The Analytic Hierarchy Process – An Application In Engineering Education

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Abstract: **Engineers often make decisions where different factors have to be weighed before taking a decision. The multi-criteria decision problems and tools are not part of the undergraduate curriculum of Rajasthan Technical University at present, though engineers are faced with such decisions in their day-to-day working. This paper reviews the Analytic Hierarchy Process, a simple and easy to use tool for dealing with multi-criteria decision situations. The paper argues that a knowledge of AHP will be useful for undergraduate engineering students. In view of the possible reluctance of students to devote their time for non-curricular learning, the paper proposes solving of a specific problem faced by students as a means of educating them in use of AHP.**

1. INTRODUCTION

Analytic Hierarchy Process (AHP) is a simple, easy to use tool for dealing with multi-criteria decision situations developed by prof. Thomas Saaty [1]. A classic example used to explain its application is the buying of an automobile, where criteria like prestige, safety, performance and price need to be considered before arriving at a decision. Another common application is found in vendor selection where cost, quality, delivery and service are considered. AHP also finds wide application in allocation of resources. For a tool that has such broad applicability, the analytical hierarchy process (AHP) is not widely known [2]. By reducing complex decisions to a series of pair-wise comparisons, and then synthesizing the results, the AHP helps to capture both subjective and objective aspects of a decision. AHP incorporates a useful technique for checking the consistency of the decision maker's evaluations, thus reducing the bias in the decision making process [3].

AHP is a tool for making choices. Typical examples of AHP applications are vendor selection [4-6] , project selection [7-8], product selection [9]. Faculty selection has been reported as one application of AHP [10].

Engineers have to take resource allocation or selection decisions routinely in their daily working. As such, it would be good for them to be aware of simple techniques that can help them in arriving at and justifying their decisions. While the AHP is not included in the syllabus of the undergraduate (UG) engineering program, its utility, ease of use and ready adaptability to situations where a choice needs to be made from several alternatives, it is suggested that even the UG engineering students need to be familiar with this versatile tool.

The structure of an AHP hierarchy is shown in Figure 1. The Goal or the Objective is resolved into a number of criteria, which could be dependent on one or more sub-criteria. The criteria govern the different alternative choices. Thus in the simplest form, an AHP hierarchy consists of three levels – Goal, Criteria and alternatives.

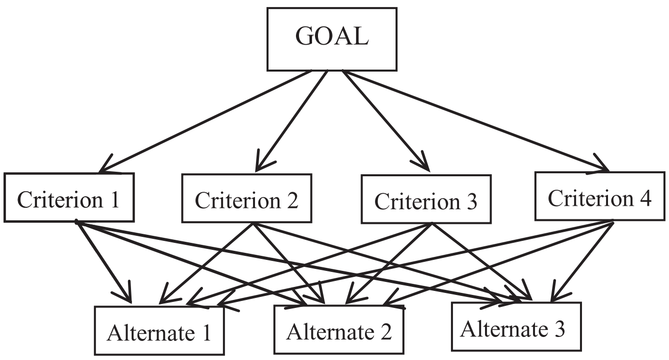

Fig 1: Structure of Hierarchy of AHP

The AHP selection process essentially consists of four steps:

1. Decide upon the criteria for selection.
2. Rate the relative importance of these criteria using pair-wise comparisons.
3. Rate each potential choice relative to every other choice on the basis of each selection criterion-this is achieved by performing pair-wise comparisons of the choices with respect to each criterion independently.
4. Combine the ratings derived in steps 2 and 3 to obtain an overall relative rating for each potential choice

In view of the fact that students are likely to be reticent in devoting their time to learning something which may not contribute towards their grade, we need to select a suitable problem to be solved with AHP – such that it captures their attention and motivates them to learn of AHP.

This paper discusses a very common problem faced by the students, namely, selecting their final year project. This will ensure their interest in learning this technique as well as serve as a practical example for them to solve.

2. THE PROBLEM

Engineering students are required to carry out a project in their final year. This is a group activity with the group being of 3 to 6 students. Students are generally enthusiastic as they see this as an opportunity to create something using their learning and acquired skills across different engineering subjects. However, they have many ideas for their project, and they face a great difficulty in selecting their project. Many times they change their project after doing considerable work on one idea. AHP can help them in selecting the best of the different alternatives.

The first step in the exercise is determining the criteria for selecting the project. Some important criteria for evaluating the different ideas are Appeal, Feasibility, Utility, and Cost. Appeal would depend upon several subjective parameters such as scoring potential in examination, interesting concept for viewers, novelty of idea/product, its permanence and ability to be displayed in exhibitions as also to its potential to yield a business opportunity. Feasibility would depend on the availability of requisite information and tools, competence of the student group, local availability of required resources and inputs, availability of guidance and the certainty of completion of work within the available time. Utility would mean that the project work is contributing to augmentation of existing facilities in the Institute. Cost would be considered better if the cost is lower.

The next step is to compare these criteria in a pair-wise fashion i.e. comparing one criterion with another criterion at a time to determine their relative importance in the context of a student project. The more important criterion is assigned a numerical score between 1 to 9 in accordance to Table 1, the score of One representing equal importance and a score of Nine indicating absolute relative importance. The reciprocal of this score is then assigned to the other criterion in the pair.

Table 1: Value of Criteria [11]

Value	Description of Comparison
1	Equality
3	Somewhat greater importance of one criterion over another
5	Strong superiority of one criterion over another
7	Very strong superiority of one criterion over another (clearly seen in practice)
9	Absolute (highest possible) superiority of one criterion over another
Note: Use of intermediate values (2, 4, 6, 8) is permitted.	

The results of this operation are presented in Table 2, which shows that, for this particular project group, cost and utility are much more important than appeal.

Table 2: Pair-wise rating of selection criteria

Criterion	Appeal	Feasibility	Cost	Utility
Appeal	1	7-Jan	5	5
Feasibility	7	1	5	3
Cost	5-Jan	5-Jan	1	7
Utility	5-Jan	3-Jan	7-Jan	1
Column Total	8.4	1.676	11..143	16

The weights in Table 2 are then normalized, by dividing each entry in a column by the sum of all the entries in that column, such that they add up to one. Following normalization, the weights are averaged across the rows to derive an average weight for each criterion as shown in Table 3.

Table 3: Average Weight of selection criteria

Criterion	Appeal	Feasibility	Cost	Utility	Average Weight
Appeal	0.119	0.085	0.449	0.3125	0.2414
Feasibility	0.833	0.597	0.449	0.1875	0.5166
Cost	0.024	0.119	0.089	0.4375	0.1674
Utility	0.024	0.199	0.013	0.0625	0.0746
Column Total	1.000	1.000	1.000	1.000	1.000

It is evident from Table 3 that the student project group considers Feasibility (average weight 0.5166) to be of highest importance, with Appeal (average weight 0.2414) being the next important criterion for them. It is interesting to note that Feasibility and Appeal are being considered by this group as being more important to Cost. It is very important here to note that the data in Table 2 and Table 3 reflect the considerations of a particular student project group, and other student groups may have different opinions about the relative importance of these criteria.

The next step in AHP is the pair-wise comparison of the alternative project ideas to quantify how well they satisfy each of the criteria. This project group is considering three project ideas for final selection. These are:

1. All Terrain Vehicle (ATV)
2. Modification of existing manual rickshaw for physically challenged persons (Modi), and
3. Dual Powered (Human power + Solar power) Tricycle (DPT)

Thus our AHP structure is as shown in Figure 2.

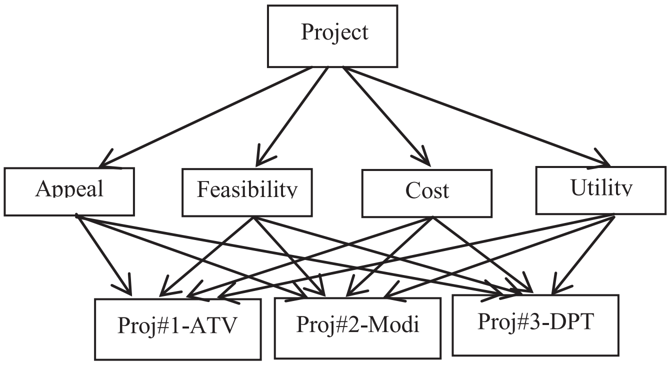

Fig 2: AHP Structure of Student Project Selection Problem

For each pairing within each criterion, the better project is awarded a rating on a scale between 1 (equally good) and 9 (absolutely better), whilst the other project in the pair is awarded a rating equal to the reciprocal of this value. The results for the criterion 'Appeal' are shown in Table 4. Each entry in this matrix records how well the project idea corresponding to its row meets the 'Appeal' criterion when compared to the project idea corresponding to its column. For example, the Project Idea #3 (DPT, weighted score 0.7013) is found to have a much higher appeal than Project Idea #2 (Modi, weighted score 0.0853) and a moderately higher appeal than Project Idea #1 (ATV, weighted score 0.2133) by this project group. The ratings in these comparison matrices are normalized as before and averaged across the rows to give an average normalized rating in Table 5. A similar exercise is carried out for other criteria namely Feasibility, Cost and Utility. These computations being repetitive in nature are not shown here for considerations of space. The average normalized ratings with respect to each of the selection criteria are summarized in Table 6.

Table 4: Pair-wise rating of alternative project ideas with respect to 'Appeal' criterion

Subject	Project Idea #1	Project Idea #2	Project Idea #3
Project Idea #1 (ATV)	1	3	1/4
Project Idea #2 (Modi)	1/3	1	1/7
Project Idea #3(DPT)	4	7	1
Column Total	5.333	11	1.393

Table 5: Normalized pair-wise rating of alternative project ideas with respect to 'Appeal' criterion

Subject	Project Idea #1	Project Idea #2	Project Idea #3	Average normalized rating ($W_{pi}K_1$)
Project Idea #1 (ATV)	0.188	0.273	0.179	0.2133 ($W_{p1}K_1$)
Project Idea #2 (Modi)	0.062	0.091	0.103	0.0853 ($W_{p2}K_1$)
Project Idea #3(DPT)	0.75	0.,636	0.718	0.7013 ($W_{p3}K_1$)
Column total	1	1	1	0.9999

Table 6: Average normalized rating ($W_{pi}K_j$) of each Project (P_i) with respect to each criterion (C_j)

Criterion / Alternatives	Appeal (j_1)	Feasibility (j_2)	Cost (j_3)	Utility (j_4)
Project Idea #1 (ATV)	0.2133 (W_{11})	0.0640 (W_{12})	0.0613 (W_{13})	0.0613 (W_{14})
Project Idea #2 (Modi)	0.0853 (W_{21})	0.6690 (W_{22})	0.7230 (W_{23})	0.7230 (W_{24})
Project Idea #3(DPT)	0.7013 (W_{31})	0.2673 (W_{23})	0.2157 (W_{33})	0.2157 (W_{34})

The final step in the AHP is to combine the average normalized ratings (Table 6) with the average normalized criterion weights (Table 3) to produce an overall rating for each alternative project idea, i.e. the extent to which the project ideas satisfy the criteria is weighted according to the relative importance of the criteria.

This is done as follows:

$$Z_i = \sum_{1}^{j} W_{ij}\, C_j$$

where

Z_i = overall score for alternative project idea *i*,

W_{ij} = average normalized weight for project idea i with respect to criterion *j*, and

Cj = average normalized weight for criterion *j*

3. THE RESULT

Table 7 gives the results of this final step. These results show clearly that Project Idea #2, Modification of Tricycle for the Physically Challenged is the best project based on the given considerations. Project Idea #3, Dual Powered Tri-Cycle is the second best project idea for this project group.

Table 7: Overall Score of Alternatives

Alternative	Overall Score
Project Idea #1 (ATV)	0.099
Project Idea #2 (Modi)	0.541
Project Idea #3(DPT)	0.36

A review of the Table 6 shows that the final winner, Project Idea #2 (Modi) has scored the highest position with respect to three criteria namely feasibility, cost and utility. It has been adjudged the second best with respect to the criterion ‘Appeal’, where the project Idea #3 (DPT) has been adjudged the best. The criterion ‘Appeal’ has been rated the second most important criterion with a weight of 0.2414 against the most important criterion ‘Feasibility’ which has a weight of ‘0.5166’.

4. SENSITIVITY ANALYSIS

It has been stated above that the results are pertinent to the specific project group. This is because the computation reflects the thinking and priorities of the particular group. Another group of students may be having different priorities or preferences. The final scores for the different alternatives may then differ. It can also be argued that the pair-wise comparison scores are not absolute, and it is quite possible that a score of 7 could have been assigned where a 5 or 9 has been assigned. After all, this assignment of score is a judgemental process and not a mathematical absolute. For example, when comparing the project idea #3 (DPT) with Project Idea #1(ATV) with respect to criterion ‘Appeal’ in Table 4, while it may be clear that Project Idea #3 has more appeal than Project Idea #1, it may be difficult to rate it precisely on a scale of 1 to 9, A weight of 4 has been used to quantify the greater appeal, although scores of 3 or 5 could be justifiably assigned instead. Statements such as `slightly more important' or `very much more important' for the different scores also do not produce unique weights.

It is therefore important to know how the results will be affected by such variations in the pair-wise scores either for the alternatives or for the criteria. The robustness of the result can be tested by using sensitivity analysis. Sensitivity analysis addresses the question: `how sensitive is the overall decision to small changes in the individual weights assigned during the pair-wise comparison process’? This question can be answered by varying slightly the values of the weights and observing the effects on the decision. This process is made simple if the pair-wise comparison matrices are held in a computer. Several software, including Expert Choice® and Super decisions®, have been developed for AHP; many of these are available free of cost. Sensitivity Analysis is recommended where the final scores of two alternatives are close. A sensitivity analysis carried out for the present example using Super decisions®

reveals the following:

a) The final scores of Project Idea #3 DPT as well as of the Project Idea #1 ATV increase with the increase in weight of the criterion 'Appeal'. Project Idea #3 DPT moves ahead of Project Idea #2 MODI if the weight of Appeal increases above 0.615.

b) The final scores of Project Idea #3 DPT as well as of the Project Idea #1 ATV increase with the decrease in weight of the criterion 'Feasibility'. Project Idea #3 DPT moves ahead of Project Idea #2 MODI if the weight of Feasibility decreases below 0.187.

c) The increase in weights of 'Cost' or 'Utility' does not affect the final ranking of the alternates for this project.

Sensitivity analysis helps in identifying the pair wise comparison weights that the overall decision is most sensitive to. These weights are the ones that must be assigned with the greatest accuracy and the AHP results should be qualified by referring to these sensitivities [12].

5. CONCLUSION

The AHP makes the selection process very systematic and transparent [12]. It helps in conditioning imprecise data and approximations for mathematical treatment. Most important, it generates a precise logic as well as a record behind the decision which can be understood as well as reviewed at a later date. A sensitivity analysis helps in checking the robustness of the decision, thus assuring the decision maker of its validity.

The use of AHP demands that the criteria for evaluating the different alternatives are spelled out, and their relative importance be identified. Thus students using AHP learn to resolve problems by systematic identification of pertinent factors thereby enhancing their depth of understanding of the problem. It further augments their understanding of the alternative solutions since these must be understood if their relative merits are to be assessed correctly.

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