

A Review of Selected Multi-Criteria Decision Analysis Techniques and Applications

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Abstract

This paper presents a review of various multi-criteria decision analysis techniques. The focus of this research is to identify suitable techniques to be used to assign weights between different factors that influence user acceptance of software technology in the healthcare industry. Three widely known methodologies used for identifying, classifying and evaluating various alternatives are briefly described, namely the Analytic Hierarchy Process, Fuzzy Cognitive Maps and Fuzzy AHP, in order to identify the applicability and suitability of each in addressing our research problem.

1 Introduction

Almost every year, new technologies are being introduced to the healthcare sector. Various industries are taking advantage of new technology to develop the functions and structures of their industry, including the healthcare industry. Almost a billion dollars are being spent on the procurement of new technologies with the aim to improve organization performance as well as quality of service delivered to the patient. Although technology often brings benefits to an organization, sometime its implementation does fail (Southon et al., 1999). This is largely due to the low level of user acceptance of the technology. Much research has been carried out to identify the critical factors that influence success or failure of systems (Yusof et al., 2008; Despont-Gros et al., 2005; Shaw, 2002).

However, we believe that simply identifying the factors that influence user acceptance of technology is not sufficient and so is unlikely to help organisations to reduce the risk of implementation failure. Organisations also need to identify which of these factors are the most important factors, i.e. which *highly* influence user

acceptance of technology. To achieve this, we need to know how to assign weights between the factors, such that those factors that score the highest weight(s) are the crucial factors. By assigning weights or ranking the factors, it is not the case that the lowest factors are not important, rather it indicates the users' perceptions about the importance of various factors that influence their acceptance of the technology. This can help the organisation take any necessary action to reduce the risk of implementation failure. The focus of the current research is to develop an evaluation model to evaluate factors that influence user acceptance of the healthcare software technology and to propose suitable methods or techniques to assign weights between the factors, in order to help organizations understand the significant or importance of these factors.

Thus, the aim of this paper is to review existing methodologies used for identifying, classifying, evaluating and assigning weights among different factors or alternatives. These methodologies hopefully can be used to rank or assigning weights between factors that influence user acceptance of the technology. Although there have been many applications of Analytic Hierarchy Process (AHP), Fuzzy Cognitive Maps (FCM), Fuzzy Analytic Hierarchy Process (FAHP) etc. in the medical context, to our knowledge none have been applied to rank the factors that influence user acceptance of technology which is the focus of our research.

2 An Overview of Techniques

Multi-criteria decision analysis (MCDA), also called multi criteria decision making (MCDM) or multi-attribute decision-making (MADM), is a discipline aimed at supporting decision makers who are faced with making numerous and conflicting evaluations. MCDA also has the capacity to analyse both quantitative and qualitative evaluation criteria together.

A number of models have been developed for solving MCDA problems such as goal programming (GP), multi-attribute value theory (MAVT), data envelopment analysis (DEA), Analytic Hierarchy Process (AHP) and many others. All these decision methodologies are differentiated by the way the objective and alternative weights are determined, as prescribed by axiomatic and/or rule-based structures. Although there exist many different MCDM techniques, we have found that three of these techniques/methodologies are suitable to address our research problem and these methodologies are described briefly below.

2.1 Analytic Hierarchy Process

Analytic Hierarchy Process (AHP) is a technique used for dealing with problems which involve the consideration of multiple criteria simultaneously. Among other known multi-criteria decision making methods, AHP is one of the most widely used multiple criteria decision-making tools. The use of AHP does not involve cumbersome mathematics, but uses principles of decomposition, pairwise comparison, and priority vector generation and synthesis.

The AHP technique was developed in 1977 by Saaty who derived his ‘theory of prioritised hierarchies’. Since then, AHP has been used by decision makers all over the world to model problems in diverse application areas including resource allocation, strategic planning and public policy. AHP is used to rank, select, evaluate and benchmark a wide variety of decision alternatives (Wasil and Golden, 2003). The scale ranges from 1/9 for the ‘least valued than’, to 1 for ‘equal’ and to 9 for ‘absolutely more important than’ covering the entire spectrum of the comparison (Vaidya and Kumar, 2006).

According to Liberatore and Nydick (2008), the main uniqueness of AHP is its inherent capability to weight a large number of different factors, of different natures, including both qualitative and quantitative data, in order to make a decision based on a formal and numerical process. AHP uses the principle of pairwise comparison. Making Pairwise comparisons seems to be a more reliable way of obtaining the actual weights than obtaining them directly, as it is generally easier to evaluate the relative weights of each attributes with respect to the others (Salmeron and Herrero, 2005). AHP is also a flexible method in that it can be integrated with other techniques such as linear programming, quality function deployment, fuzzy logic,

etc. (Vaidya and Kumar, 2006).

AHP involves several steps, as follows: (Douligeris and Pereira, 1992)]

- Step 1: Set up the hierarchy.
- Step 2: Collect input data by pair-wise comparisons of decision elements. Every attributes on each level is compared with adjacent attributes in respect of their importance to the parent.
- Step 3: Use the ‘eigenvalue’ method to estimate the relative weight of decision elements.
- Step 4: Aggregate the relative weights of decision elements to arrive at a set of ratings for the decision alternatives. The scores reflecting the weights given to each attribute are adjusted and then summed to yield a final score for each option.

2.1.1 Integrated Approaches of AHP

AHP has been used widely in many areas and applications. As AHP became an established technique, many combined methods were experimented and used. This, however, does not mean that AHP is no longer a stand-alone model. Large numbers of researchers are still using AHP as a stand-alone tool to address problem domains. AHP is a flexible tool that is able to be combined with many different techniques effectively. (Ho, 2008).

Badri (2001), for example, studied combining AHP with a Goal Programming method. Goal Programming (GP) is a mathematical technique and a variation of linear programming which is capable of handling decision-making problems having multiple, conflicting goals. These two techniques were combined to model quality of control systems. After assigning weights to the various locations, a GP model was formulated to select the best combination of alternatives based on resource limitations such as budget, and then used to determine the allocation of products from locations to distribution centres.

Kwong and Bai (2002) combined AHP with Quality Function Deployment (QFD) and applied the combined AHP-QFD approach to aid new product development. They argued, however, that the normal pairwise comparison in the general AHP which was suggested by Saaty (1980) seemed to be insufficient and imprecise to obtain the relative importance weightings of the customer requirements and so introduced the use of fuzzy numbers in pairwise comparisons.

2.1.2 AHP in Medical Fields

AHP has been used in many areas including medical and healthcare decision making, including as a tool for health technology assessment. Recently, there has been increased interest in its application for evaluating health care facilities.

Rossetti and Selandari (2001) used AHP for multi-objective analysis of middle to large size hospital delivery systems. Aspects were evaluated to check whether a group of robots could replace human-based delivery, transportation and distribution services. Three factors were considered for evaluation: *technical, economic, and social, human and environmental*.

Singpurwalla et al. (1999) used AHP as a tool to facilitate decision making of two specific healthcare populations. The use of AHP helped to improve physician-patient communication by assisting shared health decisions, and helped the patients to evaluate and understand their healthcare options rather than relying completely on the doctor's decision.

AHP is a widely used technique for assigning priorities and making ranking, which has been used in diverse areas. Despite the fact that the AHP technique has proven to be successful in addressing multi-attribute decision making problems, it does have limitations, as shown in Table 1.

2.2 Fuzzy Cognitive Maps

According to Kosko (1986), the concept of cognitive maps was first introduced by Alexrod to represent social scientific knowledge and to describe methods used for decision making in social and political systems. These initial ideas were then enhanced by Kosko by incorporating fuzzy values for the concepts of the cognitive map and fuzzy degrees of relationships between concepts.

Fuzzy cognitive maps (FCMs) can be regarded as a combination of fuzzy logic and neural networks. Viewed graphically, an FCM seems to be a signed directed graph with feedback, consisting of nodes and weighted arcs. Nodes of the graph stand for the concepts that are used to describe the behaviour of the system, and they are connected by signed and weighted arcs representing causal relationships that exist between the concepts. All the values in the graph are fuzzy, so concepts take values in the range $[0, 1]$ and the weights of the arcs are in the interval $[-1, 1]$ (Kosko, 1986).

2.2.1 Applications of FCMs

As described by Lee and Ahn (2009), FCM was used to support the design of e-commerce web-based system (ECWS) controls that led to high ECWS performance. These controls included system continuity, access control, communication control and informal controls. The relationships, directions and strengths were identified using structural equation modelling (SEM). Using FCM it was possible to show the state or movement of one control component to influence the state or movement of others, which was important to the design of ECWS controls.

Chin et al. (2002) proposed the use of FCM as a technique for supporting the decision-making process in effect-based planning. The FCM method was used to choose the best option among available alternative through assignment of weights by the experts. Several features which did not exist in classical FCMs were introduced, namely *influence possibility, influence duration, dynamic influence value-changing and influence permanence*. This proposed methodology was successfully applied in military planning.

Rodriguez-Repiso et al. (2007) used FCM to model the critical success factors of IT projects. The FCM methodology proposed used four matrices to represent the results that the methodology provided at each of its stages, namely the *initial matrix of success, fuzzified matrix of success, strength of relationships matrix of success and final matrix of success*. Data were gathered from interviews with people whose knowledge and background enabled them to identify and evaluate those factors according to their understanding which should generate a successful IT project. An example of FCM applied to a project allowing users to make small and medium payments using their mobile phones was employed to demonstrate the proposed methodology. Identified factors were mapped using an FCM and the causal relationships between factors were demonstrated.

Although FCMs have thus been successfully used in various areas, to our knowledge they have not been used to assign weights to factors that influence user acceptance of technology. Thus, this method will be further investigated to address our research problem.

2.3 Fuzzy AHP

AHP is a method for ranking decision alternatives and selecting the best when the decision maker has multiple criteria. With AHP, the de-

cision maker selects the alternatives by developing a numerical score to rank each decision alternative based on how well they match his or her decision criteria through comparison ratios. Many publications address the situation where the comparison ratios are imprecise judgements (Leung and Cao, 2000).

According to Chang et al. (2009), the uncertainty in the preference judgements give rise to uncertainty in the ranking of alternatives as well as difficulty in determining the consistency of preferences. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision makers' judgements, the fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgements of decision makers in conventional AHP approaches. Given the subjective and qualitative nature of some service evaluation criteria, decision makers find it extremely difficult to express the strength of their preferences and to provide exact pair-wise comparison judgements. Thus, conventional AHP does not reflect natural human thinking. In order to avoid these risks on performance, fuzzy AHP (FAHP), a fuzzy extension of AHP, was developed to address hierarchical fuzzy problems.

2.3.1 Applications of Fuzzy AHP

Fu et al. (2006) described the use of FAHP to assign relative weights between factors which affect the entry to an electronic marketplace in Taiwanese industries. A three-layer hierarchical structure was proposed, and data were gathered through questionnaires distributed among 20 executives and other people. This study provides novel and reliable information about strategic factors that are involved in corporate decisions about entering an electronic market.

Jaganathan et al. (2007) employed fuzzy AHP to facilitate the selection and evaluation of new manufacturing technologies. Issues such as contradiction and inconsistency on fuzzy judgement matrices, and group decision-making using FAHP was dealt with in detail. Other methods, fuzzy preference programming and a two-stage logarithmic goal programming based fuzzy prioritization method, were compared and it was concluded that fuzzy preference programming was advantageous in solving this multi-level multi-person problem.

The ability of FAHP to address the uncertainty in the judgements made by the experts is one of its distinct features compared to tradi-

tional AHP. Since the environment where technology is operating can be unstable with lots of uncertainty involved, this method is likely to be more suitable to address the problem of user acceptance of the technology.

3 Discussion

Each of above techniques has been widely used and applied in various areas. However, each has its own strength and weakness as shown in Table 1 (adapted from Kwong and Bai (2002); Macharis et al. (2004); Kok (2009)).

The AHP and Fuzzy AHP methods are not direct competitors with each other. If the users are certain with the information or evaluation, the classical AHP method may be preferred and if information is not certain, fuzzy AHP will tend to be the preferred option. Given that there exist uncertainties in the decision problem, decision makers tend to use the fuzzy approach, as taking fuzziness into account may be felt to provide less risky decisions. Once novel data have been collected, each technique will be analyzed to assess its suitability and applicability in addressing the needs of healthcare technology evaluation.

4 Conclusion

Identifying the ranking of factors that influence user acceptance of technology is important for organisations because it may help an organisation to focus on those factors which carry the most the risk of new technology being rejected by the user. This is important since the success or failure of any new systems to operate in a new environment depends largely on the acceptance of the users. More information about the expectations of final users will also help to manage the implementation process of new technologies. Three widely used methodologies to formalise the assessment of multiple factors, namely AHP, FCM and Fuzzy AHP have been briefly described. To our knowledge, none of these have been used to rank factors that influence user acceptance of technologies in healthcare. This will be the focus of our future work, in which each of these techniques will be applied and tested on its suitability to assign weights for different factors that influence user acceptance.

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Table 1: Summary of the Strengths and Weaknesses of Each Technique

Technique	Strength	Weakness
Analytic Hierarchy Process (AHP)	<ul style="list-style-type: none"> • Provides a formal multi-criteria decision-making mechanism for ranking the factors by collecting user's perceptions about the importance of the factors. • The procedures to build the hierarchy are fairly simple and easily understood even in group decision making when diverse expertise and preferences are involved. • The decision problem is presented as graphical hierarchical structures which may simplify potential risk and conflict. 	<ul style="list-style-type: none"> • Difficulties may arise when a user has to deal with a large number of factors which can lead to inconsistency in providing the estimation of the importance among the factors. • In some cases the ranking of the alternatives can be reversed when a new alternative is introduced (Rank Reversal Problem). • The fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgement of decision makers.
Fuzzy Cognitive Maps (FCM)	<ul style="list-style-type: none"> • Knowledge can be represented in a much richer way than using tables or matrices. • Can highlight positive and negative interactions/relations between factors. • Very flexible: even if the initial mapping of the problem concepts is incomplete, further additions can be included. 	<ul style="list-style-type: none"> • Requires expertise to be concrete when developing the map; however in some cases, it is not possible to include all the stakeholders/ experts. • Methods for semi-quantification are not very structured. • Relationships are only semi-quantified.
Fuzzy Analytic Hierarchy Process (FAHP)	<ul style="list-style-type: none"> • Able to deal explicitly with the vagueness and uncertainties in AHP. • The decision problem is represented as graphical hierarchical structures, easy to understand. • Use of triangular numbers to represent subjective pairwise comparison of factors in order to capture the vagueness. • Can allow the user to have freedom of estimation regarding the weight of the factors under study, so that their judgement can range from optimistic to pessimistic. 	<ul style="list-style-type: none"> • In many methodologies introduced by various authors, it is difficult to find a consistent process for determining fuzzy inputs and crisp weights, given that the consistency index method is not appropriate because of the fuzziness. • Fuzziness itself may have some bias, including decision maker's inconsistency.

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