Integrated Approach for Supplier Selection using AHP and MACBETH Method

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Abstract— This paper presents the integrated approach using AHP and MACBETH method to develop a decision making model to select the best supplier**.** Now a day, in an extremely competitive environment. Supplier selection plays a vital role in the success of any manufacturing or production organization. Selection of suitable supplier is a multi-criterion problem having both quantitative and qualitative criteria. In this paper, we develop a methodology which helps in ranking of supplier. In this study I have consider most important criteria which is quality, service, delay time and cost .in this study weights calculation for each criterion is based on analytic hierarchy process(AHP) and after that these weights are used in measuring attractiveness by a categorical-based evaluation technique (Macbeth) method for ranking.

***Key words*:** Analytic Hierarchy process (AHP), Multi-criteria decision making, supplier selection, MACBETH

I. INTRODUCTION

The aim of supplier selection is to select the suppliers which gives right services with right quality at right cost and at right time etc. The supplier having highest potential for meeting these criteria and able to fulfill firm's needs consistently is good choice for manufacturing firm. Supply chain management (SCM), as a tool, is one of the most significant techniques to become part of different product components in a system from the raw materials stage to final production delivery phase. A good SCM program plays a vital role in product development for any firm. One of the important steps on having a good SCM plan is to choose suitable suppliers. There are different criteria involved for selecting suitable suppliers, which make decision-making problem so complex.. There are severe pressures in competition that forced the organization to adopt strategies to decrease cost and also reduce time from the phases of supply chain. Therefore, selecting the right method for supplier selection has become very significant to reduce the associated purchase risk.(1)

In this paper, we present an integrated approach to select the appropriate supplier. Here I select two method first is MACBETH and second is AHP. However, MACBETH has so many elements in common with the AHP, that one can say it is not much more than another version of AHP. Both methods can incorporate tangible and intangible criteria to rank the alternatives. Both AHP and MACBETH measure intangible attributes of the alternatives with judgments inserted in pairwise comparison matrices. The quality of the input data in the pairwise comparisons in both methods is established by checking the consistency among the judgments. Finally, the relative values for the alternatives, for each criterion, must be weighted by the criterion's priority. The priority of the criteria is obtained by making pair wise comparisons, in both methods. According to the past researchers, MACBETH application can provide unreliable results, even for simple decision making problems, with small numbers of alternatives and criteria. The main features which cause the unreliable results: the use of an unjustified and unclear scale of numbers to represent judgments; the including of a virtual element in the judgments on the priorities of the criteria and another unfavorable feature of the MACBETH applications is pointed out: the use of black box software that checks the quality from the input data judgments and calculates the priorities.

For avoiding this unfavorable condition I use integrated approach. in this approach **,** The second feature of MACBETH application which is the inclusion of a virtual element for the judgments on the criteria priority that helps in finding weight is removed by AHP.

I have consider most important criteria which is quantity, quality, service and cost .in this study weights calculation for each criterion is based on analytic hierarchy process(AHP) and after that these weights are used in measuring attractiveness by a categorical-based evaluation technique (Macbeth) method for ranking. The whole methodology is illustrated with the help of a real time numerical example and finally the rank of each supplier is evaluated according to its results.

II. LITERATURE REVIEW

Supplier Evaluation and Selection problem has been studied extensively, many research methodologies have been proposed to tackle the problem. Practical models are more suitable for supplier selection. The models which can integrate qualitative and quantitative criteria are best for the practical application.

Pema wangchen bhutia (2012) proposed a model for supplier selection where some important criteria had taken such as Product Quality, Service quality ,Price and Delivery time. Evaluation of weights for each criterion depend on Analytic Hierarchy Process (AHP) and then put these weights to the TOPSIS Method to rank supplier.

Prasad karande and Shankar chakraborty(2013) proposed a new methodology for supplier selection. In this paper, the applicability and usefulness of measuring attractiveness by a categorical-based evaluation technique (MACBETH) was established to act as a decision support tool while solving two real time supplier selection problems having qualitative performance measures. The results obtained from MACBETH method exactly corroborate with those derived by the past researchers employing different mathematical approaches.

Bahar Sennaroglu and Seda Şen (2012). In this paper the Author developed the hierarchy of supplier selection criteria. Then the weights of criteria were determined using the Analytic Hierarchy Process (AHP). Finally, the ranking and selection process was carried out by the TOPSIS. The hierarchy of supplier selection criteria was determined through interviews with the decision makers in the company and accordingly the hierarchical structure of the problem was developed .The decision problem has 4 alternatives evaluated under 7 main criteria and 21 sub criteria. In this paper composite weights of criteria were found by multiplying each sub criterion weight by its related main criterion weight. The computations were carried out using Excel 2010. The decision matrix for the TOPSIS method was formed with the decision makers evaluations of 4 supplier alternatives in terms of 21 sub criteria under 7 main criteria. All criteria were benefit criteria. The author was proposed that integrated AHP and TOPSIS approach is as an efficient and effective methodology used by decision makers on supply chains in terms of its ability to deal with both qualitative and quantitative performance measures. The proposed methodology may also be applied to any other selection problem involving multiple and conflicting criteria.

Kambiz Shahroudi (2012) proposed a supplier selection methodology that consists of 5 objective such as Time, Price, Quality, Equipment and Distance. All of these objective Functions were evaluated using Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method and with the help of this method author give rank to suppliers.

Liao and Kao (2010) suggest a comprehensive method integrating Taguchi loss function, AHP and multi-choice goal programming (MCGP) for supplier selection. The Taguchi loss function was applied to calculate the loss for each supplier selection criterion, whereas, criteria weights were evaluated using AHP method. Then, an suitable MCGM model was formulated and solved to identify the most appropriate supplier**.**

Mark Velasquez and Patrick T. Hester (2013). The author performed a literature review of common Multi-Criteria Decision Making methods, examines the advantages and disadvantages of the identified methods, and explains how their common applications relate to their relative strengths and weaknesses. The analysis of MCDM methods performed in this paper provides a clear guide for how MCDM methods should be used in particular situations. The author examined advantages and disadvantages of twelve separate methods identified in the literature review will be discussed. Their common applications will also be examined to see if correlations can be drawn between the use of a given method and its advantages and disadvantages. The conclusion of the paper will reveal that certain MCDM methods were better suited for specific situations.

Weber,Current, Benton, (1991) depends on Dickson's (1966) empirical study, 23 criteria were reported which purchasing managers generally follow when selecting a supplier. Of the identified criteria on-time delivery, quality, and supplier's performance history were found very important in supplier selection regardless of the type of purchasing environment.

Over the years, a number of methods have been suggested to solve the supplier selection problem. The long list of techniques includes linear programming (LP), mathematical programming models, statistical and probabilistic methods multiple-objective programming, case-based reasoning (CBR), data envelopment analysis (DEA), cost-based methods (CBM), neural networks (NN), AHP, fuzzy set theory, Analytic network process (ANP), and techniques for order preference by similarity to ideal solution (TOPSIS). Now a days, the integration of different techniques to supplier selection process has received attention in the supply chain management literature. Faez, Ghodsypour, and O'brien (2009) suggested an integrated fuzzy case-based reasoning and mathematical programming model. Önüt, Kara, and Isik (2009) developed a supplier evaluation method based on the ANP and TOPSIS methods to help a telecommunication organization in vendor selection. Ha and Krishnan (2008) proposed a hybrid model that including AHP, DEA and NN approaches to the supplier evaluation problem. Most recently, Kokangul and Susuz (2009) proposed integrated AHP and mathematical programming to consider both non-linear integer and multiple-objective programming under certain constraints to evaluate the best suppliers.

III. MACBETH METHOD

MACBETH method is created in the context of multi-criteria decision analysis (MCDA) approach, which can be defined as a set of techniques that are designed to investigate a number of alternatives having multiple criteria and conflicting objectives (Bana e Costa & Oliveira, 2012). It is based on multi-attribute value theory. Basically, this interactive method is used to judge the performance ofalternatives with respect to a range of decision criteria expressed in ordinal (qualitative) measures. In this technique, the decision maker needs to compare two stimuli at a time with qualitative judgments about their difference of attractiveness based on a pre-defined semantic judgment scale. This technique not only provides facility to check consistency of the decision maker's judgments, but also provide improvements in the judgments.

In this method, it is possible to create compromise solutions and analyze a hierarchy of alternatives, organized according to their levels of attraction for the decision maker. In the theory of decision-making, the hierarchy of alternatives is developed depend on overall attractiveness of performance of the alternatives with respect to various influential decision criteria. Therefore, in MACBETH technique, the decision maker needs to select a set of decision criteria influencing the selection of the most appropriate alternative. The first stage in MACBETH method involves in deciding the relevant decision criteria, which are expressed in the form of a value tree. After developing the value tree, the qualitative performance levels representing the suitable performance of the alternatives with respect to a particular criterion are entered. Further, the decision maker has to define a set of reference levels for the performance of the alternatives with respect to that criterion. It is to be noted that at least two reference stages are required to be identified as upper reference level and lower reference stage (Bana e Costa et al., 2002). Each of the alternative needs to be assigned with a performance level score representing attractiveness of the alternative related to two reference levels. The upper reference level is also known as 'good' which signifies the most attractive performance score, while the lower reference level, also denoted as 'neutral', signifies the least attractive performance score. On (P. Karande and S. Chakraborty / International Journal of Industrial Engineering Computations 4 (2013). MACBETH scale, the upper reference level is assigned a score of 100, and the lower reference level has a score of 0. Here, it is to be noted that 100 does not necessarily represent the best possible score and 0 does not necessarily denote the worst performance of an alternative for a given criterion.

The next step in MACBETH is to convert the qualitative performance scales into proportional quantitative scales. Usually, the performances of alternatives with respect to various criteria are expressed using two scales, i.e. cardinal and ordinal scale. The quantitative scales are represented in numbers and can be manipulated with the help of basic mathematical operators, like addition, subtraction, addition, etc. On the other hand, qualitative scales represent comparative positions (e.g. first, more, higher etc.), therefore mathematical dealing of these scales are found to be difficult. As in case of MCDM methods, performance of the all alternatives with respect to the decision criteria needs to be compared, mathematical treatments of the data are therefore essential. Thus, the need for a decision-making method, able of converting the decision maker's ordinal opinions into proportionate quantitative scale of values arises which can be effectively taken into consideration by MACBETH method.

To convert the qualitative performance scales into proportional quantitative scales for a criterion, the performance levels are arranged in a (n×n) matrix, where n is number of performance levels selected for that criterion. The performance levels are arranged in descending order of their importance from left to right and top to bottom. Further, the decision maker is asked to map the comparison of attractiveness between ordinal performance measures of two alternatives at a time, because the difference of alternatives is done based on difference of attractiveness instead of attractiveness itself. Measuring attractiveness by a categorical-based evaluation technique provides facility to map the difference of attractiveness using seven semantic scales as 'null', 'very weak', 'weak', 'moderate', 'weak', 'strong', 'very strong' and 'extreme'. The importance of these seven semantic scales is represented in Table

Semantic scale	Equivalent numerical scale	Significance
Null	0	Indifference between alternatives
Very weak	1	An alternative is very weakly attractive over another
Weak	2	An alternative is weakly attractive over another
Moderate	3	An alternative is moderately attractive over another
strong	4	An alternative is strongly attractive over another
Very strong	5	An alternative is very strongly attractive over another
Extreme	6	An alternative is extremely attractive over another

Table. 1: Significance of MACBETH semantic scales.

The decision maker also has the freedom to choose more than one consecutive categories, if the comparison using the provided seven semantic scales is observed to be unreasonable. The judgments provided by the decision maker are checked for consistency. If the provided judgments are found to be inconsistent, M-MACBETH software suggests possible alterations to make the judgments consistent (Bana e Costa and Oliveira, 2012). Subsequently, the consistent judgments are transformed into proportional cardinal scales. The actual mathematical procedure for conversion of ordinal scales into cardinal MACBETH scores takes place as follows:

Consider a criteria *k* for which the cardinal MACBETH score is generated having Li (i = 1,2,…,n) performance levels. The performance levels for that criterion are arranged in a matrix form according to descending order of their importance from left to right and top to bottom, as shown in Table 2. To understand the procedure, an example with four performance levels, i.e. *L1*, *L2*, *L3*, and *L4* is considered here such that *L3* is the 'good' level, while *L4*is the 'neutral' level. Let the preference of importance for the performance levels is $L3 > L1 > L2 > L4$. Therefore, if *v(L1)*,*v(L2)*, *(L3)* and *v(L4)* are the quantified

MACBETH scores for levels *L1*, *L2*, *L3* and *L4*respectively, then $v(L3) = 100$, $v(L4) = 0$ and $v(L3) > v(L1) > v(L2) > v(L4)$. The next step involves in comparing the strengths of performance of the levels. For n reference levels, maximum $n(n - 1)/2$ number of comparisons are possible, but $(n - 1)$ number of comparisons, as presented parallel to the diagonal in Table 2, are sufficient for conversion of the scale. Comparison of strengths of performance is done using one of the seven semantic scales, as given in Table 1. If the decision maker does not provide any strength of performance, it is noted by positive or P in the corresponding cell of the matrix. If the decision maker prefers performance of *L1* over *L2*with a strength $h \in \{0,1,\dots,6\}$, i.e.

L1 > L2

Then,

$$v(L1) - v(L2) = h\alpha,$$

where α is a coefficient necessary to meet the condition that $v(L1)$ and $v(L2)$€$[0,100]$. The quantified MACBETH scores are obtained by solving the related equations for all the performance levels. Let the decision maker decides the strengths of performance, as expressed in Table 2, and when all the strengths of performance levels are provided, the matrix of judgments is ready for quantification of the data.

Performance level	L3	L1	L2	L4
L3(GOOD)	No	Very strong	P	P
L1		No	Weak	P
L2			No	Moderate
L4(Neutral)				No

Table. 2: Strengths of performance levels for kth criterion

From the judgments provided in Table 2, the following equations can be extracted:

$v(L3) - v(L1) = 5\alpha$, (2)

$v(L1) - v(L2) = 2\alpha$, (3)

$v(L2) - v(L4) = 3\alpha$, (4)

On solving Eqns. (2)-(4), the obtained solutions are $\alpha = 10$, $v(L1) = 50$ and $v(L2) = 30$. The quantification of performance levels for all the remaining criteria as well as the corresponding criteria weights can be obtained adopting the same procedure. The next phase of MACBETH method is to select the alternatives and their performance with respect to criteria, and enter the relevant value into M-MACBETH software. Finally, the global attractive scores are obtained to rank the considered alternatives. The additive value model of the following type is used to determine the overall global score of an alternative.

$$V(X_i) = \sum_{j=1}^{n} W_j(V_j)$$

Where W_j are the weights for j[th] criterion.

Then final ranking of the supplier is done based on V(X_i) values.

IV. ANALYTIC HIERARCHY PROCESS (AHP)

The Analytic Hierarchy Process is a procedure designed to quantify managerial judgments of the relative importance of each of several conflicting criteria used in the decision making process. In this paper, we have used the following steps of AHP to help us to measure the relative importance or the weighted values of several criteria.

Step 1

List the overall goal, criteria and decision alternatives.

Step 2

Develop a pair wise comparison matrix.

Step 3

Develop a normalized matrix.

Step 4

Develop the priority vector.

Step 5

Rank the preferred criteria.

V. PROPOSED METHODOLOGY

The suggested methodology for supplier selection problem, composed of MACBETH method, consists of three stages.

1) Identify the criteria to be used in the model.
2) Weight the criteria by using AHP.
3) Evaluation of alternatives with MACBETH and determination of the final rank.

In the first stage, we try to recognize variables and effective criteria in supplier selection and the criteria which will be used in their evaluation is extracted. After that, list of qualified suppliers are determined. In the second stage, we assign weights to each criterion by using AHP. Finally, ranks are evaluated using MACBETH method in the third stage.

VI. CASE ANALYSIS, CALCULATION AND RESULTS

A. DATA

The data has been obtained from the automobile manufacturing company dealing in manufacturing of both heavy duty and light duty vehicles.

In this part, to implement the method, we have evaluated a problem of supplier selection .the management of a manufacture wants to select their best suppliers. Based on suggested methodology, stages are applied for evaluation and selection of suppliers.

Supplier	Quality (X1)	Service (X2)	Delay Time(X3)	Cost(X4)
S1	MEDIUM POOR	GOOD	MEDIUM POOR	GOOD
S2	POOR	GOOD	MEDIUM GOOD	VERY POOR
S3	GOOD	VERY GOOD	POOR	VERY GOOD
S4	MEDIUM POOR	FAIR	FAIR	FAIR
S5	VERY GOOD	POOR	MEDIUM GOOD	POOR
S6	FAIR	MEDIUM GOOD	MEDIUM POOR	POOR

In this phase, we deal with application of these stages. We are going to evaluate 6 suppliers (S1, S2, S3, S4, S5, S6) as alternatives against product quality (X1), service quality (X2), delay time (X3) and price(X4). X1, X2 and X3 are benefit attributes and X4 is cost attribute. The table 1.1 gives us a list of suppliers and their respective attributes.

The data has been collected through industrial visit.

The performances of all the six alternative suppliers are expressed in the form of qualitative data. Product quality, service quality and delay time are beneficial attributes, whereas, price is a non-beneficial attribute. The four evaluation criteria are at first putted into M-MACBETH software to make the corresponding value tree, as shown by in Figure 1. In this value tree, the 'Benefit criteria' node contains all the three beneficial criteria, while the 'Cost criteria' node contains the only non-beneficial criterion

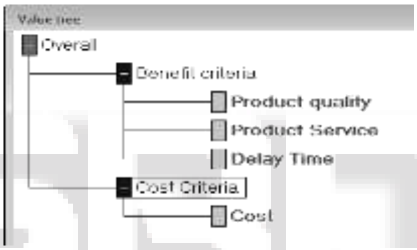

Fig. 1: MACBETH value tree for supplier selection

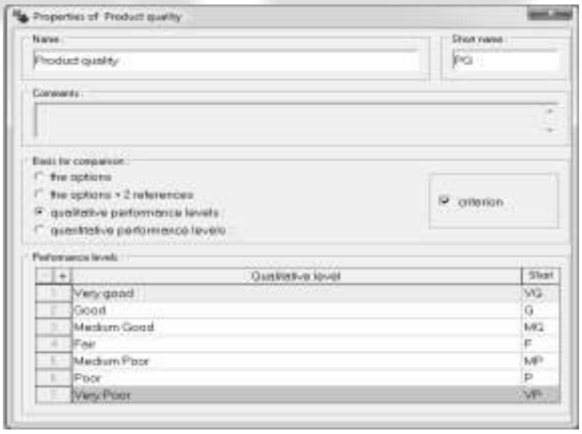

Fig. 2: Performance levels for 'product quality' criterion

the suggested performance levels are arranged in descending order of their attractiveness as 'very good', 'good', 'medium good', 'fair', 'medium poor', 'poor' and 'very poor'. For entering the performance levels into M-MACBETH software, the basis of comparison is selected as 'qualitative performance levels' because the performance of the alternatives with respect to all the considered criteria is measured depend on an qualitative scale. For all the criteria, the above seven performance levels are entered into M-MACBETH software according to descending order of their attractiveness. the most attractive performance level, i.e. very good is selected as upper reference level and the least attractive performance level, i.e. very poor is chosen as lower reference level Fig. 2 shows the selected performance levels for 'product quality' criterion for this example.

The differences of attractiveness of performance levels from seven semantic scales for 'product quality' and 'price' criteria are respectively given in Fig. 3 and Fig. 4. For example, it is observed in Fig. 3 that the performance level VG is very weakly attractive to G in case of 'product quality' criterion. Consistency of the judgments is checked and it is found that the entered judgments are entirely consistent. Further, based on the provided differences of attractiveness, M-MACBETH software changes the ordinal performance levels into proportionate cardinal MACBETH scales using appropriate linear programming models. The converted MACBETH scales of the performance levels for 'product quality' criterion are obtained by extracting a system of equations based on Eq. (1), as given below: $v(VG) - v(G) = \alpha$, $v(G) - v(MG) = \alpha$, $v(MG) - v(F) = \alpha$, $v(F) - v(MP) = \alpha$, $v(MP) - v(P) = \alpha$ and $v(P) - v(VP) = \alpha$. Here, the performance level VG is selected as upper reference level and therefore, $v(VG) = 100$. On the other hand, the performance level VP is chosen as lower reference level and hence, $v(VP) = 0$. On solving this system of equations leads to results of $\alpha = 16.67$, $v(P) = 16.67$, $v(MP) = 33.33$, $v(F) = 50$, $v(MG) = 66.67$ and $v(G) = 83.33$. The quantification of qualitative performance levels for all the remaining criteria is done using the same methodology.

Performance of alternative suppliers for example

Supplier	**Quality**	**Service**	**Delay Time**	**Cost**
S1	MP	G	MP	G
S2	P	G	MG	VP
S3	G	VG	P	VG
S4	MP	F	F	F
S5	VG	P	MG	P
S6	F	MG	MP	P

Table. 4: Table of performance

Thereafter, entered the all values of performance level in the table of performance. that is shown in table.

Supplier	**Quality(X1)**	**Service(X2)**	**Delay Time(X3)**	**Cost(X4)**
S1	33.33	83.33	33.33	83.33
S2	16.67	83.33	66.67	0
S3	83.33	100	16.67	100
S4	33.33	50	50	50
S5	100	16.67	66.67	16.67
S6	50	66.67	33.33	16.67

Table. 5: Table of performance cardinal measures

Using AHP, we calculate the weighted values for each criterion as follows:

Compared to the 2nd alternative, the 1st alternative is:	Numerical Rating
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1

Assumption

For supplier selection problem let us assume:

1) Product quality is moderately preferred, strongly preferred and very strongly preferred to service quality, price and delay time respectively.
2) Service quality is moderately preferred and strongly preferred to price and delay time respectively.
3) Price is moderately preferred to delay time.

Performing different steps of AHP:

	X1	X2	X3	X4
X1	1	3	7	5
X2	1/3	1	5	3
X3	1/7	1/5	1	1/3
X4	1/5	1/3	3	1
	X1	X2	X3	X4
X1	105/176	45/68	7/16	15/28
X2	35/176	15/68	5/16	9/28
X3	15/176	3/68	1/16	1/28
X4	21/176	5/68	3/16	3/28

Table. 7: weight evaluation

X1=(105/176+45/68+7/16+15/28)=.5579(w1)
X2=(35/176+15/68+5/16+9/28)=.2633(w2)
X3=(15/176+3/68+1/16+1/28)=.0569(w3)
X4=(21/176+5/68+3/16+3/28)=.1219(w4)

Supplier	**Quality(X1)**	**Service(X2)**	**Delay Time(X3)**	**Cost(X4)**
S1	33.33	83.33	33.33	83.33
S2	16.67	83.33	66.67	0
S3	83.33	100	16.67	100
S4	33.33	50	50	50
S5	100	16.67	66.67	16.67
S6	50	66.67	33.33	16.67
Weight	.5579	.2633	.0569	.1219

Table. 8: Overall scores and ranking for supplier selection

Supplier	**Quality (X1)**	**Service (X2)**	**Delay Time (X3)**	**Cost (X4)**	**Overall score**	**Rank**
S1	33.33	83.33	33.33	83.33	52.59	3
S2	16.67	83.33	66.67	0	35.03	6
S3	83.33	100	16.67	100	85.95	1
S4	33.33	50	50	50	40.69	5
S5	100	16.67	66.67	16.67	66.04	2
S6	50	66.67	33.33	16.67	49.37	4

Table shows the overall score and ranking of the supplier. It is observed that supplier S3 emerges out as the best supplier, while supplier S2 is the worst choice for supplying the required components to that manufacturing organization. The ranking of the alternative suppliers obtained using Integrated method is S2-S5-S1-S6-S4-S2.

VII. Model Validation

The best judgment of the resulting solution can be obtained from the experts of the system. The model results should be acceptable to the decision maker otherwise the model may not be adequate for future use. The proposed model was validated with the manager's ranking of suppliers. In this industry the decision maker/ the manager have ranked the suppliers according to the number of times they have been given orders after analyzing all the evaluating criteria's.

Suppliers	Final Rank of Suppliers (Model Result)	Manager's Ranking of Suppliers
S1	3	3
S2	6	6
S3	1	1
S4	5	5
S5	2	2
S6	4	4

Table. 9: Comparison of results for supplier selection

The proposed model's ranking of suppliers was same as the manager's ranking. This result indicates that this model would be helpful to managers/ decision makers to be consistent in their evaluation of suppliers.

VIII. CONCLUSIONS

This paper presents a detailed study of the supplier selection problem. In this paper an attempt is made to select the best and optimal supplier based on the evaluating criteria .In this paper, combination of MACBETH and AHP method, belonging to the class of MCDA techniques, is applied for solving supplier selection problem. we find weight with the help of AHP which removes that features of MACBETH which may cause the unreliable results. This methodology is very simple to understand and permits the pursuit of better alternatives criterion depicted in a simple mathematical calculation.

The integrated model developed is better in dealing with the complexity associated with the supplier selection problem. The result of the study not only provided decision maker to select the best supplier from the available potential suppliers but also ranked the suppliers, so that the decision maker could go for the alternatives.

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