Expert Systems with Applications 36 (2009) 4313–4320

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Measuring the success possibility of implementing advanced manufacturing technology by utilizing the consistent fuzzy preference relations

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ARTICLE INFO

Keywords:
Consistent fuzzy preference relations (CFPR)
Analytic hierarchy process (AHP)
Advanced manufacturing technology (AMT)
Pairwise comparison

ABSTRACT

Yusuff et al. [Yusuff, R. M., Yee, K. P., & Hashmi, M. S. J. (2001). A preliminary study on the potential use of the analytical hierarchical process (AHP) to predict advanced manufacturing technology (AMT) implementation. *Robotics and Computer Integrated Manufacturing, 17*, 421–427.] presented the analytic hierarchy process (AHP) for forecasting the success of advanced manufacturing technology (AMT) implementation based on seven influential factors, including a committed and informed executive sponsor, an operating sponsor, think-tank linkage, alignment of business, integration with the existing system, natural organizational interface to the system, user commitment and support (Yusuff et al, 2001). Owing to the fact that AHP method performs complicated pairwise comparison among elements (attributes or alternatives), and it takes considerable time to obtain a convincing consistency index with an increasing number of attributes or alternatives. This study therefore applies the consistent fuzzy preference relations (CFPR) [Herrera–Viedma, E., Herrera, F., Chiclana, F., & Luque, M. (2004). Some issues on consistency of fuzzy preference relations. *European Journal of Operational Research, 154*, 98–109.] to tackle the aforementioned shortcomings of Yusuffs' et al. work. The analyzed prediction outcomes obtained by CFPR almost coincide with that ones produced by AHP approach. Notably, the ratio of the pairwise comparison times of the priority weights for the seven influential factors between CFPR and AHP is 6:21, because CFPR uses simple reciprocal additive transitivity from a set of $n-1$ preference data, rather than reciprocal multiplicative transitivity from a set of $\frac{n(n-1)}{2}$ preference values, an approach that facilitates the computation procedures as well as boosts the effectiveness of implementing the AMT decision problems. Namely, CFPR takes the least $(n-1)$ judgments in pairwise comparison, whereas the AHP uses $\frac{n(n-1)}{2}$ judgments in paired comparison to establish a preference relation matrix with n elements. Besides, the comparative results not only show that consistent fuzzy preference relations is computationally more efficient than analytic hierarchy process, but also demonstrate its applicability and feasibility in dealing with complicated hierarchical multi-attribute decision-making problems.

1. Introduction

Analytic hierarchy process, first proposed by Saaty in 1977, has emerged as a popular and practical tool for solving complicated unstructured decision problems (Cheng, Yang, & Hwang, 1999; Saaty, 1980). The AHP methodology is based on decomposing a complex decision issue into elemental problems to establish a hierarchical model. In a typical decision hierarchy, the goal is positioned at the highest level; evaluation criteria share the same interim level and the feasible alternatives are situated on the lowest level (Tang & Tang, 1998). When the decision problem is divided into smaller constituent parts in a hierarchy, pairwise comparisons of the relative importance of elements are conducted in each levels of the hierarchy for establishing a set of weights or priorities. Consequently, paired comparisons of the alternatives with respect to each criterion can be used to determine the overall ranking of the feasible alternatives (Ernstberger, 1995; Lee, Pham, & Zhang, 1999). High ranking of alternatives is associated with better performance.

AHP generally quantifies the relationship between alternatives or attributes using a nominal scale, and providing a systematic and structured method for incorporating the tangible and intangible attributes (Skibniewski & Chao, 1992). During the past 28 years, the AHP has been utilized to select, rank, evaluate, optimize, predict and benchmark decision alternatives (Chandran, Golden, & Wasil, 2005; Golden, Wasil, & Harker, 1989; Wasil & Golden, 2003). Simultaneously, applications of this technique have been presented in various areas, including energy resource allocation

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doi:10.1016/j.eswa.2008.03.019

(Ramanathan & Ganesh, 1995), machine selection (Lin & Yang, 1996), Internet access technology selection (Malladi & Min, 2005), production and distribution (Chan, Chan, Chan, & Humphreys, 2006), risk assessment (Tsai & Su, 2005), enterprise resource planning assessment (Wei, Chien, & Wang, 2005), evaluation of transport investment (Caliskan, 2006), image retrial (Cheng, Chou, Yang, & Chang, 2005), data mining (Liu & Shih, 2005) and many others. Although the AHP method is widely applied and has numerous advantages, it still suffers some certain shortcomings. Mon, Cheng, and Lin (1994) observed that the Saaty's AHP has the following drawbacks: (1) This method is primarily used in crisp decision problems. (2) This method deals with and produces unbalanced scale of judgments. (3) The AHP ranking method is not accurate enough. (4) The subjectivity, selection and preference of decision makers influence the consistency. Owing to these shortcomings of AHP, improved techniques such as Fuzzy AHP (Laarhoven & Pedrycz, 1983), referenced AHP (Schoner & Wedley, 1989), extended Fuzzy AHP (Weck, Klocke, Schell, & Rueauver, 1997), modified AHP (Tang & Tang, 1998), random AHP (Lipovestsky & Tishler, 1999), chainwise paired comparisons (Ra, 1999) and DS/AHP (Beynon, 2002) have been proposed in professional journals and conferences involving various disciplines.

Several researches in the field of advanced manufacturing technology (AMT) have been undertaken. Orr (2002) employed the financial evaluation techniques to plan and implement AMT. Talluri, Whiteside, and Seipel (2000) utilized the cone-ratio DEA in analyzing the AMT selection process. In 2001, Yusuff, Yee, and Hashmi (2001) applied AHP to determine the comparison weight for use by decision makers in predicting the success of AMT implementation because of its capability to structure complicated, multi-decision maker, multi-alternative and multi-attribute problems hierarchically. They pointed out that evaluation of AMT institutionalisation module implementation comprises a multiple criteria decision-making problem. As is well known, the main objective of AMT implementation ought to help enterprises strengthen competitiveness as much as possible, and minimize the unavoidable elimination in the dynamic market. The success or failure of AMT implementation is closely bound to enterprise survival (Beatty, 1992; Voss, 1986; Yusuff et al., 2001). Thus, an efficient method needs to be developed to help enterprises make appropriate decisions systematically. The AHP method presented in (Yusuff et al., 2001) is not efficient enough because it performs complex computation procedures in paired comparison and obtaining consistency indicators. To reduce the judgment times and avoid checking inconsistency, this study hence employs the consistent fuzzy preference relations (Herrera–Viedma, Herrera, Chiclana, & Luque, 2004), which inherits some advantages of AHP (distinct hierarchy, effective numerical assessment), to overcome certain drawbacks resulting from this conventional pairwise comparison approach (Lin & Yang, 1996).

The remainder of this paper is organized as follows. Section 2 outlines the basis and definitions of the consistent fuzzy preference relations. Section 3 then gives a brief review of the work of Yusuff et al. Next; Section 4 employs the example from (Yusuff et al., 2001) to illustrate the AMT implementation prediction process of consistent fuzzy preference relations. Section 5 discusses the results derived from the AHP and CFPR accordingly. Section 6 summarizes the related works of AMT and compares them with the method proposed in this study. Finally, conclusions are presented in Sections 7.

2. Consistent fuzzy preference relations

In decision making, when measuring preferences in relation to a set with a large number of alternatives, it is very difficult to obtain perfect consistency. Herrera–Viedma et al. (2004) proposed that the consistent fuzzy preference relations should be exportable in situations involving a reciprocal multiplicative preference relation. This method not only enables decision makers to express their preferences over a set of alternatives with the least judgments ($n-1$), but also avoids checking the inconsistency in decision-making process. The following briefly describes some definitions and propositions presented in (Chiclana, Herrera, & Herrera–Viedma, 1998; Fodor & Roubens, 1994; Herrera–Viedma et al., 2004; Tanino, 1984; Tanino, 1988). These basic definitions and notations below are used throughout this study unless otherwise specified.

2.1. Reciprocal multiplicative fuzzy preference relations

Definition 2.1. A multiplicative preference relation A on a set of alternatives X is indicated by a matrix $A \subset X \times X$, $A = (a_{ij})$, a_{ij} is the ratio of the preference degree of alternative x_i over x_j, A is assumed multiplicative reciprocal, given by

$$a_{ij} \cdot a_{ji} = 1 \quad \forall i,j \in \{1,\ldots,n\}. \tag{1}$$

Proposition 2.1. *A reciprocal multiplicative preference relation $A = (a_{ij})$ is consistent if*

$$a_{ij} \cdot a_{jk} = a_{ik} \quad \forall i,j = 1,\ldots,n. \tag{2}$$

2.2. Consistent fuzzy preference relations

Definition 2.2. Suppose a fuzzy preference relation P on a set of alternatives X is denoted by a matrix $P \subset X \times X$, this is presented by a membership function: $\mu_P : X \times X \to [0,1]$ $P = (p_{ij})$, $p_{ij} = \mu_P(x_i,x_j)$ $\forall i,j \in \{1,\ldots,n\}$. p_{ij} indicates the ratio of the preference intensity of alternative x_i to that of x_j (i.e., x_i is p_{ij} times as good as x_j). If $p_{ij} = \frac{1}{2}$ implies there is no difference between x_i and x_j ($x_i \sim x_j$), $p_{ij} = 1$ tells x_i is absolutely preferred to x_j, $p_{ij} > \frac{1}{2}$ indicates that x_i is preferred to x_j ($x_i > x_j$). P is assumed additive reciprocal, that is

$$p_{ij} + p_{ji} = 1 \quad \forall i,j \in \{1,\ldots,n\}. \tag{3}$$

Proposition 2.2. *Suppose there is a set of alternatives $X = \{x_1,\ldots,x_n\}$, which is associated with a reciprocal multiplicative fuzzy preference relation $A = (a_{ij})$ with $a_{ij} \in \left[\frac{1}{9}, 9\right]$. Then the corresponding reciprocal additive fuzzy preference relation $P = (p_{ij})$ with $p_{ij} \in [0,1]$ to $A = (a_{ij})$ is defined as follows:*

$$p_{ij} = g(a_{ij}) = \frac{1}{2} \cdot (1 + \log_9 a_{ij}). \tag{4}$$

With the transformation function g, a reciprocal multiplicative preference relation matrix can be transformed into kinds of preference relation.

2.3. Additive transitivity consistency of fuzzy preference relations

Definition 2.3. Additive transitivity property: $(p_{ij} - \frac{1}{2}) + (p_{jk} - \frac{1}{2}) = (p_{ik} - \frac{1}{2})$ $\forall i,j,k$, or equivalently,

$$p_{ij} + p_{jk} + p_{ki} = \frac{3}{2} \quad \forall i,j,k. \tag{5}$$

Proposition 2.3. *Let $A = (a_{ij})$ be a consistent multiplicative preference relation, then the corresponding reciprocal additive fuzzy preference relation $P = g(A)$, verifies additive transitivity property.*

Proof. For being $A = (a_{ij})$ consistent we have that $a_{ij} \cdot a_{jk} = a_{ik}$ $\forall$ i,j,k, or $a_{ij} \cdot a_{jk} \cdot a_{ik} = 1$ $\forall$ i,j,k.