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Ashraf W Labib

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A supplier selection model: A Comparison of Fuzzy Logic and the Analytic Hierarchy Process

Ashraf W. Labib

University of Portsmouth, Portsmouth Business School, Richmond Building, Portland Street,
Portsmouth PO1 3DE, United Kingdom

Ashraf.Labib@port.ac.uk

Abstract:

This paper aims to compare two tools for decision makers that intend to support the decision of the selection of the appropriate supplier. Suppliers are crucial to both the efficiency and effectiveness of the performance of Companies. A critical success factor of these companies is the selection of the appropriate supplier. A methodology is proposed to optimise the evaluation process based on different criteria. The proposed approach extends the one proposed by Ordoobadi (2009) who proposed the application of Fuzzy Logic (FL) where we use the same example case study in order to compare the Analytic Hierarch Process (AHP) with FL.

In this paper we demonstrate how we can achieve the same objective of expressing human assessments in the form of linguistic expressions by using AHP. Moreover, we demonstrate the capability to run a sensitivity analysis which helps to understand the causal relationships among the different factors. We demonstrate how this capability can help us to explain and predict the different relationships among criteria and alternatives. Moreover, we provide a measure that is able to capture the consistency of the decision maker's preferences. In our approach we provide a single unit of scale that is not only capable of ranking suppliers but also provides an understanding of the difference in scale between different suppliers which can then help to allocate resources accordingly. These facilities are not offered by Ordoobadi (2009). The proposed approach here can help companies to identify the best supplier in changing environments. The paper describes a decision model that incorporates decision maker's subjective assessments and applies multiple criteria decision making technique to manipulate and quantify these assessments. Unlike many similar studies, two techniques have been performed on the same case study in order to improve our understanding of the differences in the proposed techniques.

1. Background and Motivation:

In recent literature, the supplier selection problem has been studied by many authors. For example, authors in this journal who have investigated supplier selection include; Chan *etal* (2008), Sevкли *etal* (2007), Jain *etal* (2007), Lee and Yang (2008), Kannan and Haq (2007), Yao *etal* (2010), Sen *etal* (2010), Liu and Zhang (2010), Ravindran *etal* (2010), Talluri *etal* (2010), and Che (2009). The authors of those papers have either proposed a certain method such as fuzzy logic, multiple criteria using for example the analytic hierarchy process (AHP), or genetic algorithms, but none have compared the same application using a hybrid of techniques. In this paper a comparison of both AHP and fuzzy logic is performed for the same case study and hence it illustrates the applicability of both methods. For a comprehensive account of the evolution of supplier selection criteria and methods, see (Zhang *etal*, 2003), and (Ho, *etal*, 2010).

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3 In an article by Ordoobadi (2009), she provides a comprehensive list of developed models
4 that focus on the identification of supplier attributes and then using various techniques for
5 evaluation of these attributes. Ordoobadi then argues that a common feature among these
6 techniques is how the rankings of the potential suppliers are determined and that most often
7 these rankings are assigned based on two factors: the importance weight of the attributes, and
8 suppliers' performance with respect to these attributes. Both of these factors are decision
9 maker-specific and thus should be solicited from the individuals. Often elicitation process is
10 conducted by asking the decision makers to express their preferences in pure numeric scales.
11 Ordoobadi then claims that the main difficulty with such an elicitation procedure is that the
12 subjectivity and imprecision associated with perceptions are lost by forcing the decision
13 makers to use numeric scales. She then proposes a method to overcome the above mentioned
14 difficulty through a mechanism that captures the subjectivity involved in expressing
15 individual preferences. Ordoobadi proposes fuzzy logic as a methodology that allows the
16 decision maker to express preferences in linguistic terms.
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21 Briefly, the proposed evaluation by Ordoobadi (2009) is performed based on the importance
22 of the selection criteria to the decision maker as well as his/her perception of the supplier's
23 performance with respect to these criteria. Using fuzzy membership functions and fuzzy
24 mathematical operators a fuzzy score is determined for each supplier. These fuzzy scores are
25 then converted to crisp values through defuzzification process to make the ranking of the
26 suppliers a straightforward task. The supplier with the highest ranking is selected.
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29 [Table I here]
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40 [Figure 1 here]
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42 [Table II here]
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44 [Table III here]
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49 The proposed approach of using Fuzzy Logic (FL) in the case study provided by Ordoobadi
50 (2009) whilst able to capture the subjectivity involved in expressing individual preferences, it
51 just provides the ranking of the three suppliers A, B, and C. The scale used to determine the
52 crisp score does not say much about how close, or far, they are from each other. There is no
53 way of identifying how the different factors affect the final score. For example what happens
54 if the importance of one of the factors is changed?
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56

57 [Table IV here]
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59 The rest of the paper is organized as follows: A brief overview of the analytic hierarchy
60 process (AHP) theory and as well as a review of its applications are provided in section 2.
Section 3 covers the development of the evaluation methodology. A numerical example is

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3 provided in section 4 to illustrate the application of the proposed model. We use the same
4 example provided by Ordoobadi (2009) in order to provide a comparison of the two methods.
5 Finally the paper concludes with summary and suggestions for future research in section 5.
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10 **2. A brief overview of the analytic hierarchy process (AHP):**

11 The Analytic Hierarchy Process (AHP) is a multi-criteria decision making (MCDM) method that
12 helps the decision-maker facing a complex problem with multiple conflicting and subjective criteria
13 such as location or investment selection, projects ranking, and so forth (Ishizaka and Labib 2009).
14

15 The AHP is designed to solve complex decision-making problems when there are multiple objectives
16 or criteria to consider. This approach has been introduced by Saaty (1977, 1980 and 1994) and
17 requires the decision maker(s) to provide judgements about the relative importance of each criterion
18 and then specify a preference on each criterion for each decision alternative. It has also been applied
19 in many industrial cases and combined with other techniques such as the work done by Vassoulla *etal*
20 (2006), Abdi and Labib (2003, 2004), Davidson and Labib (2003), Alvi and Labib (2001) and Labib
21 and Shah (2001).
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25 According to Vassoulla *etal* (2006) the first step in the AHP is the decomposition of the problem into
26 a decision hierarchy. This may take the form illustrated in **Figure 2**.
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35 **[Figure 2: here]**
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41 The next step is to establish priorities amongst the elements in the hierarchy by making pairwise
42 comparisons of the criteria and alternatives. Given *Criterion i* and *Criterion j*, these comparisons are
43 carried out using Saaty's (1980) predefined one-to-nine ratio scale as listed in Table V.
44

45 **[Table V here]**
46
47

48 The pairwise comparisons are carried out for all factors to be considered and the $n \times n$ positive
49 reciprocal matrix A is generated for C_1, \dots, C_n , $n \geq 2$ criteria, with elements α_{ij} , indicating the value of
50 the criterion i relative to criterion j . Where $\alpha_{ii} = 1$ (i.e. on the diagonal) and if $\alpha_{ij} = k$, then $\alpha_{ji} = 1/k$
51 (reciprocity property).
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$$\begin{matrix}
 & C_1 & \dots & C_j & \dots & C_n \\
 C_1 & \alpha_{11} & \cdot & \alpha_{1j} & \cdot & \alpha_{1n} \\
 & \cdot & \cdot & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \alpha_{ii} & \alpha_{ij} & \alpha_{ik} & \cdot \\
 C_j & \alpha_{ji} & \alpha_{ji} & \alpha_{jj} & \alpha_{jk} & \alpha_{jn} \\
 & \cdot & \cdot & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \cdot & \cdot & \cdot \\
 C_n & \alpha_{n1} & \cdot & \alpha_{nj} & \cdot & \alpha_{nn}
 \end{matrix}$$

Approximating the weight vector of the above matrix A, with n objectives, takes the form illustrated below. Where $w_i > 0, i = 1, \dots, n$, denotes the weight of objective i . The next step is the calculation of a list of the relative weights of the criteria under consideration. This requires to normalise each column j in A such that $\sum_j a_{ij} = 1$.

$$\begin{matrix}
 & C_1 & C_2 & \dots & C_n \\
 C_1 & \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdot & \frac{w_1}{w_n} \\
 C_2 & \frac{w_2}{w_1} & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \cdot & \cdot \\
 & \cdot & \cdot & \cdot & \cdot \\
 C_n & \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdot & \frac{w_n}{w_n}
 \end{matrix}$$

↓ normalise columns

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 \end{array}$$

	C_1	C_2	...	C_n
C_1	w_1	w_1	...	w_1
C_2	w_2	.	.	.
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.
.
C_n	w_n	w_n

For each row i in the resulting matrix above the average value is computed, such that $w_i = \frac{1}{n} \sum_j a_{ij}$.

Where w_i is the weight of criterion i in the weight vector $w = [w_1, w_2, \dots, w_n]$ recovered from matrix A , with n criteria, by finding a (non-trivial) solution to a set of n equations with n unknowns. This is achieved by solving the eigenvector problem: $Aw = \lambda_{\max} w$. The sum of the weights is taken as equal to 1, resulting in a unique non-trivial solution. Where λ_{\max} is the principle eigenvalue for the pairwise comparison matrix A .

One of the most practical issues in the AHP methodology is that it allows for slightly non-consistent pairwise comparisons. If all the comparisons are perfectly consistent, then the relation $\alpha_{ij} = \alpha_{ik} \alpha_{kj}$ should always be true for any combination of comparisons taken from the judgement matrix.

In practice, however, perfect consistency sparingly occurs. The pairwise comparisons in a judgement matrix are considered to be adequate if the corresponding consistency ratio (CR) is less than 10% (Saaty, 1980). First the consistency index (CI) will be estimated by computing Aw and approximating the maximum eigenvalue, λ_{\max} , using the following:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^n \frac{i^{\text{th}} \text{ entry in } Aw}{i^{\text{th}} \text{ entry in } w}$$

Then, the CI value is calculated by using the formula:

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

Next the consistency ratio (CR) is obtained by dividing the CI by the Random Index (RI) as given in Table VI. The RI is the average value of CI for randomly chosen entries in A (provided that $\alpha_{ij} = 1$ and $\alpha_{ji} = 1/\alpha_{ij}$).

[Table VI here]

The synthesis step follows, after the alternatives have been compared with each other in terms of each one of the decision criteria and the individual priority vectors have been derived. The priority vectors become the columns of the decision matrix (not to be confused with the judgement matrices of the pairwise comparisons). The weights of importance of the criteria are also determined using pairwise comparisons. Therefore, given there is one goal, m criteria and n alternatives, the decision maker will create one $m \times m$ for the criteria and $m \times n$ matrices for the alternatives. The $n \times n$ matrices will contain the results of $n(n-1)/2$ pairwise comparisons between the alternatives. Finally, given a decision matrix the final priorities, denoted by A_{AHP}^i , of the alternatives in terms of all the criteria combined are determined according to the following formula:

$$A_{AHP}^i = \sum_{j=1}^n a_{ij} w_j, \text{ for } i = 1, 2, 3, \dots, m.$$

Clearly, the AHP is most efficiently applied when the total number of criteria and alternatives is not excessive. Several computer software packages are available to perform the AHP calculations, although the user is always obligated to input the pairwise comparison scores. For the purposes of the current work, the AHP has successfully been programmed into a spreadsheet workbook.

3 The development of the suppliers evaluation methodology

The illustrative example is for XYZ Co. as presented by Ordobadi (2009), and we use the Expert Choice Software package to translate the diagram shown in Figure (2) into a hierarchy as shown in Figure (3) below.

[Figure 3 here]

We then perform pair-wise comparison on each level with respect to the level above. For example, for the first level we will compare each factor (criterion) with the other as represented in Figure (4).

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10 [Figure 4 here]

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13 Figure 5 shows how a questionnaire can be used to perform the pair-wise comparison. We
14 use the Saaty's scale in Tale (5) and utilise the mapping of the fuzzy scale given in Table I
15 into a linear AHP scale as shown n Table VII below.
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19 [Table VII Here]

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29 [Figure 5 here]

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32 The same comparison is then carried out across the rest of the hierarchy. We use the Saaty's
33 scale in Tale (5) and utilise the mapping of the fuzzy scale given in Table II into a linear AHP
34 scale as shown n Table VIII below.
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38 Once the pair-wise comparison is completed, the calculations of the overall suppliers ranking
39 is obtained as shown in Figure (6).
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43 [Figure 6 here]

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46 There are three outputs that can be produced from the AHP model as shown below:

- 47 1) An overall ranking as shown in Figure (6) were the summation of rankings is equal to
48 unity. This helps to in case one needs to allocate resources among alternative
49 suppliers. It also helps in understanding how each supplier is compared to the other.
50 Notice that in the fuzzy logic approach as shown in Table (IV) it is not possible to
51 relate to the differences in the values of the crisp score.
52
- 53 2) A measure of Overall Inconsistency f the decision maker's preferences which is a
54 useful feedback for validation of consistency, as explained before. Overall
55 consistency less than 10% is normally acceptable as a measure of consistent
56 preferences.
57
- 58 3) A facility to perform sensitivity analysis (what-if analysis) which provides inforation
59 about the causal relationships among the different factors. This capability can help us
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4 to explain and predict the different relationships among criteria and alternatives, a
5 facility that is not offered by Ordoobadi (2009). This facility has been applied by
6 Chen *et al* (2007) in the field of selection of suppliers in the airline industry. In the
7 next section we demonstrate the sensitivity analysis.
8
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10 **4. Results of Sensitivity Analysis:**

11 The results of sensitivity analysis can be shown in Figure (7), where the criteria are depicted
12 as columns; for example the criterion of quality is more important than both cost and delivery
13 and both are more important than cost. It also shows the performance of each of the three
14 suppliers with respect to each of the criterion; for example with respect to Service (at the
15 third column from the left) we notice that supplier C is better than B and B is better than A.
16 Whereas with respect to Cost, supplier B is better than C and C is better than A. Also taking
17 into consideration all the different criteria the overall ranking of suppliers is shown at the
18 column titled 'Overall'.
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25 [Figure 7 here]

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27 Now what happens if the importance of criterion 'Service' is increased and 'Quality'
28 decreased? We notice in Figure (8) that the overall ranking of suppliers will change into C
29 better than B better than A. This What-if analysis is very powerful as it can help us to predict
30 the importance of suppliers in changing environments that will affect the importance of
31 different criteria.
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35 [Figure 8 here]

36 **5. Summary and suggestions for future research.**

37
38 In this paper we have shown that both techniques, AHP and FL, address the issue of the
39 subjectivity inherent in human assessments that often cannot be expressed in pure numeric
40 scales and requires linguistic expressions. To capture this subjectivity Ordoobadi (2009) has
41 applied fuzzy logic that allows the decision makers to express their preferences/opinions in
42 linguistic terms. However, in our paper we demonstrated how we can achieve the same
43 objective by using AHP. Moreover, we demonstrated the capability to run a sensitivity
44 analysis which helps to understand the causal relationships among the different factors.
45 Moreover we presented how this capability can help us to explain and predict the different
46 relationships among criteria and alternatives, a facility that is not offered by Ordoobadi
47 (2009). In addition, we provided a measure that is able to capture the consistency of the
48 decision maker's preferences. As with Ordoobadi's work the final scores are then translated
49 into ranking of suppliers. However, in our approach we provide a single unit of scale that was
50 not only capable of ranking suppliers but also provided us with an understanding of the
51 difference in scale between different suppliers which can then help to allocate resources
52 accordingly.
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59 **6. Acknowledgement:**

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Table(s) with caption(s) (on individual pages)

Table I: The linguistic importance scale

Linguistic Expressions for Importance	Fuzzy Importance Scale
Low importance (L)	(0.0, 0.0, 0.2, 0.4)
Moderate importance (M)	(0.2, 0.4, 0.4, 0.6)
High importance (H)	(0.4, 0.6, 0.6, 0.8)
Very high importance (VH)	(0.6, 0.8, 1.0, 1.0)

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Table II The linguistic performance scale. Adapted from Ordoobadi (2009).

Linguistic Expressions for Performance	Fuzzy Performance Scale
Poor performance (P)	(0, 0, 2, 4)
Good performance (G)	(2, 4, 4, 6)
Very good performance (VG)	(4, 6, 6, 8)
Excellent performance (EX)	(6, 8, 10, 10)

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Table III Suppliers' performance ratings with respect to the selection criteria. Adapted from Ordoobadi (2009).

Selection criteria

	Supplier A	Supplier B	Supplier C
Customer reject rate	G	EX	VG
Quality control reject rate	VG	VG	G
Delivery lead time	P	G	P
Change in delivery date	EX	P	VG
Special requests	G	P	VG
Reliability	P	G	EX
Access	VG	EX	P
Understanding	G	P	G
Purchase price	P	G	G
Logistics costs	VG	G	P

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Table IV: Ranking of Supplies. Adapted from Ordoobadi (2009).

	Fuzzy Scores	Crisp Scores	Rank
Supplier A	(1.936, 8.272, 12.144, 31.648)	13.5	3
Supplier B	(3.12, 11.2, 15.488, 33.328)	15.78	2
Supplier C	(2.32, 9.776, 13.12, 32.56)	14.44	1

For Peer Review Only

Table V: Scale of relative importance (Saaty, 1980)

Intensity of importance	Value description	Explanation
1	<i>Criterion i</i> and <i>j</i> are of equal importance	Two activities contribute equally to the objective
3	<i>Criterion i</i> is weakly more important than <i>j</i>	Experience and judgement slightly favour one activity over another
5	<i>Criterion i</i> is strongly more important than <i>j</i>	Experience and judgement strongly favour one activity over another
7	<i>Criterion i</i> is very strongly more important than <i>j</i>	An activity is strongly favoured and its dominance demonstrated in practice
9	<i>Criterion i</i> is absolutely more important than <i>j</i>	The evidence favouring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent values	When a compromise in judgement is needed
Reciprocal of above (non-zero)	If <i>criterion i</i> has one of the above non-zero numbers assigned to it when compared with <i>criterion j</i> , then <i>j</i> has the reciprocal value when compared with <i>i</i> .	

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Table VI: RI values for different n values

n	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI_n	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

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Table VII: Mapping of fuzzy expressions for importance to the AHP scale

Pair-wise relationship of fuzzy linguistic expressions for importance as in Table (I)	AHP equivalent values in the questionnaire
VH>H	2
VH>M	4
VH>L	6
H>M	2
H>L	4
M>L	2

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Table VIII: Mapping of fuzzy expressions for performance to the AHP scale

Pair-wise relationship of fuzzy linguistic expressions for performance as in Table (II)	AHP equivalent values in the questionnaire
EX>VG	2
EX>G	4
EX>P	6
VG>G	2
VG>P	4
G>P	2

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List of Figures Captions

Figure 1: The criteria and sub criteria used for selection of suppliers, Ordoobadi (2009).

Figure 2: A typical AHP decision hierarchy

Figure 3: The AHP Model based on the case study provided by Ordoobadi (2009).

Figure 4: Criteria of the selection process.

Figure 5: The completed questionnaire for pair-wise comparison

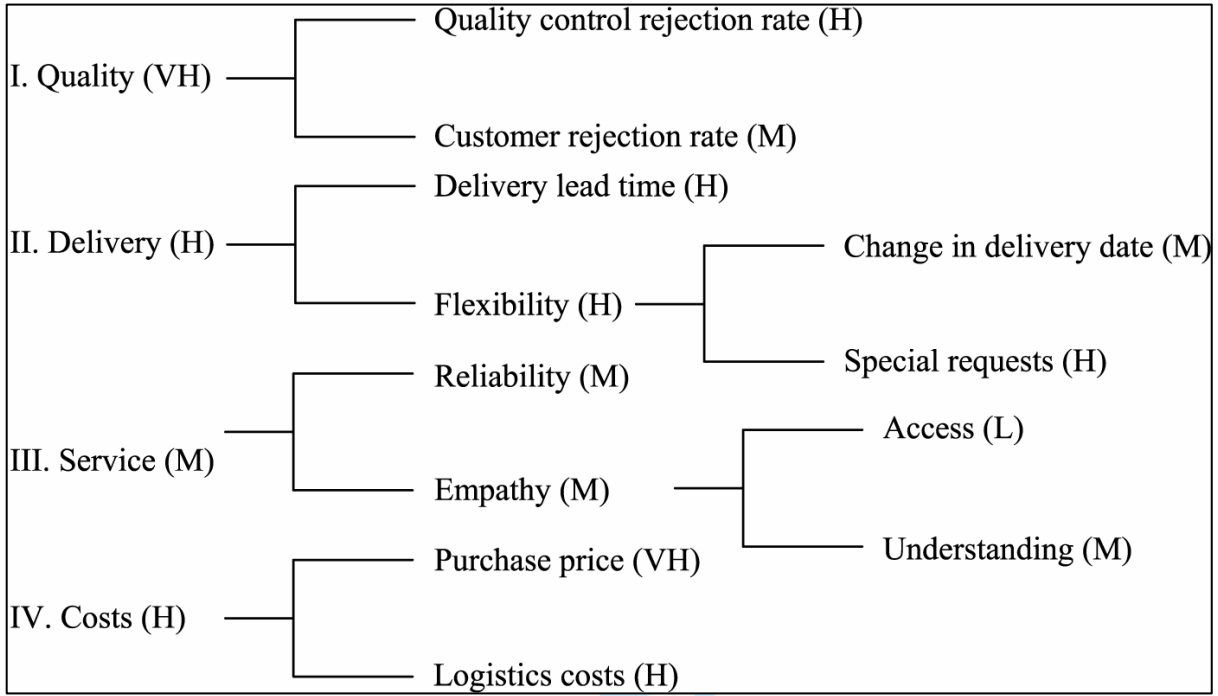
Figure 6: The overall ranking of suppliers

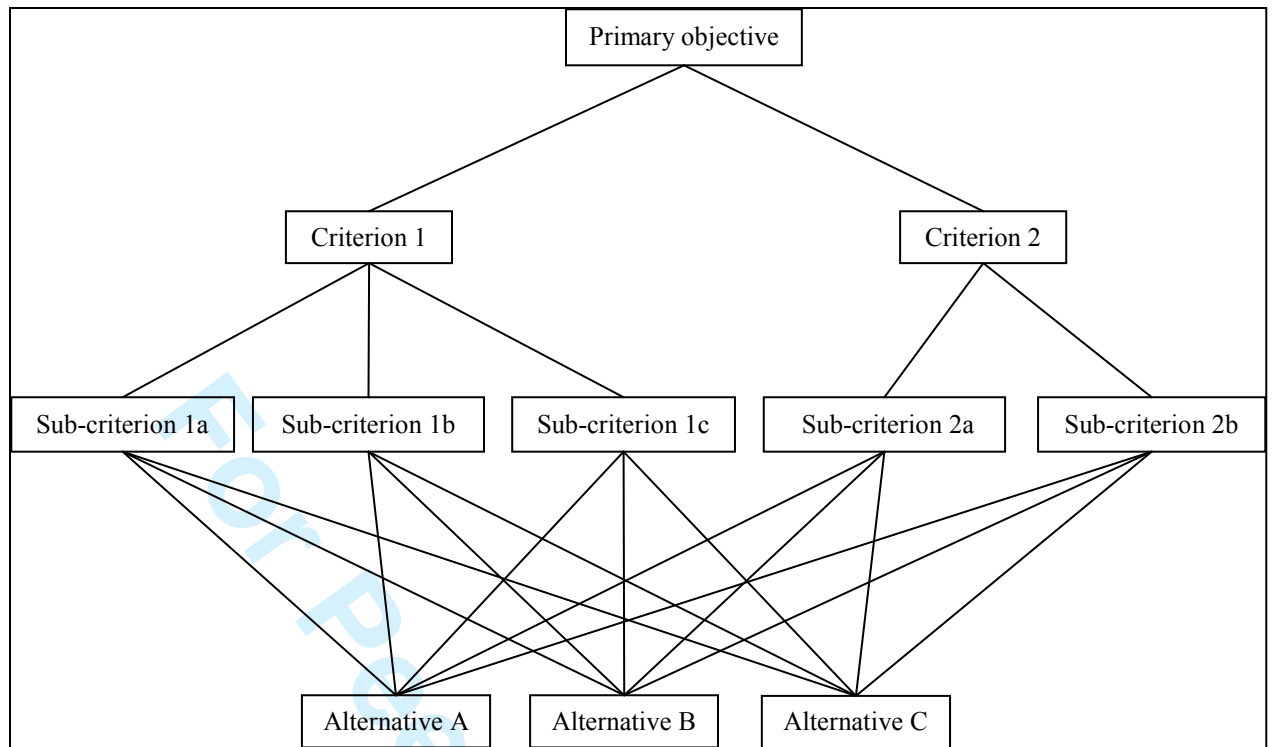
Figure 7: Sensitivity Analysis

Figure 8: What if Analysis

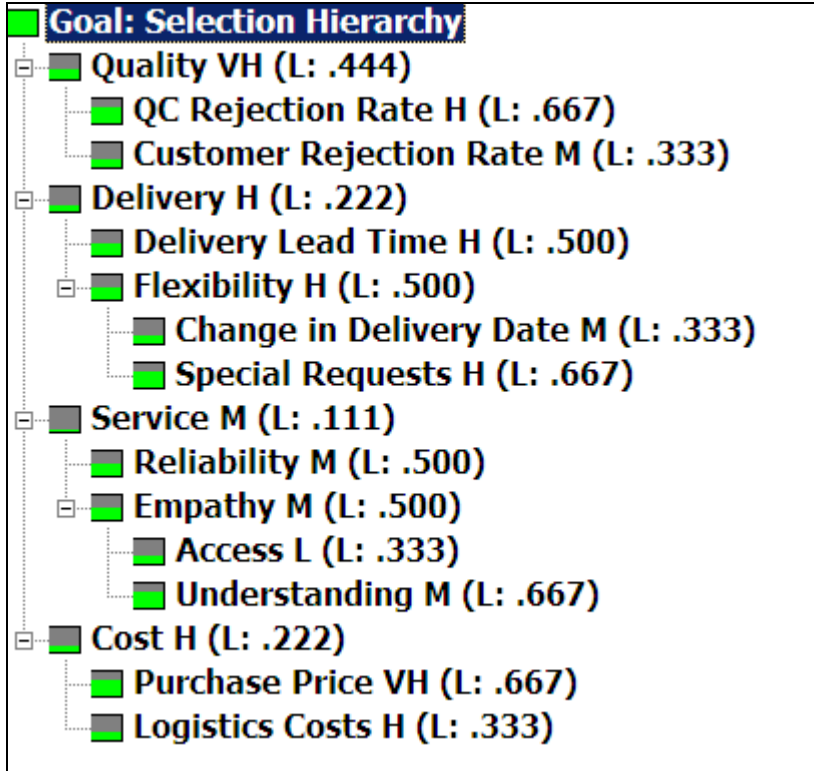
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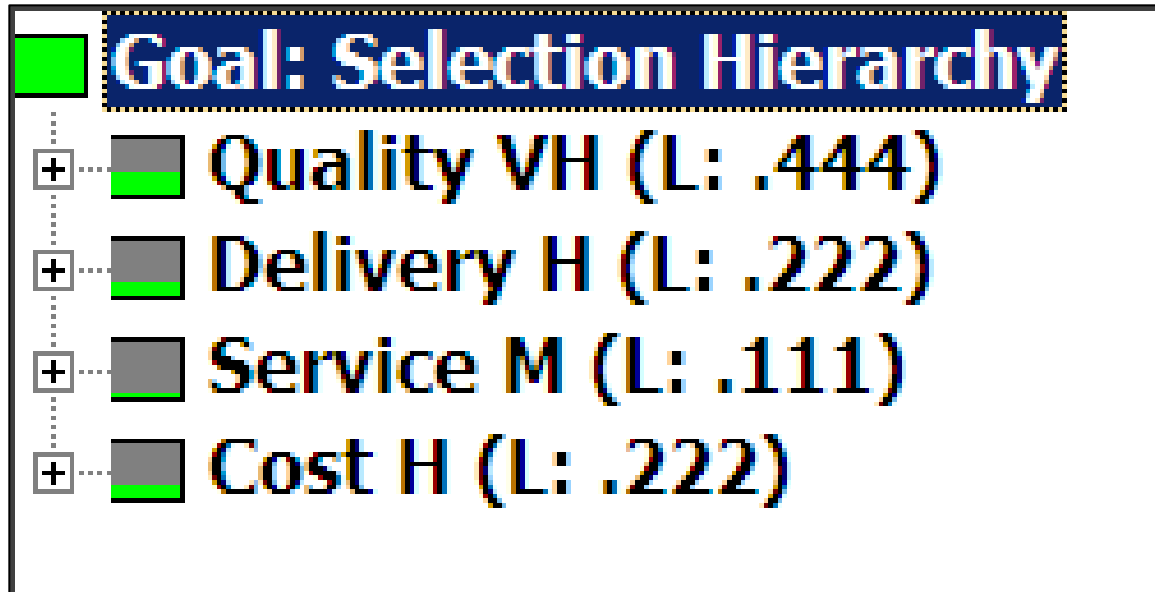




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Questionnaire

File Edit Assessment Go Help

Compare the relative importance

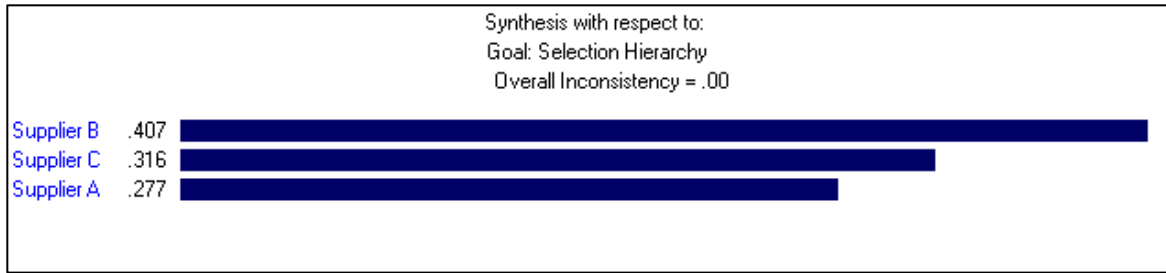
QUALITY VH versus **DELIVERY H**

with respect to: Goal: Selection Hierarchy

1	Quality VH	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Delivery H
2	Quality VH	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service M
3	Quality VH	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost H
4	Delivery H	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service M
5	Delivery H	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost H
6	Service M	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Cost H

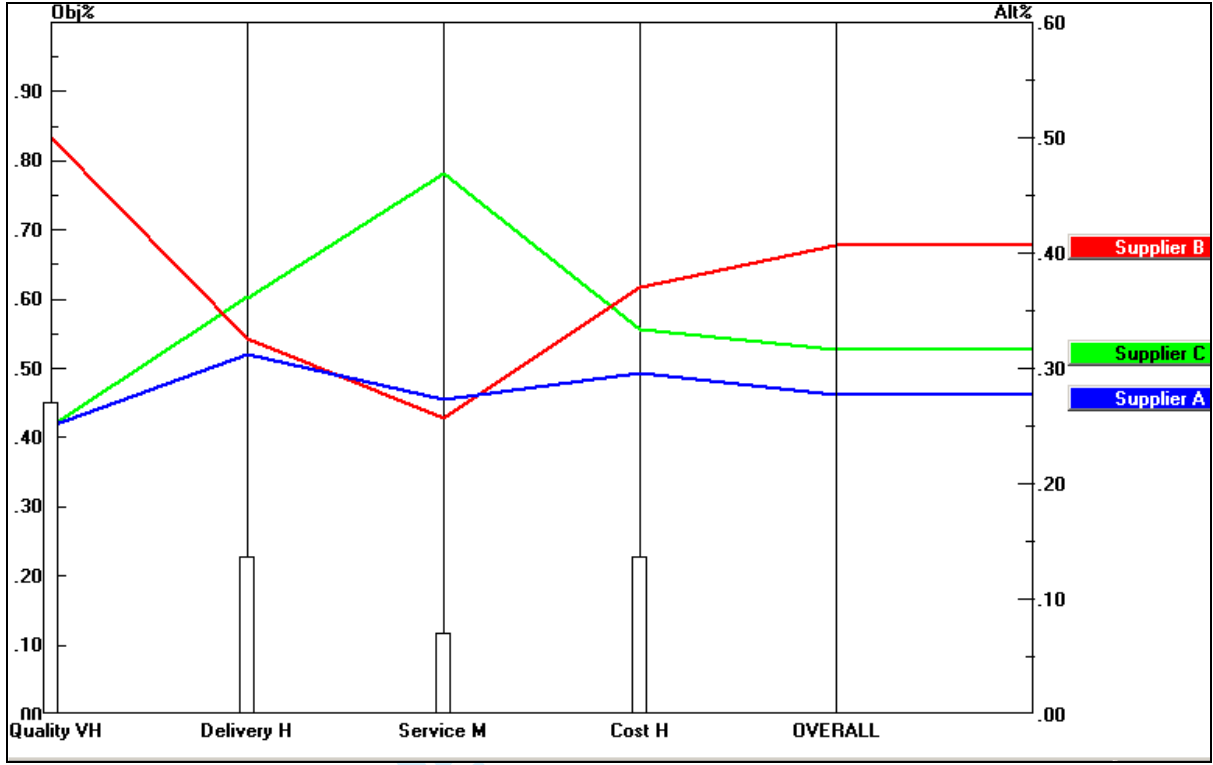
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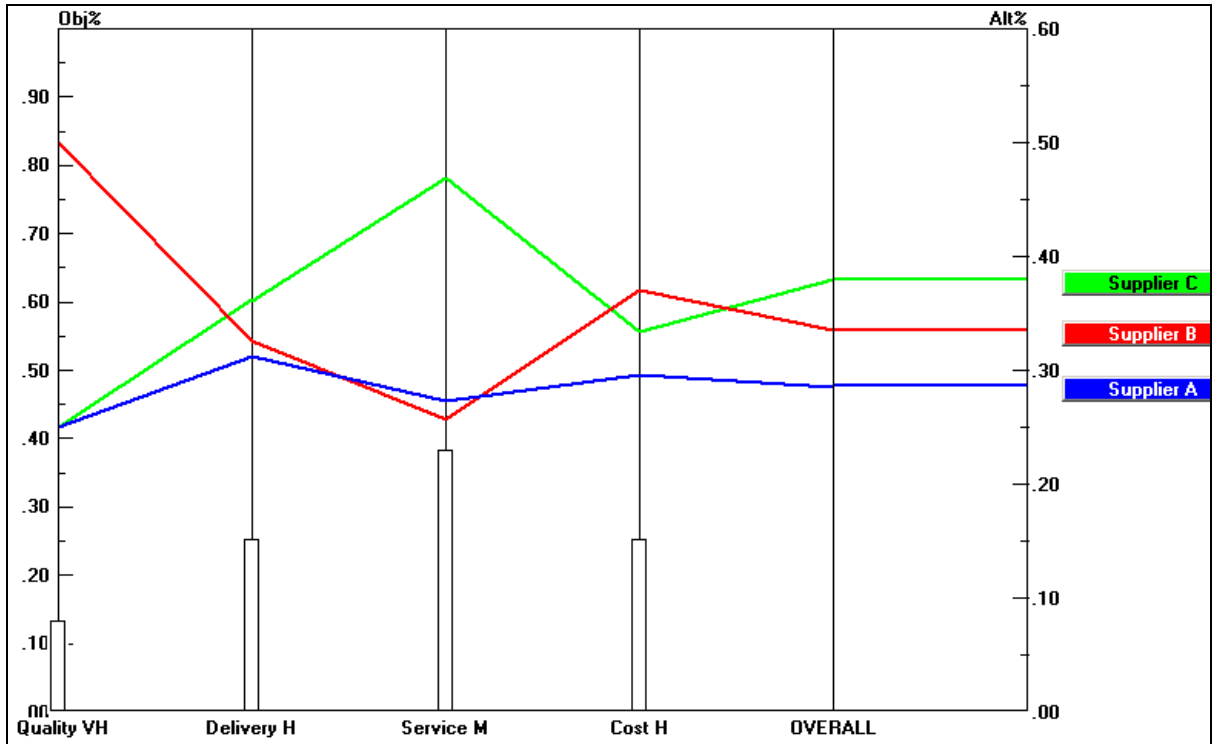
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