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Implementation of the AHP in Construction Project Management

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***Abstract* - This paper presents the Analytical Hierarchy Process (AHP) as a possible deciding method to be used in project management. The contractor prequalification problem is employed as an example. A hierarchical data structure is made for the prequalification criteria and therefore the contractors wishing to prequalify for a project. By applying the AHP, the prequalification criteria are often prioritized and descending-order lists of contractors are often made so on pick the only contractors to perform the project. Sensitivity analyses are often performed to see the sensitivity of the ultimate decisions to minor changes in judgements. The paper presents group decision-making using the AHP. The AHP implementation steps are going to be simplified by using the 'Expert Choice' professional software that's available commercially and designed for implementing AHP. It is hoped that this might encourage the appliance of the AHP by project management professionals.**

Index Terms: — Analytical hierarchy process; AHP; Project management; Contractor prequalification

1. INTRODUCTION

The Analytical Hierarchy Process (AHP) is a decision-aiding method developed by Saaty [24–27]. This aims at quantifying relative priorities for a given set of alternatives on a ratio scale, supported the judgment of the decision-maker, and stresses the importance of the judgments of a decision-maker also because the consistency of the comparison of alternatives within the decision-making process [24]. A decision-maker check judgment on knowledge and knowledge, then makes decisions accordingly, the AHP approach agrees well with the behaviour of a decision-maker. The strength of this approach is that it organizes tangible and intangible factors during a scientific way, and provides a structured yet relatively simple solution to the decision- making problems [29]. In addition, by breaking a drag down during a logical fashion from the massive, descending in gradual steps, to the smaller and smaller, one is in a position to attach, through simple paired comparison judgments, the tiny to the massive. The objective of this paper is to introduce the appliance of the AHP in project management. This paper will briefly review the concepts and applications of the multiple criteria decision analysis, the AHP's implementation steps, and demonstrate AHP application on the contractor pre-qualification problem. It is hoped that this may encourage its application within the whole area of project management.

2. Multiple criteria decision analysis (MCDA)

A. Team managers are faced with decision environments and problems in projects that are complex. The elements of the issues are numerous, and therefore the interrelationships among the weather are extremely complicated. Relationships between elements of a drag could also be highly nonlinear; changes within the elements might not be related by simple proportionality. Experts value and judgment systems are integral elements of project problems. Therefore, the power to form sound decisions is extremely important to the success of a project. In fact, Schuyler makes it a skill that is certainly near the top of the list of project management skills, and notices that few folks have had formal training in decision making. Multiple criteria decision-making approaches are major parts of decision theory and analysis. They give to take explicit account of more than one criterion in supporting the decision process. The purpose of MCDM methods is to assist decision-makers study the issues they face, to find out about their own and other parties' personal value systems, and find out attributes and objectives, and through exploring these in the context of the problem to guide them in identifying a preferred. This tool MCDA is useful in circumstances which necessitate the consideration of different courses of action, which cannot be evaluated by the measurement of a simple, single dimension.

B. Researcher published a comprehensive survey of multiple attribute decision making methods and applications. These are two types of the problems that are common in the project management that best fit MCDA models are evaluation problems and design problems. The evaluation problem cares with the evaluation of, and possible choice between, discretely defined alternatives. Matter is concerned with the identification of a preferred alternative from a potentially infinite set of alternatives implicitly defined by a set of constraints.

3. ANALYTIC HIERARCHY PROCESS

It is a powerful tool for decision-making technique and had been delivered by Saaty , and developed a decision method for measuring the priorities of all alternatives according to the ratio scale. This tools approach depends on evaluating pairs' options, within pertinent criteria. This value compares the criteria consistent with their intensity and preferences. This tool is a procedure of evaluating options that meets a selected group of criteria and goals. Risk magnitude might be assessed by considering two parameters: Risk severity and Risk likelihood. The result is based totally upon a number of alternative evaluations in terms of some of criteria. These application strategies offer a powerful tool to handle subjectivities and uncertainties arising in the construction procedures and assist for solving complex problems. It was used by hierarchical multilevel of objectives, sub criteria hierarchical structure, criteria hierarchical structure with alternatives hierarchical structure using pair wise comparisons. All value was utilized to find importance weights for decision-making criteria plus relative performance of alternative measures of individual criterion, in case of comparisons are not consistent completely, there after it improves consistency mechanism. Saaty developed the following steps for applying the AHP:

1. Define the problem and determine its goal.
2. Structure the hierarchy from the top (the objectives from a decision-maker's viewpoint) through the intermediate levels (criteria on which sub- sequent levels depend) to the lowest level which usually contains the list of alternatives.
3. Construct a set of pair-wise comparison matrices (size n x n) for each of the lower
4. Levels with one matrix for each element in the level immediately above by using the relative scale measurement shown in Table 1.
   The pair-wise comparisons are done in terms of which element dominates the other.
5. There is n (n -1) / judgments required to develop the set of matrices in step 3. Reciprocals are automatically assigned in each pair-wise comparison.
6. Hierarchical synthesis is now used to weight the eigenvectors by the weights of the criteria and the sum is taken over all weighted eigenvector entries corresponding to those in the next lower level of the hierarchy.
7. Having made all the pair-wise comparisons, the consistency is determined by using the eigen value, λ_{max}, to calculate the consistency index, CI as follows: $CI = (\lambda max - n) / (n - 1)$, where is the matrix size. Judgment consistency can be checked by taking
   the consistency ratio (CR) of CI with the appropriate value in Table 2. The CR is acceptable, if it does not exceed 0.10. If it is more, the judgment matrix is inconsistent. To obtain a consistent matrix, judgments should be reviewed and improved.
8. Steps 3−6 are performed for all levels in the hierarchy.

Table1. AHP pair wise comparison between two parameter scales.

Rating	Preferences judgments
09	Excessively agree
08	Very strongly – excessively
07	Very strongly agree
06	Strongly – very strongly
05	Strongly agree
04	Moderately – strongly
03	Moderately agree
02	Equally – moderately
01	Equally agree

Table 2. Average values of random consistency index (Data from Saaty 1980)

Matrix size	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

1) Pair wise and consistency

AHP help for measures of evaluation with provide helpful technique for examine evaluations consistency for reducing all conflicts in decision making. This structure is divided into detailed appropriate level, recognizing more criteria included, less important of each individual criterion. Between top and bottom levels establish decision problem relevant attributes such as objectives and selection criteria. Next, each item's relative weights are established at corresponding level. All criteria summation should be equal to 1. It can be said the matrix of (i&j&k) ai,j=ai.k ak.j ai,j= 1/aj,i where i&j & k are alternatives of studied matrix.

2) 6.3. Illustrative example

This example explains the steps for the contractor prequalification problem for assumption construction project according to the experience using the Analytical Hierarchy Process. Table 3 shows an Illustrative example for which contractors A, B, C, D, and E wish to prequalify. Using AHP procedures which was described, hierarchy problem could be illustrated and interpreted as presented.

Table 3 Example

Factors	Contractor A	Contractor B	Contractor C	Contractor D	Contractor E
Experience	6 years experience	11 years' experience	15 years' experience	15 years' experience	10 years' experience
Financial Stability	3.2crore assets	16.6 crore assets	350 crore assets	1.75 crore assets	3.2 crore assets
Quality Performance	Good	Average	Good	Average	Good
Manpower Resources	90 labours	730 labours	750 labours	250 labours	900 labours
Equipment Resources	4 Mixer Machines	6 Mixer Machines	1 Batching Plant	4 Mixer Machines	2 Mixer Machines
	1 JCB, 10 others	1 JCB	1 JCB ,2 RMC Trucks	1JCB, 8 others	10 others

Current works load	2 big projects ending	2 projects ending	6 projects started	10 big projects are in Progres s	4small projects started

Level 1 Goal	Selecting the most suitable contract					
Level 2 Goal	EXP.	FS	QP	MPR	ER	CWL
Level 3 Goal	CONTRACTORS					
	A	A	A	A	A	A
	B	B	B	B	B	B
	C	C	C	C	C	C
	D	D	D	D	D	D
	E	E	E	E	E	E

A, B, C, D, E are the contractors being prequalified Then, the following can be done manually or automatically by the AHP software.

1. Synthesizing the pair-wise comparison matrix (example: Table 5);
2. Calculating the priority vector for a criterion such as experience (example: Table 5);
3. Calculating the consistency ratio;
4. Calculating λ_{max};
5. Calculating the consistency index, CI;
6. Selecting appropriate value of the random consistency ratio from Table 2; and
7. Checking the consistency of the pair-wise comparison matrix to check whether the decision-maker's comparisons were consistent or not.

The calculations for these items will be explained next for illustration purposes. Synthesizing the pair-wise comparison matrix is performed by dividing each element of the matrix by its column total. For example, the value 0.08 in Table 5 is obtained by dividing 1 (from Table 4) by 15.5, the sum of the column items in Table 4 (1 . 5 . 3 . 6 . 1/2).

Table 4 Pair-wise comparison matrix for Experience

Experience	A	B	C	D	E
A	1	1/5	1/3	1/6	2
B	5	1	2	1/2	4
C	3	1/2	1	1/3	3
D	6	2	3	1	7
E	1/2	1/4	1/3	1/7	1

The priority vector in Table 5 can be obtained by finding the row averages. For example, the priority of contractor A with respect to the criterion `experience' in Table 5 is calculated by dividing the sum of the rows (0.08 . 0.082 . 0.073 . 0.078 . 0.118) by the number of contractors (columns), i.e., 5, in order to obtain the value 0.086. The priority vector for experience, indicated in Table 5, is given below.

$$\begin{bmatrix} 0.073 \\ 0.269 \\ 0.165 \\ 0.440 \\ 0.053 \end{bmatrix}$$

Now, estimating the consistency ratio is as follows:

Table 5 Synthesized matrix for experience.

Experience	A	B	C	D	E	Priority Vector
A	0.064	0.050	0.050	0.077	0.125	0.073
B	0.322	0.253	0.300	0.223	0.25	0.269
C	0.193	0.126	0.150	0.148	0.176	0.165
D	0.387	0.506	0.450	0.446	0.411	0.440
E	0.032	0.063	0.050	0.063	0.058	0.053

$$0.073\begin{bmatrix} 1 \\ 5 \\ 3 \\ 6 \\ 1/2 \end{bmatrix} + 0.269\begin{bmatrix} 1/5 \\ 1 \\ 1/2 \\ 2 \\ 1/4 \end{bmatrix} + 0.165\begin{bmatrix} 1/3 \\ 2 \\ 1 \\ 3 \\ 1/3 \end{bmatrix} + 0.440\begin{bmatrix} 1/6 \\ 1/2 \\ 1/3 \\ 1 \\ 1/7 \end{bmatrix}$$

$$+0.053\begin{bmatrix} 2 \\ 4 \\ 3 \\ 7 \\ 1 \end{bmatrix} = \begin{bmatrix} 0.360 \\ 1.067 \\ 0.823 \\ 2.282 \\ 0.273 \end{bmatrix}$$

Dividing all the elements of the weighted sum matrices by their respective priority vector element, we obtain:

$\frac{0.360}{0.073} = 4.931$, $\frac{1.397}{0.269} = 5.193$, $\frac{0.823}{0.165} = 4.987$, $\frac{2.282}{0.440} =$ 5.186, $\frac{0.273}{0.053} = 5.150$

We have computed the average of these values to obtain λ max

$$\lambda \text{ max} = \frac{(4.931 + 5.193 + 4.987 + 5.186 + 5.150)}{5} = 5.089$$

We find the consistency index, CI, as follows:

$$CI = \frac{\lambda max - n}{n-1} = \frac{5.089 - 5}{5-1} = \frac{0.0894}{4} = 0.0223$$

Selecting appropriate value of random consistency ratio, RI, for a matrix size of five using Table 2, we find RI = 1.12. We then calculate the consistency ratio, CR, as follows:

$$CR = \frac{CI}{RI} = \frac{0.0223}{1.12} = 0.0199$$

λ max = 5.089, CI = 0.0223, RI = 1.12, CR = 0.0199 < 0.1 OK.

Table 6 Pair-wise comparison matrix for financial stability (FS)

Experience	A	B	C	D	E	Priority vector
A	1	5	3	2	7	2.31
B	1/5	1	1/4	1/2	3	0.404

C	1/3	4	1	1/3	5	0.837
D	1/2	2	3	1	7	1.198
E	1/7	1/3	1/5	1/7	1	0.197

λ_{max} = 5.252, CI = 0.063, RI = 1.12, CR = 0.056 < 0.1 OK. As the value of CR is less than 0.1, The judgement is acceptable.

Table 7 Pair-wise comparison matrix for quality performance (QP)

Experience	A	B	C	D	E	Priority vector
A	1	8	1/3	2	7	1.344
B	1/8	1	1/5	1/4	4	0.353
C	3	5	1	4	8	2.25
D	1/2	4	1/4	1	6	0.80
E	1/7	1/4	1/8	1/6	1	0.163

λ_{max} = 5.43, CI = 0.108, RI = 1.12, CR = 0.096 < 0.1 OK. As the value of CR is less than 0.1, The judgement is acceptable.

Table 8 Pair-wise comparison matrix for manpower resources (MPR)

Experience	A	B	C	D	E	Priority vector
A	1	1/4	1/3	4	5	0.79
B	4	1	1/2	5	7	1.59
C	3	2	1	6	4	1.84
D	1/4	1/4	1/2	1	2	0.43
E	1/5	1/7	1/4	1/2	1	0.20

λ_{max} = 5.79, CI = 0.19, RI = 1.12, CR = 0.017 < 0.1 OK. As the value of CR is less than 0.1, the judgements are acceptable.

Table 9 Pair-wise comparison matrix for equipment resources (ER)

Experience	A	B	C	D	E	Priority vector
A	1	1/8	1/6	3	2	0.438
B	8	1	¼	7	5	1.445
C	6	4	1	9	9	2.636
D	1/3	1/7	1/9	1	2	0.268
E	1/2	1/5	1/9	1/2	1	0.211

λ_{max} = 5.412, CI = 0.10, RI = 1.12, CR = 0.091 < 0.1 OK. As the value of CR is less than 0.1, the judgements are acceptable.

Table 10 Pair-wise comparison matrix for current work load (CWR)

Experience	A	B	C	D	E	Priority vector
A	1	1/3	1/5	3	3	0.623
B	3	1	3	6	6	1.879
C	5	1/3	1	2	2	1.039
D	1/3	1/6	1/2	1	2	0.366
E	1/3	1/6	1/2	1/2	1	0.255

λ_{max} = 5.552, CI = 0.138, RI = 1.12, CR = 0.12 < 0.1 OK. As the value of CR is less than 0.1, the judgements are acceptable

Table 11 Pair-wise comparison matrix for the six criteria

Experience	FS	QP	MPR	ER	CWL	Priority vector
Exp.	2	3	6	6	5	2.272
FS	1	3	6	6	5	1.583
QP	1/3	1	4	4	3	1.06
MPR	1/6	1/4	1	2	½	0.336
ER	1/6	1/4	1/2	1	¼	0.222
CWL	1/5	1/3	2	4	1	0.4987

λ_{max} = 6.40, CI = 0.080, RI = 1.24, CR = 0.064 < 0.1 OK. As the value of CR is less than 0.1, the judgements are acceptable.

Table 12 priority matrix for contractor prequalification.

EXP	EXP (2.27)	FS (1.58)	QP (1.06)	MPR (0.33)	ER (0.22)	CWL (0.49)	Priority vector
A	0.073	2.31	1.344	0.79	0.438	0.623	5.82
B	0.269	0.404	0.353	1.59	1.445	1.879	3.38
C	0.165	0.837	2.25	1.84	2.636	1.039	5.775
D	0.440	1.198	0.80	0.43	0.268	0.366	4.116
E	0.053	0.197	0.163	0.20	0.211	0.255	0.839

Overall priority of contract A
= 2.27(0.073) + 1.58(2.31) +1.06(1.344) +0.33 (0.79) +0.22(0.438) +0.49(0.623)
= 0.165 +3.64 +1.124 +0.260 +0.096 +0.23 +0.305 = **5.82**

Overall priority of contract B
= 2.27(0.269) + 1.58(.404) +1.06(.353) +0.33 (1.59) +0.22(1.445) +0.49(1.879)
= 0.610 +0.638 +0.374 +0.524 +0.317 +0.920 = **3.383**

Overall priority of contract C
= 2.27(0.165) + 1.58(.837) +1.06(2.25) +0.33 (1.84) +0.22(2.63) +0.49(1.039)
= 0.374 +1.322 +2.385 +0.607 +0.578 +0.509 = **5.775**

Overall priority of contract D
= 2.27(0.440) + 1.58(1.198) +1.06(0.80) +0.33 (0.43) +0.22(0.268) +0.49(0.366)
= 0.998 +1.892 +0.848 +0.141 +0.058 +0.179 = **4.116**

Overall priority of contract E
= 2.27(0.053) + 1.58(0.197) +1.06(0.163) +0.33 (0.20) +0.22(0.211) +0.49(0.255)

= 0.120 +0.311 +0.172 +0.066 +0.046 +0.124 = **0.839**
For prequalification purposes, the contractors are now ranked according to their overall priorities, as follows:

A, C, D, B, and E, indicating that A is the best qualified contractor to perform the project Expert Choice does provide facilities for performing sensitivity analysis, where the decision-maker can check the sensitivity of his judgements on the overall priorities of contractors by trying different values for his comparison judgements.

7. SUMMARY

Project management involves complex deciding situations that need discerning abilities and methods to form sound decisions. This study has presented the AHP as a decision-making method that permits the consideration of multiple criteria. Study of contractor requalification was created to demonstrate AHP application in project management.

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