A FRAMEWORK FOR EVALUATION OF VENDORS IN THE AUTOMOTIVE INDUSTRY

Raman Kumar
Associate Professor, Department of Mechanical Engineering, Chandigarh University, Mohali-140413, India
ramankakkar@gmail.com

Harwinder Singh
Professor, Department of Mechanical Engineering, Guru Nanak Dev Engineering College, Ludhiana, Punjab- 141006, India
harwin75@rediffmail.com

Amrinder Singh
Assistant Professor, North West Institute of Engineering and Technology, Punjab-142053, India
amrinderbirdi@gmail.com

ABSTRACT

Vendor selection is the first step in the product realization process that starts with the purchasing of materials and ends with delivering the products. The objective of the present research is to select the best vendor in a leading automobile organization. The multi-criteria decision making techniques of fuzzy quality function deployment (QFD) and the Analytical Network Process (ANP) were applied to achieve reliable results. A case study of a manufacturing unit in northern India was used to validate the proposed framework. The output of the QFD showed the pre-qualified vendors as V3, V2 and V7 with relative user requirement (RUR) values of 0.188, 0.145 and 0.134, respectively. The final ranking of the vendors is presented using the ANP model.

Keywords: vendor selection; ranking; multi-criteria decision making; QFD; ANP

1. Introduction

The process of vendor ranking is essential to effectively purchase items such as raw materials, spare parts, etc. (John et al, 2005). In a vendor selection problem, the following two factors are critical; the performance of the materials and the performance of the vendors. The vendor or supplier selection problem is considered a typical problem due to involvement of multiple criteria and their respective sub-criteria (Kumar et al., 2012). In manufacturing industries, approximately 50% of quality rejection is due to the poor quality of the material purchased from various vendors (Talluri and Narasimhan, 2003). Undoubtedly, many of the world's successful organizations have a competitive advantage because of their direct and indirect networks in the vendor chain. Therefore, it is vital to complete a thorough investigation on the assessment of vendor selection

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because it can expand consumer loyalty by enhanced quality and focused capacity (Onut et al, 2009).

The selection of a vendor is the responsibility of the purchasing department and needs to consider both qualitative and quantitative factors. The vendor selection problem is vital for both the private and public sectors. However, the private sector also concentrates on this issue to survive in today's turbulent market scenario. The previous research discovered four explicit criteria such as quality, service, delivery and price for vendor selection in both the public and private sectors. In addition, reputation and location are also important, but their relative significance is subject to discussion. A proficient vendor selection process should be established and is of vital significance for effective supply chain management (Sonmez, 2006).

1.1. Needs in vendor selection

- Assess and monitor supplier performance in order to reward suppliers who meet a company's expectations.
- Provide benchmark data, which will allow vendors to establish where they are placed in relation to the best performers in their industry so they can improve their overall competitiveness in the market.
- Provide feedback so that specific actions can be taken to correct identified performance weaknesses.

1.2 Quality Function Deployment (QFD)

Quality Function Deployment is an important tool in multi-criteria decision making developed in the late 1960s in Japan by Akao (1990). The aim of QFD is to improve the level of customer satisfaction and organization profitability. The steps involved in QFD are presented below:

Step1: Identify the required attributes for the product
The first step in QFD provides the required attributes for the product to fulfill the requirements of the manufacturer, for example, percentage rejection, on time/every time delivery, lead time, product durability, etc.

Step 2: Identify the required enablers to rate the performance of the vendors
Through benchmarking, literature review and opinions from the organization at all levels, identify the required enablers to rate the performance of the vendors, for example, product cost, annual turnover, and geographical location.

Step 3: Transform linguistic expressions into quantitative values
Rao (2013) presented the systematic conversion of the qualitative value into a crisp number using the fuzzy concept. The triangular fuzzy function is shown in Figure 1. The conversion of the linguistic term into crisp scores is shown in Table 1.

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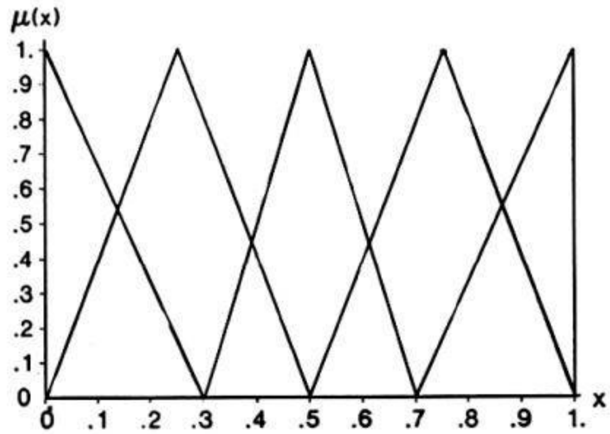

$$\mu_{M1}(x) = \begin{cases} 1, x = 0 \\ (0.3\text{-}x) / (0.3), 0 \leq x \leq 0.3 \end{cases}$$

$$\mu_{M2}(x) = \begin{cases} (x\text{-}0)/ (0.25), 0 \leq x \leq 0.3 \\ (0.5\text{-}x) / (0.25), 0.25 \leq x \leq 0.5 \end{cases}$$

$$\mu_{M3}(x) = \begin{cases} (x\text{-}0.3)/ (0.2), 0.3 \leq x \leq 0.5 \\ (0.7\text{-}x)/ (0.2), 0.5 \leq x \leq 0.7 \end{cases}$$

$$\mu_{M4}(x) = \begin{cases} (x\text{-}0.5)/ (0.25), 0.5 \leq x \leq 0.75 \\ (1.0\text{-}x)/ (0.25), 0.75 \leq x \leq 1.0 \end{cases}$$

$$\mu_{M5}(x) = \begin{cases} (x\text{-}0.7)/ (0.3), 0.7 \leq x \leq 1.0 \\ 1, x = 1 \end{cases}$$

Figure 1 Triangular Fuzzy function

Table 1
Conversion of linguistic terms into crisp scores (5-point scale)

Linguistic term	**Fuzzy number**	**Crisp score**
Low	M1	0.115
Below average	M2	0.295
Average	M3	0.495
Above average	M4	0.695
High	M5	0.895

Step 4: Determine the relationship between the criteria and the enabler
Identify the relationship between the criteria and the enabler through the team of managers completing the questionnaire. The relative weights of the enablers can be calculated by computing the Technical Significance Rating (TSR) and the Relative Technical Significance Rating (RTSR).

Step 5: Determine relationship between the enablers and the vendors
Identify the relationship between the enablers and the vendors through objective data and

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the team of managers completing the questionnaires. To measure the functioning of each alternative supplier with respect to enablers, the User Requirement (UR) and the Relative User Requirement (RUR) is computed using the technical significance rating.

Step 6: Mathematical model formulation
The mathematical model is divided into two sub-problems because of two contradictory objectives:
i. Maximizing the user requirements
ii. Minimizing lead time.

First, the sub-problem is solved by considering Total Consumer Satisfaction (TCS) as the objective function of integer programming and the predetermined value of the maximum threshold level of lead time.

*Step 7: Identify potential vendors using the TORA software ((*Palanisamy and Zubar, 2012)
Potential vendors are identified through the Taha Operational Research Algorithm (TORA) software and a vendor pool is formulated.

1.3 Analytic Network Process methodology (ANP)

The ANP converts a decision problem into a network and performs pairwise comparisons to measure the weights of the network elements and rank the alternatives. Only unidirectional hierarchical relationships are represented with the AHP. The ANP allows for multifaceted interrelationships among the decision levels and attributes.

The steps involved in the Analytical Network Process (ANP) are presented below:

Step 1: Identify the criterion and sub-criterion for vendor ranking
Identify the criteria and sub-criteria for ranking the pre-qualified vendors through literature review, brainstorming and soliciting the opinions of employees at all levels in the organization.

Step 2: Construct the ANP model
The model is a framework that in some ways represents something in the real world. The model starts with an idea of what the decision is about, what the alternatives are and what criteria should be used in the network. Then, the model is built using the SuperDecisions software that produces results including the factors and alternatives of the problem and their structure and how they are connected. A benefits/opportunities/costs/risks (B/O/C/R) model was suggested for evaluation and selection of venders and suppliers.

Step 3: Degree of preference
The intensity of importance on a scale of 1-9 is used to represent compromises among the preferences (Saaty, 1996).

Step 4: Perform pairwise comparisons to determine the priorities of the criteria and sub-criteria
Perform the pairwise comparisons and determine the priorities of each criteria and sub-criteria by inputting the data collected from the questionnaire into the SuperDecisions

software ((Palanisamy and Zubar, 2012). The questionnaire is completed by the expert team of managers.

Step 5: Perform pairwise comparisons to determine the priorities of the alternatives
Perform pairwise comparisons of the alternatives with respect to the criteria to determine the priorities of the alternatives from the data obtained from the questionnaire.

Step 6: Check the inconsistency ratio
After the pairwise comparisons, it is necessary to verify the consistency of the judgments. If the judgments are not consistent, a mistake may have occurred in the judgments or in the formulation of the problem, making it necessary to correct the pairwise comparisons or the formulation of the problem. Inconsistency is calculated automatically while inputting data from the questionnaire into the SuperDecisions software and the inconsistency value should be less than 0.1. However, if the judgments are consistent, the next step should be executed (Saaty, 1996)

Step 7: Construct unweighted, weighted and limit matrices
An unweighted matrix indicates pairwise comparisons whose direct or indirect relationships among all of the elements are performed in the network. A weighted supermatrix is the form of an unweighted matrix which is stochastic, in other words, the column totals are equal to 1. A limit matrix is obtained by taking the power of the weighted matrix until its rows become fixed. A limit matrix signifies the suitable alternative.

Step 8: Rank the vendor alternatives according to synthesized priorities
Rank the vendors according to the overall synthesized priorities of the alternatives of the whole model.

The AHP/ANP are the most commonly used techniques for the vendor selection problem. The complexity of the vendor selection process depends on the business type, size of the organization and budget of the purchasing department [6]. However, due to its complexity, researchers have focused on implementing hybrid MCDM tools to achieve the most reliable results. In the present work, the fuzzy concept is used to minimize subjective error while experts score the vendors. The organization of the paper is as follows. Section 2 presents a review of the relevant literature. Section 3 describes the present work. The last section concludes the paper as well as presents guidelines for further research.

2. Literature review

Zhang et al. (2004) proposed an application of the Analytical Network Process (ANP) for vendor selection in an electronic company. An ANP model was formulated and applied to the problem of evaluating eleven vendors based on the following criteria: quality, price, delivery, reciprocal arrangements and service capacity. The cluster weights and priorities of all of the sub-criteria were combined to determine the overall priority weights of the vendor systems. The results showed that quality had the priority weight of 0.6280 and was the most important criterion in the evaluation of the vendors. Kirytopoulos et al. (2008) presented a systematic methodology for the ranking of suppliers in the pharmaceutical industry. The ANP was implemented for the evaluation of the best supplier offer. The results indicated that the supplier Brand Co. ranked first for the service provider in the pharmaceutical industry. It was shown that the proposed model was accurate for priority changes and the result was unaffected when a sensitivity analysis was applied.

Ho et al. (2009) presented a hybrid approach for the evaluation of the best strategic 3PL. The integrated QFD and AHP approaches comprised a series of three houses of quality. A case example of a hard disk components supplier was examined and the QFD approach was used for the analysis of the criteria that affected the supplier selection. The integrated approach including QFD and AHP provided a benchmark, and the results were reliable. Li et al. (2011) used fuzzy Analytical Network Process (FANP) for evaluation of 3PLs.The FANP was implemented to overcome the limitations of the ANP. The proposed methodology has the advantage that it adequately deals with the judgments derived from the information and the problem of interdependence and feedback among the elements of the system. A case example of an optical company was examined with the help of the proposed method. The presented approach is capable of capturing the vagueness and fuzziness during value judgment elicitation.

Palanisamy and Zubar (2012) proposed a hybrid multi-criteria decision making model for ranking vendors in an automobile organization. The vendor ranking was based on benefits, opportunities, costs and risks. The proposed methodology consisted of two techniques as follows: Quality Function Deployment implemented for pre-qualification of vendors and an Analytical Network process-based final ranking of vendors. V2 ranked first followed by V5, V7 and V16. Andronikidis (2014) presented a hybrid multi-criteria decision making model of QFD and ANP to design high quality services in the banking sector. The QFD integrated quantitative techniques and the ANP was used to determine the priority of customers' bank selection criteria. The proposed model was implemented with a case problem in the banking sector and the priorities concluded that better service offerings to meet or exceed customers' needs lead to improved sales and higher customer satisfaction. The rest of the relevant literature review is presented in Table 2.

Table 2
Literature review

Author/'s	**Years**	**Description**
Kirytopoulos, Leopoulos and Voulgaridou	2008	Presented a model for supplier selection in pharmaceutical organizations. The ANP was implemented for the selection of the best supplier offer. The supplier Brand Company ranked first in supplier selection.
Qian	2009	Made an attempt to introduce the concept of an artificial neural network algorithm in the domain of vendor selection. The proposed framework had the ability to perform analyses according to changes in the business environment.
Koul and Verma	2011	Provided a new direction by solving the problem of vendor selection with a time axis. The mathematical system was developed which had the capability to capture the effect of uncertainty in vendor selection.
Hui and Yang	2013	Developed a two-step service method (i.e., field index library, match description of service patterns, service composition description) as a solution for the vendors. This methodology can have a significant impact on solving the practical needs of vendors.
Palanisamy, and Zubar	2013	Implemented MCDM techniques to formulate a hybrid process with fuzzy QFD and ANP to rank the vendors in terms of their overall performances. When compared to the individual approaches, the proposed hybrid model effectively assisted the vendor ranking process.
Shih et al.	2014	Analyzed the environmental issues in the selection of a vendor. An AHP-BOCR frame model was presented to obtain reliable results.
Kamath et al.	2016	Developed a framework for selection of a vendor using the AHP in an Indian steel pile manufacturing organization. The managerial implications were presented to achieve the most reliable results.
Kant and Dalvi,	2017	Presented a systematic questionnaire to measure the importance of supplier selection criteria. The validity of the questionnaire was demonstrated by collecting responses from a total of 34 automobile industries in India.
Mathiyazhagan,	2017	Provided a framework for the evaluation of a supplier

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Sudhakar and Bhalotia		with respect to environmental criteria. A case study was demonstrated using the AHP technique to validate the proposed framework.
Aggarwal et al.	2018	Made an attempt to solve a multi-objective optimization problem of vendor selection and order allocation. Significant managerial implications were provided and thoroughly discussed.
Suraraksa and Shin	2019	Presented an integrated model including both a quantitative and qualitative approach. The AHP was applied to evaluate the selection of vendor criteria.
Mohammed et al.	2019	Developed a hybrid MCDM algorithm for the selection of a vendor. A framework consisting of traditional and resilience criteria was proposed to select an appropriate vendor using the ELECTRE and TOPSIS methods. It has been proven that resilience criteria have a significant role in the selection of a vendor

3. Present work

In this research work, a hybrid multi-criteria decision making methodology consisting of fuzzy QFD-ANP was used to evaluate the vendors. Fuzzy QFD was used to create a pool of pre-qualified vendors based on certain criteria and sub-criteria and the ANP was implemented to achieve the final ranking of the pre-qualified vendors.

3.1 Introduction to the case organization

A leading manufacturer in the Indian automotive components industry began its journey in 1938 in Ludhiana. This automotive manufacturing company is a proud supplier of components to various Indian original equipment manufacturers (OEMs) and has established itself as a reliable supplier for many years. The annual turnover of this company is 150 crore (approx. 2.03 crore dollars). The list of OEM customers includes Telco, Volvo India Limited, Swaraj Mazda Limited, Mahindra & Mahindra, Maruti Udyog Limited, Ashok Leyland, and Punjab Tractors Limited, etc. The company employs approximately 1,000 employees and has an infrastructure that includes modern testing facilities equipment and workshops, a casting shop, a machine shop, wire drawing, electroplating, heat treatment, a welding shop, a paint shop, a tool room, packaging and dispatch. This leading manufacturing industry faces problems with rating vendors of SAE-8620 material in the purchasing department. Spring pins and king pins of all types are made from this material and its monthly consumption is very high at approximately 35 tons per month.

3.2 Implementation of fuzzy Quality Function Deployment (QFD)

Fuzzy QFD was applied to reduce the number of potential vendors by screening them with certain basic criteria and sub-criteria. The mathematical model was solved using integer programming and TORA, and provided the decision makers with the optimal number of vendors (Palanisamy and Zubar, 2012).

Step1: Identify the required attributes for the product

The first step in QFD is to provide the required attributes for the product to fulfill the requirements of the manufacturer. In this research, three criteria and six sub-criteria were included in the QFD to create a pool of pre-qualified vendors as shown in Table 3.

Table 3
Criteria and sub-criteria selected

CRITERIA	SUB-CRITERIA	DEFINITION
QUALITY	Percentage rejection	Number of rejections per total produced.
	Product durability	Life of the product.
DELIVERY	Order lead time	Duration of time between setting up an order and receipt of the order.
	Delivery on time/every time	Consistency of meeting delivery deadlines.
FLEXIBILITY	Volume flexibility	Ability to adjust product volume demanded.
	Customization	Ability to customize the product demanded by the buyer.

Step 2: Identify the required enablers to rate the performance of the vendors

In this research, product cost (PC), annual turnover (AT), geographical location in KMs (GL), experience (EXP), technical capability (TC), attitude (ATT) and accuracy of order fulfillment (AOF) enablers were identified to rate the performance of vendors through benchmarking, literature review and solicited opinions from the organization at all levels.

Step 3: Determine the geometric mean value

The geometric mean of the award score given by the experts was calculated by the formula given below and the values are shown in Table 4.

$$\left(\prod_{i=1}^{n} x_i\right)^{\frac{1}{n}} = \sqrt[n]{x_1 x_2 \cdots x_n}$$

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Table 4
Values after geometric mean of data collected from the case company

	Product cost	**Accuracy of order fulfillment**	**Annual Turnover**	**Geographical location in KMs**	**Technical Capability**	**Experience**	**Attitude**
PR	0.115	0.625	0.115	0.115	0.789	0.68	0.184
PD	0.539	0.115	0.473	0.115	0.587	0.515	0.146
OLD	0.374	0.68	0.239	0.539	0.382	0.16	0.587
DOTET	0.184	0.789	0.21	0.539	0.435	0.205	0.638
VF	0.789	0.233	0.336	0.115	0.639	0.115	0.382
CUS	0.741	0.146	0.184	0.115	0.295	0.3	0.473

Step 4: Pairwise comparison
In the QFD, pairwise comparisons of the quality, flexibility and delivery criteria were performed with the SuperDecisions software (Saaty, 2006). The priorities of quality, flexibility and delivery are expressed in Figure 2.

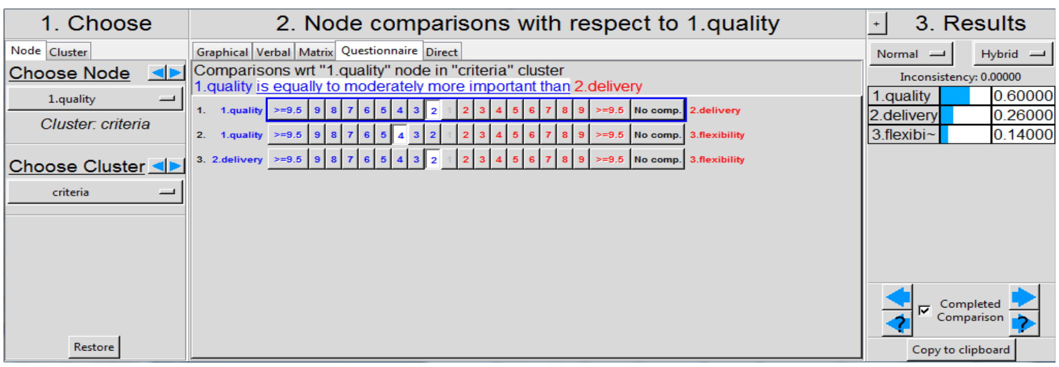

Figure 2 Comparison of criteria

Step5: Relative technical significance rating
The priority rating pi of 60 assigned to quality, TSR and RTSR was calculated for each enabler as shown in Table 5.

For example: Product Cost enabler, TSR was calculated:
TSR= 60 (0.115+0.539) + 26 (0.374+0.184) + 14 (0.789+0.740)
TSR= 75.154
RTSR was calculated by RTSR= 75.154/528.426= 0.142

$$RTSR_j = \frac{TSR_j}{\sum_{j=1}^{J} TSR_j} \quad \forall_j = 1, 2, \ldots, J$$

Table 5
Relationship between the criteria and the enabler and between the enablers and the vendors

Criteria	Sub-criteria	Product cost	Accuracy of order fulfillment	Annual Turnover	Geographical location in KMs	Technical Capability	Experience	Attitude
Quality (60)	Percent Rejections	0.115	0.625	0.115	0.115	0.789	0.680	0.184
	Product durability	0.539	0.115	0.473	0.115	0.587	0.515	0.146
Delivery (26)	Order Lead Time	0.374	0.680	0.239	0.539	0.382	0.16	0.587
	Delivery on time every time	0.184	0.789	0.210	0.539	0.435	0.205	0.638
Flexibility (14)	Volume Flexibility	0.789	0.233	0.336	0.115	0.639	0.115	0.382
	Customization	0.741	0.146	0.184	0.115	0.295	0.3	0.473
TSR		75.154	87.9	54.24	45.048	116.864	85.6	63.62
RTSR		0.142	0.166	0.103	0.85	0.221	0.162	0.120

Step 6: Relative user requirements
For calculation of user requirements (UR) and relative user requirements (RUR), each vendor was rated against each enabler.

$$\boldsymbol{UR}_n = \sum_{j=1}^{J} \boldsymbol{RTSR}_j \, \boldsymbol{WA}_{nj} \quad \forall_n = 1, 2, 3, \ldots, \boldsymbol{n}$$

$$\boldsymbol{RUR}_n = \frac{UR_n}{\sum_{n=1}^{N} UR_n} \quad \forall_n = 1, 2, 3, \ldots, \boldsymbol{N}$$

The UR and RUR were calculated in Table 6.

Step 7: Mathematical model formulation
The qualitative data namely, quality, delivery and flexibility were transformed into quantitative data using fuzzy QFD. This data was combined with lead time to formulate the mathematical model. The lead times of the vendors are mentioned in Table 7. The team decided that lead time must not exceed 45 days as shown in Figure 3. Since RUR has to be maximized, the first sub-problem is Palanisamy and Zubar, 2012:

$$Max\ TCS = \sum_{i=1}^{n} RUR_i X_i,$$

$$\text{s.t} \quad \sum_{i=1}^{n} T_i X_i \leq 45,$$

Table 6
User requirements and relative user requirement

S.No	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**
Product Cost(0.142)	0.104	0.104	0.104	0.146	0.115	0.125	0.146	0.156
Accuracy Of order Fulfilment (0.166)	0.147	0.147	0.147	0.118	0.118	0.103	0.132	0.088
Geographical Location (0.85)	0.172	0.171	0.214	0.168	0.172	0.0009	0.150	0.144
Technical capability (0.221)	0.168	0.168	0.168	0.071	0.062	0.109	0.168	0.853
Annual Turnover(.103)	0.239	0.287	0.837	0.002	0.075	0.120	0.170	0.022
Experience(0.16 2)	0.125	0.174	0.156	0.081	0.067	0.096	0.220	0.078
Attitude(0.120)	0.158	0.158	0.147	0.103	0.077	0.112	0.147	0.087
UR	0.286	0.298	0.386	0.224	0.223	0.1	0.276	0.262
RUR	0.139	0.145	0.188	0.109	0.109	0.049	0.134	0.127

Table 7
Lead time of vendors (data provided by organization)

S. No	Vendors	Lead time in days
1	Vendor 1	45
2	Vendor 2	40
3	Vendor 3	45
4	Vendor 4	50
5	Vendor 5	47
6	Vendor 6	45
7	Vendor 7	42
8	Vendor 8	50

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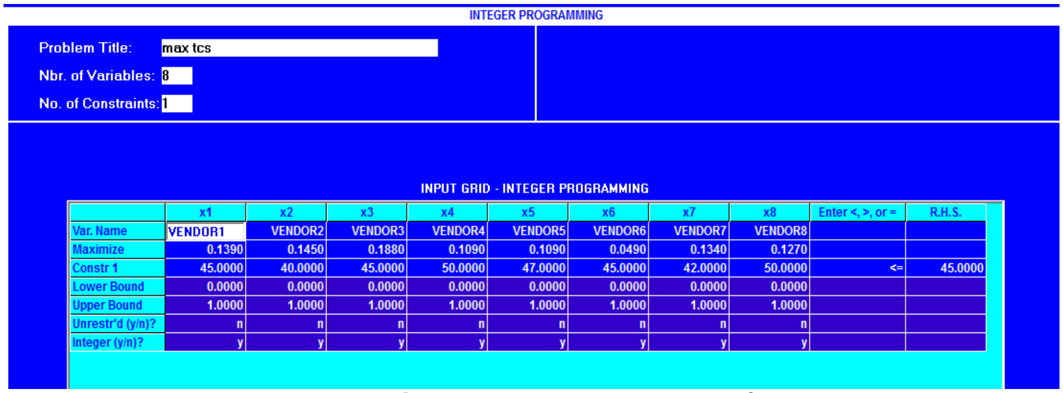

	x1	x2	x3	x4	x5	x6	x7	x8	Enter <, >, or =	R.H.S.
Var. Name	VENDOR1	VENDOR2	VENDOR3	VENDOR4	VENDOR5	VENDOR6	VENDOR7	VENDOR8		
Maximize	0.1390	0.1450	0.1880	0.1090	0.1090	0.0490	0.1340	0.1270		
Constr 1	45.0000	40.0000	45.0000	50.0000	47.0000	45.0000	42.0000	50.0000	<=	45.0000
Lower Bound	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000		
Upper Bound	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000		
Unrestr'd (y/n)?	n	n	n	n	n	n	n	n		
Integer (y/n)?	y	y	y	y	y	y	y	y		

Figure 3 Lead time constraint in TORA software

Formulate minimizing the lead time problem in TORA software

The outcome of maximizing the TCS problem was 0.188 for the given threshold value of lead time. To obtain alternative optimal solutions, the minimum value of TCS was relaxed to 0.100 in the minimum lead time problem and the problem becomes: (Palanisamy and Zubar, 2012)

$$\text{Min T} = \sum_{i=0}^{n} T_i X_i$$

$$\text{s.t} \quad \sum_{i=1}^{n} \text{RUR}_i X_i \geq 0.100$$

$$X_n \in (0,\ 1)\ n = 1,\ 2\ldots\ldots\ldots\ ($$

Step 8. Output of QFD

QFD was implemented on eight vendors of SAE-8620 steel and the pre-qualified vendors are shown in Table 8. The expert team decided that a pool of three vendors was satisfactory for making the final selection.

Table 8
QFD result

Alternate Solutions		
RUR	Lead Time	Vendors
0.188	43	V3
0.145	40	V2
0.134	42	v7

3.3 Implementation of the Analytic Network Process (ANP)

Step 1: Construct the ANP model

The process of decision making for vendor ranking requires an evaluation of the decision according to the Benefits (B), Opportunities (O), Cost (C), Risk (R) model. In this research, many sub-criteria under Benefits, Opportunities, Cost, and Risk were identified for ranking vendors in the SuperDecisions software as shown in Figure 4.

Step 2. Design of the ANP model in SuperDecisions software

The network model was constructed using the design module of the SuperDecisions software (Saaty, 2003). The ANP model was constructed with control criteria and sub-criteria classified by four merits namely, benefits, opportunities, costs and risks as shown in Figure 5. For each control criterion of the B, O, C, R, the priorities for the alternatives of the decision are derived from all of the significant influences that cause some of the alternatives to have higher priorities.

Step 3. Pairwise comparison of different control criteria with respect to vendor selection

The pairwise comparison matrix was developed using group decision making with four experts who work at different levels in the organization. The pairwise comparison of the control criterion with respect to the vendor selection cluster was done with the software and the priorities of the control criteria were obtained as shown in Figure 6.

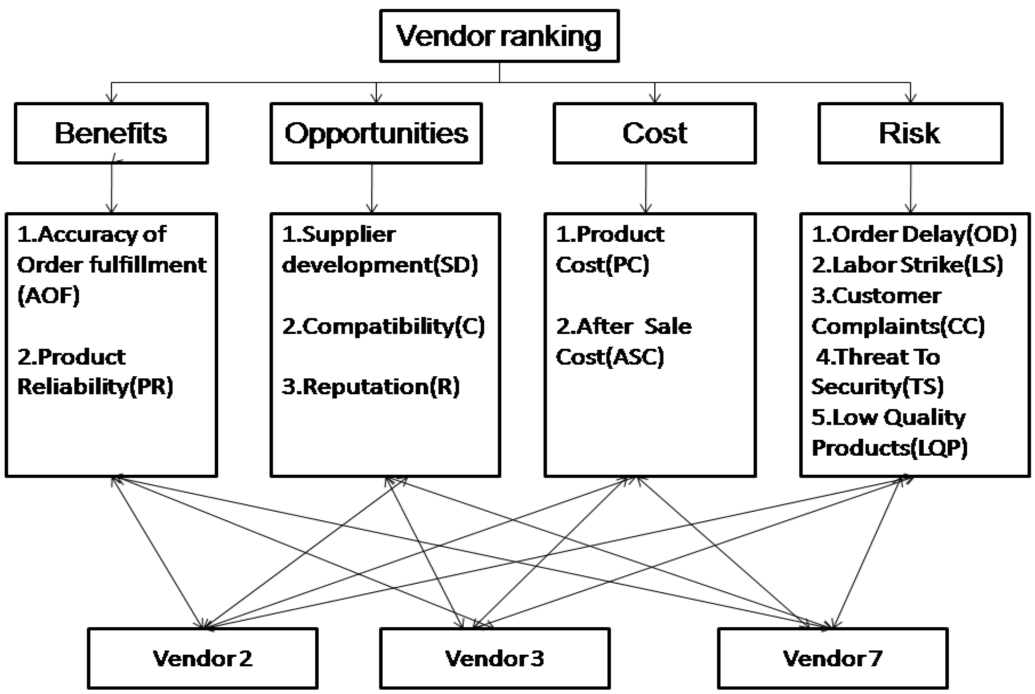

Figure 4 ANP-BOCR model

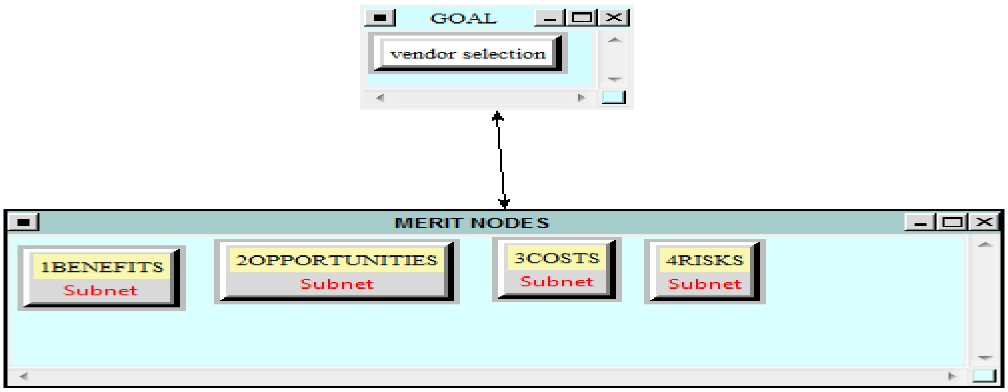

Figure 5 Design of ANP–BOCR model in SuperDecisions software

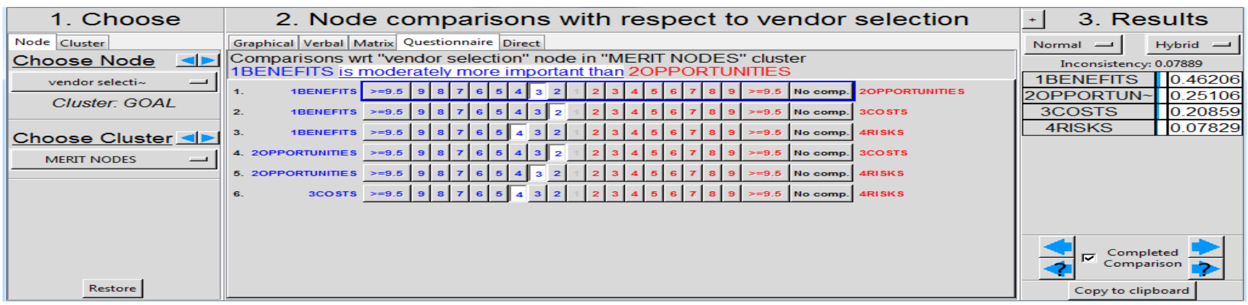

Figure 6 Node comparison with respect to vendor selection

Step 4. Verification of the consistency of the judgments

After the pairwise comparisons are made, the consistency of the judgments must be confirmed. If the judgments are not consistent, there may have been a mistake in the judgments or in the formulation of the problem, and it is necessary to correct the pairwise comparisons or the formulation of the problem. Four experts at different levels in the organization were selected to complete the questionnaire. The inconsistency was automatically calculated while the data from the questionnaire was input into the software, and the inconsistency value must be less than (0.1) as shown in Figure 7.

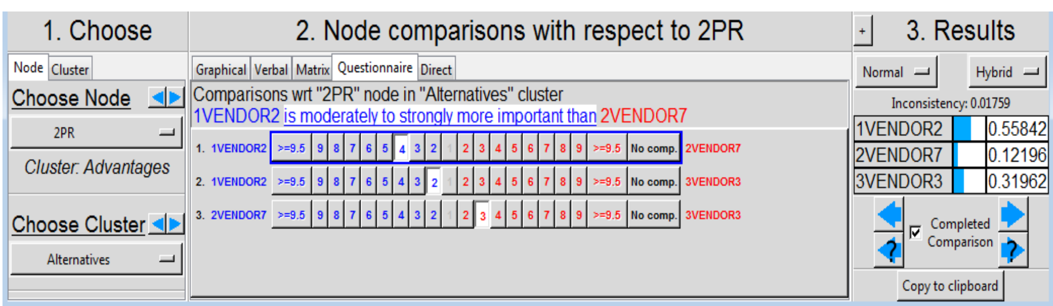

Figure 7 Representation of inconsistency

Step 5. Priorities determined with the Analytical Network Process (ANP) model

The limiting values of the BOCR model were obtained from the supermatrix and the priorities of the BOCR model were obtained by normalizing the respective cluster.

Step 6: Ranking of vendors based on benefits, opportunities, costs and risks

The output was obtained from the ANP-BOCR network model, and vendor V2 is the best vendor with respect to the benefits merit, followed by V3 and V7. With respect to opportunities, V2 is the best vendor, followed by V3 and V7. With respect to costs, V7 is the best supplier, followed by V3 and V2. With respect to risks, V2 is the best supplier, followed by V3 and V7 and is shown in Figure 8. All of the results were obtained based on normal values.

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Subnet under 2OPPORTUNITIES

Name	Graphic	Ideals	Normals	Raw
1VENDOR2		1.000000	0.530733	0.176911
2VENDOR7		0.207576	0.110167	0.036722
3VENDOR3		0.676610	0.359099	0.119700

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Subnet under 3COSTS

Name	Graphic	Ideals	Normals	Raw
1VENDOR2		0.368696	0.196900	0.092172
2VENDOR7		1.000000	0.534043	0.249996
3VENDOR3		0.503811	0.269057	0.125951

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Subnet under 4RISKS

Name	Graphic	Ideals	Normals	Raw
1VENDOR2		1.000000	0.507755	0.169252
2VENDOR7		0.447275	0.227106	0.075702
3VENDOR3		0.522179	0.265139	0.088380

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Subnet under 1BENEFITS

Name	Graphic	Ideals	Normals	Raw
1VENDOR2		1.000000	0.509425	0.169808
2VENDOR7		0.210653	0.107312	0.035771
3VENDOR3		0.752345	0.383263	0.127754

Figure 8 Ranking of vendors with respect to benefits, opportunities, costs and risks

Step 7. Overall synthesized priorities of vendors in the ANP–BOCR model

The overall synthesized priorities of the vendors in the ANP-BOCR were obtained based on normal values and the overall ranking of the vendors is V2, V3, andV7. Therefore, vendor V2 is the best vendor from among the three vendors as shown in Figure 9.

Here are the overall synthesized priorities for the alternatives. You synthesized from the network Super Decisions Main Window: ANP MODEL.sdmod: formulaic

Name	Graphic	Ideals	Normals	Raw
1VENDOR2		1.000000	0.462572	0.705668
2VENDOR7		0.357857	0.165534	0.252528
3VENDOR3		0.803970	0.371894	0.567337

Figure 9 Overall synthesized priorities of vendors in ANP-BOCR model

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4. Results and discussion

Fuzzy (QFD) was used to form a pre-qualified vendor pool and the House of Quality (HOQ) was used to convert the experts' responses from linguistic expressions to quantitative data. The relative importance rating indicates the priority for any engineering characteristic and becomes the basis for the decision making about what actions should be taken to improve the particular engineering characteristics. The QFD and ANP ranking results were compared with the organizational rating of vendors. The first HOQ gives the Technical Significance Rating (TSR) and the Relative Technical Significance Rating (RTSR) as shown in Figure 10. The second HOQ gives the Relative User Requirements (RUR) as shown in Figure 11.

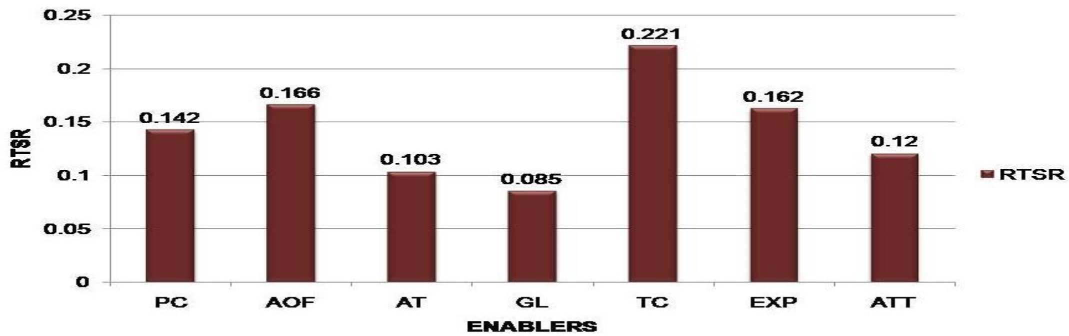

Figure 10 Relative Technical Significance Rating

After the formation of the vendor pool, the pairwise comparisons were input into the SuperDecisions software and based on the ranking of vendors that was obtained, a final selection was made. The following results were obtained which illustrate the ranking of the vendors under the four merits of benefits, opportunities, costs, risks and the total ranking. Vendor V2 is the best vendor with respect to the benefits merit, followed by V3 and V7. The evaluation of the vendors was done based on normal values as shown in Figure 12.

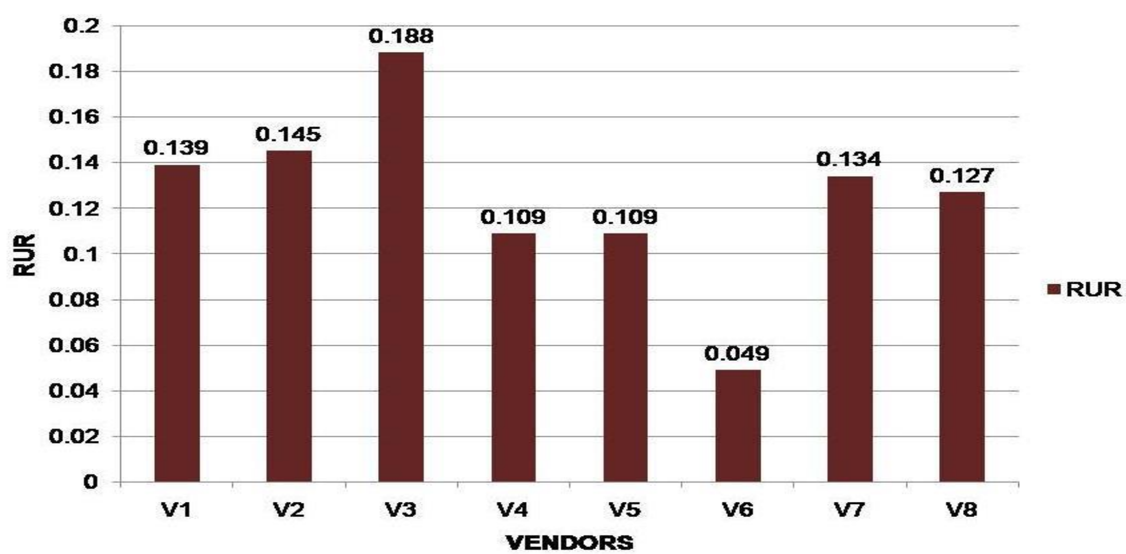

Figure 11 Relative User Requirements

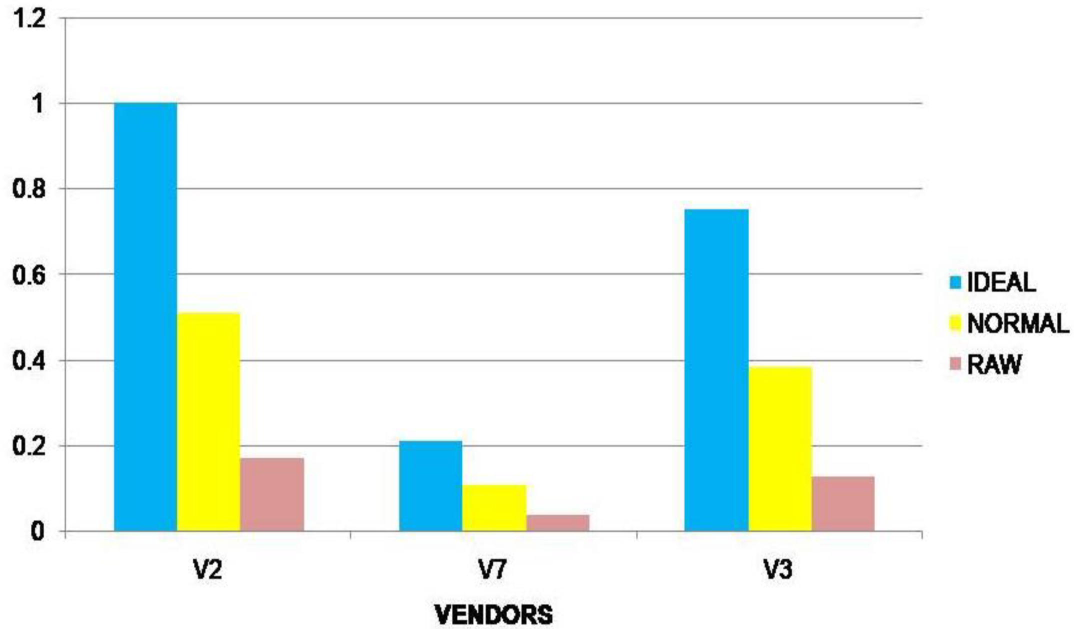

Figure 12 Ranking of vendors with respect to benefits

- Vendor V2 is the best vendor with respect to the opportunities merit, followed by V3 and V7. The evaluation of the vendors was done based on normal values as shown in Figure 13.
- Vendor V7 is the best vendor with respect to the costs merit, followed by V3 and V2. The evaluation of the vendors was done based on normal values as shown in Figure 14.

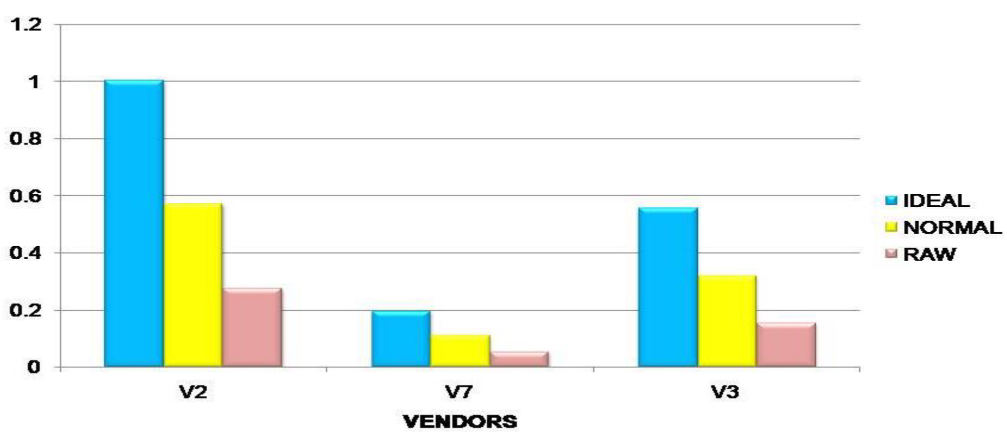

Figure 13 Ranking of vendors with respect to opportunities

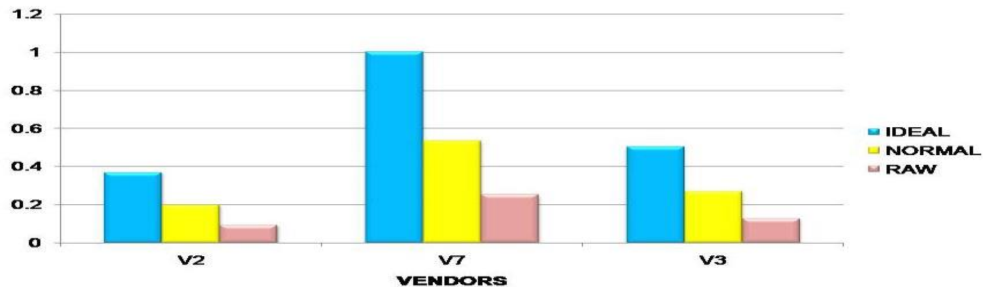

Figure 14 Ranking of vendors with respect to costs

- Vendor V7 is the best vendor with respect to the risks merit, followed by V3 and V2. The evaluation of the vendors was done based on normal values as shown in Figure 15.

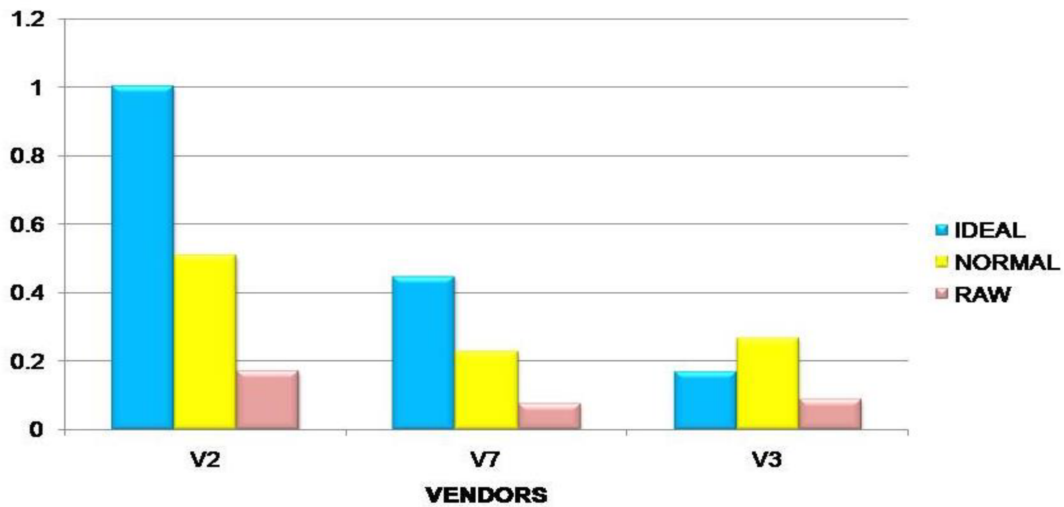

Figure 15 Ranking of vendors with respect to risk

- Vendor V7 is the best vendor with respect to the total ranking of the ANP-BOCR, followed by V3 and V2. The evaluation of the vendors is done based on normal values as shown in Figure 16.

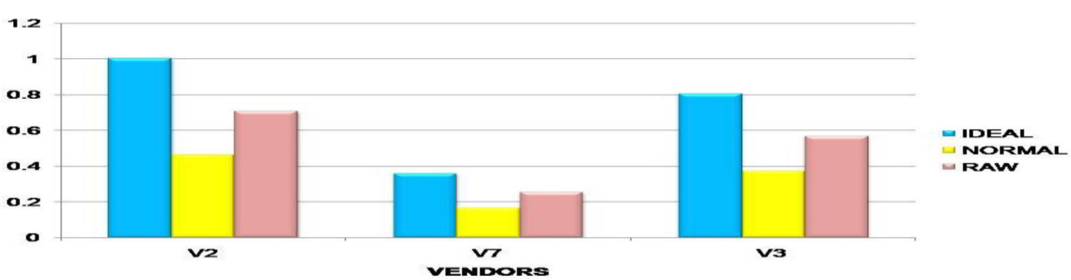

Figure 16 Ranking of vendors with respect to the total ranking of the ANP-BOCR model

- Overall, the synthesized priorities of the vendors in the ANP-BOCR were obtained based on normal values and the overall ranking of the vendors is V2, V3, andV7. Therefore, vendor V2 is the best vendor as shown in Table 9.

Table 9
Ranking of qualified vendors of SAE-8620 steel based on the ANP-BOCR model

Alternatives	**Raw values**	**Ideal values**	**Normal values**	**Ranking**
Vendor V2	0.705668	1	0.462572	1
Vendor V3	0.567337	0.803970	0.371894	2
Vendor V7	0.25258	0.357857	0.165534	3

Table 10 shows the comparison of the vendor ranking done by the organization and the hybrid multi-criteria decision making approach of the QFD and ANP. The organization had not adopted any multi-criteria decision making framework for the selection of a vendor; in fact, they provided the ranking based only on their expertise. According to the organization, the vendor V2 ranked second, V3 ranked third, and V7 ranked fourth. However, in the ranking from the hybrid multi-criteria decision making approach of QFD-ANP, vendor V2 ranked first, followed by V3 and V7. The results of the vendor ranking showed that when it is done based only on the quality, delivery and quality of the system criteria it is not satisfactory for evaluation of the best vendors. The criteria included in this research are also very crucial for ranking and evaluating the best vendors.

Table 10
Comparison of the case organization's vendor ranking with the QFD-ANP method

Vendors	Organization vendor ranking	QFD-ANP vendor ranking
V2	2	1
V3	3	2
V7	4	3

5. Conclusions and future work

In the present work, a model was implemented for the problem of vendor selection in an automotive industry. The combined QFD and ANP approach was implemented to obtain reliable results. TORA and Super Decisions software were used to minimize the computation time and chance for error. The result of the QFD show that vendor V2, V3 and V7 are good suppliers of the SAE-8620 material. The final ranking of the vendors was achieved using the ANP approach. The results showed that the technical capability is the best enabler based on the subjective weights in the selection of vendors for the selected organization. The outcome of the proposed work was that V2 is the best vendor for the selected case company. This work could be extended by using a sensitivity analysis. Other decision making approaches such as TOPSIS and VIKOR could be implemented to compare the results. A limitation of this work is that the proposed ANP model is only applicable to the case company.

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