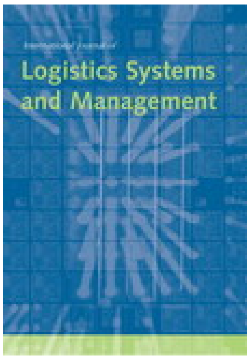

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Supplier evaluation using AHP for a small scale iron and steel plant in eastern India

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Supplier evaluation using AHP for a small scale iron and steel plant in eastern India

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Abstract: The paper presents a multi-criteria decision-making model for evaluation of suppliers using the analytic hierarchy process (AHP) for a small-scale sponge iron and steel plant in eastern India. A systematic research framework has been proposed for the same. The process uses a pair-wise comparison of the criterion importance based on decision-makers' opinions to find their relative weights. The main criteria are identified based on literature review and experts' opinions. The criteria are cost, delivery, quality, location, communication, management, performance history and reputation. The next stage involves a pair-wise comparison of the suppliers based on each criterion to find their relative importance. Overall sensitivity analysis has been conducted using MS Excel to inspect the flexibility of the model for evaluating suppliers, i.e., how the change in the ranking of the suppliers occurs when there is a change in relative weightage of criteria.

Keywords: supplier selection; iron and steel plant; analytic hierarchy process; AHP; sensitivity analysis; India.

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1 Introduction

Evaluation of suppliers in a supply chain has become an essential strategic drive for manufacturing companies. Periodic evaluation of suppliers can be made operational as a part of core supply chain strategy because of many reasons. Some of those reasons are:

1 continuous cost consideration and assessment to remain competitive in the global market
2 maintaining efficient delivery mechanism in place
3 enhancing and assuring quality of the raw materials, processes and products
4 capturing advantages of geographical locations in supply chain
5 adopting state of the art communication features and modes in view of the latest communication and information technology for all the supply chain partners
6 partnering with the suppliers having tunable and friendly management for productive supply chain partnerships
7 partnering with the suppliers having recognisable performance history
8 maintaining and enhancing reputation by associating with the reputed suppliers in the market.

This study shows how a multi-criteria decision-making (MCDM) model can be developed by analytic hierarchy process (AHP) for selection of suppliers based on a case study of an iron and steel plant in eastern India. The current study has identified and focused on critically very important criteria such as cost, delivery, quality, location, communication, management, performance history and reputation after analysing the real issues of case company. Being a developing nation, India's iron and steel industry plays a vital role in industrial development. Many large scale industries entirely depend on iron and steel industries for the source of raw materials. Railways, shipbuilding, bridge construction, and various other industries rely entirely on iron and steel industry. Hence iron and steel industries are known as the heart of all industries.

The beginning of the Iron and Steel industry started at Kulti, West Bengal in 1875. However, the production came into light after the establishment of the iron and steel industry in Jamsedhpur in 1907 (Krishnan et al., 2008). However, only after independence, the industry was able to find a strong foothold in the country. After independence, Bokaro and Bhilai Steel Plant were established with the help of Union of Soviet Socialist Republics (USSR). Different policies and initiatives were undertaken by the Indian Government which gave propulsion in the growth of iron and steel industry. New measures are being adopted by the plants that already exist as well as various new units are being built in various regions of the country. The plants are also being modified with new advanced technologies. The Indian Ministry of Steel is known for promoting the growth and development of the iron and steel industry in the country. Government of India's National Steel Policy (2017) has aimed to achieve over 300 million tonnes of steel making capacity in 2030–2031. As per report of World Steel Association (2020), India has now become the second largest producer of crude steel during 2018–2019, from its third largest status in 2017. India produced 111.2 million tonnes (MT) crude steel in 2019. India has become the third largest finished steel consumer in the world after China and USA in 2019. India was the largest producer of sponge iron (37.1 MT) in the world in 2019. Production of pig iron in 2019–2020 was approximately 5.42 million tonnes, hence showing a decline of around 15.5% over the last year.

The Indian steel industry has been flourishing very rapidly. The steel demand continues to demonstrate positive growth with the growth of economy and steel intensity. The iron and steel industry remains one of the largest manufacturing sectors in the country. The basic raw materials needed for the iron and steel industry are mainly iron ore and coal. Since there are many suppliers in the country which are extracting coal and iron ore and supplying to steel industries, a genuine selection of suppliers is needed in order to enhance the industry's growth. Economic development depends upon gross domestic product (GDP) which in turn relies upon the per capita consumption of steel. Therefore, in order to get the best output from the industry, supplier evaluation is very much needed for boosting up the nation's economy.

1.1 Supplier selection

Supplier selection is a method of selecting the best supplier to obtain materials in order to continue and enhance the throughput of the firm. The most suitable supplier is decided by analysing suppliers' attributes. Supplier selection is a MCDM problem, which includes attributes that are both qualitative and quantitative. The selection process involves the assessment of different criteria along with suppliers' characteristics (Kahraman et al., 2003). A sound supplier selection today can reduce or prevent a host of problems tomorrow. Supplier selection depends on a wide range of criteria apart from cost, delivery, and quality. Criteria such as reliability, service, location, communication, internal management, technical support, performance history, financial stability, reputation, etc. also impart importance in this decision-making process. The significance of these different criteria will solely depend upon the business plan and policy. Nilay Serbest and Vayvay (2008) have considered that the supplier selection is an important problem that can affect the future competitiveness and performance of an organisation in logistic sector. They presented a comprehensive hierarchical structure for selecting the distribution channel, it also affects on the supplier performance. AHP-based methodology is used to evaluate the different criteria like risk factors, cost and quality. Stević et al. (2017) proposed a novel-integrated multi-criteria model to evaluate supplier selection in the construction company. Badi et al. (2018) developed a new combinative distance-based assessment (CODAS) method to handle MCDM problems in a steel making company in Libya. The proposed method is applied to deal a real-world case problem for ranking the suppliers in the Libyan iron and steel company. It also enhances the decision-making technique for selecting the best suppliers for the selected case company. Ebrahimnejad et al. (2018) proposed a supplier selection model and quota allocation based on conflicting criteria, where the accessible data are imprecise. It selects the best suppliers from a large number in terms of conflicting objectives. Raut et al. (2020) have applied MCDM-based approach to evaluate the performance of existing suppliers to rationalise the supplier base and to find out top strategic suppliers. It also guides the policy and decision makers in formulating the strategies for the effective supplier selection in highly competitive environments. Selecting the right supplier ends up in reducing the purchase risk. For the past decade, the approach to supplier selection is about selecting the suppliers entirely based on cost (Van Weele, 2009). Nowadays many criteria are being considered during supplier selection such as quality, delivery, performance history, production capacity, technical capability, financial position, reputation, location, etc. They may also be related to environmental, communal, or political perspectives. These criteria are certain aspects based on which the suppliers are evaluated.

1.2 Analytic hierarchy process

The AHP is a MCDM mathematical approach, which is used to solve complicated decision problems. It was introduced by Thomas L. Saaty in the late 1970s. It uses a hierarchical structure of goal, criteria, and alternatives where pair-wise comparisons are made to procure the relative weights of the criteria and the alternatives concerning each criterion (Saaty, 1999).

The pair-wise comparisons of decision criteria concerning the objective are made in order to get the relative weightage (RW) to know which criteria are the most important and which criteria are the least. The pair-wise comparisons can be quantitative or qualitative. If it is quantitative, then the comparison is easy, but it becomes difficult to compare when the information is qualitative. In order to make the qualitative comparisons easy, Thomas L. Saaty developed a scale in 1980 shown in Table 1 (Saaty, 1980).

Table 1 Saaty 1–9 scale

Important scale	*Definition*	*Explanation*
1	Equally important	'i' and 'j' are equally important
3	Moderately important	'i' is moderately important over 'j'
5	Strongly important	'i' is strongly important over 'j'
7	Very strongly important	'i' is very strongly important over 'j'
9	Extremely important	'i' is extremely important over 'j'

Notes: Where 'i' and 'j' are two elements which are being compared to each other.
2, 4, 6, 8 are intermediate values.

2 Literature review

The literature on supplier selection problems is rich and the timespan of literature is very wide. The articles have been assorted and presented here on the basis of sheer relevancy and consistency. Dickson (1966) assorted 23 different factors out 50 distinct factors such as price, quality, delivery, performance history, warranty, technical capability, financial position, etc. for selecting the supplier. He exhibited four different cases to assess the importance of factors on the different types of purchases. Zadeh (1975) introduced a concept of linguistic variable in fuzzy set theory and its application to approximate reasoning. The applications were found to be very useful in dealing with supplier selection problems. Saaty (1980) proposed one of the essential and flexible weighted scoring decision-making processes to help people set importance and make the best decision. In industrial practice and academic research, AHP is one of the essential MCDM methods that has been widely used to solve the vendor selection problem. Weber et al. (1991) reviewed 76 articles that addressed supplier selection criteria in manufacturing and retail environments. They claimed that strategic decisions clearly affected the relative importance that the various criteria had in supplier selection process. Kontio (1996) presented off-the-shelf-option (OTSO) method that relied on the use of AHP for selection of commercial off-the-shelf software (COTS). Siguaw and Simpson (2004) identified an extensive list of 84 different criteria for the evaluation of suppliers. They identified supplier characteristics that could be considered to add potential value for a buying partner. They discussed the importance of measuring such characteristics. The findings are drawn out to determine the standardised criteria and methods for evaluating suppliers based on the value in the firm. Wang et al. (2004) related product characteristics to supply chain method and adopted the supply chain operations reference (SCOR) model level I performance metrics as the decision criteria. A preemptive goal programming (PGP) and AHP-based MCDM approach were then established to accommodate both qualitative and quantitative factors in supplier selection. The presented case study demonstrated that SCOR model was incorporated in AHP approach successfully to permit a more flexible and inclusive use of data in supplier selection decisions. Shyur and Shih (2006) proposed and presented a hybrid MCDM model based on modified analytic network process (ANP) for strategic supplier selection. Chen et al. (2006) proposed a fuzzy decision-making approach to solve supplier selection problems. They divided the nature of criteria as qualitative and quantitative. For example, price and delivery are categorised under quantitative nature, while quality and flexibility performance are categorised under qualitative nature. They proposed linguistic values to evaluate the ratings and weights for different criteria. These linguistic ratings were transformed into trapezoidal or triangular fuzzy numbers. Boran et al. (2009) presented TOPSIS method combined with intuitionistic fuzzy set for supplier selection.

Liao and Kao (2010) observed that choosing the best supplier was one of the difficult tasks in the competitive market. The authors mentioned supplier selection as an MCDM problem. The Taguchi loss function, AHP, and multi-choice goal programming (MCGP) models are combined together to solve the supplier selection problems. This method provides a lead in allowing experts to set multiple aspiration levels for the decision attribute. Ishizaka and Labib (2011) developed a new multi-criteria decision aid (MCDA) for ordering alternatives in a group decision by using the group AHP ordering (GAHPO) method. The backbone of this technique was AHP which was unglued into two hierarchies for a cost and a benefits analysis. The model was implemented to achieve four significant benefits such as, substantial minimisation of time and effort in the decision process, lack of difficulty for the decision makers to reach unanimity, improvement of the judgement quality and documentation rationalisation of the decision preparation. Liao and Kao (2011) presented an integrated fuzzy TOPSIS and MCGP MCDM model to solve the supplier selection problem. Considering both tangible and intangible criteria, the authors concluded that the integrated fuzzy TOPSIS was more suitable for order preference by similarity to ideal solution. The integrated model aided decision makers to set multiple aspiration levels for supplier selection and the same was illustrated by an example in a watch firm. Lin (2012) and Arikan (2013) proposed similar integrated model for multi-objective supplier selection by presenting a fuzzy solution approach. Nazari-Shirkouhi et al. (2013) aimed to solve a supplier selection problem under multi-price level and multi-product using interactive two-phase fuzzy multi-objective linear programming (FMOLP) model. Their analytical results had shown that the adopted approach was effective in uncertain environments and yielded a reliable decision tool. Dargi et al. (2014) used a fuzzy-ANP approach for supplier selection in an Iranian automotive industry. Deng et al. (2014) observed that supplier selection played a vital role in supply chain management and solely depended on the expert's appraisal. They proposed a modernised and a new production method called the D numbers which was a D-AHP method for the supplier selection problem. The method was an extension of the classical AHP. In this method, D numbers extended the fuzzy preference relation to represent the pairwise comparison decision matrix. Kar (2015) presented the application of a hybrid technique for group decision support in supplier selection problem. AHP, fuzzy set theory, and neural network were assimilated to provide group decision support under unanimity. Discriminant analysis was used for supplier base rationalisation, through which suppliers could be grouped as less suitable and highly suitable supplier classes. Dweiri et al. (2016) proposed a decision support model for supplier selection on the basis of AHP and illustrated a case of the automotive industry in a developing country like Pakistan. They also conducted sensitivity analysis to measure the robustness of the supplier selection problem. The proposed model identified the main criteria (price, quality, delivery and service) and ranked the criteria based on the expert's opinions by using AHP. The study made three distinct contributions in the area of supplier selection, and it aided the case company in reducing the rejection rate during an incoming inspection of raw materials.

Lidinska and Jablonsky (2017) evaluated the performance of employees in a middle-size management consulting company. The most potent and flexible MCDM method AHP was applied in human resources evaluation, allocation and planning. Parkouhi and Ghadikolaei (2017) proposed a resilience approach for supplier selection to select appropriate suppliers corresponding with resilient capabilities of the company's supply chain. They used fuzzy analytical network process (ANP) and grey VIKOR techniques to determine the importance level of the elements effective in resilient supplier selection. Santos et al. (2017) designed a segmentation model created on the relationship with suppliers competent for aggregating quantitative and qualitative criteria. The AHP was used to conclude the relative significance of each criterion, to evaluate the suppliers with a combination of chronological quantitative data and qualitative data by using fuzzy 2-tuple, a prominent computing with word (CWW) methodology. An illustrative application of the proposed model was carried out in the pharmaceutical supply centre (PSC) of a teaching hospital. Assellaou et al. (2018) investigated a case of a well-known refining company in Africa for supplier selection problem by applying an integrated DEMATEL-ANP-TOPSIS methodology to select the best supplier providing the most customer satisfaction for the determined criteria. Sreekumar and Rajmohan (2018) proposed an integrated MCDM method to determine the sustainability criteria and to prioritise the given sustainability strategy. The AHP and preference ranking organisation method for the enrichment of evaluations (PROMETHEE) techniques were used to solve the MCDM problem. The proposed methodology was used to solve a real-time supply chain decision-making issue of an Indian manufacturing industry. Ahmad and Mondal (2019) presented a supplier selection model under changing criteria environment, which was based upon the market because all suppliers in the market were not capable to perform potentially under the considered set of criteria. They proposed a fuzzy TOPSIS method for supplier selection. Also, the methodology was validated through realistic data taken from an Indian automotive company. Fu (2019) studied an integrated approach of AHP with a type of performance rating involving the determination of a degree of utility by additive ratio assessment (ARAS) and MCGP to select catering suppliers. Mohammed et al. (2019) proposed a hybrid MCDM and fuzzy multi-objective optimisation (FMOO) approach for a sustainable supplier selection and order allocation by considering economic, environmental and social criteria. Buriticá et al. (2019) proposed a four-phase methodology-diagnosis, program design, assignment and proposal to select the supplier. The proposed model focused on the supplier clustering and fuzzy-AHP in the retail sector for supplier selection. It improved the supply chain performance for organisations with many suppliers requiring development programs. Guarnieri and Trojan (2019) proposed a multi-criteria model to support supplier selection process during outsourcing activities in a textile industry. The proposed model used the mixed MCDA approaches (Copeland/AHP/ELECTRE-TRI) to show that suppliers could be classified based on social, environmental, economic criteria and related ethical issues, considering opinion from customers and experts. Vishnu et al. (2019) investigated the interdependence among the various supply chain risk inter-relationships and possible mitigation in Indian scenario. An ISM-AHP integrated approach was used to solve the supply chain risk factors. The ISM incorporated the strength of the interrelationships. The AHP was applied for the prioritisation and selection of appropriate mitigation strategies. Fazli-Khalaf and Nemati (2019) developed a bi-objective multi-period supplier selection model that aimed to minimise total of costs of network besides maximising social responsibility. The constrained probabilistic programming model was proposed to cope with uncertainty of parameters. Finally, the proposed supplier selection model was employed in a real-world case study of pharmaceutical department of an Iranian hospital to show efficiency and practicability. Gardas et al. (2019) employed a three-stage MCDM approach for the evaluation and selection of suppliers. AHP method was used to identify the relative weights of the selection criteria and TOPSIS method was used to shortlist the ranks of suppliers. Goal programming (GP) was used for the quantity allocation. The proposed methodology assisted the organisational managers in formulating policies and strategies for selecting the effective supplier in the competitive environment. Laghrabli et al. (2020) conducted study on mapping supplier selection methods and criteria in the scoring and assessment sourcing process in case of logistics activities. Tham et al. (2020) developed an integrated ISM and fuzzy TOPSIS methodology for selecting the suitable supplier of a plastic packaging company. ISM method was employed on a set of 23 criteria to analyse the relationships among the criteria. Then, fuzzy TOPSIS method was employed to evaluate criteria and rank the suppliers. Azadfallah (2020) proposed a new TOPSIS-based algorithm to determine the regret measure in the group decision-making process. He discussed a numerical example that involved a multi-criteria supplier selection problem in supply chain.

2.1 Problem definition and research objectives

The literature on supplier selection is extensive. In the literature review, most of the existing models are found to deal with supplier selection problem but did not account for an iron and steel industries in India. At the same time, different supplier selection problems across the world are being dealt with in other industries. After interacting with an iron and steel plant in eastern India, it is found that they are facing problems such as high rejection rate during an inspection of manufactured products. After discussion with different decision makers and panel of experts of that industry, it has been found out that there are different reasons due to which the plant is facing real problems. One of the reasons was inferior raw materials provided by the suppliers. In view of theses challenging issues, sincere attention for systematic research study has been inevitable. Thus, the following research objectives have been outlined:

- to develop a research framework for systematic study on the case company in the question based on AHP method
- to implement the multi-criteria-based decision-making approach in view of knowledge from literature and experts' opinion
- to select the appropriate supplier and conduct the detailed sensitivity analysis on the outcomes of the study.

3 Methodology

A decision support hierarchical structure is made to understand the relationships among different elements. In AHP, the problem is disintegrated into a hierarchical model as shown in Figure 1. Next, the decision makers or experts compare each criterion with respect to each other taking two at a time according to their impact on the goal. While making comparisons, the decision makers can use actual data about the elements like cost, delivery, location, etc. The AHP converts these data to a numerical pair-wise comparison matrix of criteria and alternatives. It is then evaluated to obtain a numerical priority of each element. Then the numerical priorities of each alternative are calculated and ranked according to their values.

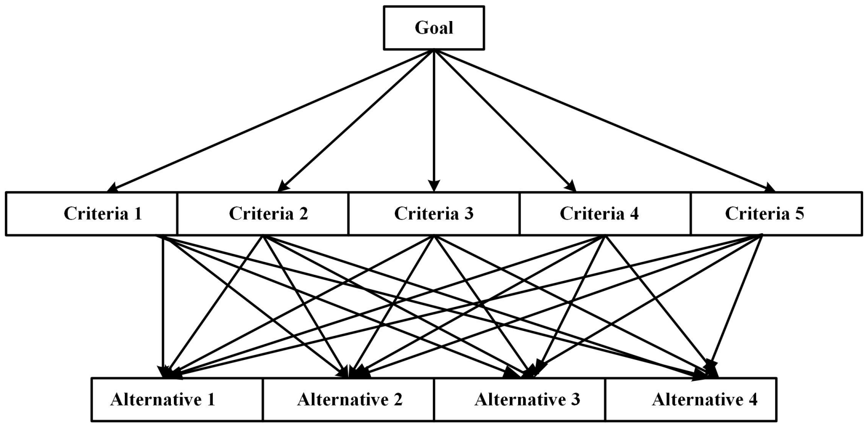
It is the primary step to initiate the AHP process. To implement the AHP process, the entire process is classified into four steps (Saaty, 1980).

Steps of AHP

- The first step is to break up the decision problem into a hierarchical model as shown earlier in Figure 1, i.e.,

  1. a goal at the top
  2. criteria
  3. alternatives at the bottom.

Figure 1 AHP structure for supplier selection



- To construct a pair-wise comparison matrix as shown below. By using the fundamental 1–9 scale given by Thomas L. Saaty the ratings of each criterion with respect to each other and the alternatives are given,

$$\begin{bmatrix} & C_1 & C_2 & C_3 & \dots & C_n \\ C_1 & a_{11} & a_{12} & a_{13} & \dots & a_{1n} \\ C_2 & a_{21} & a_{22} & a_{23} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \dots & \vdots \\ C_n & a_{n1} & a_{n2} & a_{n3} & \dots & a_{nn} \end{bmatrix}$$

- To normalise the pair-wise comparison matrix for both criteria and alternative and calculate their relative weights with respect to each other. Each element of every column of pair-wise comparison matrix is divided by the sum of entries of that corresponding column. The relative weights are the fractional values or the relative percentage of importance among each other.

Table 2 Random index (RI) used in decision-making process

n	1	2	3	4	5	6	7	8	9	10
R.I	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Note: According to Thomas L. Saaty, CR should always be less than 0.1 for the rating to be accepted.
Source: Saaty (1980)

Check the consistency of each matrix in order to know whether the ratings given by the experts are consistent or not. Also, to know that the matrix is consistent and calculate consistency ratio (CR) by using the given formula,

CR = Consistency index/Random index

Consistency index (CI) = $(\lambda max - n)/(n - 1)$

where λmax is the maximum eigen value of the matrix and 'n' is order of the matrix.

Consistency index is further compared with its respective random index value which is taken from the random index table developed by Saaty as shown in Table 2.

- To formulate an overall priority matrix denoting the rating of each alternative with respect to each criterion and finally multiplied with the relative weights of each criterion in order to get the final weightage of the alternatives. The alternative with the most weightage value is selected as the best choice among others.

4 Proposed research framework

A systematic research framework is essential to achieve the appropriate supplier evaluation and implementation. Thus a systematic research framework has been developed and shown in Figure 2. The proposed research framework is distinguished in three stages as described below:

Stage I: Criteria identification

The supplier selection related criteria and alternatives are identified in the first stage of the proposed framework. The company's requirements, priorities, and operating strategies are covered by using these evaluation criteria. The supplier selection related evaluation criteria have been compiled through literature and experts' opinion.

Stage II: Implementation of AHP

Once hierarchical structure is established, then the decision group started to assign the ratings to calculate the weights of supplier selection dimensions and criteria by using AHP. In AHP method, the pair-wise comparison among decision criteria were made using experts' judgements based on importance scale. According to the AHP methodology, consistency checking is considered to prove that the decision makers are rational. Consistency ratio (CR) is defined to check the level of inconsistency. The value of CR below 0.1 is considered to be acceptable but if CR value is above 0.1 then it is reconsidered for discussion with experts' team.

Stage III: Supplier selection and sensitivity analysis

In the last stage, the framework enabled the effective selection of suppliers based on the results of the two previous stages. First, the criteria and importance scales are used to evaluate supplier selection. Then, a pre-selection of these suppliers was made by allowing them to be placed into a hierarchy according to the established organisational objectives. Finally, all suppliers are ranked and the most efficient supplier is chosen among the alternatives. Then, sensitivity analysis has been conducted by using MS Excel to understand the consequences of changing weights of the main criteria on the ranking of suppliers.

Figure 2 Schematic representation of current research framework to evaluate suppliers

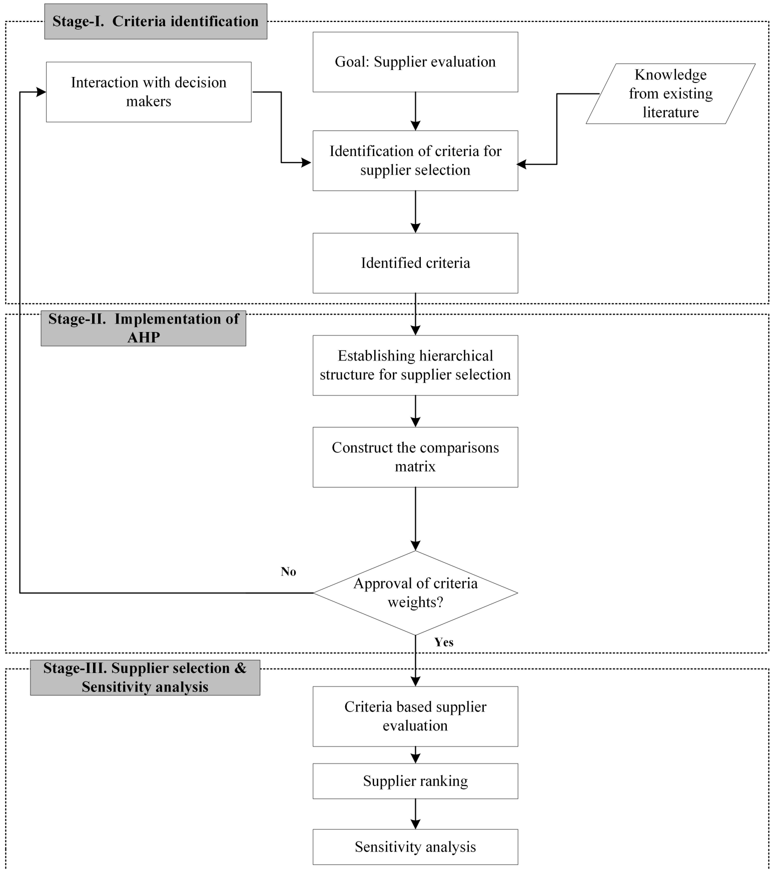


Table 3 Suppliers' information for coal

S. no.	*Supplier name*	*Distance (km)*	*Estb. year*	*Company size*
1	S1	600	1975	Large
2	S2	400	1975	Large
3	S3	250	1962	Medium
4	S4	10	1774	Large

Table 4 Suppliers' information for iron ore

S. no.	*Supplier name*	*Distance (km)*	*Estb. year*	*Company size*
1	S5	400	1962	Large
2	S6	420	1950	Medium
3	S7	500	1918	Large
4	S8	510	1986	Medium

Table 5 Experts' pair-wise comparison ratings of criteria

Criteria	*Cost*	*Delivery*	*Location*	*Quality*	*Communication*	*Management*	*Performance history*	*Reputation*
Cost	1	3	4	3	7	7	5	6
Delivery	1/3	1	2	1/2	6	6	5	5
Location	1/4	1/2	1	1/2	6	5	4	4
Quality	1/3	2	2	1	7	6	5	4
Communication	1/7	1/6	1/6	1/7	1	1/3	1/4	1/5
Management	1/7	1/6	1/5	1/6	3	1	1/3	1/4
Performance history	1/5	1/5	1/4	1/5	4	3	1	3
Reputation	1/6	1/5	1/4	1/4	5	4	1/3	1

Table 6 Normalised pair-wise comparison matrix

Criteria	*Cost*	*Delivery*	*Location*	*Quality*	*Communication*	*Management*	*Performance history*	*Reputation*	*Relative weightage**
Cost	0.389	0.415	0.405	0.521	0.179	0.216	0.239	0.256	0.328
Delivery	0.130	0.138	0.203	0.087	0.154	0.186	0.239	0.213	0.169
Location	0.097	0.069	0.101	0.087	0.154	0.155	0.191	0.171	0.128
Quality	0.130	0.276	0.203	0.174	0.179	0.186	0.239	0.171	0.195
Communication	0.056	0.023	0.017	0.025	0.026	0.010	0.012	0.009	0.022
Management	0.056	0.023	0.020	0.029	0.077	0.031	0.016	0.011	0.033
Performance history	0.078	0.028	0.025	0.035	0.103	0.093	0.048	0.128	0.067
Reputation	0.065	0.028	0.025	0.043	0.128	0.124	0.016	0.043	0.059

Note: *Relative weightage (RW) of each criterion is calculated as the average of their corresponding row.

4.1 Case study

The case study is based on a small-scale iron and steel industry located in eastern part of India. Being a developing nation, India is one of the fastest emerging economies in the world and the second nation in Asia. In India, iron and steel industry plays a vital role for industrial development. Many large scale industries entirely depend on iron and steel industries for the source of raw materials.

Evaluation of criteria for suppliers is carried by AHP method. The eight different evaluating criteria are considered against four decision alternatives (suppliers) ($S1, S2, S3, S4$) of coal as core materials and four decision alternatives (suppliers) ($S5, S6, S7, S8$) of iron ore as core materials for an iron and steel industry. In this study, three experts (decision makers) have been entrusted to rate the criteria. Due to the confidentiality policy, the name of the concerned iron and steel manufacturing company and its suppliers' names are not disclosed.

This study is concerned with the evaluation of four suppliers for coal and four suppliers for iron ore based on the plant's inputs. Table 3 provides information about the selected suppliers for coal, and Table 4 provides information about the selected suppliers for iron ore. After prolonged deliberation, the eight different criteria are considered to evaluate the suppliers. The eight main criteria are delivery, cost, quality, location, communication, management, performance history, and reputation. The experts did a survey and ranked them based on the criteria. Experts made a pair-wise comparison of the criteria based on the Saaty scale. The pair-wise comparison matrix of criteria is shown in Table 5. The matrix is then normalised, and the relative weights of criteria are calculated as shown in Table 6. The relative weights of the each criterion are shown in Table 7.

To check the consistency, the maximum eigen value is calculated as 8.896.

$$\text{Consistency index (CI)} = (\lambda max - n)/(n-1) = (8.896 - 8)/(8-1) = 0.128$$

$$\text{Random index (RI)} = 1.41 \text{ (from Table 2)}$$

$$\text{Consistency ratio (CR)} = \text{CI/RI} = 0.128/1.41 = 0.0908$$

Since 0.0908 < 0.1, the CR is acceptable and so are the ratings.

Table 7 Final weightage of criteria

Criteria	*Weights*
Cost	0.327
Delivery	0.168
Location	0.128
Quality	0.194
Communication	0.022
Management	0.032
Performance history	0.067
Reputation	0.058

Table 8 Weightage of coal suppliers with respect to each criteria

	Cost	*Delivery*	*Location*	*Quality*	*Communication*	*Management*	*Performance history*	*Reputation*
Supplier 1	0.077	0.057	0.048	0.3889	0.200	0.5	0.096	0.5193
Supplier 2	0.077	0.057	0.100	0.1534	0.200	0.166	0.096	0.2008
Supplier 3	0.186	0.316	0.222	0.3889	0.078	0.166	0.251	0.2008
Supplier 4	0.659	0.568	0.628	0.0686	0.519	0.166	0.554	0.0788

Table 9 Weightage of iron ore suppliers with respect to each criteria

	Cost	*Delivery*	*Location*	*Quality*	*Communication*	*Management*	*Performance history*	*Reputation*
Supplier 5	0.210	0.128	0.497	0.307	0.3	0.1100	0.1	0.214
Supplier 6	0.075	0.128	0.3157	0.307	0.3	0.2627	0.4	0.214
Supplier 7	0.154	0.056	0.109	0.307	0.3	0.5767	0.4	0.525
Supplier 8	0.559	0.685	0.0769	0.076	0.1	0.0504	0.1	0.045

Similarly, a collective decision was made by the experts to rate the four suppliers of coal and four suppliers of iron ore. Based on their collective decision, the ratings of the suppliers are also provided by experts with respect to each criterion. After evaluation in a similar pattern, the final weightage values of each supplier are obtained according to each criterion, as shown in Tables 8 and 9.

In order to get the final rankings of the suppliers Tables 8 and 9 are multiplied with the relative weights of the criteria as given in Table 7. After performing the matrix multiplication, the final rankings of the suppliers are obtained as shown in Tables 10 and 11.

5 Discussions on results and sensitivity analysis

5.1 Discussions on results

Figure 3 shows the final results of the ranking order of coal suppliers in the form of a bar diagram. After completion of the calculation using the AHP process, it has been deduced that supplier 4 is the most suitable coal supplier for the plant with a relative weightage of 0.466 or 46.6%. Supplier 3 is the second suitable supplier for coal with a relative weightage of 0.2545 or 25.45%. Supplier 1 is the third suitable supplier for coal with a relative weightage of 0.1749 or 17.49% and supplier 2 is the fourth suitable supplier for coal with a relative weightage of 0.1059 or 10.59%.

Figure 4 shows the final results of the ranking order of iron ore suppliers in the form of a bar diagram. The final results regarding the selection of iron ore supplier suggest that supplier 8 is the most suitable iron ore supplier for the plant with a relative weightage of 0.336 or 33.6%. Supplier 5 is the second suitable supplier for iron ore with a relative weightage of 0.2439 or 24.39%. Supplier 7 is the third suitable supplier for iron ore with a relative weightage of 0.2176 or 21.76% and supplier 6 is the fourth suitable supplier for iron ore with a relative weightage of 0.2017 or 20.17%.

Table 10 Final weightage of coal suppliers

Supplier	*Weightage*	*Ranking*
Supplier 1	0.1748	3rd
Supplier 2	0.1059	4th
Supplier 3	0.2545	2nd
Supplier 4	0.4645	1st

Table 11 Final weightage of iron-ore suppliers

Supplier	*Weightage*	*Ranking*
Supplier 5	0.2438	2nd
Supplier 6	0.2016	4th
Supplier 7	0.2175	3rd
Supplier 8	0.3368	1st

Figure 3 Final ranking of coal suppliers (see online version for colours)

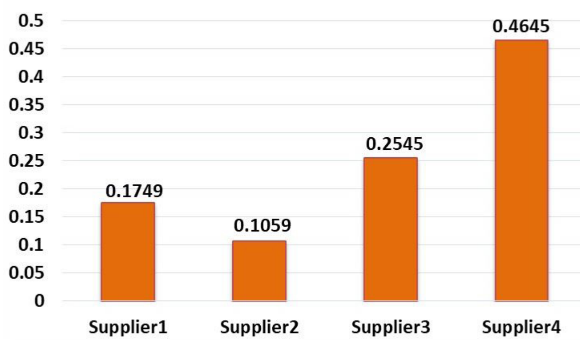
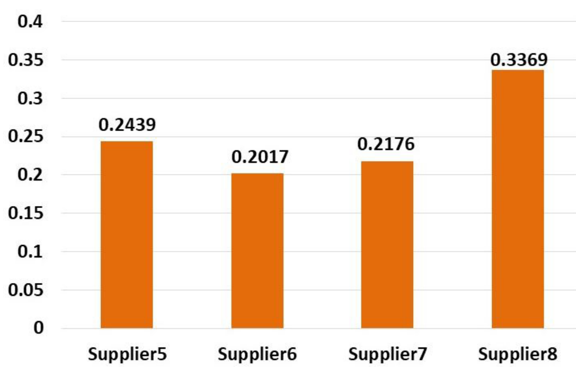


Figure 4 Final ranking of iron ore suppliers (see online version for colours)



5.2 Sensitivity analysis

Sensitivity analysis has been conducted in this case study by combining all the criteria and the alternatives in a single graph. With the use of Microsoft Excel, the graph is plotted by merging the criteria weightages and the alternative weightages. The graph is very useful as any change in input anywhere in the process will be detected, and the output will be updated with an immediate effect.

Figure 5 shows the overall analysis graph of coal suppliers where all the eight criteria have been taken into consideration along with the alternatives. The graph shows the x-axis as the criteria, and the y-axis on the left side of the graph shows the criteria weightage ranging from 0 to 1 and on the right-hand side of the graph shows the alternative weightage ranging from 0 to 1. The diagram (light grey) shows the criteria weightage that was calculated earlier in this study, i.e., cost (0.327), delivery (0.168), location (0.128), quality (0.194), communication (0.022), management (0.032), performance history (0.067), reputation (0.059). Based on each criterion, each supplier was rated to find out which was the best for them. Like for cost, supplier 4 (purple) stands out the best supplier with a weightage of 0.66, as shown in the graph. Supplier 3 (green) stands as the second best supplier based on cost with a weightage of 0.19 and supplier 1 (yellow) ties up with supplier 2 (maroon) with equal weightage of 0.075 as shown in the graph.

Figure 5 Sensitivity analysis of coal suppliers (see online version for colours)

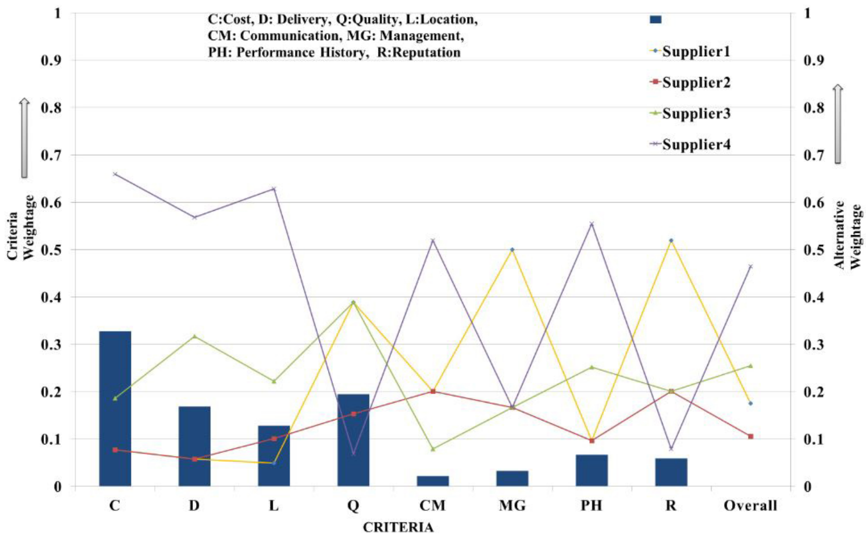
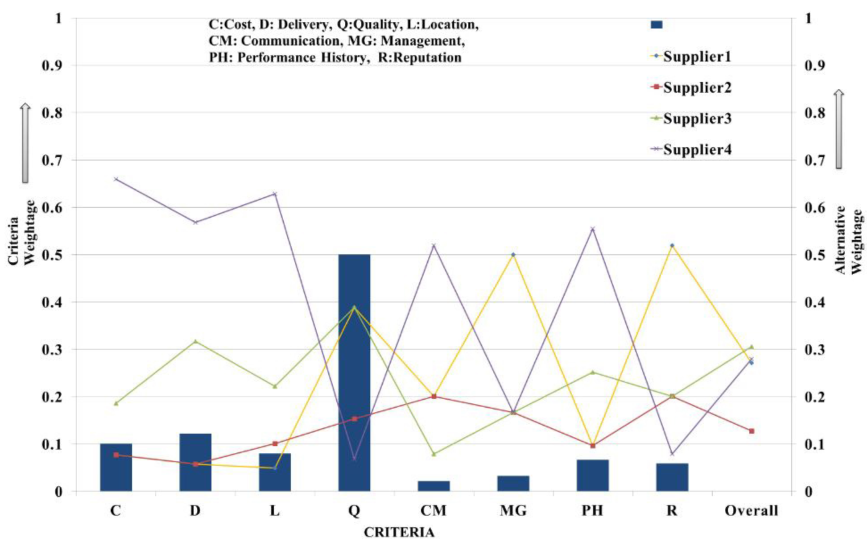


Figure 6 Sensitivity analysis of coal suppliers after change in criteria (quality) weightage (see online version for colours)



Similarly, for each criterion, it is shown that which supplier is the best for them. Finally, on completion of calculations the rankings of the suppliers are shown in the graph. So, the best supplier for coal is supplier 4 with a weightage of 0.464. Supplier 3 stands the second best supplier for coal with a weightage of 0.254.

Figure 6 shows the change in the output when input changes. Here criterion quality is increased while the rest of the criteria weightage decreases accordingly and it is concluded that supplier 3 becomes first with a weightage of 0.308 replacing supplier 4.

Figure 7 Sensitivity analysis of coal suppliers after change in criteria (reputation) weightage (see online version for colours)

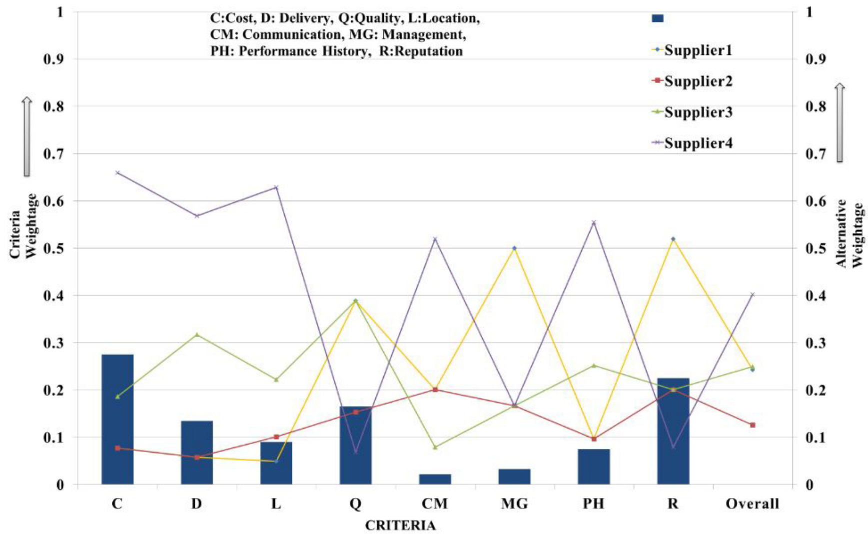
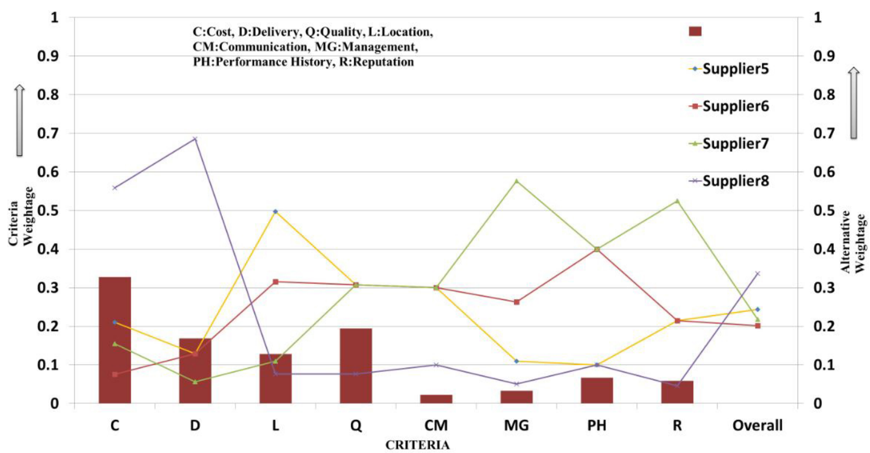


Figure 8 Sensitivity analysis of iron ore suppliers (see online version for colours)



Similarly, from Figure 7 it can be deduced that ranking of supplier 3 and supplier 1 just interchanges with each other when the weightage of criterion reputation is increased.

Figure 8 shows the overall analysis graph of iron ore suppliers where all the eight criteria have been taken into consideration along with the alternatives. The graph shows the x-axis as the criteria, and the y-axis on the left side of the graph shows the criteria weightage ranging from 0 to 1 and on the right-hand side of the graph shows the alternatives' weightage ranging from 0 to 1. The diagram (light grey) shows the criteria weightage that was calculated earlier in this study, i.e., cost (0.327), delivery (0.168), location (0.128), quality (0.194), communication (0.022), management (0.032), performance history (0.067), reputation (0.059). Based on each criterion, each supplier was rated to find out which is the best for them. Like for cost, supplier 8 (purple) stands out the best supplier with a weightage of 0.56, as shown in the graph. Supplier 5 (yellow) stands as the second best supplier based on cost with a weightage of 0.21.

Figure 9 Sensitivity analysis of iron ore suppliers after change in criteria (location) weightage (see online version for colours)

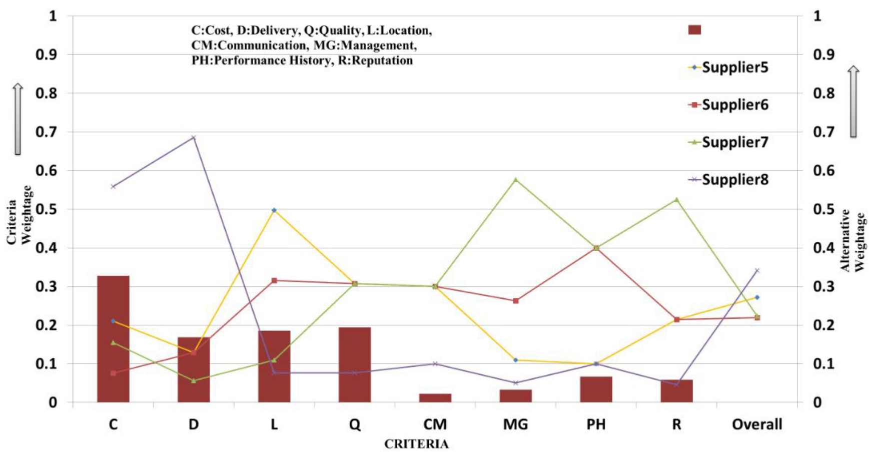
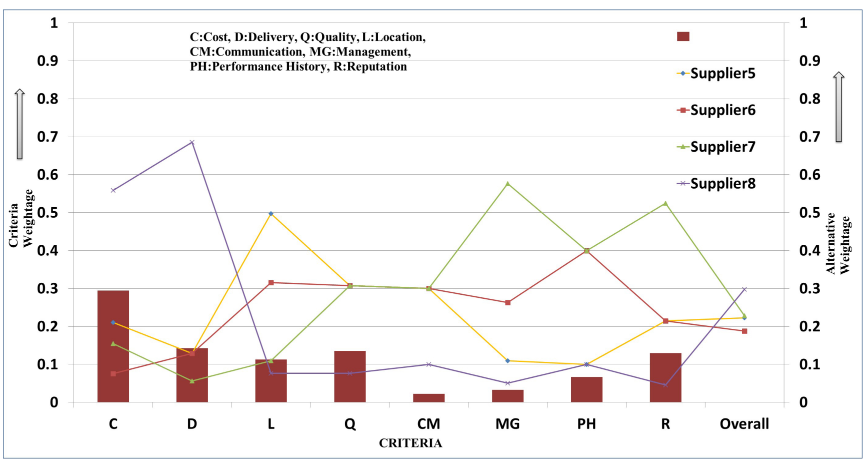


Figure 10 Sensitivity analysis of iron ore suppliers after change in criteria (reputation) weightage (see online version for colours)



Similarly, for each criterion, it is shown that which supplier is the best for them. Finally, after calculations, the rankings of the suppliers are obtained and shown in the graph. It shows the final weightage values of the suppliers. So the best supplier for iron ore is supplier 8 with a weightage of 0.336. Supplier 5 stands the second best supplier for iron ore with a weightage of 0.243.

Figure 9 shows the change in the output when input changes. Here criterion location is relatively increased over quality and it is concluded that suppliers 6 and 7 interchanges their ranking positions accordingly.

Similarly, from Figure 10 it can be deduced that ranking of suppliers 5 and 7 just interchanges with each other when the weightage of criterion reputation is increased.

5.3 Theoretical and managerial implications

There are several managerial implications of the current study for supply chain managers, academicians and practitioners. The presented research framework (Figure 2) is simple but comprehensive to execute for any similar case company in general. Accordingly, the research framework has been executed for this current (small scale) case company of iron and steel manufacturing. The same research framework has applicability to medium and large scale companies with swift ease. So, the scalable and generalisable research framework with AHP method as presented can be highly motivating for further research studies The AHP has found extensive implementations in decision-making problems, involving multiple criteria in multi-level systems. AHP model facilitates the capturing of uncertainties and ambiguity of respondents. Thus, it also helps decision managers to assess the fluctuating responses according to the requirements of specific industry.

The important theoretical implication of the current study is to encourage analysts to determine classified criteria to select the appropriate suppliers. The criteria can be determined in view of dominant nature and level of perceived satisfaction on its fulfilment. The identified criteria can be prioritised according to its traditional and non-traditional characteristics. The current study has focused on the prioritised traditional criteria.

The outcomes of the current study were cognised with the concerned experts and found in good agreement. Thus, it can be deduced that the current research framework as executed is capable of yielding customised solutions as per the requirements of the industry with little modifications. Furthermore, suppliers would like to be satisfied with performance evaluation and look at their association with a greater degree of pertinence. Thus, a periodic evaluation of suppliers can be made as an essential core strategy of supply chain management to remain competitive in the dynamic global market.

6 Conclusions

The study has several unique *contributions* in the relevant area of supply chain management. This study demonstrated the importance of supplier selection in a small scale iron and steel plant. In order to improve the products' quality along with customer's satisfaction, choosing the right supplier is essential in a supply chain. A perfect supplier provides the good quality of materials at a good price, in right time with good service. This paper proposed a hierarchical mathematical model by using AHP for ranking of suppliers in small scale iron and steel industry. Based on the literature review and experts' opinion the main criteria are chosen. The criteria are cost, delivery, quality, location, management, communication, performance history, and reputation. After evaluation by using pair-wise comparison matrix, the relative rankings of the criteria are obtained as price 32.7%, quality 19.4%, delivery 16.8%, location 12.8%, performance history 6.7%, reputation 5.8%, management 3.2% and communication 2.2%. Suppliers were ranked similarly based on the type of raw materials, i.e., coal and iron ore. It is concluded that for coal, supplier 4 is the most suitable supplier with a relative importance of 46.46% and for iron ore, supplier 8 stays as the ideal supplier with a relative importance of 33.69%. Finally, a sensitivity analysis is performed to understand what will be the change in output, i.e., ranking of suppliers when there is a change in the input, i.e., weightage of the attribute. The detailed sensitivity analysis clearly shows the relative influences of the criteria among themselves in the final decision-making procedure. Another important contribution is that the entire study has been conducted using simple MS Excel which is easily available and user friendly. It signifies that other specialised and (sometimes) costly softwares (like Expert Choice, PriEsT, Make It Rational, Super Decision, etc.) can be avoided and replaced with full competence and efficiency for the entire execution. It is concluded that in the case of coal suppliers the criteria cost and delivery are the most robust criteria in comparison to others, as the ranking of coal suppliers remain unchanged except for cost and delivery.

There are several *theoretical and managerial implications* (Section 5.3) of the current study. The presented research framework is scalable and generalisable for any medium and large scale companies for supplier evaluation. The criteria identification is very important as the criteria directly influence final decision. The conducted sensitivity analysis will guide to determine the important criteria for further study. Thus, traditional and non-traditional characteristics of criteria can be studied systematically. The concerned experts are in good agreement having the cognisance of the current study. The study has highlighted the need of periodic supplier evaluation as a core supply chain management strategy. Thus, suppliers would also like to be satisfied with their evaluated performance.

There are few *limitations* associated with the current study as far as the present scopes are concerned. The research framework has only been implemented in a small scale iron and steel manufacturing company. The study has considered only the important traditional criteria for evaluating the suppliers.

The following *future research directions* can be highlighted. The research framework can be implemented for other medium and large companies considering non-traditional criteria (such as sustainability). The other multi-criteria based hybrid techniques such as fuzzy TOPSIS, fuzzy VIKOR, DEMATEL can be used for supplier selection.

References

Ahmad, M.T. and Mondal, S. (2019) 'Supplier selection model under changing criteria environment', *International Journal of Logistics Systems and Management*, Vol. 33, No. 1, pp.97–125.

Arikan, F. (2013) 'A fuzzy solution approach for multi objective supplier selection', *Expert Systems with Applications*, Vol. 40, No. 3, pp.947–952.

Assellaou, H., Ouhbi, B. and Frikh, B. (2018) 'A hybrid MCDM approach for supplier selection with a case study', *Recent Developments in Metaheuristics*, pp.179–197, Springer.

Azadfallah, M. (2020) 'A supplier selection model using group decision-making systems under multiple criteria considering regret factor', *Int. J. Supply Chain and Operations Resilience*, Vol. 4, No. 2, pp.150–170.

Badi, I., Abdulshahed, A.M. and Shetwan, A. (2018) 'A case study of supplier selection for a steel making company in Libya by using the combinative distance-based assessment (CODAS) model', *Decision Making: Applications in Management and Engineering*, Vol. 1, No. 1, pp.1–12.

Boran, F.E., Genç, S., Kurt, M. and Akay, D. (2009) 'A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method', *Expert Systems with Applications*, Vol. 36, No. 8, pp.11363–11368.

Buriticá, N.C., Matamoros, M.Y., Castillo, F., Araya, E., Ahumada, G. and Gatica, G. (2019) 'Selection of supplier management policies using clustering and fuzzy-AHP in the retail sector', *International Journal of Logistics Systems and Management*, Vol. 34, No. 3, pp.352–374.

Chen, C-T., Lin, C-T. and Huang, S-F. (2006) 'A fuzzy approach for supplier evaluation and selection in supply chain management', *International Journal of Production Economics*, Vol. 102, No. 2, pp.289–301.

Dargi, A., Anjomshoae, A., Galankashi, M.R., Memari, A. and Tap, M.B.M. (2014) 'Supplier selection: a fuzzy-ANP approach', *Procedia Computer Science*, Vol. 31, pp.691–700, DOI: 10.1016/j.procs.2014.05.317.

Deng, X., Hu, Y., Deng, Y. and Mahadevan, S. (2014) 'Supplier selection using AHP methodology extended by D numbers', *Expert Systems with Applications* Vol. 41, No. 1, pp.156–167.

Dickson, G.W. (1966) 'An analysis of vendor selection systems and decisions', *Journal of Purchasing*, Vol. 2, No. 1, pp.5–17.

Dweiri, F., Kumar, S., Khan, S.A. and Jain, V. (2016) 'Designing an integrated AHP based decision support system for supplier selection in automotive industry', *Expert Systems with Applications*, Vol. 62, pp.273–283, DOI: 10.1016/j.eswa.2016.06.030.

Ebrahimnejad, S., Rahimi, V. and Moosavi, S.A. (2018) 'A proposed grey fuzzy multi-objective programming model in supplier selection: a case study in the automotive parts industry', *International Journal of Logistics Systems and Management*, Vol. 29, No. 4, pp.409–435.

Fazli-Khalaf, M. and Nemati, N.G. (2019) 'A socially responsible supplier selection model under uncertainty: case study of pharmaceutical department of an Iranian hospital', *International Journal of Logistics Systems and Management*, Vol. 32, No. 1, pp.69–90.

Fu, Y-K. (2019) 'An integrated approach to catering supplier selection using AHP-ARAS-MCGP methodology', *Journal of Air Transport Management*, Vol. 75, pp.164–169, DOI: 10.1016/j.jairtraman.2019.01.011.

Gardas, B.B., Raut, R.D. and Shrivastav, A. (2019) 'Efficient supplier selection-a three-stage multi-criteria decision-making approach', *International Journal of Logistics Systems and Management*, Vol. 34, No. 3, pp.375–394.

Government of India, Ministry of Steel (2017) *National Steel Policy (NSP)* [online] https://steel.gov.in/sites/default/files/draft-national-steel-policy-2017.pdf (accessed 6 January 2021).

Guarnieri, P. and Trojan, F. (2019) 'Decision making on supplier selection based on social, ethical, and environmental criteria: a study in the textile industry', *Resources, Conservation and Recycling*, Vol. 141, pp.347–361.

Ishizaka, A. and Labib, A. (2011) 'Selection of new production facilities with the group analytic hierarchy process ordering method', *Expert Systems with Applications*, Vol. 38, No. 6, pp.7317–7325.

Kahraman, C., Cebeci, U. and Ulukan, Z. (2003) 'Multi-criteria supplier selection using fuzzy AHP', *Logistics Information Management*, Vol. 16, No. 6, pp.382–394.

Kar, A.K. (2015) 'A hybrid group decision support system for supplier selection using analytic hierarchy process, fuzzy set theory and neural network', *Journal of Computational Science*, Vol. 6, pp.23–33, DOI: 10.1016/j.jocs.2014.11.002.

Kontio, J. (1996) 'A case study in applying a systematic method for cots selection', *Proceedings of the 18th International Conference on Software Engineering, ICSE '96*, IEEE Computer Society, Washington, DC, USA, pp.201–209 [online] http://dl.acm.org/citation.cfm?id=227726.227761 (accessed 6 January 2021).

Krishnan, R.M., Shirvastava, K.N. and Banerjee, T. (1959) *The Development of Iron and Steel Industry in India's Five Year Plans*, pp.342–352 [online] http://eprints.nmlindia.org/3067 (accessed 6 January 2021).

Laghrabli, S., Benabbou, L. and Berrado, A. (2020) 'Mapping supplier selection methods and criteria in the scoring and assessment sourcing process: case of logistics activities', *International Journal of Logistics Systems and Management*, Vol. 36, No. 4, pp.495–516.

Liao, C-N. and Kao, H-P. (2010) 'Supplier selection model using Taguchi loss function, analytical hierarchy process and multi-choice goal programming', *Computers & Industrial Engineering*, Vol. 58, No. 4, pp.571–577.

Liao, C-N. and Kao, H-P. (2011) 'An integrated fuzzy TOPSIS and MCGP approach to supplier selection in supply chain management', *Expert Systems with Applications*, Vol. 38, No. 9, pp.10803–10811.

Lidinska, L. and Jablonsky, J. (2017) 'AHP model for performance evaluation of employees in a Czech management consulting company', *Central European Journal of Operations Research*, Vol. 26, No. 1, pp.239–258.

Lin, R-H. (2012) 'An integrated model for supplier selection under a fuzzy situation', *International Journal of Production Economics*, Vol. 138, No. 1, pp.55–61.

Mohammed, A., Harris, I. and Govindan, K. (2019) 'A hybrid MCDM-FMOO approach for sustainable supplier selection and order allocation', *International Journal of Production Economics*, Vol. 217, pp.171–184, DOI: 10.1016/j.ijpe.2019.02.003.

Nazari-Shirkouhi, S., Shakouri, H., Javadi, B. and Keramati, A. (2013) 'Supplier selection and order allocation problem using a two-phase fuzzy multi-objective linear programming', *Applied Mathematical Modelling*, Vol. 37, No. 22, pp.9308–9323.

Nilay Serbest, G. and Vayvay, O. (2008) 'Selection of the most suitable distribution channel using fuzzy analytic hierarchy process in Turkey', *International Journal of Logistics Systems and Management*, Vol. 4, No. 5, pp.487–505.

Parkouhi, S.V. and Ghadikolaei, A.S. (2017) 'A resilience approach for supplier selection: using fuzzy analytic network process and grey VIKOR techniques', *Journal of Cleaner Production*, Vol. 161, pp.431–451, DOI: 10.1016/j.jclepro.2017.04.175.

Raut, R.D., Gardas, B.B., Narkhede, B.E. and Zhang, L.L. (2020) 'Supplier selection and performance evaluation for formulating supplier selection strategy by MCDM-based approach', *International Journal of Business Excellence*, Vol. 20, No. 4, pp.500–520.

Saaty, T.L. (1980) *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*, McGraw-Hill International Book Company, New York.

Saaty, T.L. (1999) 'Fundamentals of the analytic network process', *Proceedings of the 5th International Symposium on the Analytic Hierarchy Process*, pp.12–14.

Santos, L.F.d.O.M., Osiro, L. and Lima, R.H.P. (2017) 'A model based on 2-tuple fuzzy linguistic representation and analytic hierarchy process for supplier segmentation using qualitative and quantitative criteria', *Expert Systems with Applications*, Vol. 79, pp.53–64, DOI: 10.1016/j.eswa.2017.02.032.

Shyur, H-J. and Shih, H-S. (2006) 'A hybrid MCDM model for strategic vendor selection', *Mathematical and Computer Modelling*, Vol. 44, No. 7, pp.749–761.

Siguaw, J.A. and Simpson, P.M. (2004) 'Toward assessing supplier value: usage and importance of supplier selection, retention, and value-added criteria', *Journal of Marketing Channels*, Vol. 11, Nos. 2–3, pp.3–31.

Sreekumar, V. and Rajmohan, M. (2018) 'Supply chain sustainability strategy selection using integrated multi-criteria decision-making method', *International Journal of Logistics Systems and Management*, Vol. 31, No. 4, pp.483–505.

Stević, Ž., Pamučar, D., Vasiljević, M., Stojić, G. and Korica, S. (2017) 'Novel integrated multi-criteria model for supplier selection: case study construction company', *Symmetry*, Vol. 9, No. 11, p.279.

Tham, T.T., Duc, N.T.T., Dung, T.T.M. and Nguyen, H-P. (2020) 'An integrated approach of ISM and fuzzy TOPSIS for supplier selection', *Int. J. Procurement Management*, Vol. 13, No. 5, pp.701–735.

Van Weele, A.J. (2009) *Purchasing and Supply Chain Management: Analysis, Strategy, Planning and Practice*, Cengage Learning EMEA, Thomson, Australia.

Vishnu, C., Sridharan, R. and Kumar, P.R. (2019) 'Supply chain risk inter-relationships and mitigation in Indian scenario: an ISM-AHP integrated approach', *International Journal of Logistics Systems and Management*, Vol. 32, Nos. 3–4, pp.548–578.

World Steel Association (2020) [online] https://www.worldsteel.org/ (accessed 6 January 2021).

Wang, G., Huang, S.H. and Dismukes, J.P. (2004) 'Product-driven supply chain selection using integrated multi-criteria decision-making methodology', *International journal of production economics*, Vol. 91, No. 1, pp.1–15.

Weber, C.A., Current, J.R. and Benton, W. (1991) 'Vendor selection criteria and methods', *European journal of operational research*, Vol. 50, No. 1, pp.2–18.

Zadeh, L.A. (1975) 'The concept of a linguistic variable and its application to approximate reasoning – I', *Information Sciences*, Vol. 8, No. 3, pp.199–249.