A strategic model using structural equation modeling and fuzzy logic in supplier selection

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ABSTRACT
Supplier selection attained the state of paramount importance for companies in the current scenario because of increasing global competition. Improper selection of suppliers will have an adverse impact on the overall performance of the company. The number of available alternatives in the current market is on a rise, and hence it becomes difficult to select a supplier from among a large lot. An attempt has been made to develop a new composite model using structural equation modeling and fuzzy analytic hierarchy process technique, based on the results of a survey of 151 respondents. Based on the criteria that influence the selection of suppliers, the model has been developed. The study also examines the supplier selection criteria and measures the supplier selection score using the developed model.

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1. Introduction
Supplier selection is one of the most important stages in the course of any supply chain. It has been prominently studied thoroughly in the past four decades. It determines the success of any supply chain or rather, of any organization. Satisfying the customer with high quality products in the shortest time possible at lowest cost is the key to success of any organization in the market. The cost of any product includes the raw material and component costs which constitute 70% of the total costs. This total cost can therefore be reduced by reducing the raw material and component costs, which mainly depend on the supplier. Hence, proper selection of suppliers is very important for the profitability of an organization. Selection of raw material suppliers initiates the supply chain. Supplier selection is the stage in the buying process when the intending buyer or the retailer chooses the preferred supplier or suppliers from those qualified as suitable. When the suppliers are able to provide the retailer with the right quantity of the right product/service at the right time in the right place, they are qualified as ‘suitable’ (Mandal & Deshmukh, 1994; Sarkis & Talluri, 2002). Supplier selection is a strategic decision in any organization. It is a multi-criteria decision making process involving various criteria which may be quantitative as well as qualitative. The criteria for the supplier selection are determined by the buyer/retailer according to his requirement. The criteria may differ according to the situation.

There have been many analytical models proposed for the supplier selection problem in the extant literature. However, to the best of our knowledge, no author has developed an integrated model of structural equation modeling (SEM) and fuzzy analytic hierarchy process (AHP) for supplier selection to arrive at score value. This paper fills that gap. The reason for selecting the model is that structural equation modeling approach uses a combination of quantitative as well as qualitative data to test and estimate causal relationship. SEM does not have a limitation on the number of variables, and is hence considered as the best approach. Since SEM takes the confirmatory approach rather than exploratory approach, there is no difficulty in hypothesis testing. This model also takes measurement error into account when analyzing the data statistically. Moreover, fuzzy AHP considers the vagueness of the opinion into account. This brings out a more reliable and effective evaluation process. We, in this paper, describe a generic theoretical model taking into consideration the criteria that influence the supplier selection: management and organization, quality, technical capability, production facilities and capabilities, financial position, delivery, services, relationships, safety and environmental concerns and cost.

The model thus developed is demonstrated through a real life example. The example has been considered by a public sector company in India. The company uses steel alloys for manufacturing their main product – boilers. This paper attempts to use our generic model to select the right suppliers for structural steel sections by identifying the criteria which influence the supplier selection.
2. Review of literature

Supplier/vendor selection is used to describe various phenomena in supply chain management. In the past few decades, there have been major changes in the supplier selection practices. The competition has risen and the market has become globally operating. In such a scenario, it has become highly difficult for industries to produce low cost and high quality products successfully without proper suppliers (Weber, Current, & Benton, 1991). This makes supplier selection a very important factor in production and logistics management of many industries. Determining suitable suppliers in the supply chain has become a key strategic decision. An efficient or a successful supply chain is said to be one which delivers the right quantity and desired quality of the final product at the right place in the right time (Mandal & Deshmukh, 1994; Sarkis & Talluri, 2002). Significant reduction in purchasing costs and improvement in the corporate competitiveness can happen by proper selection of suppliers (Ghodsypour & O'Brien, 2001). Supplier selection is an order quantity and order timing decision (Slack, Chambers, & Johnston, 2004).

Supplier selection process is divided into two stages – identification of the criteria influencing the selection process and using a specific decision making technique to arrive at the preference of the suppliers (Chan, Lau, Chan, & Choy, 2006). Another division of the process of supplier selection is given by Davidrajuh (2003). He divided the vendor selection process into pre-selection, selection and the post-selection procedures. Strategic goal setting is necessary before the selection procedure and hence it comes under the pre-selection procedure. The selection procedure is further divided into the following stages: bidder selection, partner selection, and performance evaluation. Proper relationship must be maintained with the supplier after the selection process. Hence, relationship maintenance comes under the post-selection procedure. Chen and Li (2007) gave multiple phase suppliers sorting model based on the supplier development orientation using multiphase selection methods and unconventional criteria combination. The model classified selection into three phase: pre-selection, evaluation and development. Few other authors like Nydick and Hill (1992), Ghodsypour and O'Brien (1998) and Karpak et al. (2001) studied multiple objective sourcing selection.


The conceptual approach of supplier selection is outlined in this section. Outsourcing is a management approach by which a company assigns some noncore functions to service providers (Frenschini, Galetto, Pignatelli, & Varetto, 2003). In the era of “global market” and “e-economy”, outsourcing is one of the main supports to conceive the relationships among companies. Kakouris, Polychronopoulos, and Binioris (2004) proposed a framework for purchasing and outsourcing decisions together with a process model for evaluating and assessing possible suppliers. They focused in particular on the “planning” and “qualifying” phases of the process. Dickson (1966) proposed 23 criteria for selecting the suppliers, based on a survey in industries. Nydick and Hill (1992) considered four prominent criteria in the supplier selection: quality, price, delivery and service. Park and Krishnan (2001) examined the supplier selection practices among 78 small business executives and adopted 15 criteria from Ellram (1990). The relationship between supplier selection criteria was thoroughly studied by Chapman (1989); Tullous and Munson (1991), Tracey and Vonderembse (1998), Tracey and Tan (2001) and Zhang et al. (2006). The supplier selection criteria are very crucial in the supply chain’s success and thereby, in the success of the organization. Supplier selection is an order quantity and order timing decision making problem (Slack et al., 2004) involving multi-criteria decision making. In the past literature of supply chain, the supplier selection problem is considered as an optimization problem which needs the formulation of a single objective function (Nukala & Gupta, 2007). However, all the supplier selection criteria cannot be quantified, because of which, only a few quantitative criteria are included in the problem formulation.

Now, we present some of the empirical study of supplier selection models. Schurr (2007) studied the important interactions that fundamentally strengthen or fatally weaken relationship development. Humphreys, Mak, and McIvor (1998) explained how dimensional analysis approach can be used to measure not only suppliers’ performance, but also the contribution to the purchasing relationship from the buyer organization and stated its benefits over traditional assessment. Purdy and Safayeni (2000) developed a framework for supplier evaluation based on whether the supplier evaluation focuses on information from product-based or process-based domains and whether the information acquisition mode used is direct or indirect. In doing so, various merits and demerits related to each approach were identified. The suppliers’ perception of the buying firm’s supplier evaluation communication process and its impact on suppliers’ performance was studied by Prahinski and Benton (2004). An intelligent supplier relationship management system is developed by integrating a company’s customer relationship management system, supplier rating system and product coding system by the case based reasoning technique to select preferred suppliers during the new product development process (Choy, Lee, & Lo, 2004). The opportunities and challenges faced in improving the supply chain performance by coordinated application of inventory management and capacity management was discussed by Jammeringeg and Reiner (2007). Cormican and Cunningham (2007) discovered that reducing the number and improving the quality of suppliers resulted in increased quality, reduced lead time and a reduction in the number of errors and defects, by evaluating supplier performance from a large multinational organization. Handfield and Nichols (1999) emphasized on the environmental issues in supplier evaluation.

We now review the analytical models given for supplier selection problems. Many analytical models for solving the multiple criteria decision making supplier selection problem have been proposed. These models consider different criteria and facilitate selection of the best supplier for the manufacturer. These criteria are ranked and given weights according to their importance considered by the company or the organization, and scoring is done for each of the initial shortlisted suppliers. The supplier with the maximum score will be selected finally. A combination of the criteria from the literature with the rating scheme of industrial purchasing yields a sophisticated, systematic decision matrix approach (Berens, 1972) to supplier evaluation and selection which under certain conditions can eliminate much bias and incomplete evaluation of vendors. Saaty (1988) proposed the analytical hierarchy process (AHP) to assist in multi-criteria decision making problems to overcome the difficulties associated with the categorical and simple linear weighted average criteria ranking methods. Vendor selection is multi-objective in nature. Little has been done to develop techniques for measuring vendors’ performance on multiple criteria. Weber (1996) used data envelopment analysis (DEA) as a tool for measuring the performance of vendors on multiple criteria. Weber et al. (2000) presented an approach for evaluating the number of vendors to employ in a procurement situation using multi objective programming (MOP) and data envelopment analysis (DEA). Ramanathan (2007) proposed a methodology to integrate DEA with the total cost of ownership.
(TCO) and the analytical hierarchy process (AHP) approaches for selecting appropriate suppliers for a firm. Later, fuzzy relationships were introduced in the analytical models to consider the vagueness involved in the supplier selection problem into account. Integration of two or more models, resulting in hybrid models was proposed to give a better and accurate result.

In the recent past, people started applying SEM model in the supply chain area and quite a bit of literature are also available. Zabkar (2000) studied the application of structural equation modeling in relationship quality context by considering some methodological issues. Hellier, Geursen, Carr, and Rickard (2003) discussed about the customer repurchase intention by using SEM. This is done by adding the customer views of equity, value and customer’s preference of brand to an analysis of integrated repurchase intention. Prahinski and Benton (2004) have developed a SEM model with the data taken from 139 first-tier automotive suppliers and concluded that the supplier’s view of the buying organization’s communication does not affect the performance of the supplier directly. Supplier selection was considered as one of the criteria in proposing a SEM model to study the success of buyer-supplier relationships by Kannan and Tan (2006).

The AHP method proposed by Saaty (1988) is a widely used multi-criteria decision making approach used in real life situations. But it cannot handle the uncertainty in the judgment of decision maker’s perception. Fuzzy AHP is used in this paper to consider the fuzziness resembled in the human nature. van Laarhoven and Pedrycz (1983) were among the first to use the fuzzy logic to extend the AHP using pairwise comparison matrices with the members of a triangular distribution. Mikhailov (2003) proposed a new approach using z-cuts decomposition to derive priorities from fuzzy pairwise comparison judgments. Ayag and Ozdemir (2006) applied the fuzzy AHP approach to evaluate machine tool alternatives. Chan, Kumar, Tiwari, Lau, and Choy (2008) used the same approach to solve the global supplier selection problem.

However, as mentioned in Section 1, no model has used structural equation modeling (SEM) along with fuzzy AHP for supplier selection to arrive at score value. Considering this as a gap, we have made an effort to apply this integrated model to arrive at the supplier selection score. The process is explained in the next section.

3. Criteria of supplier selection

Based on the study of the past literature, this study primarily summarizes the following criteria for supplier selection. The hypotheses are determined from these criteria obtained from it.

3.1. Management and organization

Management and organization is viewed by the manufacturer as one of the factors influencing supplier selection. Based on the past literature and expert opinions, the sub-criteria considered under this factor are physical size of the organization, geographical location, reputation and position in the industry, ethical standards, educational qualification of human resources, etc. which give a perspective of the nature of the supplier organization and its standards (Dickson, 1966; Lamberson, Diederich, & Wuori, 1976; Pearson & Ellram, 1995; Tan, 2002).

\( H_1 \): High level of management and organization criteria will lead to high chance of supplier selection.

3.2. Quality

Quality is the most important factor considered by the buyer/retailer in purchasing any material from the supplier. The literature on supplier selection adds major focus on the different aspects of quality as performance criteria for the selection of supplier (Choi & Hartley, 1996; Dickson, 1966; Weber et al., 1991). From the vast literature, the sub-criteria considered under quality can be summarized as product durability, ISO certification status, total quality management, product performance and conformance to standards, rejection rate in the incoming quality control, repair and return rate and addressing over feedback from customers. These were considered by various researchers in their models for solving the supplier selection problem (Dickson, 1966; Krause, Pagell, & Curovki, 2001; Toni & Nassimbeni, 1999; Tracey & Tan, 2001; Trelven, 1987; Chen & Li, 2007).

\( H_2 \): High level of quality will lead to high chance of supplier selection.

3.3. Technical capability

It is believed to be one of the important supplier selection criteria. It is evident that previous researchers (Browning, Zabriskie, & Huellmantel, 1983; Kannan & Noorul Haq, 2007; Timmerman, 1986; Yahya & Kingsman, 1999) suggested that technical capabilities of suppliers have a significant influence on selecting the potential supplier from among a group of suppliers. The sub-criteria of technical capability, technology and innovativeness, collaboration with research institutes, quick response capacity of product research and development, etc. come under this criterion (Chan et al., 2006; Chang, Wang, & Wang, 2007; Choi & Hartley, 1996; Liu, 2007; Silva, Davies, & Naude, 2002).

\( H_3 \): High level of technical capabilities will lead to high chance of supplier selection.

3.4. Production facilities and capacities

It is vital for all the suppliers so that supplier can get the chance to supply materials to the requirement of purchasers because of the complexity of the products. Many authors (Kannan & Noorul Haq, 2007; Narasimhan, 1983; Narasimhan & Stoyhoff, 1986) have explained the relationship between production facilities and capacities criteria with supplier selection. This factor has many sub-criteria like process flexibility, volume flexibility, training, promotion of JIT concept, handling and packaging capability, machine capacity and capability, facilities for measurement, calibration and testing (Billesbach, Harrison, & Croom-Morgan, 1991; Choi & Hartley, 1996; Kannan & Tan, 2006; Silva et al., 2002; Tan, 2002; Verma & Pullman, 1998).

\( H_4 \): High level of production facilities and capacities will lead to high chance of supplier selection.

3.5. Financial position

Every buyer has a concern about the financial position of the supplier due to the healthy global competitive environment and as a result, the high value of the products or components. Hence, it has become crucial for the suppliers to have a strong financial position to withstand the competition. Many research articles (Hahn, Kim, & Kim, 1986; Payne, 1970; Yahya & Kingsman, 1999) claimed that financial position of the supplier is important and it has relationships with supplier selection. Financial stability, credit strength, financial records disclosure with growth rate etc. come under the aspect of financial position (Chan et al., 2006; Choi & Hartley, 1996; Liu, 2007; Yuzhong & Liyun, 2007).

\( H_5 \): High level of financial position will lead to high chance of supplier selection.
3.6. Delivery

Delivery is considered as one of the important criteria which has a key influence on supplier selection. It refers to the time in which the goods are delivered to the customer or the punctuality in the right condition without any damage to the goods or services. This factor was created by criteria such as production lead time, delivery reliability, safety and security of components, appropriateness of the packaging standards. Many previous researchers have contributed to the kind of delivery that leads to supplier selection (Bender, Brown, Isaac, & Shapiro, 1985; Kannan & Noorul Haq, 2007; Kannan & Tan, 2003; Narasimhan, Srinivas, & Mahapatra, 2006; Ronen & Trietsch, 1988).

H_0: High level of delivery performance will lead to high chance of supplier selection.

3.7. Services

In today’s environment, improving the services has become essential for success of any organization. Services refer to the after sales service, spare parts availability, technical support level, sales representative’s competence, accurate rate of processing order form, the rate of delivery in time, degree of information modernized and service manner. Many of the researchers like Lehmann and O’Shaughnessy (1974), Abratt (1986), Handfield (1994), Choi and Hartley (1996), Muralidharan, Anantharaman, and Deshmukh (2001), Prahinski and Benton (2004) and Hsu et al. (2007) strongly argued that the services provided by the organizations have the most influence on selecting the supplier.

H_0: High level of service criteria will lead to high chance of supplier selection.

3.8. Relationships

Relationships is an important criterion in the selection of suppliers who are developed based on long term trust based businesses. It can be measured basically by several indices, such as the long term relationship, level of trust and understanding, share sensitive information like financial, production, supplier’s customer base, etc. (Bei et al., 2006; Choi & Hartley, 1996; Ellram, 1990; Kannan & Tan, 2006; Krause et al., 2001; Chen & Li, 2007).

H_0: High level of relationships criteria will lead to high chance of supplier selection.

3.9. Safety and environment concern

In the current environment-conscious global scenario, the manufacturers focus on safety and environment factors for the proper running of the company. Safety and environment protection is a key factor of green supply chain. It mainly includes environment protection system certification (e.g., ISO 14001 certification), usage of PPE’S (Personal Protective Equipments), incident/accident records, hazard and assessment records. The researchers like Yuzhong and Liyun (2007) and Chan et al. (2006) proved that safety and environment factors are important for supplier selection as it helps the organizations to increase their efficiencies.

H_0: High level of safety and environment criteria will lead to high chance of supplier selection.

3.10. Cost

The criterion of cost associated with the items refers to competitive price, logistics and payment terms, etc. Many of the researchers claimed that cost influences the selection of the apt supplier for the organizations (Zhang, Tian, & Sun, 2006; Kim, Bilsel, & Kumara, 2007; Lee, Ha, & Kim, 2001; Lee & Rosenblatt, 1986; Lehmann & O’Shaughnessy, 1974; Lin, 2002; Prahinski & Benton, 2004; Shin, Collier, & Wilson, 2000; Wang & Zhang, 2006)

H_0: Lower level of cost will lead to high chance of supplier selection.

4. Supplier selection measurement model

4.1. Validity of the instrument

A survey instrument was developed for our context with the help of the previously tested and validated instruments from the literature (Maloni & Benton, 2000). The criteria were changed in the instrument accordingly to reflect the buyer’s view of the supplier. Few new criteria were also developed. These new criteria were subjected to content validity through an extensive literature review and in-depth interviews conducted with the experts in the area. These interviews provided a deep understanding of the relationship between the buyer and the supplier and the supplier evaluation process. Modifications in the wording and the format were done after conducting a pre-test of the survey instrument.

We propose that the final instrument consists of 46 items which define 10 important criteria namely management and organization, quality, technical capability, production facilities and capacities, financial position, delivery, service, relationship, safety and environment concern and cost, which influence supplier selection. The criteria and their sub-criteria are presented in Appendix A.

Our generic model for the supplier selection is of the type shown in Fig. 1. The first level constitutes the criteria for the supplier selection. The second level explains the performance of each supplier with respect to each criterion. In the first level, the relative weightage of the criteria (A_i) are found out using SEM approach and in the second level, the relative weightage of the suppliers with respect to each criterion (b_ij) are found out using fuzzy AHP approach. These relative weightages are used to arrive at the supplier selection score. This has been shown clearly in Fig. 1.

SEM approach is used to arrive at the relative weightage of the criteria because there is no difficulty in hypothesis testing as it takes the confirmatory approach rather than exploratory approach. Many sub-criteria are considered under each criterion. The response is arrived for all the sub-criteria from the people involved in the decision making process. The significance of the criteria as well as the sub-criteria is tested. This is the reason why the relative weightage arrived from SEM is considered more valid than through any other approach.

Fuzzy AHP is used to arrive at the relative weightage of the suppliers with respect to each criterion because applying fuzzy logic to the AHP model considers the vagueness present in human judgment and opinion into account, thus giving a more effective and reliable model for the supplier selection problem.

4.2. Level 1 – SEM approach

The SEM model consists of twofold – one is the lower order model and another one is the higher order model. In the lower order model, the data obtained through the survey for the sub-criteria are given as the input. The construct score arrived through the lower order model are inputted to the higher order model. This construct score acts as an observed variable data for the higher order model. The macro view of this process is shown in Fig. 2.

The SEM model denotes the relationship between criteria and supplier selection. We can write the series of equations/statements that summarizes its configuration. The hypothesized conceptual
models (the higher order factor structure and the lower order factor structure) with LISREL Notations are presented in Figs. 3a and 3b. Linear Structural Relations (LISREL) model provides an integrated approach to data analysis and theory construction.

Fig. 1. Generic model for measuring supplier selection.

Fig. 2. The lower and higher models of supplier selection.
As such, we need to address the lower order factor structure. The lower order structure can be summarized as:

\[ Y = A_Y Y_g + e \]  

where \( A \) is the lower-order factor loading and \( e \) is measurement error terms.

The higher order structure can be summarized as:

\[ g = C_n + f \]  

where \( C \) is high-order factor loadings and \( f \) is residual error terms.

From the above models, we considered the higher order factor structure and the identified the significant factors. From the significant factors, the relative weightage for the criteria are calculated using the following expression.

Relative weightage for criterion

\[ A_j = \gamma_j \sum \gamma_j \]  

where \( \gamma_j \) is the high-order factor loading of the “\( j \)”th criterion and \( \sum \gamma_j \) is the sum of all the high-order factor loadings of the criteria.

4.3. Level 2– fuzzy AHP approach

Fuzzy AHP is an extension of conventional AHP and employs fuzzy set theory to take care of the imprecise judgments. The crisp values in the conventional AHP are somewhat insufficient to capture the proper judgment of the decision makers due to the inherent vagueness of human decisions or opinions. The lack of definiteness in the judgments is translated into fuzzy numbers in fuzzy AHP approach.

Pair-wise comparison is made by using a ratio scale in conventional AHP. In the fuzzy AHP, the ratios are represented in the form of fuzzy numbers or fuzzy sets incorporating the vagueness of human thought. The numerical ratio \( a_{ij} \) between two numbers \( E_i \) and \( E_j \) can be approximated with a fuzzy ratio ‘about \( a_{ij} \)’, represented by a fuzzy number \( a_{ij} \). This method can be used to:

– derive priorities from fuzzy pair-wise comparison matrices,
– prioritize from an incomplete set of judgments,
– derive crisp priorities,
– apply group decision making (Mikhailov, 2003).

The application of fuzzy AHP to arrive at the relative weightage of supplier with respect to each criterion is represented in the form of a flow chart shown in Fig. 4.

4.3.1. Step 1: Process of decision (for pair-wise comparison)

To arrive at the pair-wise comparison values, we need to get the response values from the respondents of the questionnaires. This determines the process of decision. In this paper, the response values are restricted according to Saaty’s ratio scale.

4.3.2. Step 2: Determining the type of distribution to adopt

The distribution followed by the response arrived from the questionnaire is to be determined. In a fuzzy process, there are different distributions to adopt to arrive at the \( \alpha \)-cut fuzzy comparison matrix. The values are to be given according to the distribution to specify the importance and thus to find the relative weightage. We, in this paper, assume that the values follow a triangular distribution. In a decision making scenario, most of the decision makers converge to a particular value (\( m \)) and the rest of them converge to extreme values (\( a, b \)) (Fig. 5). This is the reason for assuming that the values of the decision maker follow a triangular distribution.

4.3.3. Step 3: Defining the parameter based on the distribution adopted

Based on the distribution, the parameters are to be determined. In a triangular distribution, the parameters are the modal value and the extreme values. These are determined according to the response values for each cell of pair-wise comparison matrix. The triangular fuzzy numbers 1 to 9 are used to improve the conventional nine-point scaling scheme. The five triangular fuzzy numbers M1, M3, M5, M7, M9 are defined with the corresponding membership

Fig. 3a. The proposed SEM model-1 for measuring supplier selection.
functions in order to take the imprecision and vagueness of human assessment into consideration.

- **M1** – equally preferred.
- **M3** – moderately preferred.
- **M5** – strongly preferred.
- **M7** – very strongly preferred.
- **M9** – extremely preferred.
- **M2, M4, M6, M8** – middle values (Wang & Zhang, 2006).

4.3.4. Step 4: Determining the lower and upper limit

4.3.4.1. Defining the confidence level, $\alpha$-cut. For any sampling distribution, there has to be a cutoff value before the extreme values where most of the values are present. This interval, $\alpha$, is the interval of confidence level (shown in Fig. 6). A fuzzy number can always be represented by its corresponding left and right representation for a given $\alpha$. $\alpha$-cut is used to determine the lower and upper limits of the confidence level. The confidence level is determined by the decision makers.

4.3.4.2. Determining the lower and upper limit using $\alpha$-cut. The lower limit of the interval of confidence level is called lower bound ($l$) and the upper limit is called upper bound ($u$). Let $m$ be the modal value and $a$ and $b$ be the extreme values of the distribution. Let $\alpha$ be the confidence level of the distribution.

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Fig. 3b. The proposed SEM model-2 for measuring supplier selection.

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Fig. 4. Flow chart representing the application of fuzzy AHP.
The probability density function for any triangular distribution is given by
\[
f(x) = \begin{cases} 
\frac{2(x-a)}{(b-a)(b-m)}, & a \leq x \leq m \\
\frac{2(x-m)}{(b-m)(b-a)}, & m \leq x \leq b 
\end{cases}
\]
Since the distribution is symmetrical, \((b-a) = 2(b-m) = 2(m-a)\)
Therefore, the density function becomes,
\[
f(x) = \begin{cases} 
\frac{(x-a)}{(m-a)}, & a \leq x \leq m \\
\frac{(x-m)}{(b-m)}, & m \leq x \leq b 
\end{cases}
\]
To find the lower limit \(l\) (Fig. 7):
\[
\int_a^l f(x)\,dx = \frac{(1-\alpha)}{2}
\]
\[
\int_a^l \frac{(x-a)}{(m-a)}\,dx = \frac{(1-\alpha)}{2}
\]
\[
\left[ \frac{(x-a)^2}{2(m-a)} \right]_a^l = \frac{(1-\alpha)}{2}
\]
\[
(l-a)^2 = 0 = (1-\alpha)(m-a)^2
\]
\[
l = a + (m-a)\sqrt{1-\alpha}
\]
To find the upper limit \(u\) (Fig. 8):
\[
\int_u^b f(x)\,dx = \frac{(1-\alpha)}{2}
\]
\[
\int_u^b \frac{(b-x)}{(b-m)^2}\,dx = \frac{(1-\alpha)}{2}
\]
\[
\left[ \frac{(b-x)^2}{2(b-m)^2} \right]_u^m = \frac{(1-\alpha)}{2}
\]
\[
- [0 - (b-u)^2] = (1-\alpha)(b-m)^2
\]
\[
u^2 = b - (b-m)\sqrt{1-\alpha}
\]
By defining the interval of confidence level \(\alpha\), the triangular fuzzy number can be characterized as:
\[
\mathcal{M}_\alpha = [l^\alpha, u^\alpha] = [a + (m-a)\sqrt{1-\alpha}, b - (b-m)\sqrt{1-\alpha}] \quad \forall \mu \in [0, 1]
\]
By substituting the corresponding values in the above equation for different modal values (for ex. 1, 3, 5, 7, 9) and extreme values, the lower and upper bound values for all the fuzzy numbers are found out.
For the parameters appearing in Table 1, the generalized formula for any \(\alpha\) to find out the lower bound and upper bound is given below
The lower and upper bounds for a given modal and extreme values can be found from the above general equation for any value of $x$. (Table 1).

But the limits cannot be non-integers as they are evaluated based on Saaty's ratio scale. Hence, these limits are approximated to the nearest integers, i.e. $[1,2]$ for 1, $[2,4]$ for 3, $[4,6]$ for 5, $[6,8]$ for 7 and $[8,10]$ for 9.

4.3.5. Step 5: Determining the index of optimism $\mu$

A fuzzy number $M$ can be expressed as $(l,m,u)$ where $m$ is the modal value of the fuzzy number and $l$ and $u$ are the lower and upper bounds respectively, representing the extent of the fuzziness. A triangular fuzzy number is denoted as $M = (l,m,u)$, where $l \leq m \leq u$, has the following triangular membership function:

$$\mu_M(x) = \begin{cases} 
0, & x < l \\
\frac{x-l}{m-l}, & l \leq x \leq m \\
\frac{u-x}{u-m}, & m \leq x \leq u \\
0, & x > u 
\end{cases}$$

(9)

4.3.6. Step 6: Finding out the estimate to be placed in the cell using the upper and lower limit by constructing $\alpha$-cut fuzzy comparison matrices

The lower and upper bound values from the above generalized equation are found (see Fig. 9 for an example) and substituted in the following formula:

$$a_{ij}^{\alpha} = \mu_M a_{ij}^{\alpha} + (1 - \mu_M) a_{ij}^{\beta} \quad \forall \mu \in [0, 1]$$

(10)

where $a_{ij}^{\alpha}$ is the upper bound value and $a_{ij}^{\beta}$ the lower bound value for a given $\alpha$.

This calculated value is the crisp value of the fuzzy numbers which appear in the cell of the pair-wise comparison matrix.

4.3.7. Step 7: Arriving at the priority using fuzzy AHP

The priority vectors are found out for each supplier with respect to each criterion using the crisp values derived from the comparison matrix.

5. Application

The above model is demonstrated with the help of an example of a public sector company in the southern part of India whose main product of manufacture is boiler. In the manufacturing of the boiler, steel alloys are used. Structural steel sections are mainly used for distribution of boiler columns. They also find application within the boiler like wind box, ceiling girder, etc. This company has considered five suppliers for structural steel sections. It has shortlisted these suppliers on the basis of important criteria that influence their selection: management and organization, quality, technical capability, production facilities and capacities, financial position, delivery, service, relationships, safety and environment concern and cost.

6. Results and discussion

6.1. Measurement assessment

After determining the face validity through experts and further to ensure convergent and discriminant validity, the confirmatory factor analysis was performed and respective factors are taken for item analysis to measure the reliability of the scale items. The factor
loading and the respective items’ Cronbach alpha scores have gained high loadings, which indicate a good convergent validity and reliability. Moreover, the factor estimate and its respective t-values prove that all the variables attained significance level at p-value < 0.05 and this is shown in Appendix B and the lower and the higher order models are portrayed in Figs. 10a and 10b. Two hundred questionnaires were distributed in the company for which 151 responded. The values were obtained by the results of these
questionnaires. The responses to the questions were collected and the values were tabulated. This has been mainly done to arrive at the relative weightage for the criteria.

6.2. Hypothesis testing

The conceptual model is tested by SEM (causal model), which is performed in LISREL 8.8v. The y model includes the endogenous dependent observed variables (Y) related to management and organization (y1 to y5), quality (y6 to y12), technical capability (y13 to y17), production facilities and capacities (y18 to y24), financial position (y25 to y26), delivery (y27 to y31), service (y32 to y36), relationship (y36 to y39), safety and environment concern (y40 to y43) and cost (y44 to y46). Appendix B further shows results of y models. Overall, the y model has resulted that the variables are valid due to its indicators’ parameter estimates and their statistical significance. The t-value of all y model variables ranges from 5.69 to 13.67 with attained levels of significance at 0.05.

The same is proved further with the goodness of fit indices (which is shown in Table 2). The test of the model has achieved a reasonable fit. Though the $\chi^2$ test is highly significant ($\chi^2 = 1969.12/944$; RMSEA = 0.13; $p < 0.01$), the RMSEA value is an acceptable one. Other fit indices like SRMSR, NNFI and CFI all provide good result for the model.

In the higher order model, as we have already mentioned, the construct score acts as observed variable.

![Fig. 10b. Higher-order model.](image-url)
The results of higher order model exhibits that all the path coefficient values are positive; all the t-values of the variables are statistically significant at $p < 0.05$. Thus, the structural model supports all the ten hypotheses of the proposed model which is shown in Table 3. The hypotheses are represented in the structural model shown in Fig. 10b.

The influence of management and organization, quality, technical capability, production facilities and capacities, financial position, delivery → supplier selection, services → supplier selection, relationship → supplier selection, safety & environment concern → supplier selection, and cost → supplier selection has been proved by hypotheses H1, H2, H3, H4, H5, H6, H7, H8, H9, H10. So the proposed model explained a significant percentage of variance in supplier selection. Thus, the SEM model ensures that the proposed model is consistent and gains acceptable level.

### 6.3. Calculation of relative weightage of criteria ($A_i$)

The higher order factor (Latent factors) given by SEM model is considered for the relative weightage of the criteria. The relative weightage of the criteria are found out and tabulated in Table 4.

### Table 3

**Results of hypothesis table.**

<table>
<thead>
<tr>
<th>Causal path</th>
<th>Hypothesis</th>
<th>Point estimate</th>
<th>t-value</th>
<th>Hypothesis support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management and organization → Supplier selection</td>
<td>H1</td>
<td>0.63</td>
<td>8.46</td>
<td>Yes</td>
</tr>
<tr>
<td>Quality → Supplier selection</td>
<td>H2</td>
<td>0.78</td>
<td>11.24</td>
<td>Yes</td>
</tr>
<tr>
<td>Technical capability → Supplier selection</td>
<td>H3</td>
<td>0.71</td>
<td>9.95</td>
<td>Yes</td>
</tr>
<tr>
<td>Production facilities and capacities → Supplier selection</td>
<td>H4</td>
<td>0.84</td>
<td>12.53</td>
<td>Yes</td>
</tr>
<tr>
<td>Financial position → Supplier selection</td>
<td>H5</td>
<td>0.93</td>
<td>15.01</td>
<td>Yes</td>
</tr>
<tr>
<td>Delivery → Supplier selection</td>
<td>H6</td>
<td>0.89</td>
<td>13.96</td>
<td>Yes</td>
</tr>
<tr>
<td>Services → Supplier selection</td>
<td>H7</td>
<td>0.71</td>
<td>9.84</td>
<td>Yes</td>
</tr>
<tr>
<td>Relationship → Supplier selection</td>
<td>H8</td>
<td>0.63</td>
<td>8.43</td>
<td>Yes</td>
</tr>
<tr>
<td>Safety &amp; Environment concern → Supplier selection</td>
<td>H9</td>
<td>0.70</td>
<td>9.62</td>
<td>Yes</td>
</tr>
<tr>
<td>Cost → Supplier selection</td>
<td>H10</td>
<td>0.62</td>
<td>8.22</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Table 4

**Relative weightage of criteria.**

<table>
<thead>
<tr>
<th>M&amp;O</th>
<th>Q</th>
<th>TC</th>
<th>PFC</th>
<th>FP</th>
<th>D</th>
<th>S</th>
<th>R</th>
<th>SEC</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0847</td>
<td>0.1048</td>
<td>0.0955</td>
<td>0.1129</td>
<td>0.1250</td>
<td>0.1196</td>
<td>0.0954</td>
<td>0.0847</td>
<td>0.0941</td>
<td>0.0833</td>
</tr>
</tbody>
</table>

The weightage arrived shows the importance of the criteria for the organization. This is common for the organization irrespective of the suppliers.

### 6.4. Calculation of relative weightage of suppliers with respect to each criterion ($b_{ij}$)

To find the relative weightage of the suppliers with respect to each attribute, the consensus of the top management in a public sector company involved in vendor selection and materials management was considered in the development of pair wise matrices. The five structural steel sections suppliers who were chosen by the company, namely Jindal Steel & Power Ltd. (JSPL), Steel Authority of India Ltd. (SAIL), Rashtriya Ispat Nigam Ltd. (RINL), Sujana Metal Products and Kanisk Steel Industries, have a long standing establishment in long products, where the comparison takes place. SAIL, the major producer of steel in India, is involved in both steel making as well as steel rolling and their product stands to be a more quality one because of their own manufacturing. All range of steel sections – lower, medium and higher – are available with this supplier. RINL is a supplier which is limited to the medium and lower sections and has high volume of production. JSPL is a private com-
pany which has established itself in medium and higher sections and has continuous rolling of higher sections. Sujana Metal Products has a good range in all the three sections and its overhead costs are comparatively lower. Kanisk Steel Industries exclusively rolls certain sections which are not done by the other large suppliers. Sujana and Kanisk, being small companies get steel from the other three major companies and hence the quality of steel is ensured. These are the reasons to select these five suppliers. Every vendor has their own specialty and strategy to manage their business. According to the process explained earlier, fuzzy crisp matrices were developed. By using Eigen value method, we calculated the relative weightage of the supplier with respect to each criterion. For example, Table 5 shows the membership functions of one criterion, quality.

Using these values from Table 5, the crisp values are derived and tabulated in Table 6.

Similarly, the relative weightages of the suppliers with respect to criteria are found using the derived comparison matrices of each supplier with respect to other criteria and tabulated in Table 7.

The Consistency Index (CI) is found using the formula \( C_{\text{max}} - N \) \(/ \) \( N - 1 \), where \( N \) is the order of matrix 5. Then from the table of random consistency, the value for corresponding \( N \) is found out to be 1.12. CR is the ratio between CI and this table value. It is found that the relative weightage values are consistent.

6.5. Calculation of supplier preference measure for the suppliers

As per the proposed model, ten variables are found to have influencing power on supplier selection. The supplier preference measure for a supplier \( i \),

\[
SPM_i = \sum_{j=1}^{n} A_{ij} b_{ij}
\]

\( b_{ij} \) is the relative weightage for supplier \( i \) with respect to \( j \)th criteria; \( A_{ij} \) the relative weightage for the criteria \( j \); \( SPM_i \) the supplier preference measure for supplier \( i \).

The final supplier selection scores will be calculated by substituting their weightage in the above equation. The relative weightage of a supplier with respect to the criteria are calculated by using the fuzzy AHP model. Five suppliers are taken for study and their selection is measured by using the above supplier preference measure. The supplier preference measure values are calculated and the ranking of each supplier is shown in Table 8.

7. Managerial implications

In this section, an analysis of the outcome of this research has been done to find out what it provides in enhancing the performance of the organization as well as the supplier. In our study, Jindal Steel & Power Ltd. (JSPL) stands first in the criteria having high influence on supplier selection. It has the highest supplier preference measure as it scored high on the criteria that have high influences on supplier selection. For example, Jindal Steel & Power Ltd. scored high in criteria of quality (0.59), cost (0.50) and production facilities and capacities (0.48) which make it the supplier with high supplier preference measure. In contrast, Kanisk Steel Industries scored low in all the factors and it has created less impact on supplier selection. Rashtriya Ispat Nigam Ltd. should score high on the criteria of cost, quality and technical capability. Also, Steel Authority of India Ltd. should score high on the criteria of quality, delivery, service and relationships. In addition, Sujana Metal Products should score high in almost all the factors. The third, fourth and fifth ranked suppliers should perform well to enhance their performance in the corresponding criteria at which they are weak.

7.1. Sensitivity analysis

The outcome of the study is analyzed to provide managerial implications for the organization. Sensitivity analysis has been carried out for the rank of the suppliers. From the research done, we have arrived at the rank of the suppliers for a crisp value between the lower and upper limits. Any value that falls between the lower and upper limits is an acceptable value. This crisp value has to be found out by varying the \( \mu \) value. As \( \mu \) value changes from 0 to 1, we have tried to find out the change of rank in the suppliers for \( \mu = 0.35 \) and \( \mu = 0.65 \) in addition to what we have done taking \( \mu = 0.5 \). In all the three cases, the ranking of the suppliers is found out to be the same. This analysis is clearly shown in Table 9.

From the sensitivity analysis carried out, it can be implied that for any value between the lower and upper limits, the rank of the suppliers does not change. Hence, in future if there is any complaint that there is a problem in the already ranked suppliers, there is no need to carry out the whole process. If the response value for each cell falls between the lower and upper limits, then they need not accept the other's claim that there is a problem in the ranking which implies the performance of the supplier. However, if the value does not fall between the limits, then the supplier preference measures have to be recalculated to find out the rank of the suppliers again. The change in supplier ranking will pave the way to analyze the reason for change. For future research, a simulation study may be carried out as an extension of this study by considering \( \mu \) as a random variable.

8. Conclusion

Survival of the fittest is the present principle of the current competitive market. To sustain the rising competition, it is necessary for the industries to develop supplier selection. Supplier selection is a multi-criteria decision making problem. Having done an extensive theoretical research, we developed a model for determining supplier selection including multidimensional constructs both tangible and intangible criteria, using SEM and fuzzy AHP, thus considering the fuzziness of human opinion also into account. The model proposed that management and organization, quality, technical capability, production facilities and capacities, financial position, delivery, service, relationship, safety and environment concern and cost have influencing power on the supplier selection. The relative weightage of the above criteria were mainly given importance in determining the supplier selection score. This model paves the way to mitigate the uncertainties in the strategic decision such as supplier selection.
Appendix A. Criteria and sub criteria for the supplier selection

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sub-criteria</th>
</tr>
</thead>
</table>
| 1. Management and organization (M&O) | 1. Physical size  
2. Geographical location and transportation  
3. Reputation and position in industry  
4. Education qualifications of human resources  
5. Ethical standards |
| 2. Quality (Q) | 1. Product durability  
2. ISO certification Status  
3. Total quality management  
4. Product performance and conformance to standards  
5. Rejection rate in the incoming quality control  
6. Repair and return rate  
7. Addressing over feedback from customers |
| 3. Technical capability (TC) | 1. Design capability  
2. Technology and innovativeness  
3. Collaboration degrees with research institute  
4. Quick response capacity of product research and development  
5. Assessment of future manufacturing facilities and equipment capabilities |
| 4. Production facilities and capacities (PFC) | 1. Process flexibility  
2. Volume flexibility  
3. Facilities for measurement, calibration and testing  
4. Machine capacity and capability  
5. Handling and packaging capability  
6. Promotion of JIT concept  
7. Training |
| 5. Financial position (FP) | 1. Financial records disclosure with growth rate  
2. Financial stability and credit strength |
| 6. Delivery (D) | 1. Production lead time  
2. Delivery reliability  
3. Safety and security of components  
4. Appropriateness of the packaging standards  
5. Degree of product matching |
| 7. Service (S) | 1. After sales services  
2. Spare parts availability  
3. Technical support level  
4. Sales rep’s competence |
| 8. Relationship (R) | 1. Long term relationship  
2. Level of trust and understanding,  
3. Share sensitive information (financial, production, R&D, etc.)  
4. Supplier’s customer base |
| 9. Safety and environment concern (SEC) | 1. Environment protection system certification (e.g., ISO 14001 certification)  
2. Usage of PPE’S (Personal Protective Equipments)  
3. Incident/accident records  
4. Hazard and assessment records |
| 10. Cost (C) | 1. Competitive price  
2. Logistics costs  
3. Payment terms |

Appendix B. Reliability and convergent validity

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor estimate</th>
<th>t-value</th>
<th>Error variance</th>
<th>$R^2$</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management and organization ($\eta_1$)</td>
<td>0.63</td>
<td>8.46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical size ($y_1$)</td>
<td>1.02</td>
<td>9.13^{*}</td>
<td>1.10</td>
<td>0.49</td>
<td>0.822</td>
</tr>
<tr>
<td>Geographical location and transportation ($y_2$)</td>
<td>0.98</td>
<td>9.62^{*}</td>
<td>0.87</td>
<td>0.52</td>
<td></td>
</tr>
</tbody>
</table>

(continued on next page)
### Appendix B (continued)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor estimate</th>
<th>t-value</th>
<th>Error variance</th>
<th>$R^2$</th>
<th>Cronbach’s Alpha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reputation and position in industry ($y_1$)</td>
<td>0.84</td>
<td>9.19*</td>
<td>0.73</td>
<td>0.49</td>
<td></td>
</tr>
<tr>
<td>Education &amp; qualifications of human resources ($y_4$)</td>
<td>0.92</td>
<td>9.93*</td>
<td>0.69</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>Ethical standards ($y_5$)</td>
<td>0.74</td>
<td>7.66*</td>
<td>0.93</td>
<td>0.37</td>
<td></td>
</tr>
</tbody>
</table>

#### Quality ($\eta_2$)
- Product durability ($y_6$) | 0.61 | 7.47* | 0.71 | 0.35 | 0.760|
- ISO certification status ($y_7$) | 0.79 | 8.76* | 0.77 | 0.45 | |
- Total quality management ($y_8$) | 0.55 | 6.01* | 0.95 | 0.24 | |
- Product performance and conformance to standards ($y_9$) | 0.69 | 6.99* | 1.06 | 0.31 | |
- Rejection rate in the incoming quality control ($y_{10}$) | 0.76 | 7.07* | 1.24 | 0.32 | |
- Repair and return rate ($y_{11}$) | 0.65 | 5.69* | 1.51 | 0.22 | |
- Addressing over feedback from customers ($y_{12}$) | 0.71 | 6.98* | 1.13 | 0.31 | |

#### Technical capability ($\eta_3$)
- Design capability ($y_{13}$) | 0.68 | 6.85* | 1.05 | 0.31 | 0.791|
- Technology and innovativeness ($y_{14}$) | 0.88 | 9.57* | 0.71 | 0.52 | |
- Collaboration degrees with research institute ($y_{15}$) | 0.97 | 10.06* | 0.74 | 0.56 | |
- Quick response capacity of product research and development ($y_{16}$) | 0.78 | 8.50* | 0.78 | 0.43 | |

#### Assessment of future manufacturing facilities and equipment capabilities ($y_{17}$)
- Production facilities and capacities ($\eta_4$) | 0.84 | 12.53 | | |
- Process flexibility ($y_{18}$) | 0.57 | 5.86* | 1.07 | 0.23 | 0.809|
- Volume flexibility ($y_{19}$) | 0.65 | 6.83* | 0.99 | 0.30 | |
- Facilities for measurement, calibration and testing ($y_{20}$) | 0.74 | 7.04* | 1.17 | 0.32 | |
- Machine capacity and capability ($y_{21}$) | 0.80 | 8.39* | 0.89 | 0.42 | |
- Handling and packaging capability ($y_{22}$) | 0.84 | 8.44* | 0.95 | 0.43 | |
- Promotion of JIT concept ($y_{23}$) | 0.91 | 9.48* | 0.80 | 0.51 | |
- Training ($y_{24}$) | 0.86 | 8.70* | 0.92 | 0.45 | |

#### Financial position ($\eta_5$)
- Financial records disclosure with growth rate ($y_{25}$) | 1.06 | 11.30* | 0.60 | 0.65 | 0.784|
- Financial stability and credit strength ($y_{26}$) | 0.94 | 11.25* | 0.49 | 0.65 | |

#### Delivery ($\eta_6$)
- Production lead time ($y_{27}$) | 0.75 | 9.46* | 0.57 | 0.50 | 0.825|
- Delivery reliability ($y_{28}$) | 0.77 | 9.50* | 0.59 | 0.50 | |
- Safety and security of components ($y_{29}$) | 0.81 | 10.09* | 0.54 | 0.55 | |
- Appropriateness of the packaging standards ($y_{30}$) | 0.87 | 9.76* | 0.69 | 0.52 | |
- Degree of product matching ($y_{31}$) | 0.65 | 7.88* | 0.70 | 0.38 | |

#### Service ($\eta_7$)
- After sales services ($y_{32}$) | 0.91 | 9.86* | 0.76 | 0.52 | 0.832|
- Spare parts availability ($y_{33}$) | 0.90 | 10.21* | 0.67 | 0.55 | |
- Technical support level ($y_{34}$) | 1.06 | 12.78* | 0.38 | 0.75 | |
- Sales rep's competence ($y_{35}$) | 0.82 | 9.10* | 0.78 | 0.46 | |

#### Relationship ($\eta_8$)
- Long term relationship ($y_{36}$) | 0.63 | 8.43 | | |
- Level of trust and understanding ($y_{37}$) | 1.09 | 11.92* | 0.57 | 0.68 | |
- Share sensitive information (financial, production, R & D etc.) ($y_{38}$) | 0.93 | 9.68* | 0.85 | 0.51 | |
- Supplier’s customer base ($y_{39}$) | 1.05 | 10.04* | 0.96 | 0.53 | |

#### Safety and environment concern ($\eta_9$)
- Environment protection system certification (e.g., ISO 14001 certification ($y_{40}$) | 0.91 | 8.10* | 1.34 | 0.38 | 0.839|
- Usage of PPE’S (Personal Protective Equipments) ($y_{41}$) | 0.90 | 9.34* | 1.05 | 0.48 | |
- Incident/accident records ($y_{42}$) | 1.26 | 13.67* | 0.38 | 0.81 | |
- Hazard and assessment records ($y_{43}$) | 1.35 | 12.15* | 0.82 | 0.69 | |

#### Cost ($\eta_{10}$)
- Competitive price ($y_{44}$) | 1.15 | 10.92* | 0.83 | 0.61 | 0.854|
- Logistics costs ($y_{45}$) | 1.24 | 13.20* | 0.39 | 0.80 | |
- Payment terms ($y_{46}$) | 1.17 | 10.75* | 0.91 | 0.60 | |

* Variables significant at $P \leq 0.05$. 

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