{ij}\) be denoted as \(X_{ij}\) only for simplicity of expression. For each column \(j\), add all the fuzzy sets. The summation of each column is done and then the relative contribution of \(X_{ij}\) to the summation value of the column is calculated as follows:

### Table 3: Final fuzzy weights of criteria

<table>
<thead>
<tr>
<th>criteria</th>
<th>1</th>
<th>2</th>
<th>-</th>
<th>(n_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(X_{1,1}/\sum_{ni}X)</td>
<td>(X_{1,2}/\sum_{ni}X)</td>
<td>-</td>
<td>(X_{1,ni}/\sum_{ni}X)</td>
</tr>
<tr>
<td>2</td>
<td>(X_{2,1}/\sum_{ni}X)</td>
<td>(X_{2,2}/\sum_{ni}X)</td>
<td>-</td>
<td>(X_{2,ni}/\sum_{ni}X)</td>
</tr>
<tr>
<td>3</td>
<td>(X_{3,1}/\sum_{ni}X)</td>
<td>(X_{3,2}/\sum_{ni}X)</td>
<td>-</td>
<td>(X_{3,ni}/\sum_{ni}X)</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>(n_i)</td>
<td>(X_{ni,1}/\sum_{ni}X)</td>
<td>(X_{ni,2}/\sum_{ni}X)</td>
<td>-</td>
<td>(X_{ni,ni}/\sum_{ni}X)</td>
</tr>
</tbody>
</table>

Now across each row, the mean value is calculated for each criterion and denoted by \(W_i\) which is essentially another fuzzy set, the weighted mean of which is used as a representative fuzzy weight of the set. This \(W_i\) would give the relative importance of the criteria in the overall multi-criteria decision making problem. Now scores for each criterion can be weighted using these weights \(W_i\) to find out overall score for a multi-criteria decision making problem.

### 5. Methodology

To select the criteria which would be most
relevant for the evaluation of suppliers, first a survey following the Delphi methodology was undertaken. The sample size for the study was 30, and the respondents consisted of a mix of supply chain managers, procurement managers of manufacturing companies, consultants, supply chain researchers from operations management area and information technology professionals who work in the supply chain domain for IT companies supplying solutions to manufacturing companies. All the respondents were of Indian origin and had a mean work experience of 7.2 years in the problem domain. The 30 respondents were chosen from 29 firms. Most Delphi studies have a sample size of 5 to 20 respondents and 2 iterations are often sufficient to achieve consensus as per Hsu et al. (2007).

For the initial survey, already established criteria from the studies of Petroni et al. (2000) and Bottani et al. (2005) were selected. In the second round for the Delphi study, convergence was achieved. The gap between the lowest percentage acceptance of those accepted criteria and the highest percentage acceptance for those rejected criteria among the 30 respondents had a difference of 40% of the sample size. A K-Means cluster analysis was also done which formed two distinct clusters on the final results of the second iteration of the Delphi, namely relevant and not-relevant criteria based on the responses. This was achieved in 3 clustering iterations and the minimum distance between the two clusters was 2.236 using the results of the second iteration of the Delphi.

On the basis of the Delphi study, the following criteria were selected for the study, as being crucial among all industries in the Indian context: product quality, compliance with the delivery date, price, supplier's technological capability, supplier's production capability, supplier's financials and the supplier's electronic transaction capability.

The seven criteria had been defined in the questionnaire and selected as follows:

- Product quality depends on meeting the requirement specifications of the buyer firm and the cost of a component rejection by the buyer and is to be measured on a 7 point scale. Lower total cost from product rejection means better product quality.
- Compliance with the agreed date can be computed as the average percentage of in-time deliveries over the last 'n' supplies by the supplier to all his customers.
- Price has been defined as the ratio of the quoted price with respect to the average price of the item to be purchased in the market.
- The supplier's technological capability is calculated based on the percentage of the total staff that has formal technical education.
- Production capability may be measured as the ratio of average manufacturing capacity of the supplier and the customer's average consumption per unit time.
- Financial position of supplier has been defined as the mean of 2 financial indicators debt ratio and current ratio.
- Electronic transaction capability: The supplier is rated on electronic catalog management, electronic order management, electronic financial settlements and supplier e-skills on a 7 point scale.

A questionnaire with 22 items was administered to evaluate the relative importance of these criteria was provided to 52 supply chain and procurement professionals, and their responses were analyzed using the proposed Multi-Response Fuzzy Analytic Hierarchy Process. Out of the 52 respondents, 4 responses had to be rejected due to the mismatch of expected profiles, work experience and incomplete responses. The rest of the 48 respondents were obtained from 41 organizations across multiple industries and the respondents had a mean work experience of 9.8 years. These 48 responses were subjected to consistency tests, and out of those, 28 responses were consistent with the ratio of consistency index and random index for 7 items, less than 0.1. Only these consistent responses were coded to find out the relative importance of criteria for supplier evaluation for selection in the Indian context. The reason for doing this is that for the inconsistent responses, the relative importance of criteria won’t add up to 1 and thus they would affect the overall relative weights of the criteria, not as outliers, but as improper data points.

6. Results

The multi-response Analytic Hierarchy Process threw up the relative importance of the selected seven criteria for supplier evaluation for evaluation, namely, product quality, delivery compliance, price, technological capability, production capability, financial position and electronic transaction capability.

The weights for the following based on the responses of the 28 consistent responses from the supply chain (procurement) professionals, in the Indian context are as follows.

- Product quality ~0.24
• Delivery Compliance \(-0.18\)
• Financial Position \(-0.15\)
• Price \(-0.14\)
• Production capability \(-0.12\)
• Technological capability \(-0.09\)
• e-Transaction capability \(-0.08\)

These weights reflect the relative importance paid by supply chain managers and procurement managers while evaluating suppliers in the Indian context. The results indicate that the most important criteria for supplier evaluation and selection is product quality while electronic transaction capability and technological capability (according to the definitions) holds the lowest importance in the decision making process.

These results indicate that in the current e-procurement scenario, in manufacturing industries, these seven criteria have the following degree of importance. The results will help the suppliers of manufacturing industries get a clearer idea of the expectations from them. Also if in a firm, the degree of importance of any criteria is significantly different, the study would allow the procurement managers to focus on the divergence and investigate the reasons for the divergence, whether the same is justified due to the nature of the business or not. Also, the results could guide a relatively less experienced procurement manager to set his priorities on the criteria for supplier selection.

7. Limitations and future research

The limitation of this study is the sample size of 28 that provided consistent responses from the initial sample size of 52 respondents. In the future, the same study will be extended to a much larger sample size, so that more representative weights of the relative importance of the criteria may be obtained, for the Indian manufacturing scenario.

Also, the consistency of the responses had been measured using Saaty’s consistency index, while the responses were actually taken for the fuzzy analytic hierarchy domain. This limitation is due to the absence of a widely accepted measure of consistency for responses taken for fuzzy analytic hierarchy process. Future research could be also to address this limitation of current methodologies.

8. References


