ANALYTIC HIERARCHY PROCESS

AN APPROACH TO DETERMINE MEASURES FOR BUSINESS PERFORMANCE

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Abstract *This paper discusses the use of the analytic hierarchy process (AHP) in assigning weights to a group of elements. The weighting of elements has two major functions. First, it is employed to prioritize (rank) elements so that the key elements can be determined. This may for example help to establish the key measures for business performance. Second, assigning weight to selected measures (or criteria) may provide a more accurate judgement. It is, therefore, useful in making business decisions, such as the evaluation of alternative marketing strategies, the selection of candidates for jobs, etc. In addition, AHP employs a consistency test to purify the usable questionnaire responses and an iterative process to improve consistency, which differentiate it from other research methods. Comments and discussions regarding the AHP method are also provided.*

Keywords *Decision making, Performance measurement, Analytical hierarchy process, Methods, Selection*

Introduction

Analytic hierarchy process (AHP) is becoming quite popular in research due to the fact that its utility outweighs other research methods. The development of AHP could be traced back to the early 1970s in response to the scarce resources allocation and planning needs for the military (Saaty, 1980). As the methodological procedure of AHP can easily be incorporated into multiple, objective programming formulations with interactive solution process (Yang and Lee, 1997), it has received a wider attention in various fields. AHP considers both qualitative and quantitative approaches to research and combines them into a single empirical inquiry. It uses a qualitative way to decompose an unstructured problem into a systematic decision hierarchy. In the quantitative sense, it employs a pair-wise comparison to execute the consistency test to validate the consistency of responses.

In practice, AHP aims at assigning weights to tested elements. Weighting of elements has two major functions. First, it is employed to prioritize (rank) elements so that the key elements can be determined. With respect to business practices, it helps to establish the key measures for business performance. Second, as it can assign weights to the key business measures, it helps to make more accurate business decisions, such as evaluation of alternative marketing strategies, selection of candidates for jobs, determination of key information for business practices, etc.

This paper is intended to introduce the use of AHP by demonstrating a hypothetical case to select the right person for a job from a group of candidates. This example also serves to highlight some critical issues in using AHP. For cumulative insights, this paper presents the AHP method and provides some suggestions for improving the use of it.

The AHP method

AHP is a hierarchical representation of a system. A hierarchy is an abstraction of the structure of the system, consisting of several levels representing the decomposition of the overall objective to a set of clusters, sub-clusters, and so on down to the final level. The clusters or sub-clusters can be forces, attributes, criteria, activities, objectives, etc. As shown in Figure 1, an eight-step method is presented for weighting elements of construction information. For illustrating the functions of AHP, a step by step description of the method is used in this paper.

Step 1. Decision problem: weighting the selection criteria

The decision problem should be defined clearly since it drives the whole process. Before the use of AHP, users must ensure that it is an appropriate method for their study objectives. They should clearly explain what their problems are and why AHP has to be used. The

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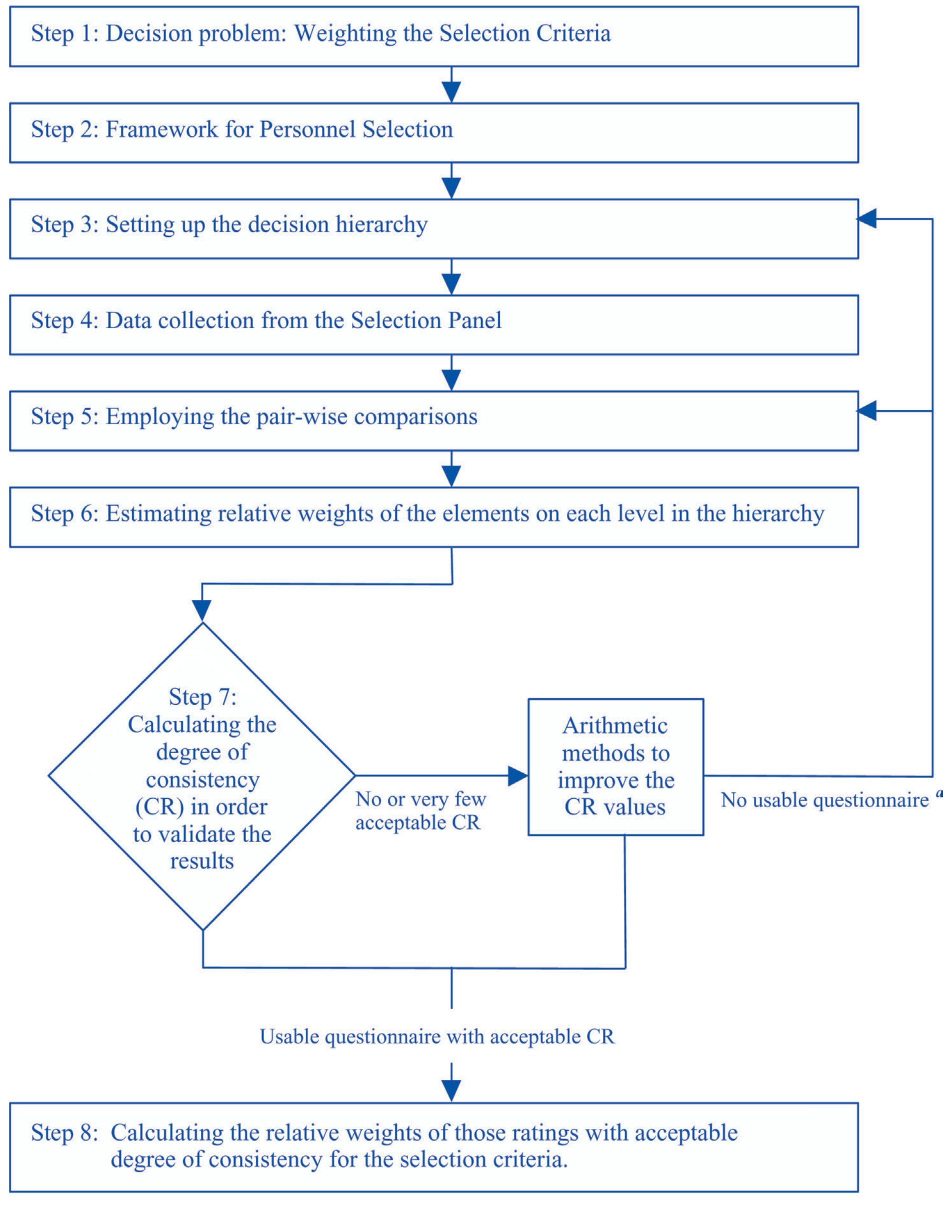
Figure 1 — The AHP method for weighting the construction information



Note: [a] A loop jumps back to Step 5 in case of no usable questionnaire. If the "re-comparisons" still cannot reduce the consistency ratio to an acceptable level so that any usable questionnaire can be distilled out, jump back to Step 3 would be necessary

following is a brief background of the working example including the problem to be studied.

This example is about NetSearch (International) Company Limited which posted an advertisement to recruit a Marketing Manager for their new South-east Asia Development Division. They would like to use AHP to develop a more precise set of criteria for selecting the right candidate for the post. The AHP method helps to assign weight to the criteria.

In the absence of a weighting instrument, measuring the relative weights of the sources is acceptable (Saaty, 1994). This usually relies on the subjective judgments made by decision makers and/or experts. A simple method is to guess each element according to an absolute rating scale, and compare it with other elements in the whole set by dividing its weight by the total to get its relative weight, where those with heavier weights are key elements. However, such a simple rating method cannot prevent the respondents from providing their

> **"Decomposing the complexity of a problem into different levels or components and synthesizing the relations of the components are the underlying concepts of AHP."**

answers arbitrarily, mistakenly, or carelessly; also the method cannot determine if the respondents are the real experts. In other words, the traditional rating method cannot filter out the inconsistency of responses.

AHP is a structured method that can elicit biased opinions of decision makers in weighting and prioritization. It has two advantages over the simple rating method. First, AHP adopts a pair-wise comparison process by comparing two objects at one time to formulate a judgment as to their relative weight. With an adequate measurement, this method is more accurate (with less experimental error) to achieve a higher level of consistency since it requires the respondents to think precisely before giving their answers. Usually, the more a person knows a situation, the more consistent the results which can be expected from this person.

Moreover, the AHP method employs the consistency test that can screen out inconsistent responses. Inconsistency refers to a lack of transitivity of preferences (Saaty, 1980). Those who filled the questionnaire but could not build up their judgements logically would not achieve the consistent comparisons.

Step 2. Framework for personnel selection

Decomposing the complexity of a problem into different levels or components and synthesizing the relations of the components are the underlying concepts of AHP. In this example, the decomposition of a problem refers to the aggregation of similar criteria into different groups, while the synthesis of relations is the integration of them in a systematic way.

In this example, the company had identified four selection dimensions and associated criteria as shown in Table I. It is expected that these criteria would collect the necessary information regarding the background of the candidates for evaluation and comparisons. However, the level of importance of these criteria had not been determined. They would use AHP to calculate relative weights of these dimensions and criteria.

Step 3. Setting up the decision hierarchy

A schematic representation of the decision hierarchy is shown in Figure 2. Such a chain of hierarchy represents the system of the problem. The formation of the hierarchy is based upon two assumptions, without which a problem cannot be dealt with using AHP:

(1) It is expected that each element of a level in the hierarchy would be related to the elements at the adjacent levels. AHP recognizes the interaction between elements of two adjacent levels.

(2) There is no hypothesized relationship between the elements of different groups at the same level.

This reiterates what is mentioned in the first step, that a problem should be clearly defined. As shown in Figure 2, this hierarchy consists of three levels and starts from the zero level, i.e. selection of the right person, which is the core problem of this example. It is then broken up into four personnel selection dimensions, which form the first level. The criteria associated with each of the dimensions form the second level.

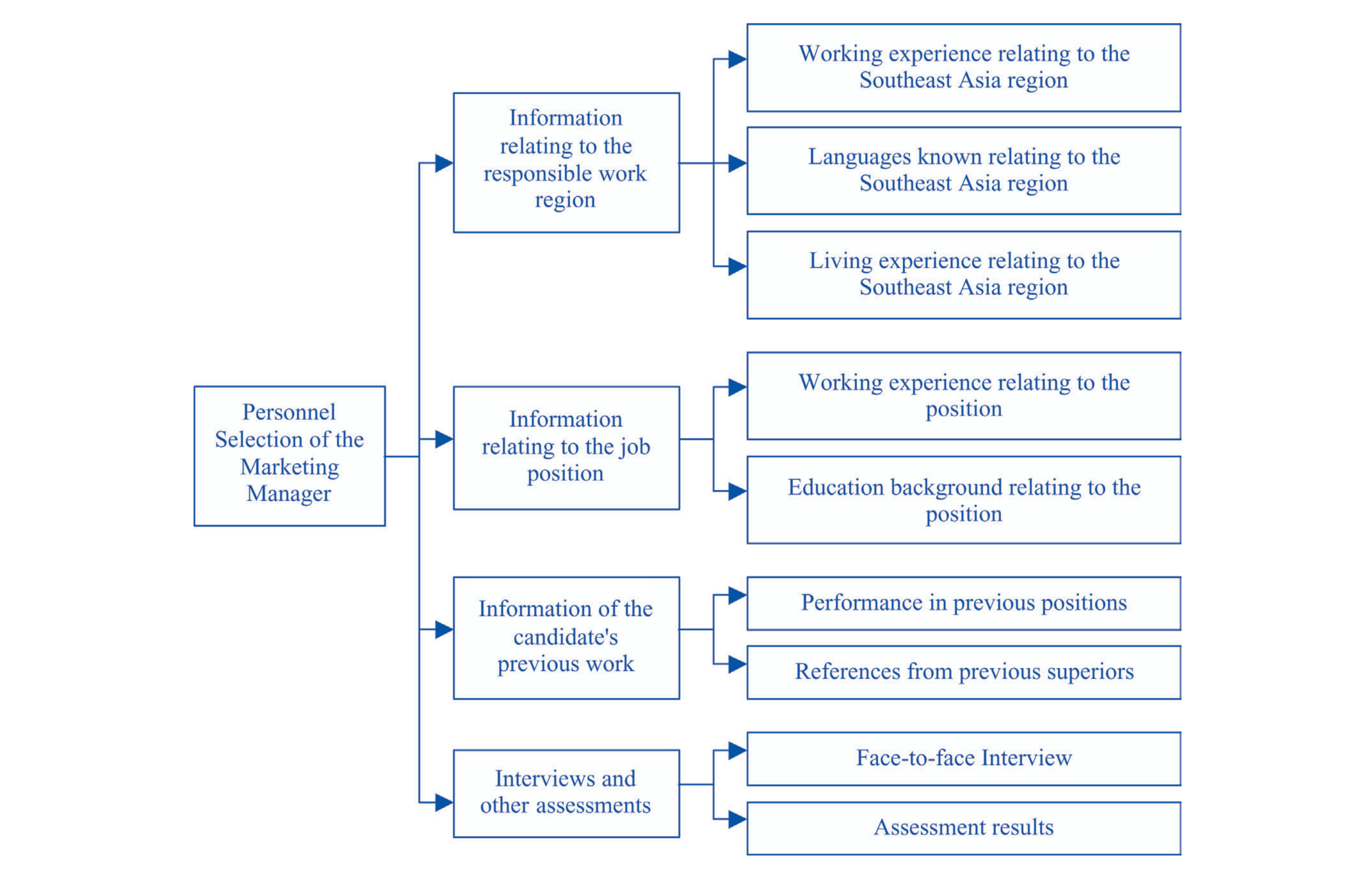
Step 4. Data collection from the selection panel

Data are obtained by direct questioning experts who are actively involved in the decision problem. A questionnaire is designed to collect data that are useful to assign weights to the elements of the decision hierarchy. This involves the employment of the pair-wise

Table I — Personnel selection dimensions and criteria

Selection dimension	Selection criteria
Information relating to the responsible work region	Work experience relating to the Southeast Asia region Languages known relating to the Southeast Asia region Living experience relating to the Southeast Asia region
Information relating to the job position	Work experience relating to the position Education background relating to the position
Information of the candidate's previous work	Performance in previous positions Reference from previous superiors
Interviews and other assessments	Face-to-face interview Assessment results

Figure 2 — Decision hierarchy of the selection problem



comparison matrix that will be described in step 5. In this example, 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) were responsible to assign weights to the elements of the decision hierarchy (i.e. selection dimensions and criteria).

It is noted that the AHP approach is a subjective methodology that does not necessarily involve a large number of experts to take part in the AHP process. Certainly, in an academic research, a small sample might only provide a very rough picture. However, with reference to important business decisions, opinions from a small group of key executives of the company are sufficient for generating reliable and useful results. Sometimes, some very important business decisions involve discretion on the part of only one person, usually the managing director of the company, who is the one and only one to fill in the questionnaire.

Step 5. Employing the pair-wise comparisons

The elements of each level of the decision hierarchy are rated using the pair-wise comparison. The Saaty's scale of measurement used to rate the intensity of importance between two elements is adopted; this is shown in Table II (Saaty, 1980). After all elements have been compared with the priority scale pair by pair, a paired comparison or judgement matrix is formed. Table III illustrates a sample of the priority rating of a level with four elements at that level. This matrix is composed of four rows and four columns (i.e. a 4×4 matrix). In this table, as element A dominates over element B, a whole number 3 is entered in row A column B, and the reciprocal (i.e. 1/3) is entered in row B column A. In addition, as the elements of A and C are expected to be equal in weight, a "1" is assigned to both positions. A "1" is also assigned when the same element is compared in row and column.

Step 6. Estimating relative weights of elements on each level in the hierarchy

After the pair-wise comparison matrix is developed, a vector of priorities (i.e. a proper or eigen vector) in the matrix is calculated and is then normalized to sum to 1.0 or 100 per cent. This is done by dividing the elements of each column of the matrix by the sum of that column (i.e. normalizing the column); then, obtaining the eigen vector by adding the elements in each resulting row (to obtain "a row sum") and dividing this sum by the number of elements in the row (to obtain "priority or

Table II — Saaty's scale of measurement in pair-wise comparison

Intensity of importance (1)	Definition (2)	Explanation (3)
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favor one over another
5	Strong importance	Experience and judgement strongly favor one over another
7	Very strong importance	An activity is strongly favored and its dominance is demonstrated in practice
9	Absolute importance	The importance of one over another affirmed on the highest possible order
2,4,6,8	Intermediate values	Used to represent compromise between the priorities listed above
Reciprocals of above non-zero numbers		If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*

Source: Saaty (1980)

Table III — A pair-wise comparison matrix

Level (1)	A (2)	B (3)	C (4)	D (5)	Relative weight (6)
A	1	3	1	9	0.410
B	1/3	1	1/3	4	0.148
C	1	3	1	8	0.398
D	1/9	1/4	1/8	1	0.044
CR value =					0.006

relative weight"). As shown in Table III, the relative weights of the elements of the sample are listed in column 6.

Step 7. Calculating the degree of consistency in order to validate the results

It is known that people are often inconsistent in answering questions, and thus one of the important tasks of AHP is to calculate the consistency level of the estimated vector. Consistency ratio (CR) is used to measure the consistency in the pair-wise comparison. Saaty (1994) has set the acceptable CR values for different matrices' sizes; the CR value is:

(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.

If the consistency level falls into the acceptable range, the weight results are valid. Crowe *et al.* (1998) provided a procedure, which is adapted from Canada and Sullivan (1989), for calculating the consistency ratio:

(1) Calculate a new vector C by multiplying the pair-wise comparison matrix A on the right by the estimated solution vector B.

In mathematical terms, the equation for multiplying the matrix A (a_{ij}), vector B (b_j) to obtain vector C (c_i) is:

$$c_i = \sum_{j=1}^{n} a_{ij}\, b_j \qquad (i = 1,\ 2, \ldots\ldots, \ n)$$

(2) Calculate the eigen vector D by dividing the vector C by its corresponding element in vector B.
(3) Calculate the maximum eigenvalue (λ_{max}) by averaging the numbers in vector D.
(4) Calculate the consistency index (CI) for a matrix of size n according to the formula: CI = $(\lambda_{max} - n)/(n - 1)$.
(5) Calculate the consistency ratio (CR) using the formula: CR = CI/RI where RI is the random index for the matrix size, n. Table IV is a random index table which is obtained by approximating random indices for matrices of order 1 to 10 using a sample size of 500 (Saaty, 1980).

Referring to Table III again, the CR value of the sample is 0.006, which is much smaller than the acceptable value with a 4-by-4 matrix. If the CR is greater than the acceptable value, this empirically reveals excessive intransitivity of preferences. CR provides a very good estimation of the consistency of the respondents in answering the questions.

With respect to the selection problem, all the comparison matrices were shown to have acceptable consistency. If there was more than one questionnaire where these questionnaires had acceptable consistency, they were then aggregated to obtain the combined judgements on the weight of the elements at each hierarchy level. On some occasions, such as no usable

Table IV — Average random index values

Size of matrix (1)	Average RI (2)
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	1.45
10	1.49

Source: Saaty (1980)

questionnaire or research requiring more usable questionnaires, the application of the "looping" procedures (as shown in Figure 1) would be considered. These procedures include:

(1) If there is no usable questionnaire, the arithmetic methods suggested by Saaty (1980) for judgmental revision would be used to improve consistency. However, these methods may destroy the initial logic expected by the respondents. Therefore, the use of these methods may need special consideration. For example, if the results of the original consistency test are too far away from the acceptable consistency, these methods could not be adopted. When using it, the adjustment of the initial paired comparisons must be as small as possible.
(2) If the arithmetic methods are not suitable, then another recourse to reduce the CR values is by re-estimating preferences for improving the quality of judgements in making pair-wise comparison (i.e. move back to Step 5 as shown in Figure 1). That is to request the participants to provide another set of answers.
(3) If the second procedure fails, then the last resort is to jump back to step 3 so that the problem can be structured more accurately by grouping similar elements under a more meaningful attribute schema. In other words, it may be necessary to re-develop the decision hierarchy and construct alternative questions so that another set of answers can be obtained.

Table V exhibits the results of the selection problem. Columns 2 and 3 of the table show the relative weights of the selection dimensions and associated criteria respectively. Column 4 indicates the final relative weights of all selection criteria that were ready for calculating the scores for the candidates. CR values are also shown to have acceptable consistency.

Step 8. Calculating the relative weights of those ratings with acceptable degree of consistency for the selection criteria

The relative weights of all selection criteria of this example were calculated, which were used to calculate the scores for the candidates (as shown in Table V). The panel had interviewed three candidates who were expected to be most appropriate to be selected for the position among a pool of applicants. They gave the score for each criterion (10 scores for each criterion based on individual scales for each criterion) and calculated the final score for each candidate. The formula for calculating the final score for each candidate is shown below:

Final score = 0.08(X1) + 0.05(X2) + 0.03(X3) + 0.18(X4) + 0.16(X5) + 0.15(X6) + 0.10(X7) + 0.15(X8) + 0.10(X9)

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

Table VI lists the rating results for each candidate. From the table, the panel chose candidate B for the new position as the candidate had the highest final score. If they 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

Table V — CR values and relative and final weights for the hierarchy

Selection dimensions and criteria	Relative weight of the selection dimension matrix	Relative weight of the four criteria matrices	Final weight to each selection criterion	CR value of the criteria matrix
Information relating to the responsible work region	0.16			
1. Working experience relating to the Southeast Asia region		0.50	0.08	
2. Languages known relating to the Southeast Asia region		0.31	0.05	
3. Living experience relating to the Southeast Asia region		0.19	0.03	0.001
Information relating to the job position	0.34			
4. Working experience relating to the position		0.53	0.18	
5. Education background relating to the position		0.47	0.16	na
Information of the candidate's previous work	0.25			
6. Performance in previous positions		0.60	0.15	
7. References from previous superiors		0.40	0.10	na
Interviews and other assessments	0.25			
8. Face-to-face interview		0.60	0.15	
9. Assessment results		0.40	0.10	na
CR value of the selection dimension matrix =	0.0011			
Total weight of all selection criteria =			1.00	

Note: na = not applicable. The CR value could not be computed for a two-element matrix due to the limitation of the equation. However, a two-element matrix has a perfect consistency

Table VI — The rating results for the candidates

Candidate	Criterion no. 1 0.08	2 0.05	3 0.03	4 0.18	5 0.16	6 0.15	7 0.10	8 0.15	9 0.10	Final score
A	6	5	6	8	8	6	7	7	7	6.98
B	5	5	5	9	8	8	8	8	8	7.70
C	9	8	9	7	7	6	7	7	7	7.12

of A = 6.67; B = 7.11; C = 7.44). The AHP method gave the selection panel a more objective approach to choose the right candidate for the job.

Hints on using AHP

AHP is likely to be more reliable than simple rating methods because it is able to prevent respondents from responding arbitrarily, incorrectly, or non-professionally by employing the consistency test. Specifically, the consistency test validates the utility of data by means of matrix computation, while it adopts a re-thinking process (an iterative process) for improving the quality of responses. For improving the judgements made for the paired comparison matrices, four useful suggestions are given below:

(1) If there is more than one respondent and if collective thinking is encouraged, the respondents should be allowed to discuss with each other prior to filling the matrix form so that they could rate the matrices with a compromised solution. This method was used in the demonstrated example.

(2) If that rating is performed individually, participants do not have to make collective decisions. However, discussion prior to rating may be allowed for clarifying some issues. A highly subjective judgement process is still maintained.

(3) If an independent investigator is involved in an AHP rating, he/she is responsible to answer the queries from respondents. This establishes a collaborative process between the investigator and the respondents. The investigator should be careful not to be involved too much to address personal preferences.

(4) Independent investigators should explain in detail to participants about AHP and the consistency concept that may affect the usefulness of their questionnaires.

The above suggestions would increase the consistency of the responses, resulting in enhancing the usability of AHP.

Conclusions

This paper is intended to introduce the use of AHP in decision making in business practices. It demonstrates a hypothetical example of how to select the right candidate for a posted position from a set of weighted selection criteria. The paper presents an eight-step AHP method, which enhances the utility of a consistency test by using it to select usable questionnaires. It is supported that AHP is useful to make more precise business decisions that may help the company to achieve a competitive edge.

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