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ANALYTIC HIERARCHY PROCESS: A DECISION-MAKING METHOD FOR CONSTRUCTION MANAGEMENT

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ABSTRACT
This paper discusses the use of the analytic hierarchy process (AHP) in making construction management decisions. AHP involves assigning weights to a group of elements. The weighting of elements serves two purposes. First, it can be employed to prioritize (rank) elements in order to identify the key elements. This may for example help to establish the key measures for project performance. Second, assigning weight to selected measures (or criteria) may provide a more accurate judgement. It is, therefore, useful in making management decisions, such as the selection of contractors' tenders or candidates for jobs. In order to illustrate its utility, two examples adopting the AHP are presented. The first is the selection of a group of candidates for a construction management job, while the second is about the determination of the key factors for project success. In addition, descriptions and comments regarding the AHP method are also provided, including ways to improve consistency.

KEYWORDS
Construction management, Analytic hierarchy process, Multi-criteria decision making, Methods

1. INTRODUCTION

Analytic hierarchy process (AHP) becomes one of the popular methods for making business decisions. It is a kind of multi-criteria decision-making (MCDM) (Arbel and Orgler, 1990). It has been used as the quantitative tool of quality function deployment (QFD). Saaty (1980) developed AHP in the early 1970s in response to the scarce resources allocation and planning needs for the military. It involves the establishment of a framework that consists of groups of elements for rating and the use of a tailor-made questionnaire to collect the perceptions from experts or decision- makers on those groups of elements. Saaty claimed that AHP has several benefits. First, it helps to decompose an unstructured problem into a rational decision hierarchy (similar to a decision tree). Second, it can elicit more information from the experts or decision-makers by employing the pair-wise comparison of individual groups of elements. Third, it sets the computations to assign weights to the elements. Fourth, it uses the consistency measure to validate the consistency of the rating from the experts and decision-makers. It is therefore argued to be composed of both qualitative and quantitative substances.

In practice, AHP has two basic applications. First, the traditional use of it is to assign weights to tested elements (e.g. criteria, factors) and then make a decision out of several scenarios or alternatives. For example, it can assign weights to several criteria in the personnel selection exercise. Then, the markers can give each candidate the scores to the weighted criteria and choose the one with the highest total score. Second, it can help to prioritize (rank) elements in order to identify the key elements. This application is useful for organizations in determining the allocation of resources. When an organization works on several projects simultaneously, ranking the relative importance level of individual tasks may help better allocate the resources in order to minimize the costs for storage, extra transportation, and risks of out of stock and stoppage. For example, Chua et al (1999) used it to identify the critical factors for project success (CSFs). Project participants may focus on how to assign adequate resources to achieve the conditions for these factors.

Despite its emergence for more than two decades, its application has long been undesirable. It may be due to the lack of relevant computer software programs supporting its function. Recently, with the development of some commercial software packages (e.g. Expert Choice for Windows, 1996) that can use AHP, the accelerated growth of its utilization is anticipated. This paper is intended to support the use of it by introducing it to project participants. In addition, two examples are demonstrated to exhibit the differences in its practical usage. However, the writers of this paper do not imply that AHP is the only method for making business decisions or ranking of elements, but a good alternative along with other basic linear weighting methods.

2. ANALYTIC HIERARCHY PROCESS

As the term discloses, AHP involves a process. In general, it has six major steps described as follows (Saaty, 1980):

1. *Define the unstructured problem* – People have to make sure what their problems are. If they are not clear about their problems, how can they decide AHP is the appropriate method for solving the problem?

2. *Decompose the problem into a systematic hierarchical structure* – A hierarchy is similar to a decision tree. It attempts to decompose an unstructured problem into several integrated dimensions (or components or elements). This forms the first level of the hierarchy, while the problem itself is called the zero level. Each of these dimensions may be decomposed into another set of elements and so on until no further decomposition is needed. That means further decompositions will generate the second level, the third level, and so on.

3. *Employ the pair-wise comparison method* – Each group on the hierarchy will form a matrix. For example, if the group has four elements, it forms a 4-by-4 matrix. People (usually the decision-makers or experts) will compare each of the paired elements in the matrixes that form the questionnaire. Saaty (1980) recommended the use of a nine-point scale. It is understood that some very important business decisions may only involve discretion on the part of a small group of key executives of a company (Cheng and Li, 2001). However, in an academic research, a much larger sample would be required in order to be able to generalize the results to the target population.

4. *Carry out the consistency measure* – This uses to screen out the inconsistency of responses (Cheng and Li, 2001). The available commercial software packages can compute the consistency ratio (CR). A certain thresholds of CR have to be achieved for ascertaining consistent responses. Although many recently published papers still followed the old threshold values (Saaty, 1980), Saaty (1994) has set the new acceptable CR values for different matrixes' sizes. The new threshold CR values are: (1) the CR value is 0.05 for a 3-by-3 matrix; (2) 0.08 for a 4-by-4 matrix; and (3) 0.1 for larger matrices.

5. *Estimate the relative weights for the components of each level of the hierarchy* – The matrixes created would go through a sequence of calculations to attain the relative weights of the elements in each matrix. Again, the commercial software packages can do the computations. For the conceptions behind the calculations, refer to Saaty (1980) or Cheng and Li (2001).

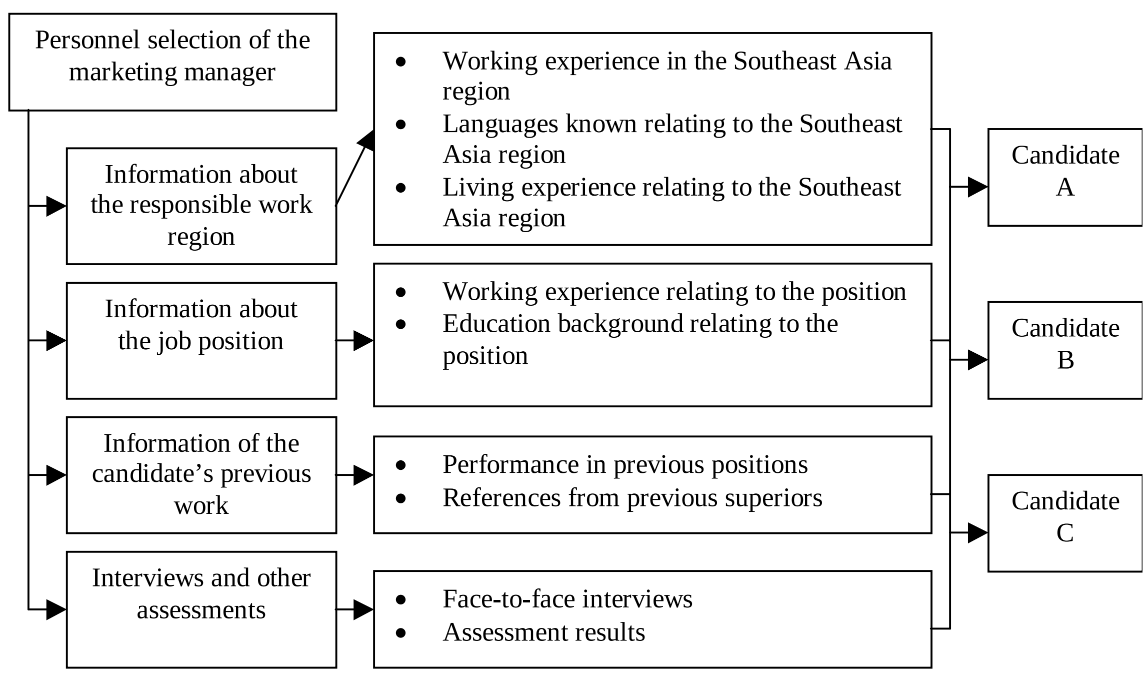
6. *Use the relative weights for different purposes* – For decision making that involves a set of scenarios or alternatives, the weighted criteria will be scored by the decision-makers so that the total score can be calculated. Personnel selections or contractor's tender selections are examples. For identifying key elements (e.g. critical factors of project success) in only one decomposed level, the elements with higher relative weights are more important. For identifying key elements in more than one decomposed level, the composite relative weights of each element of the final level will be calculated. This will be elaborated more in the example of determination of the key factors for project success.

The following sections are two examples demonstrated to show the various practices of AHP. These examples are adapted or extracted from different published papers. The examples represent the common usage of AHP, are easy to understand, and reveal the values of AHP.

3. EXAMPLE 1 – PERSONNEL SELECTION IN A CONSTRUCTION COMPANY

This example is adapted from Cheng and Li (2001). The original paper demonstrated the recruitment of a marketing manager for the new Southeast Asia Development Division of a company. This may also be a common practice of many multinational construction companies when they target to expand their businesses to other countries or regions. So, we simulated a situation that a large contractor would like to expand its business to the Far East region. They would then like to recruit a marketing manager for the new set up regional office in Hong Kong. They used AHP because they would like to assign weights to the selection criteria so that a more precise decision can be finalized.

They had already defined the decision problem that was the selection of the marketing manager. They also thought that they should develop a specific set of criteria for the selection exercise. First, they determined four selection dimensions. This was the process to decompose the decision problem into the first level of the decision hierarchy. Then, under each of these dimensions, they determined different groups of sub-dimensions, which were the selection criteria. This formed the second level of the hierarchical structure. In this case, the four dimensions had individual sets of associated criteria. The criteria of one dimension had no interaction with the criteria of other dimensions. However, at the final stage, all the weighted criteria would be used to calculate a composite score for each candidate. The candidates form the final level of the hierarchy. A schematic representation of the decision hierarchy is shown in Figure 1, assuming that there are three candidates for the selection exercise.



Note: Source from Cheng and Li (2001)

Figure 1: Hierarchy Structure of the Selection Problem

As they used AHP to assign weights to these criteria, they established a questionnaire for the selection panel to fill in. This questionnaire consists of paired matrixes created from the selection dimensions and associated criteria. For example, the four dimensions formed a 4-by-4 matrix, while the three criteria to the first dimension formed a 3-by-3 matrix. Altogether there were five matrixes for comparisons. The selection panel consists of four key members of the company (i.e. the managing director, assistant managing director, director of the new Southeast Asia development division, and director of the human resources division). They were responsible to compare the paired matrixes one by one by assigning points to them collectively. As mentioned previously, a nine-point scale could be used (Saaty, 1980).

After the data entry of the panel's answers, the computer software would perform the calculations. It is worth noting that Cheng and Li (2001) used a hypothetical example where the relative weights were trivially assigned. Yet, they intended to demonstrate an example to show how the use of AHP circumvents other basic linear weighting methods. Thus, we changed to use a different set of results that had been computed from actual pair-wise comparisons for the five matrixes of the dimensions and the criteria until the relative weights of all the criteria could be finalized. Table 1 shows the relative weights to the dimensions and criteria, the final weights to the criteria, and the consistency ratios of the matrixes. Now, the weighted criteria were ready to select the candidates once the panel assigned scores (1 to 10 to each criterion in this example) to the criteria for them.

Table 1: Relative and Final Weights and CR Values for the Hierarchy

Selection Dimensions and Criteria	Relative weight of the selection dimension matrix	Relative weight of the four criteria matrixes	Final weight to each selection criterion	CR value of the criteria matrix
Information about the responsible work region	0.14			
1. Working experience in the Southeast Asia region		0.56	0.08	
2. Languages known relating to the Southeast Asia region		0.32	0.04	
3. Living experience relating to the Southeast Asia region		0.12	0.02	0.015
Information about the job position	0.4			
4. Working experience relating to the position		0.67	0.27	
5. Education background relating to the position		0.33	0.13	n.a.
Information of the candidate's previous work	0.23			
6. Performance in previous positions		0.67	0.15	
7. References from previous superiors		0.33	0.07	n.a.
Interviews and other assessments	0.23			
8. Face-to-face interview		0.5	0.12	
9. Assessment results		0.5	0.12	n.a.
CR value of the selection dimension matrix =	0.022			
Total weight of all selection criteria =			1.00	

Notes: n.a. = not applicable. The CR value could not be computed for a 2-element matrix due to the limitation of the equation. In fact, a 2-element matrix has a perfect consistency.
Source from Cheng and Li (2001) with adjusted weights' results

The panel selected three candidates from a pool of applicants, who entered into the final stage of interviews and tests. After scoring from the interviews and tests, they calculated the final score for each candidate. Cheng and Li (2001) stated the formula for calculating the final score for each candidate. The formula was set to simply multiply the weights with their respective scores and sum them up to generate the final score. The formula for this study is shown below:

$$\text{Final score} = 0.08(X1)+0.04(X2)+0.02(X3)+0.27(X4)+0.13(X5)+0.15(X6)+0.07(X7)+0.12(X8)+0.12(X9)$$

where X1 to X9 are the scores based on individual scales for criterion 1 to 9 respectively.

Table 2 lists the rating results for each candidate. From the table, the panel chose candidate B for the new position because the candidate had the highest final score. Noteworthy, if the panel had not used the AHP method and simply computed the non-weighted mean scores, they would have chosen candidate C (the non-weighted mean score of A = 6.67; B = 7.11; C = 7.44). The AHP method gave the selection panel a more precise decision to choose the right candidate for the job.

Table 2: The Scoring Results for the Candidates

Candidate	**Criterion No.**									**Final Score**
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
	0.08	**0.04**	**0.02**	**0.27**	**0.13**	**0.15**	**0.07**	**0.12**	**0.12**	
A	6	5	6	8	8	6	7	7	7	7.07
B	5	5	5	9	8	8	8	8	8	7.85
C	9	8	9	7	7	6	7	7	7	7.09

Note: Source from Cheng and Li (2001) with adjusted weights' results

4. EXAMPLE 2 – DETERMINATION OF THE KEY PROJECT SUCCESS FACTORS

This example is extracted from Chua et al (1999). The original paper presented the determination of the key factors for project success, which are also known as critical success factors (CSFs). Chua et al (1999) undertook the study based on the views that the current two popular methods for identifying CSFs are not so effective. They provided two examples:

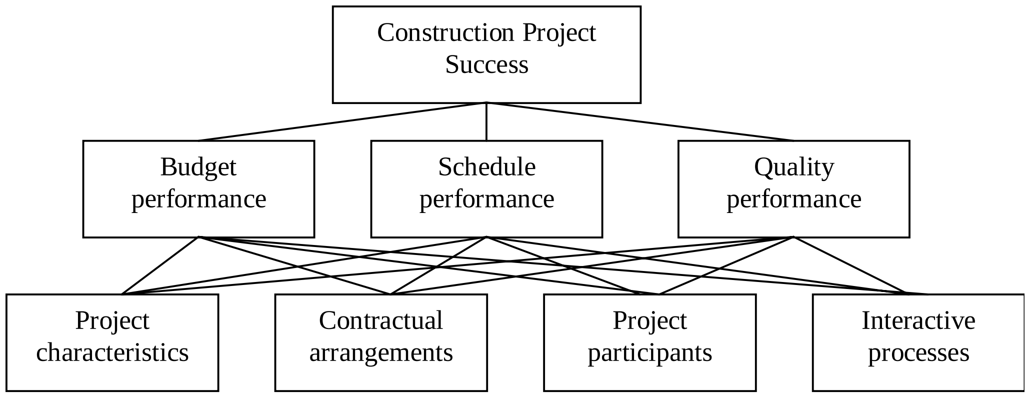
- The first method requires respondents to identify and rate a list of CSFs (Pinto and Slevin, 1987). Yet, due to difference in nomenclature and scope, the critical factors could hardly be consistent (Chua et al, 1999).

- The second method requires respondents to rate a list of pre-determined CSFs based on a scale (Chan and Kuramaswamy, 1997). If the list contains more than a few factors, it is also difficult to ensure the consistency in rating.

They use AHP because it can help to identify a proven list of potential factors by systematically decomposing the unstructured problem into a hierarchical structure and can achieve the consistency in rating. After having reviewed the appropriate literature, they developed a hierarchical model of construction project success. Figure 2 shows the zero, first, and second levels of the hierarchy. The zero level was the decision problem of the study, which was decomposed further to the first level, then to the third level, and so on. Nevertheless, this example is different from the previous one because elements of the first level were decomposed to an identical set of four elements. In other words, each of the three elements of the first level integrated with the four elements of the second level. For the detailed hierarchical model, refer to the paper of Chua et al (1999).

There were twenty construction professionals participating in the study. Although Chua et al (1999) did not disclose how the 67 potential factors were rated (e.g. either all in pairs or in different groups for paired comparison), it is understood that the more the number of elements in a matrix, the increased the difficulty in passing the consistency ratio. Due to the anticipated difficulties, they organized a briefing session to the respondents about the methodology and reminded them to pay attention to the observing consistency in their answers. They had to organize the second meeting to refine respondents' answers to achieve the consistency threshold. The prioritizing results of the twenty respondents were compared using Kendall's sampling distribution test. This statistical method is intended to compare ranks from the respondents in order to indicate whether there is positive association between the ranks. If there is significant positive association, the respondents have similar ranks giving to the 67 factors.

This paper will not go into details of how they discussed about their findings. According to their paper, they first discussed a table (see Table 3) about the relative importance of the factors under interactive processes. As shown in Table 3, the three performance objectives were the first level of the hierarchy, while the interactive processes were decomposed into the four elements (communication, planning, monitoring and control, and project organization) that formed the third hierarchical level. Then, they went to discuss about the six factors of monitoring and control which was the most important factor under the interactive processes.



Note: Source from Chua et al. (1999)

Figure 2. Hierarchy Structure for Construction Project Success

As Chua et al (1999) did not explain how they achieved the relative importance of the factors in Table 3, it is not possible to repeat the same calculations. We attempt to re-establish their analyses using the structure attached to interactive processes (see Figure 3). Under this structure, several sets of relative importance of elements had to be determined. These were a set for the three performance objectives (see Table 3), individual sets for the four factors of the second level with respect to the three performance objectives, and a set for the four factors under interactive processes. For example, under budget performance: the relative importance of communication = B x E1 x F where B, E1, and F were the relative importance of budget performance, interactive processes, and communication respectively. It is noted that there were three different values of relative importance of interactive processes with respect to the three performance objectives, say E1, E2, and E3, as in Figure 3. The same calculation was made for the other three factors, and repeated for the other two performance objectives. The three individual sets of relative importance of the four factors were normalized with 1.00 for the most important factor. This gave the relative values to the four factors under the three columns of the performance objectives as shown in Table 3. According to our estimation, the three relative importance sets of the factors under interactive processes with respect to the three performance objectives (i.e. column 2, 3, and 4 in Table 3) should be identical set when normalized with 1.00 for the most important factor. Yet, as shown in Table 3, there were three different sets belonging to individual performance objectives. We could not explain this and so leave it to Chua and his colleagues for clarification when necessary.

Table 3. Relative Importance of the Factors under Interactive Processes

Interactive processes	Budget performance (0.314)	Schedule performance (0.360)	Quality performance (0.325)
Communication	0.507 (0.18)	0.408 (0.16)	0.502 (0.22)
Planning	0.866 (0.31)	0.796 (0.31)	0.443 (0.19)
Monitoring and control	1.000 (0.36)	1.000 (0.39)	1.000 (0.44)
Project organization	0.426 (0.15)	0.349 (0.14)	0.349 (0.15)

Notes: (1) Numbers in parenthesis are the relative importance of individual sets of factors normalized to 1.00.
(2) The relative importance values of the four factors under interactive processes are normalized with 1.00 for the most important factor.
(3) “Normalized to 1.00” is different from “normalized with 1.00 for the most important factor”. The former is that sum of all relative values of the factors should be 1.00. The latter is that the relative value of the most important factor is 1.00.

Since Chua et al. (1999) did not provide all the relevant data, it is not possible to re-calculate to ascertain the process. Notwithstanding, if we have any misinterpretation about their calculations, we appreciate any clarifications.
In fact, their analytic strategy to normalize individual sets of factors with 1.00 for the most important factor is effective to form a common base for comparisons and amplify the effects of the values so that discussions about the

factors would be easier. They have provided additional benefit to the use of AHP in construction management research.

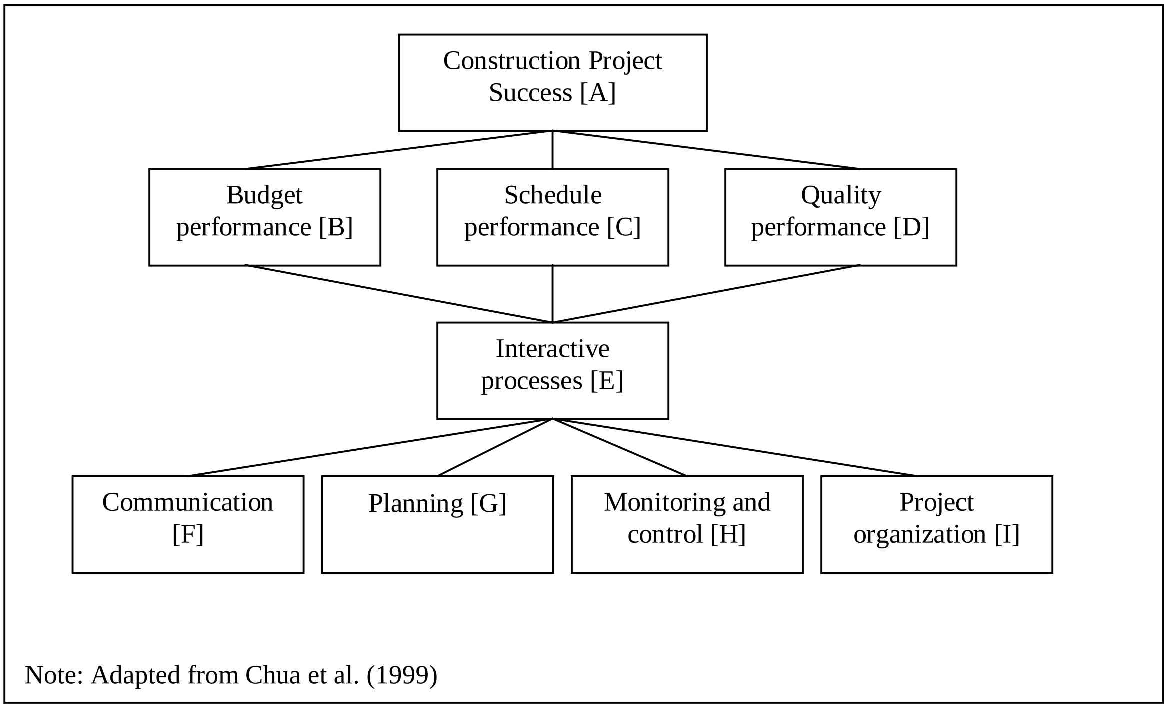


Figure 3. Hierarchical Structure Attached to Interactive Processes

5. CONCLUSIONS

This paper presents the use of AHP in construction management to make business decisions as well as conduct construction research. Two examples are demonstrated to introduce the various applications of it. The first example is about making personnel selection decision. AHP helps to develop a set of weighted criteria for the selection exercise. The selection panel assigned scores to the weighted criteria collectively. That means there were only one set of score results. The usual formula for calculating the final score is also provided. The second example is about determining the critical factors for project success. As an academic research, there were data from twenty people. In order to ascertain the consistency of responses, it is suggested to use the Kendall's sampling distribution test. This paper also simulates the analytic strategy of that paper. Normalizing the individual sets of factors with 1.00 for the most important factor is a good way to form a common base for comparisons and amplify the relative importance of the factors so that discussions would become easier. Last but not least, in order to increase the consistency of the answers, two procedures are adequate. First, the respondents should be briefed with the methodology of AHP so that they have to pay attention to the observing consistency in their answers. Second, if consistency does not achieve, researchers should require the respondents to fill in the questionnaire again but could not attempt to rely on the inconsistent answers for analysis.

6. ACKNOWLEDGEMENT

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