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REGULAR ARTICLE

A combined application of structural equation modeling (SEM) and analytic hierarchy process (AHP) in supplier selection

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Abstract

Purpose – The purpose of this paper is to develop a new composite model using structural equation modelling (SEM) and analytic hierarchy process (AHP) for the selection of suppliers.

Design/methodology/approach – In this paper the authors have made an attempt to arrive at the supplier selection score using SEM and AHP. An attempt has been made to develop a new composite model using SEM and AHP technique, based on the survey of 151 respondents. Attributes' weightage are found out using cluster analysis.

Findings – Based on the output from the composite model, cluster analysis has been carried out to find out the strengths and weakness of each supplier on the influencing factors. Based on these findings, the supplier can improve on factors where they lag and can maintain the factors where they excel.

Originality/value – In this paper the authors have made an attempt to arrive at the supplier selection score using SEM and AHP.

Keywords Supply chain management, Supplier evaluation, Selection, Analytical hierarchy process, Structural equation modelling, Cluster analysis, Supplier preference measure

Paper type Research paper

1. Introduction

In the past literature, much has been talked about supplier selection. The key to success in the market is to meet the customer's demands in the shortest time at least cost and therefore, the emphasis is on the reduction of total costs and the delivery time. Analysis reveal that the cost of the raw materials and the component parts themselves carry around 70 percent of the total cost of the product (Weber *et al.*, 1991). The total cost will reduce considerably by reducing these costs, which mostly depend on the supplier. Hence, supplier selection becomes a very important requirement in the course of the flow of supply chain. Supply chain starts with selecting the right supplier for

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the raw materials. The stage in the buying process when the intending buyer or the retailer chooses the preferred supplier or suppliers from those qualified as suitable is known as supplier selection. It is a strategic decision. Qualifying the suppliers "suitable" depends on the suppliers being able to provide the retailer with the right quantity of the right product/service at the right time in the right place (Mandal and Deshmukh, 1994; Sarkis and Talluri, 2002). Much of the success in a supply chain depends on the supplier. The supplier may be a raw material supplier to the manufacturer or a component supplier or a service supplier, i.e. contractor. The supplier must adhere to all the required criteria to satisfy the buyer and thereby, the end customer. Thus, supplier selection process becomes a multiple criteria decision making problem involving various criteria which may be quantitative as well as qualitative.

Many analytical models have been proposed for supplier selection. However, to the best of our knowledge, no author has used structural equation modelling (SEM) for supplier selection to arrive at a score value, which is an objective value used for comparisons among different suppliers. This paper fulfills that gap. SEM approach is used to test and estimate causal relationship using a combination of statistical data and qualitative causal assumptions. It is considered as the best approach because SEM, unlike other methods, does not have a limitation on the number of variables. There is no difficulty in hypothesis testing in SEM because it takes the confirmatory approach rather than exploratory approach. This model also takes measurement error into account when analyzing the data statistically. SEM is capable of estimating or assessing measurement error. It can incorporate both observed and latent variables. SEM models require less reliance on basic statistical methods. We, in this paper, describe a generic theoretical model considering 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 model has been considered in 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

Many researches and practitioners use the term supplier (vendor) selection to describe various phenomena in supply chain management. Major changes have been experienced in supplier selection practices in the past few decades. In the current scenario of globally operating competitive environment, it is not practicable for the industries to successfully produce low cost, high quality products without right vendors (Weber *et al.*, 1991). Hence, supplier selection has become an important constituent of production and logistics management for many industries (Weber, 1998). Significant reduction in purchasing costs and improvement in the corporate competitiveness can happen by proper selection of suppliers (Ghodsypour and O'Brien, 2001). Supplier selection decision and supplier evaluation have vital importance in the field of production and logistics management, in many industries.

The process of supplier selection is divided into pre-selection, selection and the post-selection procedures (Davidrajuh, 2003). 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. Xu and Xiang-yang (2007) gave multiple phase suppliers sorting model based on the supplier development orientation using multiphase selection methods and unconventional criteria combination. The model classified the selection into three phases: pre-selection, evaluation and development. Few authors have studied multiple objective sourcing selection (Nydick and Hill, 1992; Karpak *et al.*, 2001).

Past literature and in particular Bei *et al.* (2006), classify the supplier selection process into three categories namely:

(1) empirical study (Edwards, 1967; Chapman, 1989);

(2) conceptual approach: emphasizing the strategic importance of the process of supplier selection (Hahn *et al.*, 1986; Treleven, 1987); and

(3) analytical models (Berens, 1972; Saaty, 1988; Weber, 1996; Zabkar, 2000; Hellier *et al.*, 2003).

We outline the conceptual approach of supplier selection. Outsourcing is a management approach by which a company assigns some noncore functions to service providers (Franeschini *et al.*, 2003). In the era of "global market" and "e-economy", outsourcing is one of the main supports to conceive the relationships among companies. Kakouris *et al.* (2004) proposed a framework for purchasing and outsourcing decisions together with a process model for possible suppliers. They focused in particular on the "planning" and "qualifying" phases of the process.

Dickson (1966) proposed 23 criteria used 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 business executives and adopted 15 criteria from Ellram (1990). The relationship between supplier selection criteria was thoroughly studied by Chapman *et al.* (2001). 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 (Nulala and 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.

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 *et al.* (1998) explained how dimensional analysis approach can be used to measure not only supplier's performance, but also the contribution to the purchasing relationship from the buyer organization and stated its benefit over traditional assessment. Purdy and Safayeni (2000) developed a framework for supplier evaluation. It is based on whether the supplier evaluation focuses on information from product-based or process-based domains and whether the information acquisition model used is direct or indirect. In the process, various merits and demerits related to each approach are identified. The supplier's perception of the buying firm's supplier evaluation communication process and its impact on supplier's

performance was studied by Prahinski and Benton (2004). An intelligent supplier relationship management system was 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 *et al.*, 2004). The opportunities and challenges faced in improving the supply chain performance by coordinated application of inventory management and capacity management was discussed by Jammernegg and Reiner (2007). Cormican and Cunningham (2007) emphasized the environmental issues in supplier evaluation.

We now review the analytical models 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 in selecting the best supplier for the manufacturer. These criteria are ranked and given weights according to their importance considered by the company, 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 ranking methods. Vendor selection is multi-objective in nature. Little has been done to develop techniques for measuring vendor's performance on multiple criteria. Weber (1996) used data envelopment analysis (DEA) as a tool for measuring the performance 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 and DEA. Ramanathan (2007) proposed a methodology to integrate DEA with the total cost of ownership and the analytical hierarchy process (AHP) approaches for selecting appropriate suppliers for a firm. Later, fuzzy relationships were introduced in the analytical methods 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. Meade and Sarkis (1998) have used analytic network process (ANP) for selection of logistics strategy. There are also few lesser known methods of supplier selection like TOPSIS, PROMOTHEE, ELECTREE, VIKTOR, etc. ANP was also used for supplier selection by Gencer and Gurpinar (2007).

In the recent past, people started applying SEM model in the supply chain area and quite some literature is also available. Zabkar (2000) studied the application of SEM in relationship quality context by considering some methodological issues. Hellier *et al.* (2003) discussed 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. Tsigilis *et al.* (2004) proposed a model to determine the multivariate relationship between employee tiredness and job satisfaction using SEM. Prahinski and Benton (2004) 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). Lin *et al.* (2005) also used supplier selection along with the supplier participation as the factors in the SEM model to show the correlation between the quality management practices and organizational performance. However, as mentioned in the introduction, no model has used SEM for supplier selection to arrive at score value. Considering this as a gap, we have made an effort to apply SEM model to arrive at the supplier selection score.

3. Justification for the use of SEM

The supplier selection score is arrived through two phases. In phase I, through SEM, the relative weightage for each criterion is arrived for the group of products which have a commonality in size or shape, etc. this is the reason why we have collected the response from the concerned people.

In phase II, the pair wise comparison matrix using AHP is done for each product in the group. For this, the responses from less number of people are enough to arrive at the score. In a nut shell, for level I, the relative weightages for the attributes are constant irrespective of the products in the group using SEM. But the relative weightage varies for each product using AHP while arriving at the selection score.

The other reason for the use of SEM: SEM approach is used to test and eliminate causal relationship using a combination of statistical data and qualitative caused assumptions. It is considered the best approach because SEM unlike other methods does not have limitation on the number of variables. There is no difficulty in hypothesis testing in SEM because it takes the confirmatory approach rather than the 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. This model also takes measurement error into account when analyzing the data statistically. SEM is capable of estimating or assessing measurement error. It can incorporate both observed and latent variables. SEM models require less reliance on basic statistical methods.

4. Measures of selection of suppliers

We have gone through the literature survey. The sub-criteria for each constructs are identified with the help of literatures. We have ensured that the criteria and the sub-criteria under each criterion are mutually exclusive and collectively exhaustive.

Based on these literatures, this study primarily considers the following constructs.

Management and organization

Management and organization refers to the physical size of the organization, reputation and position in the industry, ethical standards, etc. which give a perspective of the nature of the supplier organization and its standards. Researchers like Bernard (1989) and Lamberson *et al.* (1976), studied the relationship between management and organization criteria and supplier selection and discovered that an effective and efficient management decision is essential in selecting a supplier for a long-term relationship or a significant commitment. Lin (2002) and Tan (2002) have considered the physical size as an important criterion in supplier selection. Pearson and Eilram

(1995) and Bhutta and Huq (2002) have considered geographical location and transportation as a vital factor in the selection of suppliers. Few other scholars like Dickson (1966) and Lehmann and O' Shaughnessy (1974) have emphasized on the reputation and the position in industry. Few of them focused on ethical standards (Tan, 2002), education of human resources, etc.:

H1. Management and organization criteria influence supplier selection.

Quality

The literature on supplier selection lays major focus on the different aspects of quality as performance criteria for the selection of supplier (Dickson, 1966; Weber *et al.*, 1991). Several studies by Croell (1980) and Benton and Krajewski (1990) have considered the quality criteria for supplier selection decision. In a similar study on supplier selection, Newman (1988) and Weber *et al.* (1991) claimed quality as the most important criteria. Lin *et al.* (2005) considered quality and cost factors for supplier selection and found that quality correlated more significantly with supplier selection. The criterion of quality refers to the product durability, ISO certification status, total quality management, product performance and conformance to standards, repair and return rate, etc. Product durability was considered by Tracey and Tan (2001) and Krause *et al.* (2001). Toni and Nassimbeni (1999) and Hemsworth *et al.* (2005) focused on ISO certification status, while TQM was emphasized by Xu *et al.* (2007) and Yuzhong and Liyun (2007). Product performance and conformance to standards was considered by Krause *et al.* (2001):

H2. A high level of supplier commitment influences supplier selection.

Technical capability

It is believed to be one of the important supplier selection criteria. It is evident from previous researchers, Timmerman (1986) and Kannan and Haq (2007) suggested that technical capabilities of suppliers have a significant influence on selecting the potential supplier from among the group of suppliers. The sub-criteria of design capability, technology and innovativeness, collaboration with research institutes, quick response capacity of product research and development, etc. come under this criterion. Choi and Hartley (1996) considered design capability in technical capability and Xu *et al.* (2007) considered technology and innovativeness for the selection of suppliers. Liu (2007) and Chang *et al.* (2007) focused on quick response capacity of product research and development, while Chan *et al.* (2006) emphasized the assessment of future manufacturing facilities and equipment capabilities in selecting the suppliers:

H3. High levels of technical capabilities have an influence on supplier selection.

Production facilities and capacities

It is vital for all the suppliers to supply materials to the requirement of purchasers because of the complexity of the products. Many authors, namely Narasimhan (1983) and Kannan and Haq (2007) 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. Kannan *et al.* (2006) considered process flexibility while Choi and Hartley (1996) considered volume flexibility in the supplier

selection process. Dickson (1966) proposed handling and packaging capability while selecting the suppliers. Billesbach *et al.* (1991) and Tan (2002) made their model considering promotion of JIT concept as one of the factors in supplier selection:

H4. High level of production facilities and capacities influence supplier selection.

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 competition. Many research articles, Hahn *et al.* (1986) and Kraljic (1983) claimed that financial position of the supplier is important and it has relationships with supplier selection. The above claim is also supported by researchers like Yahya and Kingsman (1999) and Tan (2002). Financial stability, credit strength, financial records disclosure with growth rate, etc. come under the aspect of financial position. Choi and Hartley (1996) discussed the importance of financial records disclosure with growth rate in financial position. Willis and Huston (1990) and Liu (2007) have considered the financial stability as one of the criteria in financial position which will affect the chances of supplier selection. Liu (2007) and Yuzhong and Liyun (2007) have taken credit strength into consideration while solving the supplier selection problem:

H5. A better financial position influence supplier selection.

Delivery

Delivery is considered one of the important criteria which have 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 attributes such as production lead time, delivery reliability, safety and security of components, appropriateness of the packaging standards. Gurler, in his research on supplier selection concluded that delivery is the second highest important criteria. Likewise many previous researchers contribute to the kind of delivery that leads to supplier selection (Bender *et al.*, 1985; Ronen and Trietsch, 1988). Many authors like Billesbach *et al.* (1991) and Kannan and Tan (2003) have considered the delivery reliability as one of the sub-criteria in delivery. Kannan and Haq (2007) studied the safety and security of components while Toni and Nassimbeni (1999) considered appropriateness of the packaging materials in delivery criteria which influence the selection of suppliers:

H6. High level of delivery performance influence supplier selection.

Services

In today's environment, improving the services has become essential for the success of any organization. Service refers to the after sales service, spare parts availability, technical support level, sales representative's competence, accurate rate of processing order form, degree of information modernized and service manner. Many of the researchers like Choi and Hartley (1996) and Hsu *et al.* (2007) strongly argue that the services provided by the organizations have the most influence on selecting the supplier. Abratt (1986) and Bevilacqua and Petroni (2002) considered after sales service while Kannan *et al.* (2006) and Tan (2002) discussed spare parts availability's influence

on supplier selection in their analytical models. The sub-factor of technical support level in service was discussed by Billesbach *et al.* (1991) and Bei *et al.* (2006), while Lehmann and O' Shaughnessy (1974) and Lin (2006) considered sales representative's competence as one of the factors in service which influence supplier selection:

H7. High level of service criteria will influence supplier selection.

Relationships

A relationship 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, etc. supplier's customer base, etc. It is known from a research paper written by Choi and Hartley (1996) that the relationships of the enterprise are one of the main influences in selecting the supplier. Willis and Huston (1990) and Bei *et al.* (2006) studied the effect of long-term relationship on the selection of supplier, while Kannan *et al.* (2006) discussed the effect of level of trust and understanding on supplier selection. Sharing sensitive information like financial, production, R&D, etc. has a considerable influence on supplier selection (Toni and Nassimbeni, 1999; Krause *et al.*, 2001). The customer base of the supplier is also considered a factor in relationships which influences the selection of suppliers (Ellram, 1990):

H8. High level of relationships criteria influences supplier selection.

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), use of personal protective equipments (PPEs), incident/accident records, hazard and assessment records. 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:

H9. High level of safety and environment criteria influence supplier selection.

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 (Prahinski and Benton, 2004; Chang *et al.*, 2007). Previous research strongly validated the point that price contributes to supplier selection (Lee and Rosenblatt, 1986). Lehmann and O' Shaughnessey (1974) and Kim *et al.* (2007) studied the effect of competitive price on supplier selection. Fu-jiang *et al.* (2006) and Wang and Zhang (2006) considered logistics cost as one of the cost criteria which influences the selection of supplier, while Lin (2006) and Kannan and Haq (2007) considered payment terms as one of the factors in cost which influences the supplier selection:

H10. Lower level of cost has an influence on supplier selection.

5. Supplier selection measurement model

A survey instrument was developed for our context with the help of the previously tested and validated instruments from the literature (Carr and Pearson, 1999; Maloni and Benton, 2000). The measures were changed in the instrument relevantly to reflect the buyer's view of the supplier. Few new measures were also developed. These new measures were further validated. These measures 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 ten 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 measures and their factors are presented in Table I.

Our generic model is of the type shown in Figure 1. The first levels, namely the attributes, are the criteria for the supplier selection. The second level explains the performance of each supplier with respect to each attribute. In the first level, the relative weightage of the attributes (Ai) are found out using SEM model and in the second level, the relative weightage of the suppliers with respect to each attribute (bij) are found out using AHP model. These relative weightages are used to arrive at the supplier selection score. This has been shown clearly in Figure 1.

To arrive at the relative weightage for the attributes, we have adopted the SEM approach. SEM approach is considered because there is no difficulty in hypothesis testing as it takes the confirmatory approach rather than exploratory approach. It can incorporate both observed and latent variables. Moreover, no one has used SEM approach to arrive at supplier selection score. The SEM model consists of two folds – one is the lower order model and the other 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. This is shown in Figure 2. Then, the factor loading of each measure on supplier selection are tested for significance and the magnitude of each measure, irrespective of the sign, will give the influence of that criteria on supplier selection. These values are used for arriving at the relative weightage of attributes.

To carry out the above process, SEM model with LISREL notation (LISREL 8.8 of Scientific Software International, USA) was developed by assuming the relationship between the observed variables and their underlying factors. The SEM model denotes the relationship between attributes 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 8.8 Notations are shown in Figure 3(a) and (b).

As such, we need to address the lower order factor structure. The lower order structure can be summarized as:

$$Y = A_Y \eta + \varepsilon \tag{1}$$

where A is the lower order factor loading and ϵ is measurement error term.

Criteria	Sub-criteria
1. Management and organization	1. Physical size
	2. Geographical location and transportation
	3. Reputation and position in industry
	4. Education qualification of human resources
	5. Ethical standards
2. Quality	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	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 capabilities	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	1. Financial records disclosure with growth rate
	2. Financial stability and credit strength
6. Delivery	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	1. After sales services
	2. Spare parts availability
	3. Technical support level
	4. Sales rep's competence
8. Relationship	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	1. Environment protection system certification (e.g. ISO 14001 certification)
	2. Usage of PPEs
	3. Incident/accident records
	4. Hazard and assessment records
10. Cost	1. Competitive price
	2. Logistics costs
	3. Payment terms

Table I.
Criteria and sub-criteria for the supplier selection

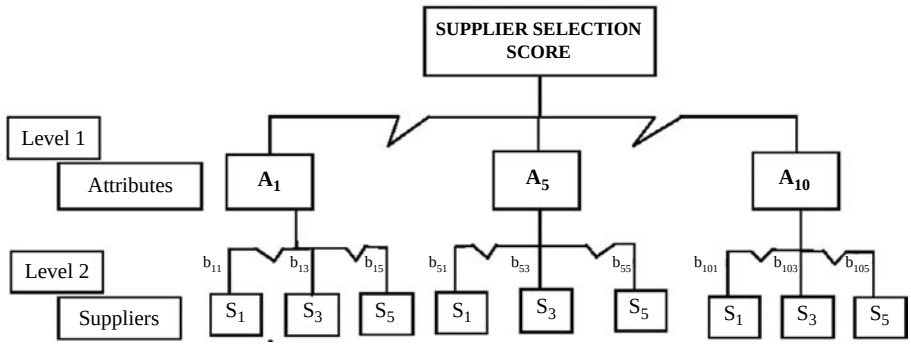

Figure 1.
Generic model for measuring supplier selection

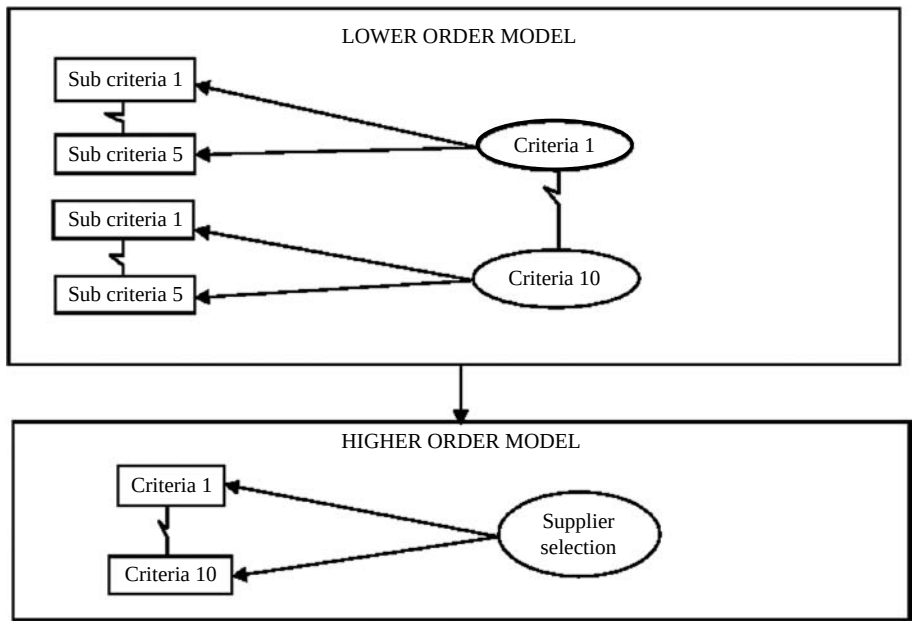

Figure 2.
The lower and higher models of supplier selection

The higher order factor loading can be summarized as:

$$\eta = \Gamma\xi + \zeta \tag{2}$$

where Γ is the higher order factor loadings and ζ is residual error term.

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

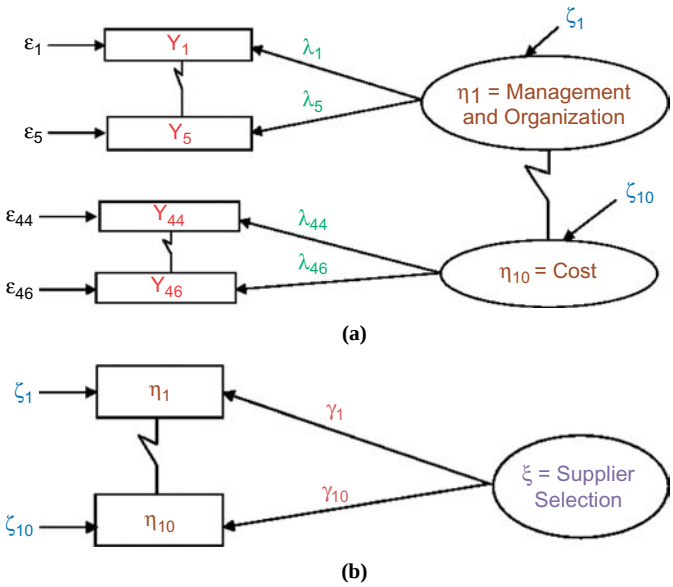

Figure 3.
(a) The proposed SEM model-1 for measuring supplier selection and (b) the proposed SEM model-2 for measuring supplier selection

Relative weightage for attribute:

$$A_j = \frac{\gamma_j}{\sum \gamma_j} \tag{3}$$

where:

γj is the high order factor loading of the "j"th attribute.

$\Sigma \gamma j$ is the sum of all the high order factor loadings of the attributes.

As mentioned previously, the structural equations can be used to develop the model for measuring supplier selection score along with the analytic hierarchy process (AHP) model. The AHP is one of the multi-criteria decision making methods initiated by Professor Thomas L. Saaty. The AHP model is used to find out the relative weightage of suppliers with respect to each attribute. Analytic hierarchy process is a mathematical decision making technique that allows consideration of both qualitative and quantitative aspects of decisions. It increases the simple decisions by the way of reducing the complex decision to a series of one-on-one comparisons, and then synthesizes the results. Relative weightage of supplier on each attribute will be calculated using pair wise comparison matrix of suppliers with respect to attributes identified for supplier selection measurement.

This matrix is a general matrix for the attribute j and the relative weightage of each supplier is arrived at by the AHP. It denotes the score obtained by supplier "i" in the attribute of "j". Thus, the relative weightage of attribute and the relative weightage of supplier with respect to attribute are arrived at by using SEM and the AHP model.

The supplier preference measure (SPM) for a supplier i:

$$SPM_i = \sum_{j=1}^{m} A_i b_{ij} \quad (4)$$

bij relative weightage for suppliers I with respect to jth attribute.

Aj relative weightage for the attribute j.

SPMi supplier preference measure for supplier i.

6. Application

To demonstrate the above model, we have considered an example of a public sector company in the southern part of India whose main product of manufacture is boiler, used for power generation. 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 factors 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.

7. Results and discussion

7.1 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 were taken for item analysis to measure the reliability of the scale items. The factor loading and the respective items' Cronbach's α scores has 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 and this is shown in Table III. In total, 200 questionnaires were distributed in the company for which 151 responded. The values were obtained from the results of these questionnaires. The response to the questions was collected and the values were tabulated. This has been mainly done to arrive at the relative weightage for the attributes.

7.2 Hypothesis testing

The conceptual model was tested by SEM (causal model), which is performed in LISREL 8.8 v. The y model includes the endogenous dependent observed variables (Y) related to management and organization (y1-y5), quality (y6-y12), technical capability (y13-y17), production facilities and capacities (y18-y24), financial position (y25-y26), delivery (y27-y31), service (y32-y35), relationship (y36-y39), safety and environment concern (y40-y43) and cost (y44-y46). Table II 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 influence of management and organization, quality, technical capability, production facilities and capacities, financial position, delivery, service, relationship, safety and environment concern and cost on supplier selection has been proved by hypotheses *H1-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 (Table III).

7.3 Calculation of relative weightage of attributes (Aj)

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

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

7.4 Calculation of relative weightage of suppliers with respect to each attributes (bij)

To find the relative weightage of the suppliers with respect to each attribute, the consensus of the top management in the 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,

Index	Suggested	Fit indices of SEM-I
Root mean square error of approximation		0.085[a]
Standard root mean square residual		0.078[a]
Non-normed fit index		0.92[a]
Comparative fit index		0.93[a]

Note: [a]Indicated the model is fit at accepted level

Table II.
Fit indices table of SEM

Causal path	Hypothesis	Point estimate	*t*-value	Hypothesis support
Management and organization	*H1*	0.63	8.46*	Yes
Quality	*H2*	0.78	11.24*	Yes
Technical capability	*H3*	0.71	9.95*	Yes
Production facilities and capacities	*H4*	0.84	12.53*	Yes
Financial positionĺ	*H5*	0.93	15.01*	Yes
Delivery	*H6*	0.89	13.96*	Yes
Services	*H7*	0.71	9.84*	Yes
Relationship	*H8*	0.63	8.43*	Yes
Safety and environment concern	*H9*	0.70	9.62*	Yes
Cost	*H10*	0.62	8.22*	Yes

Table III.
Results of hypothesis table

M&O	Q	TC	PFC	FP	D	S	R	SEC	C
0.0847	0.1048	0.0955	0.1129	0.1250	0.1196	0.0954	0.0847	0.0941	0.0833

Table IV.
Relative weightage of attributes

namely supplier-1, supplier-2, supplier-3, supplier-4 and supplier-5, have a long standing establishment, where the comparison takes place. Supplier-2, 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 very quality one because of their own manufacturing. All range of steel sections – lower, medium and higher are available with this supplier. Supplier-3 is a supplier which is limited to the medium and lower sections and has a high volume of production. Supplier-1 is a private company which has established itself in medium and higher sections and has continuous rolling of higher sections. Supplier-4 has a good range in all the three sections. Supplier-5 exclusively rolls certain sections which are not done by the other large suppliers. Supplier-4 and supplier-5, 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. Pair wise matrices were developed by the executives who deal with supplier selection, according to the consensus reached by the people as per Saaty's scale. By using Eigen value method, the relative weightage of the supplier with respect to each attribute was calculated and shown in Table V.

The consistency index (CI) is found using the formula ($\lambda max - N$)/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.

7.5 Calculation of SPM

As per the proposed model, ten variables are found to influence supplier selection. So the SPM equation can be written as follows:

$$SPM_1 = A_1b_{11} + A_2b_{12} + A_3b_{13} + A_4b_{14} + A_5b_{15} + A_6b_{16} + A_7b_{17} + A_8b_{18} + A_9b_{19} + A_{10}b_{110} \quad (5)$$

b_{110} is the relative weightage for supplier 1 with respect to the tenth attribute.

A_{10} is the relative weightage for the attribute 10.

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 attributes are calculated by using the AHP model. Five suppliers are taken for study and their selection is measured by using the above SPM. The model for supplier selection indicating the relative weightage value is shown in the form of a flow chart in Figure 4. The SPM values are calculated and the ranking of each supplier is shown in Table VI.

8. 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. To do that, we have carried out a cluster analysis for the generic relative weightage of the attributes which we have arrived at from the analysis. The clustering is done through hierarchical technique by inputting the relative weightage of the attributes. The reason the doing so is that even though all the ten measure have

	Management and organization	Quality	Technical capability	Production facilities and capacities	Financial position	Delivery	Service	Relationship	Safety and environment	Cost
Supplier-1	0.436652	0.587148	0.410124	0.484116	0.388693	0.431124	0.416902	0.444065	0.304685	0.508474
Supplier-2	0.266744	0.08566	0.297	0.266244	0.252776	0.125784	0.102721	0.113255	0.273156	0.2495
Supplier-3	0.201041	0.198924	0.17552	0.146843	0.252776	0.24742	0.274882	0.193146	0.304685	0.14205
Supplier-4	0.054678	0.08566	0.070533	0.06388	0.0694	0.117913	0.138559	0.177637	0.079938	0.062081
Supplier-5	0.040884	0.042608	0.046823	0.038916	0.036355	0.077758	0.066936	0.071897	0.037536	0.037896

Table V.
Summary of relative weightage of supplier with respect to each attributes

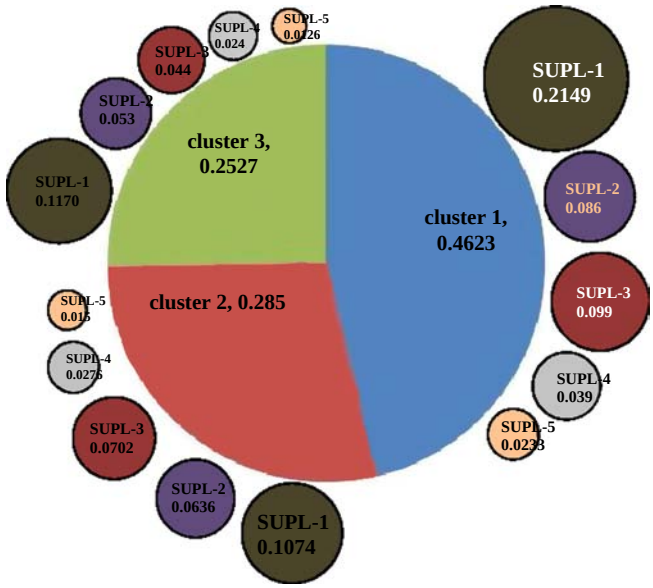

Figure 4.
A framework for managerial implication for both the organization and supplier

Suppliers	SPM	Rank
Supplier-1	0.4407	1
Supplier-2	0.2017	3
Supplier-3	0.2149	2
Supplier-4	0.0914	4
Supplier-5	0.0511	5

Table VI.
Summary of SPM of each supplier

different values of relative weightage, the difference between the values if not very much significant. Hence, it is decided to cluster the attributes.

After forming the dendrogram using hierarchical clustering single linkage method, we had a discussion with the expert of the organization in order to arrive at the right cut off point. By doing so, we have got three clusters. The second cluster contains the attributes technical capability, service and safety and environment concern while the third cluster consists of the remaining attributes – management and organization, relationship and cost. As per the cluster property, there is not much significant difference between the evaluation factors of each cluster. But between the clusters, there is significant variation.

As far as this organization is concerned, the constituents of highly ranked cluster namely financial position, delivery, production facilities and capacities and quality are given very high importance. The reason for this is, the organization in which we have conducted the study is highly quality conscious and also shows concern about their delivery time to the customers. This reflects the importance attached to the quality of products and delivery time from the suppliers.

The constituents of the second ranked cluster namely technical capability, service and safety and environment concern are given less priority when compared to the constituents of the first cluster. They get the second level importance. The constituents of the third cluster management and organization, relationships and cost are given less importance when compared to the constituents of other clusters.

Through this cluster analysis, a generic framework has been arrived at to assist both the organization as well as the suppler. The sum of the relative weightage of the constituents in each cluster is given in Table VII. The SPMs of the suppliers in each cluster were recalculated and shown in Table VIII.

A pie diagram is drawn (Figure 4) taking the area of the circle as 1 square unit and is divided into three parts as per the values of the relative weightage of the clusters obtained from Table VI. By the side of each cluster, the five suppliers are indicated in the form of circles whose areas are equal to the score of the supplier in that corresponding cluster obtained from Table VIII. The size of the circle resembles the corresponding supplier's chance of selection.

8.1 Implications for the organization

The difference between the areas of the clusters gives an idea about the relative importance of the measures considered for supplier selection for an organization. Large cluster area implies high influence of the constituents of that cluster in supplier selection. The areas of circle (supplier) close to the first supplier can also be considered for selection. The difference between the areas of the circles can be found out and if the difference between the first and the second preferred suppliers is found out to be less, then the organization can look towards the second supplier also and encourage him to increase the chance of superseding the first supplier. This paves way for the supplier partnership.

8.2 Implication for the suppliers

From the analysis, it is clear that any supplier who makes a mark in cluster 1 is the preferred supplier. The supplier who stands first in the first cluster which constitutes the highly ranked measures has a better chance to stand first in the final selection of suppliers. Suppose, the supplier is not first in the first cluster, the other way to get selected is getting high rank in the second and third clusters which when combined will

Table VII. Sum of relative weightages of constituents in each cluster

Cluster	Sum of relative weightages
Cluster 1	0.4623
Cluster 2	0.2850
Cluster 3	0.2527

Table VIII. Supplier scores in each cluster

	Supplier-1	Supplier-2	Supplier-3	Supplier-4	Supplier-5
Cluster 1	0.2149	0.0867	0.0990	0.0393	0.0233
Cluster 2	0.1074	0.0636	0.0702	0.0276	0.0152
Cluster 3	0.1170	0.0531	0.0447	0.0245	0.0126

supersede the importance of the measures in the first cluster. Thus, even a new supplier coming in can be evaluated on the basis of his position in each cluster which is determined by the importance or the relative weightage assigned to him with respect to each attribute. The suppliers must try to score high in the attributes of the first cluster to be selected. For the small suppliers, this type of figure (Figure 4) helps in identifying the areas where they are not strong enough. They must make all efforts to supersede the supplier above them. The framework will give a clear picture of where a supplier stands and what kind of strategy the supplier has to adopt to overtake the other suppliers.

In our study, supplier-1 stands first in all the three clusters. It has the highest SPM as it scored high on the attributes of quality (0.59), cost (0.51) and production facilities and capacities (0.48) which makes it the supplier with high SPM. In contrast, supplier-5 scored low in all the factors and it has created less impact on supplier selection. Supplier-3 should score high on the attributes of safety and environment, service and relationships. Also, supplier-2 should score high on the attribute of quality, service and relationships. In addition supplier-4 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 attributes at which they are weak. No doubt this framework will enable the low ranked suppliers to improve their performance and also pave the way to create a dynamic healthy competition between them.

9. Conclusion

Developing and sustaining the supplier selection is the biggest challenge in the inexorable competition market. Supplier selection is a multidimensional construct. After having strong theoretical foundation this study has developed a model for determining supplier selection including multidimensional constructs both tangible and intangible attributes. 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 an influencing power on the supplier selection. The relative weightage of the above attributes were mainly given importance in determining the supplier selection score.

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