



Evaluating machine tool alternatives through modified TOPSIS and alpha-cut based fuzzy ANP

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ARTICLE INFO

Article history:

Received 15 April 2010

Accepted 6 February 2012

Available online 15 February 2012

Keywords:

Multiple criteria decision making

Analytic network process

Fuzzy ANP

Machine tool selection

ABSTRACT

The problem of machine tool selection among available alternatives has been critical issue for most companies in fast-growing markets for a long time. In the presence of many alternatives and selection criteria, the problem becomes a multiple-criteria decision making (MCDM) machine tool selection problem. Therefore, most companies have utilized various methods to successfully carry out this difficult and time-consuming process. In this work, both of the most used MCDM methods, the modified TOPSIS and the Analytical Network Process (ANP) are introduced to present a performance analysis on machine tool selection problem. The ANP method is used to determine the relative weights of a set of the evaluation criteria, as the modified TOPSIS method is utilized to rank competing machine tool alternatives in terms of their overall performance. Furthermore, in this paper, we use a fuzzy extension of ANP, a more general form of AHP, which uses uncertain human preferences as input information in the decision-making process, because AHP cannot accommodate the variety of interactions, dependencies and feedback between higher and lower level elements. Instead of using the classical eigenvector prioritization method in AHP, only employed in the prioritization stage of ANP, a fuzzy logic method providing more accuracy on judgments is applied. The resulting fuzzy ANP enhances the potential of the conventional ANP for dealing with imprecise and uncertain human comparison judgments. The proposed approach is also applied for a real-life case in a company.

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1. Introduction and literature survey

A proper machine tool selection has been very important issue for manufacturing companies due to the fact that improperly selected machine tool can negatively affect the overall performance of a manufacturing system. In addition, the outputs of manufacturing system (i.e. the rate, quality and cost) mostly depend on what kinds of properly selected and implemented machines tools are used. On the other hand, the selection of a new machine tool is a time-consuming and difficult process requiring advanced knowledge and experience and experience deeply. So, the process can be hard task for engineers and managers, and also for machine tool manufacturer or vendor, to carry out. For a proper and effective evaluation, the decision-maker may need a large amount of data to be analyzed and many factors to be considered. The decision-maker should be an expert or at least be very familiar with the specifications of machine tool to select the most suitable among the others. However, a survey conducted by

(Gerrard, 1988a) reveals that the role of engineering staff in authorization for final selection is 6%, the rest belongs to middle and upper management (94%). The author also indicated the need for a simplified and practical approach for the machine selection process. Evaluating machine tool alternatives is a multiple-criteria decision making (MCDM) problem in the presence of many quantitative and qualitative attributes. So, we selected analytic network process (ANP) method, because it has been widely used for selecting the best alternative among others.

In AHP, a hierarchy considers the distribution of a goal amongst the elements being compared, and judges which element has a greater influence on that goal. In reality, a holistic approach like ANP is needed if all criteria and alternatives involved are connected in a network system that accepts various dependencies. Several decision problems cannot be hierarchically structured because they involve the interactions and dependencies in higher or lower level elements. Not only does the importance of the criteria determine the importance of the alternatives as in AHP, but the importance of alternatives themselves also influences the importance of the criteria. In other words, ANP incorporates feedback and interdependent relationships among decision attributes and alternatives (Saaty, 1996). This provides a more accurate approach for modeling complex

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decision environment (Ayag and Özdemir, 2007; Chung et al., 2005). Another popular MCDM method used in this study is the TOPSIS (the Technique for Order Preference by Similarity to Ideal Solution) first developed by Hwang and Yoon (1981). TOPSIS bases on the concept that the best alternative should have the shortest distance from the positive-ideal solution and the farthest distance from the negative-ideal solution. Although its concept is rational and understandable, and the computation steps involved is uncomplicated, the inherent difficulty of assigning reliable subjective preferences to the criteria is worth of noting.

In addition, a decision maker's requirements on evaluating machine tool alternatives always contain ambiguity and multiplicity of meaning. Furthermore, it is also recognized that human assessment on qualitative attributes is always subjective and thus imprecise. Therefore, conventional ANP seems inadequate to capture decision maker's requirements explicitly. In order to model this kind of uncertainty in human preference, fuzzy sets could be incorporated with the pairwise comparison as an extension of ANP. The fuzzy ANP approach allows a more accurate description of the decision making process.

Fuzzy set theory is a mathematical theory pioneered by Zadeh (1994), designed to model the vagueness or imprecision of human cognitive processes. This theory is basically a theory of classes with non-sharp boundaries. What is important to recognize is that any crisp theory can be made fuzzy by generalizing the concept of a set within that theory to the concept of a fuzzy set (Zadeh, 1994). Fuzzy set theory and fuzzy logic have been applied in a great variety of applications, as reviewed by several authors (Klir and Yuan, 1995) and (Zimmermann, 1996). Within the broad scope of the applications of fuzzy set theory, engineering design emerges as an important activity in today's organizations that has lacked tools that manage the great amount of imprecise information that is usually encountered.

In literature, we have witnessed more studies which brings AHP and TOPSIS together to solve multiple-criteria decision making problems. Some of them recently published can be summarized as follows: aimed at improving the quality and effectiveness of decision-making in a new product introduction. They proposed a systematic decision process for selecting more rational new product ideas, and used fuzzy heuristic multi-attribute utility method for the identification of non-dominated new product candidates and a hierarchical fuzzy TOPSIS method for the selection of the best new product idea. Karpak and Topcu (2010) dealt with prioritizing measures of success and the antecedents for Turkish small to medium sized manufacturing enterprises. Işıklar and Büyüközkan (2007) used AHP and TOPSIS to evaluate mobile phone options in respect to the users' preferences order. Önüt and Soner (2007) also used AHP and fuzzy TOPSIS to solve the solid waste transshipment site selection problem. Lin et al. (2008) presented a framework that integrates the AHP and TOPSIS methods to assist designers in identifying customer requirements and design characteristics, and help achieve an effective evaluation of the final design solution. Tsaor et al. (2002) applied AHP in obtaining criteria weight and TOPSIS in ranking to evaluate of airline service quality.

In literature, to the best of our knowledge, we have not come across any work that both techniques, ANP and TOPSIS are used for machine tool selection. The reason could be due to the fact that ANP developed by Saaty is a newly introduced method to the world of the multiple criteria. But, there are several works that both techniques are used in various fields. Both of them are summarized as follows: proposed a hybrid model for supporting the vendor selection process in new task situations. They used both modified TOPSIS method to adopt in order to rank competing products in terms of their overall performances, and the ANP to yield the relative weights of the multiple evaluation criteria,

which are obtained from the nominal group technique (NGT) with interdependence. In another work, (Petri Hallikainen et al., 2009) addressed the alignment between business processes and information technology in enterprise resource planning (ERP) implementation. Since the problem considered in the study involves organizational and technical issues that are connected to each other in networked manner, the analytic network process (ANP) methodology was selected for application.

In this paper, we utilize the fuzzy ANP and TOPSIS methods. The fuzzy ANP method is used to determine the relative weights of a set of the evaluation criteria, as the modified TOPSIS method is utilized to rank competing machine tool alternatives in terms of their overall performance. In this work, instead of using all the steps of the fuzzy ANP method to determine the final machine tool alternative, we integrated the fuzzy ANP with the modified TOPSIS to eliminate the time-consuming fuzzy calculations of the fuzzy ANP method. Only some steps of the fuzzy ANP method is used to weight the evaluation criteria required for the modified TOPSIS method to reflect the interdependences among them.

The proposed approach is also applied for a real-life case in a company which designs and manufacturers all kinds of cutting tools for national and international markets.

2. Proposed approach

In this paper, together with the modified TOPSIS, we propose a fuzzy ANP-based methodology using ANP of Saaty and fuzzy logic of (Zadeh, 1994) because; in the conventional ANP method, the evaluation of selection attributes is done using a nine-point scaling system, where a score of 1 represents equal importance between the two elements and a score of 9 indicates the extreme importance of one element, showing that each attribute is related with another. This scaling process is then converted to priority values to compare alternatives. In other words, the conventional ANP method does not take into account the vagueness and uncertainty on judgments of the decision-maker(s). Therefore, fuzzy logic is integrated with the Saaty's ANP to overcome the inability of ANP to handle the imprecision and subjectiveness in the pair wise comparison process. Fuzzy ANP-based methodology to machine tool selection problem is presented step-by-step below, as illustrated in Fig. 1.

In the first step, a cross-functional team is set up for machine tool selection problem. This team is also responsible of generating a number of the possible machine tool alternatives according to the needs of the company. If the number of alternatives is more than expected, it may not be effective for the proposed approach. In this case, the number of the alternatives is narrowed down using *Pareto optimality*.

After this, a set of evaluation criteria mainly expressing machine tool characteristics is determined. Next, as seen in Fig. 1, we construct two modules, one of which is the fuzzy ANP module that allows determining the relative weights of the evaluation criteria; another is modified TOPSIS method to rank the competing alternatives. Finally, the ultimate machine tool alternative is presented to the company's management for approval.

2.1. Making of fuzzy ANP-based calculations

In this study, in order to capture the vagueness, triangular fuzzy numbers, $\tilde{1}-\tilde{9}$, are used to represent subjective pair wise comparisons of selection process. Triangular fuzzy numbers (TFNs) show the participants' judgments or preferences among the options such as equally important, weakly more important, strongly more important, very strongly more important, and

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