Applied Soft Computing 10 (2010) 1001–1012

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

The analytic hierarchy and network processes: Applications to the US presidential election and to the market share of ski equipment in Italy

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ARTICLE INFO

Article history:
Received 25 April 2008
Received in revised form 5 July 2009
Accepted 27 July 2009
Available online 22 August 2009

Keywords:
AHP
ANP
Prediction models

ABSTRACT

Beyond serving in complex decision-making, both the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP) for the measurement of both tangibles and intangibles can be used in prediction rather effectively. This paper examines the potential of these models to help one discern current states and situations as well as suggest future outcomes. The first example uses the AHP to predict the Democratic Nominee in the 2008 United States presidential election and then uses that information to predict the overall election winner. The second example uses the ANP to predict the market share for ski equipment. The general structure of these models can be applied in many and diverse situations.

1. Introduction

Decision makers generally assume that logical thinking is the best and only way to make good decisions. In doing so they neglect to observe that our mind is both rational and emotional. The rational side is associated with logical and structured reasoning, whereas the emotional side is concerned with feelings intuitions and hunches. Since these two spheres cannot be separate, rationality alone is inadequate for making optimal decisions, unless one accepts losing part of the understanding of the problem one wants to model. As a matter of fact rationality only applies to the objective and measurable parts of a problem, but is incapable of capturing its subjective and qualitative aspects. Similarly, intuition is adequate for dealing with simple problems, but must be supported by rationality in more complicated situations that involve several interrelated variables. We need to remember that there are more people including well-known artists, musicians and even scientists who rely more on their intuition and experience than on reason to make their decisions and many of them manage in life better than thinkers and philosophers. How do they do it?

Until the introduction of the Analytic Hierarchy Process (AHP) [16] and its generalization to dependence and feedback the Analytic Network Process (ANP) [24], there were no effective means to combine feelings (hunches) and rationale in a structured and formal mathematical way. But now it is possible to make better decisions relying on both spheres of our mind, because the AHP and the ANP are multi-criteria decision-making (MCDM) methods that combine intuition and judgments with reason emphasizing the role of inconsistency in the decision-making process. These methods are based on a multi-criteria measurement theory which provides a general framework to deal with decisions in a structured way [9]: (i) by rigorously structuring the problem as a hierarchy or a network of all the factors and the influences among them, and (ii) by establishing the intensities of the influence relations through pairwise comparison judgments. In this manner all the relevant knowledge and intuition that have bearing on a decision are "scientifically" gathered together and it is possible to discover the rationale behind the best choice to be made and understand how quantitative reasoning underlies and guides the decision.

In addition to AHP/ANP, several multi-criteria decision-making (MCDM) methods have been proposed in technical literature. Among these one can cite the Weighted Sum Model (WSM), Weighted Product Model (WPM), the ELECTRE Method, and the TOPSIS Method, but many others exist and goods reviews can be found in [1,4,8]. However, many comparisons (see for example [2,12]) have revealed that both the AHP and the ANP possess a number of benefits over the other MCDC methods, such as: (i) they provide a realistic description of the problem, (ii) they support group decision-making, (iii) they soundly structure the decision-making process, (iv) they incorporate both quantitative and qualitative factors, (v) they clearly express the relative importance of factors, (vi) they allow the decision makers to focus on each small part of the problem, (vii) they facilitate the evaluation of alternative scenarios, by supporting what if and sensitivity analysis.

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1568-4946/$ – see front matter © 2009 Published by Elsevier B.V.
doi:10.1016/j.asoc.2009.07.013

As a matter of fact, the potentialities and the usefulness of both methods have been proved by many successful applications in virtually all the areas of management. Among others, interesting applications concern supplier selection [6,9], maintenance analysis [3], marketing analysis [29], supply chain management [28] and design optimization [26]. Literature in the subject matter is extensive and good reviews can be found in [5,30,31].

Additionally, it is worth noting that, as shown in [7,13–15,17,19], beyond their common use as decision-making tools, the AHP and the ANP can also be used in prediction rather effectively. Since this interesting and useful aspect is less known, the main aim of this paper is to thoroughly examine the AHP and the ANP to give evidence of their capabilities to help one discerning current states and situations as well as suggesting possible future outcomes.

As shown in [23,31], a way to validate the AHP/ANP and to show how intuition and feelings (supported by rationality and logic) can effectively capture the essence of a problem is to compare the results obtained through an AHP/ANP model, with something that is measurable and known. Therefore, two interesting applications are presented in this paper: in the first a hierarchic model is used to predict the winner of the US elections, and in the second a more complex network with dependence and feedback is used to estimate the market share of ski equipment in Italy without really knowing those values or using any known measurements in the process.

2. AHP methodology

The Analytic Hierarchy Process (AHP) is a flexible multi-criteria decision-making method which can be used to effectively synthesize the judgments given by a team of experts in order to make better decisions in complex settings, where both tangible and intangible criteria must be considered [16]. In particular it is based on the three following principles [21].

(1) The experts define the elements of the problem (*i.e.* decision criteria) and arrange them in the form of a hierarchy of objectives with parent elements in a given level connected to their children elements in a level below. The top level of the hierarchy represents the goal of the problem, while the bottom level contains the alternatives that can be chosen to maximize the objective. The first and the last level are connected through a series of intermediate levels, which represent the sub-criteria and other concerns in which the goal is decomposed.
(2) The experts assess (*i.e.* weight) the relative importance of criteria, sub-criteria and alternatives with respect to the elements in the higher level to which they are connected.
(3) All the judgments throughout the structure are used to derive corresponding priority scales that are then synthesized to determine the overall priorities of the alternatives.

The experts express their judgments in the form of comparisons between two elements (of the same level of the hierarchy) using the fundamental scale of absolute numbers [24] shown in Table 1. The smaller element is used as the unit and the larger element is estimated as a multiple of that unit. The comparisons are made on homogeneous elements that are close so the judgments would not be wild guesses. If they are not homogeneous, they are carefully selected to go into groups or clusters with a common element from one group to the next.

For example, if A_1 is a decision criterion and A_{11} and A_{12} are two of its sub-criteria, the experts must assess the relative importance of A_{11} over A_{12} by answering the following question: "with respect to A_1, how much more important is A_{11} than A_{12}?". The assessment is made using an integer value from the scale unless A_{12} dominates A_{11}, in which case the integer is used for this comparison and its reciprocal value is used for the first comparison.

Table 1
Fundamental scale of the AHP, adapted from [24].

Judgment	Description
1	A and B are equal
3	A is moderately dominant over B
5	A is strongly dominant over B
7	A is very strongly dominant over B
9	A is extremely dominant over B

The values 2, 4, 6, and 8 are used for judgments in between. The judgments are relative absolute numbers; consider the dominated element to be the unit and enter the judgment that expresses how many times more the dominant element is. Enter the reciprocal in the inverse position in the matrix. Decimals are allowed. If A and B are close, use 1.1, 1.2,. . ., 1.9.

Using this process, which is called a "pairwise comparison" it is possible to improve the quality of the judgments because it is easier to concentrate on just two factors at one time and to provide a comparative value from the scale than a number off the top of one's head.

To derive priorities, all the possible pairwise comparisons on the children of each parent with respect to the common property it represents should be made. It is worth noting that it is possible to reduce the number of questions that must be answered by means of short cuts, yet this approach is not advisable because it can decrease the validity of the results obtained. The criteria are pairwise compared with respect to the goal, the sub-criteria with respect to each parent criterion, and the decision alternatives with respect to the last level of sub-criteria above them.

To derive the weights of the elements of the hierarchy, each time a set of children nodes (*i.e.* sub-criteria) are pairwise compared with respect to a parent node, all the relative judgments must be arranged in a reciprocal comparison matrix $A = (a_{ij})$ where the generic *ij*th cell contains the value of the comparison of the *i*th element with respect to the *j*th one. Therefore all the elements along the diagonal are equal to one, while a generic element a_{ij} is greater than one if the *i*th element is dominant over the *j*th one and is less than one otherwise. Furthermore, due to the reciprocity of the comparisons, the value of the a_{ji} elements must be equal to $1/a_{ij}$.

A priority vector $w = (w_1, w_2, \ldots, w_n)$ is derived from each comparison matrix $A = (a_{ij})$ and its elements w_i, $i = 1, 2, \ldots, n$, are referred to as priorities or simply weights of the elements A_i. The set of n relative priorities is often normalized to sum to one, $\sum_{i=1}^{n} w_i = 1$, $w_i > 0, i = 1, 2, \ldots, n$. If $a_{ij}a_{jk} = a_{ik}$, for all *i*, *j*, *k*, the elicited judgments are said to be consistent, and the matrix is also called consistent. In this case it easy to prove that $a_{ij} = w_i/w_j$ (for *i*, $j = 1, 2, \ldots, n$), and thus w can be simply obtained by summing each row and normalizing the resulting vector or by normalizing any column of A.

When A is not consistent, and in practice it is usually not consistent because it is based on subjective judgments, Saaty [22] proved that the principal eigenvector of the matrix should be used for the priority vector w because it uniquely captures transitivity of dominance along all possible paths in the case of an inconsistent matrix. This vector is obtained by raising the matrix to very large powers until all its columns converge to the same vector which they are known to do.

An example of a comparison matrix is given in Table 2. In this case five search engines have been pairwise compared to estimate the percentage of people that uses them. For example, the values of the first row of the matrix which translate feelings to numbers by using the scale say that the number of individuals that use Google is two times (between equal and moderately) larger than those who use Yahoo, moderately or three times larger than that those who use MSN, very strongly or seven time larger than those who