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# A hybrid vendor selection model using FAHP and ARAS for solving MCDM problem for supply chain management

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**Abstract**
Multiple Criteria Decision Making (MCDM) substantially evolved during the past decades and became one of the most important area for decision making science. The Vendor selection problem is one of the strategic decisions that have a significant impact on the performance of the supply chain for any manufacturing firm. In this study, with illustrative Example it is explain how a hybrid model FAHP-ARAS is used to select the most suitable vendor providing the most satisfaction to any manufacturer by fulfilling all the criterion on optimum level. The weights of criteria are calculated using Fuzzy Analytic Hierarchy Process (FAHP) approach and then the Additive Ratio Assessment (ARAS) has been applied for the final selection.

**Keywords:** FAHP, ARAS, MCDM, vendor selection and supply chain management

## Introduction
In today's highly competitive but also interrelated business environment, the effective selection of business partners is one of the most important issues, enterprises are dealing with. For the reason, companies face a stiff competition which forces them to focus on the improved quality, cost reduction activities, and improved lead time. Therefore, they need to be very efficient to meet the dynamic market requirements and to be open to change, low cost, high quality products and supplier satisfaction. Increases of customer demands, supply/demand chain, advances of recent technologies, especially evolution in information and communication technologies, competition in a global environment, and increases in environmental consciousness have forced enterprises to focus on better supply chain management. Moreover, radical product and technology innovation demand manufacturer to turn back to the suppliers and the key partners in order to maintain their existing customer base. Nowadays more than ever, businesses are depending on strategic relations with their customers and suppliers in order to create value-added systems that will give them a competitive edge in the market.
Most of the time vendors are being selected by companies based on three basic factors, their ability to meet some quality standards, their delivery schedule and the price they offer. However, in modern management, one must take into consideration numerous other factors in order to succeed and establish a long-term relationship with its vendors and in order to consider suppliers as the best intangible assets of the organization.

## Literature Review
The main focus of this paper is to calculate the weight of criterion with the help of Fuzzy AHP, Although there are many applications of F-AHP in various fields including; personnel selection, weapon selection, energy alternatives selection, job selection and performance evaluation systems, only the recent Fuzzy AHP Applications for supplier selection problems will be elaborated in forthcoming paragraphs.
In 2010, a Fuzzy AHP method is used for supplier selection in electronic market places, according to their two-phase methodology, at the first phase, initial screening of the suppliers through the enforcement of hard constraints on the selection criteria is performed. In the second phase, final supplier evaluation is performed through the application of a modified variant of Fuzzy AHP. This methodology facilitates an easier elicitation of user preferences through the reduction of necessary user input (i.e. pair wise comparisons) and reduces computational complexity. In 2011, Fuzzy AHP approach is used for supplier selection in a washing machine company. First, they determine the criteria providing the most customer satisfaction and design the hierarchy structure including the main attributes and sub-attributes for supplier selection. The weights of the attributes and alternatives are calculated using pair wise comparison matrices. In 2012, a combination of fuzzy AHP and fuzzy objective linear programming is used to select the best supplier to develop a low carbon supply chain. At first, Fuzzy AHP is used to determine weights of predetermined criteria, and the Additive Ratio ASsessment (ARAS) method is used for further calculation of ranking of vendor.
The Additive Ratio ASsessment (ARAS) method developed by Zavadskas and Turskis. Therefore, for the ARAS method can be said, although is newly developed method, that ARAS method is very effective and easy to use when it comes to solving MCDM problems. Until now ARAS method has been applied in numerous cases to solve various decision-making problems, such as: subcontractor selection, personnel selection, ranking of companies according to the indicators of corporate social responsibility, oil and gas well drilling projects evaluation, sustainable building assessment/certification and so on. Problem solving procedure using the ARAS method, similar to other MCDM methods, begins by forming the decision matrix and determining the weights of the criteria

## FAHP Method

Fuzzy Analytic Hierarchy Process (F-AHP) embeds the fuzzy theory to basic Analytic Hierarchy Process (AHP), which was developed by Saaty. AHP is a widely used decision making tool in various multi-criteria decision-making problems. It takes the pair-wise comparisons of different alternatives with respective to various criteria and provides a decision support tool for multi criteria decision problems. In a general FAHP model, the objective is in the first level, the criteria and sub criteria are in the second and third levels respectively. Finally. The alternatives are found in the fourth level.

This study utilizes the method described by Buckley and uses triangular fuzzy membership function to calculate relative weights of criteria as well as alternatives. Reason for using triangular membership function is that while interviewing the case company which is discussed in the next section, all the approximate values for each criterion as described by the purchasing staff was around a single value instead of any standard or a range of values. Following are the steps to be performed:

Step 1: Comparing criteria and alternatives using linguistic variables shown in table 1.

**Table 1:** Linguistic Term & the Corresponding Triangular Fuzzy Numbers

| Linguistic Variables | Saaty Value | Fuzzy Triangular Values |
|---|---|---|
| Equally Important | 1 | (1, 1, 1) |
| Slightly Important | 3 | (2, 3, 4) |
| Strongly Important | 5 | (4, 5, 6) |
| Very Strongly Important | 7 | (6, 7, 8) |
| Extremely Important | 9 | (9, 9, 9) |
| The intermittent values between two adjacent scales | 2 | (1, 2, 3) |
| | 4 | (3, 4, 5) |
| | 6 | (5, 6, 7) |
| | 8 | (7, 8, 9) |

As we can see from table 1; the linguistic terms are mapped to triangular fuzzy numbers. Suppose if the expert suggests that "Criterion 1 ($Cr_1$) is strongly important than criterion 2 ($Cr_2$)", then it will take (4, 5, 6) fuzzy triangular value. On the other hand, while constructing pair-wise matrix, comparison of $Cr_2$ to $Cr_1$ will have fuzzy triangular value (1/6, 1/5, 1/4). The sample pair-wise comparison matrix "A" is shown is equation 1. Here $d_{ij}$ indicates the comparison of $i^{th}$ criterion with $j^{th}$ criterion using fuzzy triangular values as mentioned in table 1. For the above example of $Cr_1$ is strongly important than $Cr_2$, $d_{12}$ value represent this comparison and will have be equal to; $d_{12}$ = (4, 5, 6).

$$D = \begin{bmatrix} d_{11} & \cdots & d_{1n} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nm} \end{bmatrix}$$

Step 2: The geometric mean of fuzzy comparison values is calculated for each criterion which is shown in equation l

$r_i = \left(\prod_{j=1}^{n} d_{ij}\right)$, $i = 1, 2 \ldots, n$

Step 3: Find the vector summation of each $r_i$. Then find the reciprocal of summation vector and replace the fuzzy triangular value to make it in an increasing order. Then find the fuzzy weight of each criterion i ($w_i$) by multiplying each $r_i$ with this reverse vector.

$Weight\ (w_i) = r_i \otimes (r_1 \oplus r_2 \oplus \ldots \oplus r_n)^{-1}$

$= (lw_i, mw_i, uw_i)$

Operations on fuzzy numbers are defined as follows:

$a_1 \oplus a_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2)$

$a_1 \otimes a_2 = (l_1 . l_2, m_1 . m_2, u_1 . u_2)$

$$a_1^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right)$$

$$a_1^{\frac{1}{n}} = \left(l^{\frac{1}{n}}, m^{\frac{1}{n}}, u^{\frac{1}{n}}\right)$$

Step 4: In this step, the weights calculated, triangular fuzzy numbers ($lw_i$, $mw_i$, $uw_i$) are to convert them into crisp values, the centre of gravity method was applied:

$$M_i = \frac{(lw_i + mw_i + uw_i)}{3}$$

Step 5: M$i$ is a non-fuzzy member which needs to be normalized using equation 5.

$$N_i = \frac{M_i}{\sum_{i=1}^{n} M_i}$$

After finding the normalized weights of all the criteria and the alternatives, the score or rank of each alternative is calculated by multiplying each alternative weight with the related criteria. The alternative with the highest score is ranked 1st and can be selected by the decision maker. This methodology has been applied for supplier selection is a textile industry using a real case study which is discussed in the next section.

## ARAS Method

A typical MCDM problem is concerned with the task of ranking a finite number of decision alternatives, each of which is explicitly described in terms of different decision criteria which are to be taken into account simultaneously. In this paper, ARAS method is applied for performance evaluation of vendor for any manufacturing firm. According to ARAS method, a utility function determining the complex relative efficiency of a feasible alternative is directly proportional to the relative effect of values and weights of the main criteria considered in a problem.

The procedure of solving problems by using ARAS methods, in cases when MCDM problem incudes beneficial criterion and non-beneficial criterion, can be precisely described by using the following steps.

Step 1: At first, the related decision/evaluation matrix is formulated. In any MCDM problem (discrete optimization problem), the relevant data is represented by the decision matrix showing preferences form feasible alternatives rated on n criteria (attributes).

$$X = \begin{bmatrix} x_{12} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ . & . & \cdots & . \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Where m is the number of alternatives, n is the number of criteria describing each alternative and $x_{ij}$ is the value representing the performance of $i^{th}$ alternative with respect to $j^{th}$ criterion.

Step 2: Determine the optimal value of each criterion. Let $x_{0j}$ be the optimal value of $j^{th}$ criterion. If the optimal value of $j^{th}$ criterion is known, then

$x_{0j} = \max x_{ij}$ For beneficial criterion

$x_{0j} = \min x_{ij}$ For non-beneficial criterion

Now, taking into account the optimal values of all the considered criteria, the original decision matrix is reformulated as follows:

$$X = \begin{bmatrix} x_{01} & x_{0j} & \cdots & x_{0n} \\ . & . & \cdots & . \\ x_{i1} & x_{ij} & \cdots & x_{in} \\ . & . & \cdots & . \\ . & . & \cdots & . \\ x_{m1} & x_{mj} & \cdots & x_{mn} \end{bmatrix}$$

Step 3: In this step, all the initial criteria values are normalized while employing the following equations.

For beneficial criteria, $r_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}$

For non-beneficial criteria, $r_{ij}^* = \frac{1}{x_{ij}}$, $r_{ij} = \frac{r_{ij}^*}{\sum_{i=0}^{m} r_{ij}^*}$

Step 4: From the normalized decision matrix, the corresponding weighted normalized decision matrix is developed using the following equation:

$v_{ij} = w_j * r_{ij}$, $i = 1, 2, 3\ldots, m$

Where $w_j$ is the weight of j$^{th}$ criterion and $r_{ij}$ is the normalized performance of i$^{th}$ alternative with respect to j$^{th}$ criterion.

Step 5: In this stage, the optimality function value is determined.

$S_i = \sum_{j=1}^{n} v_{ij}$, $i = 0, 1, 2\ 3\ldots, m$

Where $S_i$ is the value of optimality function for i$^{th}$ alternative. The highest value of Si always signifies the best alternative, whereas, the lowest Si value identifies the least preferred alternative. Taking into account the computational process of ARAS method, it can be revealed that the optimality function $S_i$ has a direct and proportional relationship with $x_{ij}$ values and weights $w_j$ of the considered criteria and their relative influence on the final result. The priorities of the alternatives can thus be determined based on $S_i$ values. Consequently, it is convenient to evaluate and rank the decision alternatives using $S_i$ values.

Step 6: The degree of alternative utility is determined by comparing with a variant, which is often taken as the ideally best value ($S_0$). The utility degree $U_i$ of i$^{th}$ alternative can be calculated employing the following equation:

$U_i = \frac{S_i}{S_0}$, $i = 1, 2, m$

It is quite obvious that the calculated values of $K_i$ lie in the interval of [0, 1] and can be ordered in an increasing sequence to provide a complete ranking of the considered alternatives. The complex relative efficiency of the feasible alternatives can also be determined according to the utility function values.

## Illustrative Example

In the section, a numerical example is given to show applicability of the proposed model. Note that in the first step, the management of a manufacturing firm are asked to select most important vendor selection criteria. As the result, four selection criterions finalized, which are: product quality, product price, product delivery time and service after sales.

In the present study, Microsoft Excel is used for the weight calculation using FAHP and vendor ranking using ARAS method. The evaluation of ranking and the suppliers' weights processes are described below. In this paper, we have used the linguistic numbers given in Table 1 to evaluate the criteria importance, to develop pair-wise comparison of alternatives.

## Implementation of Fuzzy AHP

The classical AHP is insufficient for dealing with fuzziness and uncertainty in multi-criteria decision making (MCDM), because of incomplete information, impreciseness of human judgments and fuzzy environment. Hence, the fuzzy AHP technique can be viewed as an advanced analytical method developed from the classical AHP. The method or fuzzy AHP consists of the following five steps:

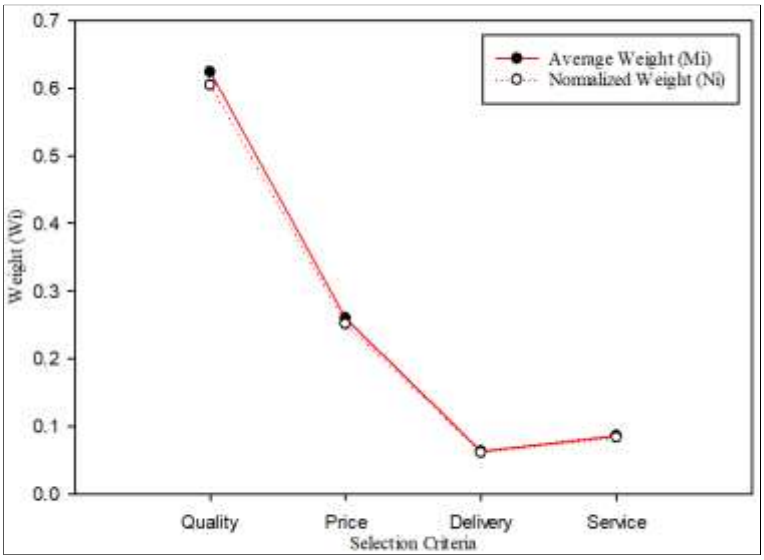
1. Obtaining the fuzzy comparison matrices.
2. Calculation of fuzzy synthetic extents.
3. Comparison of fuzzy synthetic extents.
4. Evaluation of the minimum degree of possibilities.
5. Normalization of weight vectors.

**Table 2:** Pair Wise Comparisons of Alternatives

| **Criteria** | Quality | Price | Delivery | Service |
|---|---|---|---|---|
| Quality | (1,1,1) | (2,3,4) | (6,7,8) | (9,9,9) |
| Price | (1/4,1/3,1/2) | (1,1,1) | (2,3,4) | (4,5,6) |
| Delivery | (1/8,1/7,1/6) | (1/4,1/3,1/2) | (1,1,1) | (1/4,1/3,1/2) |
| Service | (1/9,1/9,1/9) | (1/6,1/5,1/4) | (2,3,4) | (1,1,1) |

**Table 3:** Fuzzy Geometric Mean, Fuzzy Weight, Avg. Weight & Normalized Weight

| | **Fuzzy Geometric Mean Value ($r_i$)** | **Fuzzy Weight ($w_i$)** | **Average Weight (Mi)** | **Normalized Weight (Ni)** |
|---|---|---|---|---|
| Quality | (3.22, 3.71, 4.12) | (0.46, 0.61, 0.80) | 0.6237 | 0.6044 |
| Price | (1.19, 1.50, 1.86) | (0.17, 0.25, 0.36) | 0.2592 | 0.2512 |
| Delivery | (0.30, 0.35, 0.45) | (0.04, 0.06, 0.09) | 0.0629 | 0.0609 |
| Service | (0.44, 0.51, 0.58) | (0.06, 0.08, 0.11) | 0.0862 | 0.0835 |
| Total | (5.15, 6.07, 7.01) | | 1.0320 | 1.0000 |
| Inverse Value | (0.19, 0.16, 0.14) | | | |
| Increasing Value | (0.14, 0.16, 0.19) | | | |




**Graph 1:** Weight Comparison of Different Criteria

## Implementation of ARAS for Supplier Ranking

ARAS method requires the decision matrix shown in Table 3. Before normalizing the decision matrix the optimal performance ratings for each criterion are determined as the maximum values of beneficial criteria and minimum values of non-beneficial criteria. Optimal performance ratings (OPR) for each criterion are placed as V0 (Bold) in Table 3, Table 4 and Table 5.

**Table 4:** Decision Matrix

| | Quality | Price | Delivery | Service |
|---|---|---|---|---|
| OPR (V0) | 94 | 120 | 9 | 94 |
| Vendor 1 | 75 | 120 | 5 | 80 |
| Vendor 2 | 88 | 212 | 4 | 74 |
| Vendor 3 | 68 | 225 | 6 | 84 |
| Vendor 4 | 56 | 180 | 5 | 66 |
| Vendor 5 | 66 | 230 | 7 | 58 |
| Vendor 6 | 81 | 130 | 3 | 94 |
| Vendor 7 | 94 | 275 | 2 | 54 |
| Vendor 8 | 86 | 195 | 3 | 62 |
| Vendor 9 | 71 | 315 | 5 | 43 |
| Vendor 10 | 79 | 380 | 9 | 87 |
| Criteria Type | Max | Min | Max | Max |

The decision matrix is normalized by using equation mentioned in step 2, step 3 and step 4, in ARAS method and values shown in Table 4. Then normalized decision matrix is weighted by considering criteria weights derived from FAHP and values shown in Table 5.

**Table 5:** Normalized Decision Matrix

| | Quality | Price | Delivery | Service |
|---|---|---|---|---|
| V0 | 0.1096 | 0.1437 | 0.1552 | 0.1181 |
| V1 | 0.0874 | 0.1437 | 0.0862 | 0.1005 |
| V2 | 0.1026 | 0.0813 | 0.0690 | 0.0930 |
| V3 | 0.0793 | 0.0766 | 0.1034 | 0.1055 |
| V4 | 0.0653 | 0.0958 | 0.0862 | 0.0829 |
| V5 | 0.0769 | 0.0750 | 0.1207 | 0.0729 |
| V6 | 0.0944 | 0.1326 | 0.0517 | 0.1181 |
| V7 | 0.1096 | 0.0627 | 0.0345 | 0.0678 |
| V8 | 0.1002 | 0.0884 | 0.0517 | 0.0779 |
| V9 | 0.0828 | 0.0547 | 0.0862 | 0.0540 |
| V10 | 0.0921 | 0.0454 | 0.1552 | 0.1093 |
| Weight(wj) | 0.6044 | 0.2512 | 0.0609 | 0.0835 |

**Table 6:** Weighted normalized decision matrix

| | Quality | Price | Delivery | Service |
|---|---|---|---|---|
| V0 | 0.0662 | 0.0361 | 0.0095 | 0.0099 |
| V1 | 0.0528 | 0.0361 | 0.0053 | 0.0084 |
| V2 | 0.0620 | 0.0204 | 0.0042 | 0.0078 |
| V3 | 0.0479 | 0.0192 | 0.0063 | 0.0088 |
| V4 | 0.0394 | 0.0241 | 0.0053 | 0.0069 |
| V5 | 0.0465 | 0.0188 | 0.0074 | 0.0061 |
| V6 | 0.0571 | 0.0333 | 0.0032 | 0.0099 |
| V7 | 0.0662 | 0.0157 | 0.0021 | 0.0057 |
| V8 | 0.0606 | 0.0222 | 0.0032 | 0.0065 |
| V9 | 0.0500 | 0.0137 | 0.0053 | 0.0045 |
| V10 | 0.0556 | 0.0114 | 0.0095 | 0.0091 |

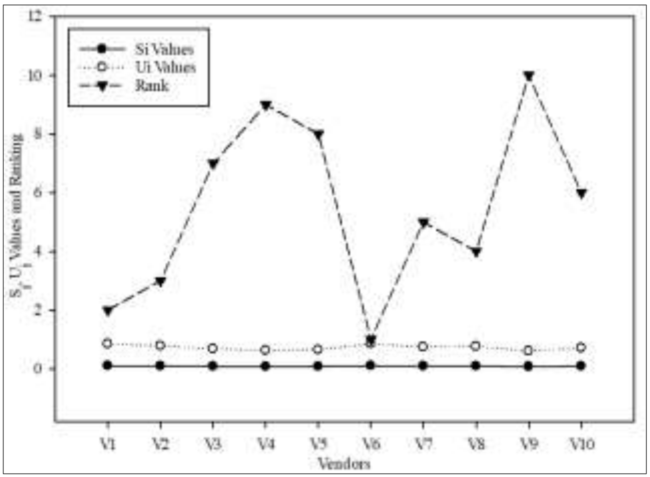
The optimality function (Si) and the utility degree (Ui) of each alternative is calculated using equation mentioned in step 5 and step 6, in ARAS method. Si and Ui values and the ranking of the alternatives are presented in Table 6.

**Table 6:** Si, Ui values and Ranking

| Vendor | Si | Ui | Rank |
|---|---|---|---|
| V0 | 0.1216 | 1.0000 | |
| V1 | 0.1026 | 0.8433 | 2 |
| V2 | 0.0944 | 0.7760 | 3 |
| V3 | 0.0823 | 0.6764 | 7 |
| V4 | 0.0757 | 0.6223 | 9 |
| V5 | 0.0788 | 0.6476 | 8 |
| V6 | 0.1034 | 0.8500 | 1 |
| V7 | 0.0897 | 0.7378 | 5 |
| V8 | 0.0924 | 0.7601 | 4 |
| V9 | 0.0735 | 0.6045 | 10 |
| V10 | 0.0856 | 0.7040 | 6 |

## Result and Conclusions

Vendor selection is a very important process and activity for any manufacturing firm, it can be said that vendor selection is one activity in which huge brain storming and trial are carried out. This MCDM problem help the selector to take most suitable decision regarding the vendor selection process. As per many literature reviews it is indicated that this is one of the most important activity is vendor selection. Hence the vendor selection procedure and, above all, the selection of an adequate method is significant, especially from the aspect of the final result. In this paper, an illustrative example was successfully conducted aimed at indicating that multi-criteria decision making can be successfully applied for the vendor selection. An approach based on the FAHP-ARAS method proved to be very easy to apply, also, should not be ignored the overall efficiency and the usability of the proposed approach.




**Graph 2:** Comparison of Alternatives Based on S., U. Values and Rank

Based on the four criteria of sustainability, a total of ten suppliers in a manufacturing firm were considered, where it was concluded that the Vendor 6 is the best solution or most suitable vendor for further business with manufacturing firm, which has been confirmed by comparison with other vendor based on optimality function (Si) and the utility degree (Ui) shown in Table 6 and comparison shown in Graph 2.

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