Multi-Criteria Supplier Selection Using Fuzzy-AHP Approach: A Case Study of Manufacturing Company

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Abstract
Supplier selection is a complex multi criteria decision making process, in which decision makers have to deal with the optimization of conflicting objectives such as quality, cost and delivery time. The conventional methods for supplier selection are inadequate for dealing with the imprecise or vague nature of linguistic assessment. To overcome this difficulty, Fuzzy multi criteria decision making methods are purposed. We present a multi- criteria decision making approach for selecting suppliers under uncertainly. The Purposed approach comprise of two steps in step 1, we identify the criteria and sub criteria for supplier selection to design the Fuzzy analytical Hierarchy process tree structure. In step 2, Fuzzy analytical Hierarchy process (FAHP) is used in determining of weights of main criteria sub-criteria and alternatives. This paper shows a successful application of FAHP to a supplier selection problem in a gear manufacturing company.

Keywords
Supply Chain, Supplier Selection, Fuzzy Set Theory, Fuzzy AHP.

I. Introduction
In most industries the cost of raw material is the major cost of the product, such that in some cases it can account for up to 70% [1]. In today's global marketplace characterized by globalization, increasing customer's value expectations, global economic crisis, and intense competitive pressure, to thrive and survive manufacturing firms must select and maintain best suppliers. Thus, supplier selection and evaluation represents one of the significant roles of purchasing and supply management functions [2]. Carr and Smeltzer [3] discussed that "the purpose of strategic purchasing is to direct all purchasing activities toward opportunities consistent with the firm's capabilities to achieve its long-term goals." The suppliers are one of the five competitive forces holding bargaining power as per the Competitive Forces Model defined by Porter of the Harvard Business School in 1979 [4]. Best suppliers increase the need for strong supply chain management (SCM). Three dimensions underlying supplier management: (1) optimal supplier selection, (2) innovative supplier development strategies and (3) meaningful supplier performance assessment mechanisms. Tahriri and Taha [5]discussed that some difficulties regarding supplier selection are included: (1) huge variety of finished products, and thus a great need for purchasing a raw material, (2) the huge fluctuations in price for purchasing the raw materials, (3) the large number of suppliers by varieties of qualitative and quantitative criteria. The supplier selection process is composed of four phases: the initial problem definition, the formulation of criteria, the qualification of potential suppliers, and the final choice among the qualified suppliers

To improve the Analytic Hierarchy Process (AHP) method and to unproblematic supplier selection process, the paper discusses a fuzzy extended AHP (FEAHP) approach using triangular fuzzy numbers to represent decision makers comparison judgments and fuzzy synthetic extent analysis [7] method to decide the final priority of different decision criteria. Fuzzy analytic hierarchy process FAHP uses the triangular fuzzy numbers as a pair-wise comparison scale for deriving the priorities of different selection criteria and attributes.

The remainder of the paper is organized as follows: First section discusses the past researches available in the area of the supplier selection and fuzzy decision making approaches. Second section contains the discussion about the different decision criteria and attributes considered in the selection of the global supplier. In Third section , the proposed FAHP is discussed. Fourth section discusses the complete implementation of the FEAHP approach. The priority weights computed for different criteria, attributes and alternatives are also discussed in this section. and last section contains the conclusion of the research particularly in context with supplier selection.

II. Literature review
In the past, several methods have been proposed for the multi-criteria decision making problem. The analytic hierarchy process (AHP) cannot effectively take into account ambiguity and uncertainty in assessing the supplier's performance because it presumes that the relative importance of attributes affecting the supplier's performance is known with certainty [8]. Supplier selection can be based on using different supply chain strategies [9]. There are many frameworks for the purpose of assessing supplier's performance [10]. These frameworks have different outcome which lead in different scenarios [11]. Yu and Jing [12] developed a new decision model to choose the optimal supplier selection and combination for Tian Jin Electric Construction Company and they showed trust between suppliers and buyers is the best criterion for selecting optimal suppliers which minimized the cost, by using AHP and Linear Programming (LP). Weber and Ellram [13] discussed the use of a multi-objective programming approach as a method for supplier selection in just in time (JIT). Liu and Hai [14] purposed a model for supplier selection by integrating a collaborative purchasing program. The authors used a new approach, based on the use of Saaty's [15] AHP method. This is called voting AHP (VAHP). VAPH allowed the purchasing manager to generate no trifling purchasing options and systematically analyzed the inherent trade–offs among the relevant criteria. Min Wu, [16] purposed class of AHP (analytical hierarchy process) technique—simulation approach for the supplier selection problem, which is valuable in examines the uncertainty in AHP and helps to minimize the uncertainty in AHP to some extent. Ali, Hadi and Awaluddin,[17] proposed an integrated model that evaluates suppliers and allocates order to them. They evaluated suppliers by qualitative criteria such as financial structure, services and loyalty with Fuzzy analytical hierarchy process (FAHP). The supplier selection procedure is a highly obligatory decision making process for companies. It is a striving to utilize ANP (Analytic Network Process) for ranking the suppliers and building the final selection. Koul. R and Verma. R.,[18] proposed an approach based on Fuzzy AHP for supplier selection problems, which makes effective decision. The criteria considered opinion in selection

of the best supplier in a dynamic environment are: Quality of the product, Delivery, Overall cost of the product and Flexibility in service and select the best supplier organization providing in order of customer satisfaction for the criteria well marked. Liu et al. [19] used data envelopment analysis (DEA) to stake up the performance evaluation of different supplier for best selection. Yesim Yayla, et. al. [20] used the fuzzy TOPSIS techniques to select the most appropriate supplier of garment 'X' operating in Turkey. Kubat and Yuce [21] suggested integrating Analytic Hierarchy Process (AHP), Fuzzy AHP and Genetic Algorithm (GA) to evaluate best suppliers. Fuzzy set has utilized linguistic factor to organize criteria and sub criteria weight, with pair wise compare with fuzzy AHP. Kahraman et al. [22] used the fuzzy AHP for domestic supplier selection with 3 criteria and 11 sub criteria and neglected the many important criteria's which create the uncertainty in supplying the products.

Supplier selection process is the need of integrating both qualitative and quantitative measures in a unique framework. In addition, companies have different weight regarding all criteria. They may up the weight of one measure and down the other one. Multi-criteria decision making (MCDM) approaches (e.g. AHP, ANP and etc.) are proper tool for the aim of weighting these criteria. Finally, considering all these concern can be a good module toward supplier selection. This research work aims to provide a supplier selection framework for automotive component industries. This framework considers the most critical factors considering the characteristics of automotive component industries.

III. Selection Criteria for Supplier

The first step is to identify the necessary criteria for which the examination of applicability is vital in the supplier selection process for making an objective and unbiased decision. In this case, the researcher first conducts a desk research [23]. Dickson [24] surveyed the criteria considered by buyers in giving contracts to suppliers. Among the 23 criteria, Dickson concluded that the particularly important criteria in deciding how much to order from the available vendors or suppliers were price, delivery, quality, and the abilities of the suppliers to meet the objectives. Sharon [25] has shortlisted authors and their contribution in this regard. Selection criteria have been compared to show the changing trends between 1966 and 2011 by Thiruchelvam [26]. The supplier selection criteria are both qualitative as well as quantitative and their significance depends on various types of purchase situations Thiruchelvam [26].

IV. Fuzzy extended Analytic hierarchy process (FEAHP)

A. AHP Model

Analytic hierarchy process (AHP) [15] is one of the mostly used approaches to handle such a multi criteria decision-making problem. However, a significant limitation of AHP is that it assumes independency among various criteria of decision-making. The analytic hierarchy process (AHP) is first introduced by Saaty in 1971 to solve the scarce resources allocation and planning needs for the military [15]. The AHP implementation can be in the form of software of Expert Choice and it has been applied in a variety of decisions and planning projects in nearly 20 countries. The scale used for comparisons in AHP enables the decision-maker to incorporate experience and knowledge intuitively and indicate how many times an element dominates another with respect to the criterion [27].

B. Calculating the consistency index and consistency ratio of fuzzy comparison matrix

To investigate the consistency, the fuzzy comparison matrices need to be converted into crisp matrices. There are some defuzzifications methods are for obtaining a crisp number from the triangular Fuzzy number. We select the fuzzy mean and spread method to defuzzify the fuzzy numbers. A triangular fuzzy number denoted as a= (l, m , u) can be defuzzified to a crisp number as follows.

$$a\_crisp=(l+m+u)/3 \qquad (1)$$

The consistence index, CI, for a comparison matrix can be computed with the use of following equation.

$$CI=\frac{\lambda \max - n}{n-1}$$

Where, λmax is the largest eigenvalue of the comparison matrix, n is the dimension of the matrix.

V. Fuzzy Set Theory

In 1965, Lotfi A. Zadeh [28] proposed a new approach to a rigorous, precise theory of approximation and vagueness based on generalization of standard set theory to fuzzy sets. Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling: uncertain systems in industry, nature and humanity; and facilitators for common-sense reasoning in decision making in the absence of complete and precise information.. Some basic definitions of fuzzy sets, fuzzy numbers and linguistic variables are reviewed [29], [30], [31].

Definition 1

A fuzzy set A in a universe of discourse X is characterized by a membership Function UA(x) which associates with each element x in X a real number in the interval [0,1].The function value U_A (x) is termed the grade of membership of x in A [31]

$$U_{\bar{A}}(x)=\begin{bmatrix} 1 & for\ \ x\in A \\ 0 & for\ \ x\notin A \end{bmatrix} \qquad (3)$$

Definition 2

A fuzzy set A in a universe of discourse X is convex if and only if $U_A(\lambda_{x1}+(1-\lambda_{x2}) \geq \min(U_A(x_1), U_A(x_2))$

For all x_1, x_2 in X and all λ ϵ [0,1], where min denotes the minimum operator [32].

VI. Triangular Fuzzy numbers and representation preferences

Definition 1

A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. Fuzzy number n in the universe of discourse X that conforms to this definition [31].

Definition 2

Suppose, a positive triangular fuzzy number (PTFN) is Ã and that can be defined as (l, m, u) shown in

$$U_{\bar{A}}(x)=\begin{bmatrix} 0 & x\leq 1 \\ \frac{x-l}{m-l} & l<x\leq m \\ \frac{u-x}{u-m} & m<x\leq u \end{bmatrix} \qquad (4)$$

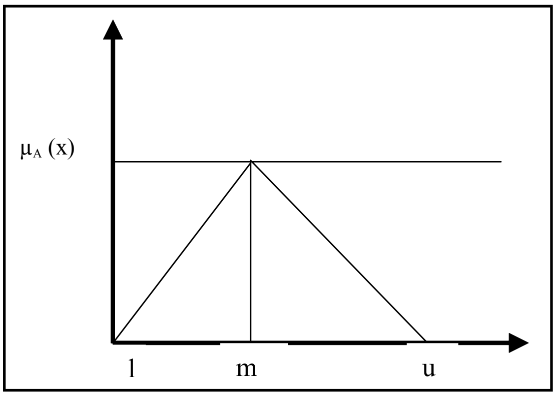

Fig. 1: The membership function of the triangular fuzzy number Ã

Table 1: Triangular scale for Fuzzy Numbers Conversion (Buyukozkan et.al. 2004)

Sr.No	Linguistic variables	Positive triangular fuzzy numbers	Positive reciprocal triangular fuzzy numbers
1	Just Equal (JE)	(1, 1, 1)	(1, 1, 1)
2	Equally Important(EI)	(1/2, 1, 3/2)	(2/3, 1, 2)
3	Weakly More Important(WMI)	(1, 3/2, 2)	(1/2, 2/3, 1)
4	Strongly More Important(SMI)	(3/2, 2, 5/2)	(2/5, 1/2, 2/3)
5	Very Strongly More Important (VSMI)	(2, 5/2, 3)	(1/3, 2/5, 1/2)
6	Absolutely More Important (AMI)	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

analytic hierarchy process (FAHP) first appeared [33] Previous studied have evaluated FAHP as applied to the overall issue of selection such as facility, vendor or building , supplier selection (Chan and Kumar, 2007).

VII. Fuzzy Analytical Hierarchy Process (FAHP)

This approach utilizes one of 'multi-criteria decision making' (MCDM) method, fuzzy analytic hierarchy process (FAHP) first appeared [33] Previous studied have evaluated FAHP as applied to the overall issue of selection such as facility, vendor or building , supplier selection (Chan and Kumar, 2007).

A. Algorithm of FAHP Method

In this study the extent FAHP is utilized, which was originally introduced by [34]. Let X = $\{x_1, x_2, x_3,......., x_n\}$ an object set, and G = $\{g_1, g_2, g_3,......., g_n\}$ be a goal set. According to the method of Chang's extent analysis, each object is taken and extent analysis for each goal performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$M_{1gi}, M_{2gi},.............M_{mgi}, \quad i = 1,2,....,n$,

where M_{jgi} (j = 1, 2, ...,m) all are TFNs. The steps of Chang's extent analysis can be given as in the following

Let $A=(a_{ij})_{max}$ be a fuzzy pairwise comparison matrix, where $a_{ij} = (l_{ij}, m_{ij}, u_{ij})$. The steps used for the Chang method are as follows. Initially, pairwise comparison is made using fuzzy numbers.

Step 1: The value of fuzzy synthetic extent with respect to the ith object is defined as:

$$\sum_{j=1}^{m} M_{gi}^{J} = (l_{i1}, m_{i1}, u_{i1}) \oplus (l_{i2}, m_{i2}, u_{i2}) \oplus (l_{im}, m_{im}, u_{im}) \quad (5)$$

$$S_i = \sum_{j=1}^{m} M_{gi}^{J} \otimes \left[\sum_{i=1}^{m} \sum_{j=1}^{m} M_{gi}^{J} \right]^{-1} \quad (6)$$

Step 2 : As M_1 (l_1, m_1, u_1) and M_2 (l_2, m_2, u_2) are two triangular fuzzy numbers, the degree of possibility of $M_2(l_2, m_2, u_2) \geq M_1$

$$V(S_i \geq S_k) = \underset{x \geq y}{SUP} \left(\min \{ U_{M_1}(x), U_{M_2}(x) \} \right) \quad (7)$$

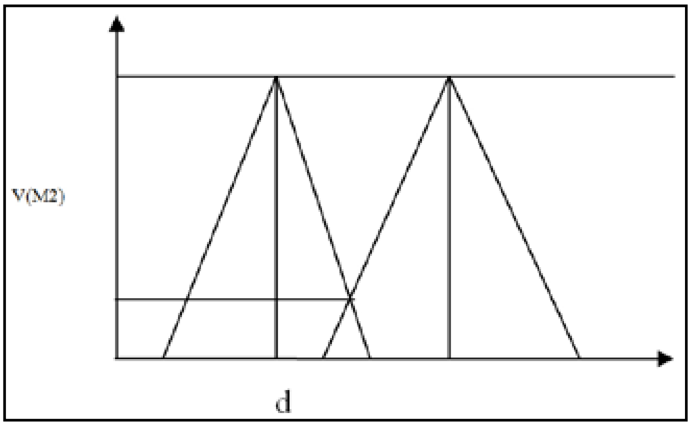

Fig. 2: Showing Degree of Possibility of M_2 (l_1, m_1, u_1) defined as:

$V(S_i \geq S_j)$= height($S_i \cap S_j$)= $U_{M2}(d)$

$$V(S2 \geq S1) = \begin{cases} 1 & \text{if } b2 \geq b1 \\ 0 & \text{if } a1 \geq c2 \\ \frac{a1-c2}{(b2-c2)-(b1-c1)}, & \text{Otherwise} \end{cases}$$

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy Mi (i=1, 2, k) numbers can be defined by

$V(M_1\ M_2....M_k = V[(M_2 \geq M_1)$ and $(M_1 \geq M_2)$ and… and $(M_i \geq M_k)$

= min V $(M \geq M_i)$ i= 1,2,3,….k

Assume that $(d(A_i)$= min $(S_i \geq S_j)$

V $(S \geq S_1, S_2, S_3,...,S_k)$ for i=1,2,3,...,k

=V $(S \geq S_1)$ and $(S \geq S_2)$ and... $(S \geq S_k)$

V= minV($S \geq S_i$) for i=1,2,3,..,.k, (9)

Then the weight vector is given by

Assume that (d' Ai) = minV (S ≥ Si) , for i=1,2,3,..,.k

Then the weight vector is defined

$W'=((d(A_1).d(A_2)......d(A_n))^T$ (10)

Where Ai (i=1, 2,3,...,n) are the n elements.

Finally, the weight vectors are then normalized as follows. And to give crisp weight vector represented by

W= (W'/ ∑W') (19)

$W = d\ (A_1),d\ (A_2),...,d\ (A_n)^T$ (11)

Where W is a non-fuzzy number and this gives the importance weights of one indicator over other.

VIII. Application and discussion of FAHP in supplier selection

The application of the fuzzy AHP approach is demonstrated for a medium-sized gear manufacturing company, This study covers the study of the complete supply chain of XYZ Ltd. and more stress given to supplier-manufacturer relationship so that, both parties are capable to respond fast with the changing scenario

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in the market and should be flexible enough in terms of quality, quantity and technological change. This study covers study of the complete supply chain of XYZ Ltd. more stress given to the user to analyze the future performance of the network and to understand the complex relationship between the parties involved. The XYZ Ltd. is one of the giant in the market of gear sector. In this study the area in which the conceptual model can be implemented properly studied thoroughly and suitable conceptual model has been recommended to the company with proper validation. Moreover, the areas in which the company is facing problems have been studied and suggestions and models have been developed with the validation. The company is the main manufacture of Gear and to remain in the market competition. This study the area in which the model can be implemented properly studied thoroughly and suitable model for Supplier Selection has been recommended to the company. Finally, the area in which the company facing the problem is studied properly and a Supplier Selection model has been developed for them which will help them in eliminating their problem.

The goal is to choose the best supplier selection for a case company. So, this goal is placed at the top of the hierarchy. The hierarchy descends from the more general criteria in the second level to sub-criteria in the third level to the alternatives at the bottom or fourth level. General criteria level involved five major criteria: Cost, delivery, quality, supplier's profile and service. Four suppliers are considered for the decision alternatives, and located them on the bottom level of the hierarchy. These are alternative supplier A, supplier B, supplier C and supplier D. In appendix fig. 3 illustrates a hierarchical representation of selecting best supplier decision-making model.

IX. Data Input and Analysis using Fuzzy AHP

Table 2: Pair –wise comparison matrix for the sub-criteria of "Delivery"

	Compliance with Delivery date	Lead time	Deliverable location	Flexibility in delivery operation
Compliance with Delivery date	1,1,1	3/2, 2, 5/3	2, 5/2, 3	1, 3/2, 2
Lead time	2/5, 1/2, 2/3	1, 1,1	2, 5/2, 3	3/2, 5/2, 3
Deliverable location	1/3, 2/5, 1/2	1/3, 2/5,1/2	1,1,1	1, 3/2, 2
Flexibility in delivery operation	1/2, 2/3, 1	1/3, 2/5,2/3	1/2, 2/3, 1	1, 1,1

Synthetic Extent Normalized Row Sum. Row sum value of Row in table using equation (5)

RS1= (5.50, 7.00, 8.50) RS2= (4.90, 6.50, 7.66) RS3= (2.66, 3.33, 4.00) RS4= (2.33, 2.73, 3.66)

The synthetic extent normalized row sums obtained from above using equation (6)

S1 = (0.230, 0.358, 0.552) S2 = (0.205, 0.332, 0.497) S3 = (0.111, 0.168, 0.25)

S4 = (0.097, 0.139, 0.237)

Degree of Possibility for 'Delivery' main Criteria using equation (8) and equation (9)

S1 ≥S2= 1.00, S1 ≥S3=1.00, S1 ≥S4=1.00

S2 ≥S1=0.911, S2 ≥S3=1.00, S2 ≥S4=1.00

S3≥S1=0.132, S3≥S2=0.247, S3≥S4=1.00

S4≥S1=0.030, S4≥S2=0.142, S4≥S3=0.810

Determine of weight vector assume that

(d' Ai) =minV (S ≥ Si) , for i=1,2,3,..,.k

d'(A1) –minV(S1>Sj)= 1.00,

d'(A2) –minV(S2>Sj)= 0.911,

d'(A3) –minV(S3>Sj) = 0.132

d'(A3) –minV(S3>Sj)= 0.132

W = (1.00, 0.911, 0.132, 0.030)

The above vector is normalized to give crisp weight vector

W'=(0.482, 0.439, 0.063, 0.0144)

Similarly weights of Criteria, Sub Criteria and of supplier selection for each Sub Criterion were determined.

X. Discussion and Managerial Implications

According to the results found in the supplier evaluation, Supplier A appears to be the best choice of all 4 suppliers based on its highest total score. A Fuzzy AHP model has been developed to maximize the manufacturer's profit by determining the production quantity of each product variant and by selecting the most suitable suppliers based on the selection criteria and their capacity and splitting the orders among these suppliers. A preferred. Since to has the highest weight of (0.31085) among four Suppliers. Suppliers B is at the second choice (0.24365) and Supplier D is at third choice (0.2275) and Supplier C the last choice (0.2180). The table of all results of criteria and sub criteria in appendix.

XI. Conclusion

Supplier selection process becomes increasingly important in today's complex environment. The selection process involves the determination of quantitative and qualitative factors to select the best possible suppliers. In this study logistics service provider selection via extent fuzzy AHP has been proposed. The decision criteria are cost, Delivery, Quality, Supplier's profile, and Service of the supplier selections. These criteria were evaluated to obtain the preference degree associated with each supplier alternative for selecting the most appropriate one for the company. By the help of the extent fuzzy approach, the ambiguities involved in the data could be effectively represented and processed to make a more effective decision. As a result of this study, Supplier is determined as the best supplier which has the highest priority weight. The company management found the application and results satisfactory and decided to work with supplier. As a result of this study, alternative A is determined as the best Supplier which has the highest priority.

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Appendix

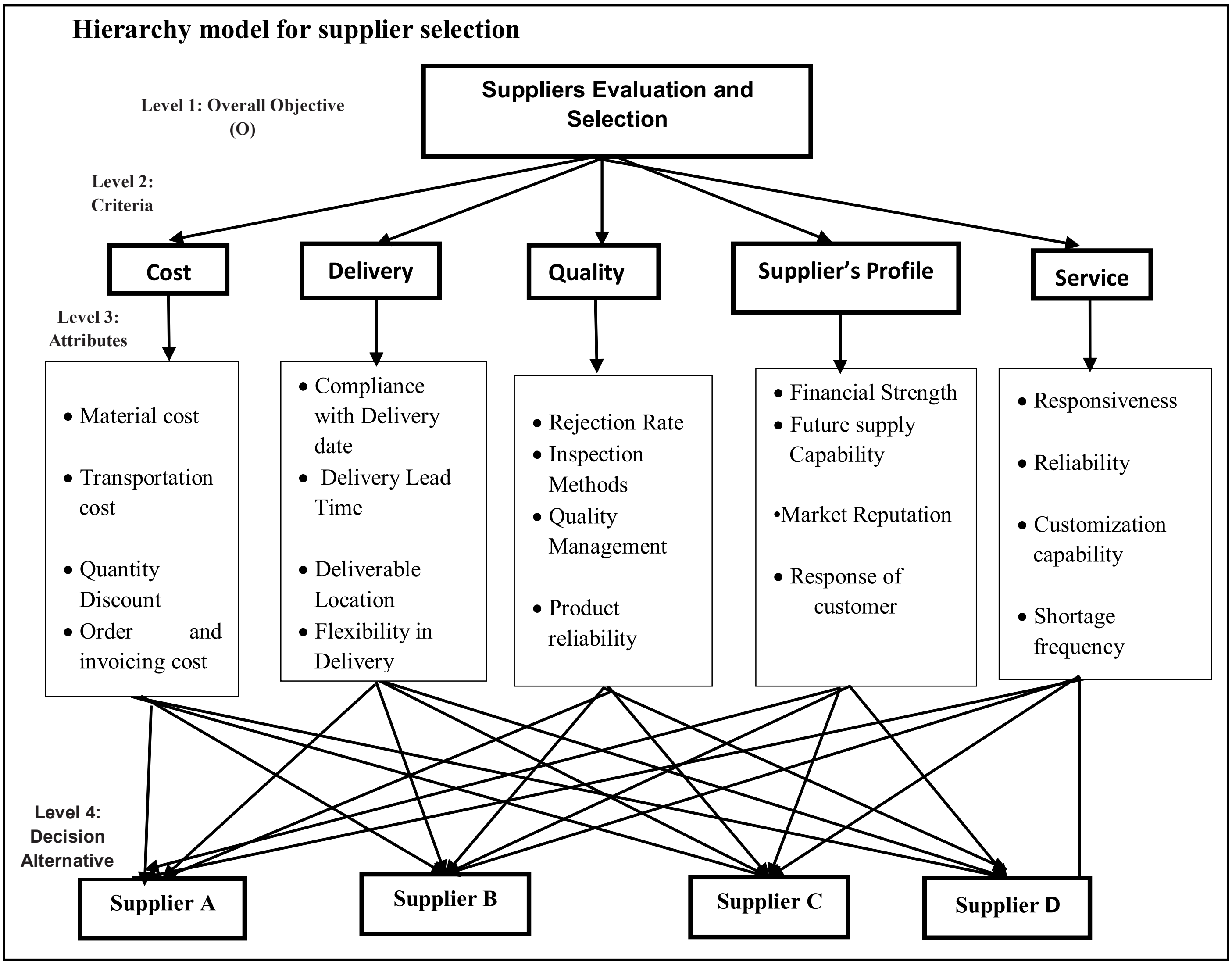

Fig. 3: Hierarchy model for Supplier Selection

Table 3: Priority weight of main and sub-attributes and alternatives

Main Criteria	Main Criteria	Sub-Criteria	Sub-Criteria	Supplier A	Supplier B	Supplier C	Supplier D	Weight A	Weight B	Weight C	Weight D
Cost	0.204	Material cost	0.329	0.246	0.217	0.346	0.190	0.0165	0.0145	0.02321	0.01274
		Transportation cost	0.258	0.124	0.242	0.341	0.291	0.00652	0.01270	0.0179	0.0153
		Quantity Discount	0.304	0.176	0.275	0.324	0.225	0.0109	0.01705	0.0200	0.01395
		Overhead cost	0.107	0.270	0.252	0.244	0.233	0.00588	0.00549	0.005319	0.005079
Delivery	0.236	Compliance with delivery date	0.482	0.445	0.231	0.186	0.138	0.05061	0.02626	0.02114	0.01569
		Lead time	0.439	0.318	0.183	0.272	0.227	0.0329	0.01895	0.02817	0.02351
		Deliverable location	0.063	0.335	0.227	0.170	0.268	0.00498	0.003373	0.002526	0.003982
		Flexibility in delivery operation	0.0144	0.394	0.152	0.277	0.177	0.001338	0.000516	0.000941	0.000601

Quality	0.265	Rejection Rate	0.539	0.295	0.273	0.175	0.256	0.04213	0.03898	0.02499	0.03655
		Inspection Methods	0.325	0.259	0.259	0.241	0.241	0.0223	0.0223	0.02085	0.02075
		Quality management	0.00	0.268	0.194	0.290	0.247	0.000	0.000	0.000	0.000
		Product Reliability	0.135	0.444	0.249	0.199	0.108	0.01585	0.00888	0.007104	0.00385
Supplier's profile	0.127	Financial Strength	0.429	0.313	0.313	0.154	0.220	0.01702	0.01702	0.008377	0.01196
		Future supply capacity	0.201	0.344	0.344	0.156	0.156	0.008781	0.008781	0.003978	0.01078
		Market reputation	0.201	0.283	0.218	0.237	0.261	0.007216	0.00559	0.006043	0.006655
Service	0.167	Responsiveness	0.281	0.405	0.347	0.085	0.163	0.01900	0.01628	0.003988	0.007647
		Reliability	0.316	0.346	0.192	0.229	0.233	0.01825	0.01013	0.01208	0.01229
		Customization capacity	0.316	0.329	0.203	0.147	0.326	0.01736	0.01071	0.007751	0.017203
		Shortage Frequency	0.084	0.360	0.133	0.231	0.276	0.00505	0.00186	0.003238	0.003869
		Total weight						**0.31085**	**0.24365**	**0.2180**	**0.2275**