A Generic Tool for the Implementation of the Analytic Hierarchy Process

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Abstract[1]

In engineering applications a decision is based on the evaluation of a number of alternatives in terms of a number of criteria. This problem may become a very difficult one when the criteria are expressed in different units. The Analytic Hierarchy Process (AHP) is an effective approach in dealing with this kind of decision problems. AHP is a multicriteria decision making approach in which factors are arranged in a hierarchical structure. This paper examines some of the practical and computational issues involved in the process of building a generic tool for the AHP solution. First the examined process is described where the hierarchy is built as a Tree view model and then for each node of the Tree the corresponding weights are determined by the user. The final priorities for each alternative are presented to the user and the final choice is made based on that priorities. This software is generic one and can be used for any problem implementing the AHP.

1. Introduction

Decision making, formalizes the way of thinking but what we have to do to make better decisions is transparent in all its aspects [1]. It involves a number of criteria and subcriteria used to rank all the available alternatives existing for any decision. A logical procedure is consisted of defining priorities for the alternatives with respect to the criteria and/or subcriteria. Priorities also have to be defined for each criterion in terms of the goal.

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The person that makes a decision has to select the factors/criteria that are important for that decision. He arranges the criteria in anhierarchical structure descending from an overall goal, which is the root of hierarch and presenting the criteria, subcriteria and finally all the alternatives in successive levels. Such a hierarchy is displayed in Fig. 1.

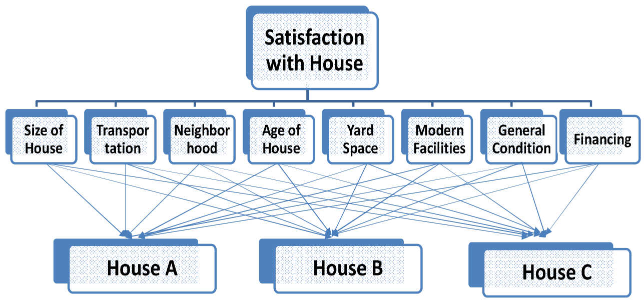

Fig 1. A Hierarchic structure with 3 alternatives.

The example shown in Fig.1 describes the hierarchy of criteria when a family is thinking to buy a house (Saaty, 1990). Most of the families identify eight criteria such as:*Size of House, Location of Bus Lines, Neighbourhood (little traffic, secure, nice view, low taxes), Age of House, Yard Space, Modern facilities, General Condition. Financing Available.*

On the other hand, Strategic Decision Making (SDM) involves fitting the internal capabilities to the external environment by choosing the best alternative [3]. SDM evaluates the different alternatives quantitatively and provides the decision maker with a rational basis for selecting the optimal solution.

In general, a decision making problem consists of the following main stages:

- Studying the problem.

- Organising multiple criteria.
- Assessing multiple criteria.
- Evaluating alternatives on the basis of the assessed criteria.
- Rank the alternatives.
- Incorporate the judgement of multiple experts.

Thus the problem can be formulated on how to derive weights for a set of activities according to their impact of the objectives of the decisions to be made. This is the process of multiple-criteria decision-making (MCDM). The weighted-sum method (WSM) [11], or the decision matrix approach, is perhaps among the earliest method employed. This method evaluates each alternative with respect to each criterion. Then it multiples that evaluation by the importance of the criterion. Then the product is summed over all the criteria for the particular alternative to generate the rank of the alternative.

$$R_i = \sum_{j=1}^{N} a_{ij} w_j \ . \quad (1)$$

where R_i is the rank of the i-th alternative, a_{ij} is the actual value of the i-th alternative in terms of the j-th criterion and w_j is the weight or importance of the j-th criterion.

There exist two variants of the decision matrix approach. One is the Forced Decision Matrix (FDM) [11] approach, where the ratings are given in terms of 0s or 1. This approach is simpler to implement since if each alternative is better on one parameter then the whole weight goes to the alternative. The second one is the weighted-product method (WPM) [11], itis very similar to the weighted-sum method. Each alternative is compared with others by multiplying a number of ratios, one for each criterion.

The Analytic Hierarchy Process (AHP) is a technique proposed and developed by T. Saaty [4]. It has been extensively used for structuring and analysing complex decision [7, 9]. It helps to structure the decision-maker's thoughts and can help in organizing the problem in a manner that is simple to follow and analyse. First, the decision is decomposed into a hierarchy of sub criteria. After building the hierarchy, the user is asked to compare the sub criteria to one another with respect to their impact on the criterion above them in the hierarchy. The AHP uses values provided by the user in order to evaluate these comparisons and a numerical value (namely priority) is derived for each sub criterion of the hierarchy. Finally, priorities are calculated for each alternative and the alternative with the highest priority must be chosen. The priorities for each alternative represent the alternative's relative ability to achieve the overall goal.

The rest of the paper is structured as follows. Section 2 provides the background of the AHP. Section 3 describes the software tool and Section 4 concludes the papers providing some insight for further refinement and possible extensions of the tool.

2. Analytic Hierarchic Process

AHP is a MCDMapproach, which uses a hierarchy to formulate the problem. At the top of the hierarchy the goal of the decision is placed. The second level includes the criteria that are used for comparison. Each criterion may have sub-criteria that are placed at the consequent levels. At the final level, all the alternative choices are placed.

Theoretically the AHP is based on four axioms according to [4]:

Axiom 1: (reciprocal axiom) The decision-maker can provide paired comparisons a_{ij} of two alternatives i and j corresponding to a criterion/sub-criterion on a ratio scale which is reciprocal, i.e. $a_{ji} = \frac{1}{a_{ij}}$.

Axiom 2: (homogeneity axiom)The decision-maker never judges one alternative to be infinitely better than another corresponding to a criterion, (otherwise there will tend to be larger errors in judgment).

Axiom 3: (synthesis axiom) The decision problem can be formulated as a hierarchy (judgments about the priorities of the elements in a hierarchy do not depend on lower level elements) [2].

Axiom 4: All criteria/sub-criteria which have some impact on the given problem, and all the relevant alternatives, are represented in the hierarchy in one go.

The AHP is decomposed into a number of steps:

Step 1

Define the hierarchy of the decision in successive levels. At the top level is placed the goal of the decision and as you move down add criteria/sub criteria to each level until the last level which is the level of the alternatives. Saaty suggests a useful way to develop the hierarchy of the problem[6]. First, work down from the goal to the alternative and then work up from the alternatives to the goal until the levels of the two processes are linked in such a way as to make comparisons possible.

Step 2

For each level of criteria compute a set of pairwise comparison matrices. Experts or decision makers provide the comparison of each element at each level. This is easily accomplished noticing that the expert who compares the elements has just only to make the comparison with respect to the contribution of the lower level elements to the upper levels. This local concentration of the decision maker is a powerful feature of the AHP procedure.

The comparison of each level is accomplished using a scale. Experts or decision makers rate the comparison as equal, marginally strong, weak, moderate, moderate plus, strong, strong plus, very strong, very very strong and extremely strong as shown below in Table 1. There are created criteria matrices that are square with diagonal elements of the matrices equal to 1. For example, the i-th criterion is stronger than the value of the j-th criterion means that the element (i, j) of the matrix of the comparisons of the criterions will have a value bigger than 1; vice versa, the element (i, j) of the matrix will be the reciprocal of the previous value if the j-th criterion is more important than the i-th criterion (Axiom 1).

Step 3

The principal eigenvalue and the corresponding eigenvector of the comparison matrix give the relative importance of the previous criteria being compared.

Table 1. The scale of the Analytic Hierarchic Process.

Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective.
2	Weak	
3	Moderate	One activity is slightly favored over another.
4	Moderate plus	
5	Strong	Judgment is favored strong over another
6	Strong plus	
7	Very Strong	One activity is favored very strong over another.
8	Veryvery Strong	
9	Extreme importance	One activity is favored to another of the highest possible order of affirmation.
Reciprocals of above	If activity i has one of the above numbers assigned to it when compared to it, then activity j has the reciprocal value when compared with i.	

Step 4

The consistency of the matrix is evaluated base on a Consistency Index (CI). If this CI fails to reach a required (tolerance) level then the provided elements (a_{ij})for the comparisons has to be re-examined. The CI value is calculated as:

$$CI = \frac{\lambda_{\max} - n}{n - 1}, \quad (2)$$

where n is the order of the matrix of the comparisons and $\lambda_{\max}$ is the maximum eigenvalue of the matrix of the comparisons. The value of the CI index is then compared with that of a random matrix index (RI) [4]. The consistency ratio (CR) is then defined as:

$$CR = \frac{CI}{RI}. \quad (3)$$

The acceptable values of the CR index are less than 0.1, and the values of the index RI are shown in Table 2.

Table 2. The Values of the index RI.

The order n of the criteria matrix	RI
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.46
10	1.49

Step 5

The rating of each alternative is multiplied by the weights of the sub-criteria and aggregated to get local ratings with respect to each criterion. The local ratings are then multiplied by the weights of the criteria and aggregated to get global ratings.

3. The Software Tool

We implemented the Analytic Hierarchy Process using the Visual C# programming language [10], with the well-known Microsoft Visual Studio 2013.The software is composed in two stages using two forms:

a. The construction of the Hierarchy of the decision making problem, 1st Form.
b. The assessment of the weights of each criterion and the computation of the global priorities of the alternatives, 2nd Form.

3.1. Construction of the Hierarchy

In this stage the user is asked to insert the hierarchical structure of the decision making problem. This is achieved by inserting nodes at the top level (by right clicking at a node) namely the goal and moving down successively to each level. In this section the example provided in the previous section will be used as our working paradigm. The values used here can be found in [5]. Fig. 2, presents this process.

Fig 2. Adding a Criterion (Node) to the initial Goal. The final hierarchy tree contains 8 nodes.

After the user has provided the hierarchy structure of the problem, he has to provide the number of alternatives of the last level of the hierarchy structure.Then he has to move to the next stage where he has to provide the pairwise comparison of each criterion for each level.

Fig. 3. ***The hierarchy structure with 3 alternatives.***

3.2. Pairwise comparison of each criterion and computation of the global priorities

At this stage the user has to provide the pairwise comparison matrices between each criterion for each level. In our example the hierarchy of the decision problem has only one level (Fig. 4).As example, element $a_{12} = 5.0$ of the criteria matrix means that the Criterion: *Size of House* is 5 times more important than the Criterion: *Transportation*.

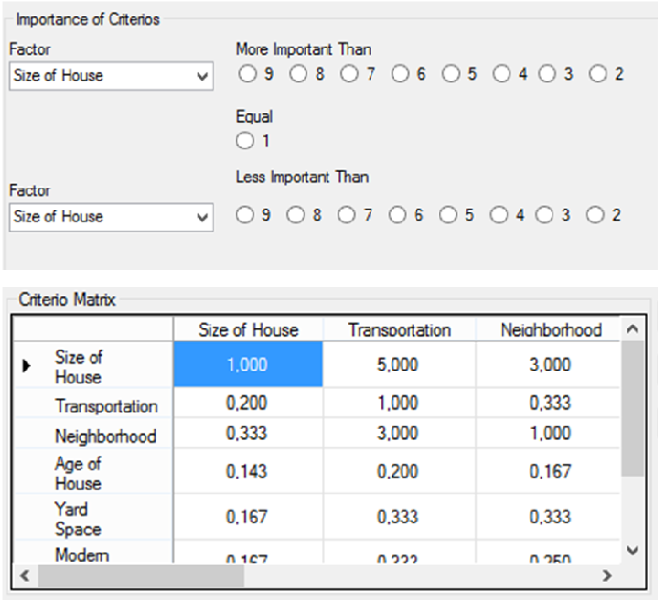

Fig. 4.Comparison matrices for between each criterion of each level of the hierarchy.

At the next stage the user has to provide the comparison matrices between each criterion and alternatives as shown below (Fig. 5).

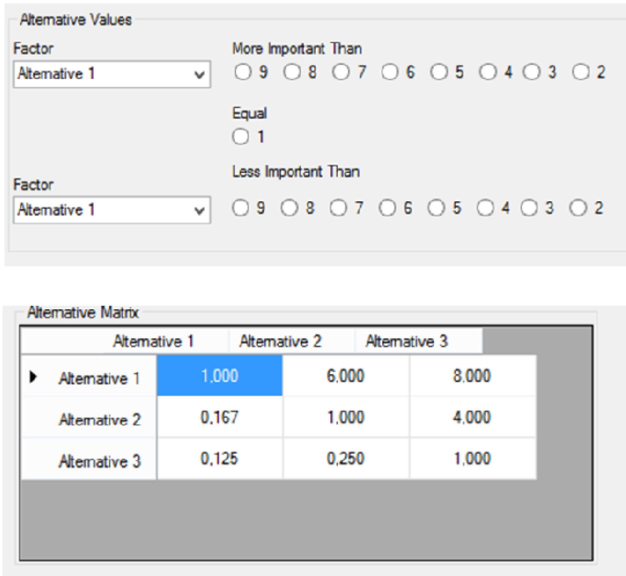

Fig. 5. Comparison matrices for between each criterion and the alternatives.

When the necessary pairwise elements have been assessed (this action is invoked by pressing a dedicated button), the user presses the button Compute and the software computesthe priorities for each alternative of the decision matrix (Fig. 6).

Fig. 6. The priorities for each alternative as computed by the AHP method.

At the right of the form the priorities of each alternative have been computed and are presented in Table 2.

Table 2. The priorities for each Alternative.

	Alternative1	Alternative2	Alternative3
Priority	0.395	0.341	0.264

4. SAIL Example

Sail project concerns the Trieste-Fernetti complex, which plays a crucial role in the Friuli Venezia Giulia region. This specific complex consists of the Trieste Port and a Dry Port operated by Fernetti (Fig. 7). Due to the increased flow of trucks and containers the first signs of traffic saturation has emerged. This kind of traffic issues between the two sites, create both traffic congestion in the city of Trieste and also affects the throughput of the Port of Trieste and its reliability and financial revenue. Therefore strategic decisions regarding ways to compensate for the increased flow should be in place.

Fig. 7. ***The Trieste- Fernetti complex.***

Within the SAIL project, the AHP software will be used to address this type of decisions. A preliminary scenario involves the assessment of three alternatives using three criteria. The three alternatives are: a) operate an extra gate at the Port (ALT1), b) establish a railway connection between the Port and the Dry-Port (ALT2) and c) establish a shuttle service to move the containers between the Port and the Dry port (ALT3). The involved criteria are: Financial, Environmental Traffic related. The Hierarchy is depicted in Fig. 8.

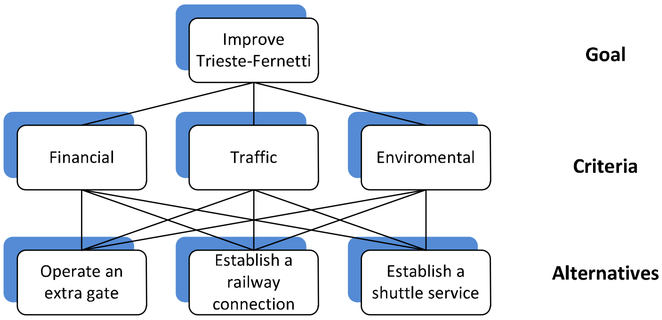

Fig. 8. The goal, criteria and alternatives of our case.

Tables 3-6 include the necessary criteria and criteria alternative matrices while Table 7, depicts the output of the software.

Table 3.The criteria matrix.

	Financial	**Traffic**	**Environmen**
Financial	1	6	3
Traffic	1/6	1	½
Environmental	¼	2	1

Table 4.Financial alternatives matrix.

	ALT1	**ALT2**	**ALT3**
ALT1	1	1/3	1/5
ALT2	5	1	3
ALT3	3	1/3	1

Table 5.Traffic alternatives matrix.

	ALT1	**ALT2**	**ALT3**
ALT1	1	2	1/3
ALT2	½	1	1/5
ALT3	3	5	1

Table 6.Environmental alternatives matrix.

	ALT1	ALT2	ALT3
ALT1	1	5	7
ALT2	1/5	1	3
ALT3	1/7	1/3	1

Table 7. The priorities for each Alternative.

	Operate an Extra gate	Establish a Railway connection	Establish a shuttle service
Priority	0.262	0.433	0.305

Where ALT1: Operate an Extra Gate, ALT2: Establish a railway station, ALT3: Establish a Shuttle Service.

5. Conclusions

We have presented a generic software tool for the implementation of the Analytic Hierarchy Process. We have described in detail the AHP method, what are the steps to build the Hierarchy tree and the pairwise weights for each criterion. Finally the computation and the presentation of the priorities of each alternative are presented and the final choice is made by the user choosing the alternative with the highest priority. The presented here, software tool can be used for any decision making problem where anyone would like to compute the AHP priorities of the alternatives.

In future work, we will also augment the tool by providing the absolute variant of the AHP as well as functionality for sensitivity analysis.Moreover we are going to implement and test the Analytic Network Process (Saaty et al. 2006), an extension of the AHP

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