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Fuzzy multi-criteria selection among transportation companies with fuzzy linguistic preference relations

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ABSTRACT

Selecting an appropriate transportation company is an important decision for an effective supply chain. This study attempts to solve transportation company selection problems initially addressed by Kulak and Kahraman in 2005, by adopting two methods. Consistent fuzzy preference relations presented by Herrera-Viedma et al. and fuzzy linguistic preference relations (fuzzy LinPreRa) developed by Wang and Chen in 2008. Analytical results indicate that both methods produce a consistent decision results from only $n - 1$ pairwise comparisons. However, assigning linguistic variables to judgments is simpler and more intuitive than fixed value judgments. Therefore, the fuzzy LinPreRa is more suitable and efficient for providing rankings of transportation companies for making decisions.

1. Introduction

Supply chain efficiency depends mainly on management decisions. Enterprises have recently shown an increasing interest in efficient supply chain management. This interest is attributed to the rising manufacturing and transportation costs, the globalization of market economies and the customer demand for diverse products of short life cycles. All of these factors raise competition among companies. These factors force organizations to find better ways to create and deliver value to customers. Therefore, transportation company selection has become an essential activity for firms.

The transportation company selection is a multi-criteria decision making (MCDM) problem. Several approaches and relevant methods have been presented to handle MCDM problems. One common MCDM method is the analytic hierarchy process (AHP), presented by Saaty (1980). AHP has been adopted in many different domains, including project management (Al-Harbi, 2001), enterprise resource planning (ERP) system selection (Wei, Chien, & Wang, 2005), risk assessment (Tsai & Su, 2005) and knowledge management tools evaluation (Ngai & Chan, 2005).

In the evaluation stage of AHP, the elements in each level of the hierarchy are compared in pairwise comparisons with respect to each element in the level directly above it. The pairwise comparisons are based on a rating scale of 1–9. However, decision makers often that assigning linguistic variables to judgments is more natural than making fixed value judgments. Therefore, data should be presented by fuzzy numbers rather than crisp numbers. Methods that extend AHP to handle fuzzy numbers have been presented. Early work in fuzzy AHP by Laarhoven and Pedrycz (1983) compared fuzzy ratios described with triangular membership functions. Buckley (1985) studied the application of fuzzy weights and fuzzy utility to extend AHP using the geometric mean to calculate the fuzzy weight. Chang (1996) introduced a novel approach using triangular fuzzy numbers for a pairwise comparison scale in fuzzy AHP. Extent analysis method (EAM) has also been adopted for synthetic extent values of pairwise comparisons. Cheng (1997) developed a new algorithm for measuring naval tactical missile systems using fuzzy AHP based on the grade value of membership function. Cheng, Yang, and Hwang (1999) proposed a novel method for assessing weapons systems using AHP according to linguistic variable weight. Zhu, Jing, and Chang (1999) discussed EAM and applications of fuzzy AHP. Leung and Cao (2000) presented a fuzzy consistency definition with tolerance deviation.

Among the above methods, EAM has been adopted in many applications because of its computational simplicity. For instance, Kahraman, Ruan, and Dogan (2003), Kahraman, Cebeci, and Ruan (2004), and Bozdağ, Kahraman, and Ruan (2003) applied EAM to select the best facility location, the best catering firm, and the best computer-integrated manufacturing system, respectively.

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Numerous other investigations have also adopted EAM (Bozbura & Beskese, 2007; Bozbura, Beskese, & Kahraman, 2007; Chan & Kumar, 2007; Erensal, Öncan, & Demircan, 2006; Tolga, Demircan, & Kahraman, 2005).

The size of a MCDM problem is based on the number of criteria and the number of alternatives. Existing MCDM methods are complex and difficult to apply to most large size real-world problems. Furthermore, the lack of consistency in decision-making can result in inconsistent conclusions. Although AHP and EAM are utilized in diverse fields, inconsistency rises as the numbers of criteria or alternatives increase. Decision makers often have difficulty in ensuring a consistent pairwise comparison between voluminous decisions.

To consider this dilemma, Herrera-Viedma, Herrera, Chiclana, and Luque (2004) presented consistent fuzzy preference relations to avoid inconsistent solutions in the decision-making processes. Furthermore, using AHP needs $n(n-1)/2$ pairwise comparisons, while consistent fuzzy preference relations need only $n-1$ comparisons. Wang and Chen (2005, 2008, 2010) and Chen (2008) developed a method that adopts fuzzy linguistic assessment variables rather than crisp values to construct fuzzy linguistic preference relations (fuzzy LinPreRa) matrices based on consistent fuzzy preference relations. Their method assures consistency, and only needs $n-1$ judgments from a set of n elements. This study solves transportation company selection problems addressed by Kulak and Kahraman (2005) by adopting consistent fuzzy preference relations and fuzzy LinPreRa. The results obtained by these methods are compared with other methods discussed by Kulak and Kahraman (2005).

The remainder of this paper is structured as follows. Section 2 reviews the consistent fuzzy preference relations. Section 3 describes the fuzzy preference relations (fuzzy LinPreRa). Section 4 presents an empirical study of transportation company selection. Finally, concluding remarks are presented in Section 5.

2. Consistent fuzzy preference relations

In many decision-making methods, the decision information is represented in the format of preference relations. Two major categories of preference relations are multiplicative preference relations and fuzzy preference relations (Chiclana, Herrera, Herrera-Viedma, & Martinez, 2003; Wang & Chang, 2007a; Wang & Chen, 2007), and are briefly described as follows:

(1) Multiplicative preference relations: The preference of a decision maker for a set of alternatives X is denoted by a positive preference relation matrix $A \subset X \times X$, $A = (a_{ij})_{n\times n}$, $a_{ij} \in [1/9, 9]$, where a_{ij} denotes the ratio of degree of preference for alternative x_i over x_j. $a_{ij} = 1$ indicates no preference between x_i and x_j, while $a_{ij} = 9$ indicates that the x_i is highly preferable to x_j. The term A is assumed to be a multiplicative reciprocal given by $a_{ij} \cdot a_{ji} = 1$ $\forall i, j \in \{1, \ldots, n\}$.

(2) Fuzzy preference relations: The preference of a decision maker for a set of alternatives X is denoted by a positive preference relation matrix $P \subset X \times X$ with membership function $\mu_p : X \times X \to [0, 1]$, where $\mu_p(x_i, x_j) = p_{ij}$ denotes the ratio of the preference intensity of alternative x_i to that of x_j. $p_{ij} = 0.5$ implies no difference between x_i and $x_j (x_i \sim x_j)$; $p_{ij} > 0.5$ implies that x_i is preferred to x_j $(x_i \succ x_j)$; $p_{ij} = 1$ indicates that x_i is absolutely preferred to x_j, and $p_{ij} = 0$ indicates that x_j is absolutely preferred to x_i. The P is assumed to be an additive reciprocal given by $p_{ij} + p_{ji} = 1$ $\forall i, j \in \{1, \ldots, n\}$.

Fedrizzi (1990) proved that a "multiplicative" formulation of a problem can be transformed into an "additive" one by function g. For a set of alternatives $X = \{x_1, \ldots, x_n\}$ associated with a reciprocal multiplicative preference relation $A = (a_{ij})$ and $a_{ij} \in [1/9, 9]$, transformation function g is adopted as in Eq. (1) to obtain the corresponding reciprocal additive fuzzy preference relation $P = (p_{ij})$, where $p_{ij} \in [0, 1]$

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

$\log_9 a_{ij}$ is considered when a_{ij} is between 1/9 and 9. If a_{ij} is between 1/7 and 7, then $\log_7 a_{ij}$ is adopted (Wang & Chen, 2007).

Herrera-Viedma et al. (2004) presented consistent fuzzy preference relations to construct the decision matrices of pairwise comparisons based on additive transitivity. They proved that, for a reciprocal additive fuzzy preference relation $P = (p_{ij})$, the following statements are equivalent:

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

$$p_{i(i+1)} + p_{(i+1)(i+2)} + \cdots + p_{(j-i)j} + p_{ji} = \frac{j-i+1}{2} \quad \forall i < j \tag{3}$$

Therefore, according to Eq. (3),

$$p_{ji} = \frac{j-i+1}{2} - p_{i(i+1)} - p_{(i+1)(i+2)} - \cdots - p_{(j-1)j} \tag{4}$$

Additionally, based on the additive reciprocal,

$$p_{ij} + p_{ji} = 1 \quad \forall i, j \in \{1, \ldots, n\} \tag{5}$$

The steps of consistent fuzzy preference relations are as follows:

Step 1. Calculate the set of preference values B as

$$B = \{p_{ij}, i < j \wedge p_{ij} \notin \{p_{12}, p_{23}, \ldots, p_{n-1n}\}\} \tag{6}$$

Step 2. Find P

$$P = \{p_{12}, p_{23}, \ldots, p_{n-1n}\} \cup B \cup \{1 - p_{12}, 1 - p_{23}, \ldots, 1 - p_{n-1n}\} \cup \neg B \tag{7}$$

Step 3. The consistent fuzzy preference relation P' is obtained as $P' = f(P)$, such that $f : [-a, 1 + a] \to [0, 1]$

$$f(x) = \frac{x + a}{1 + 2a} \tag{8}$$

The concept of this method is that, for n attributes $X = \{x_1, \ldots, x_n, \quad n \geqslant 2\}$, the pairwise preference relation data $\{p_{12}, p_{23}, \ldots, p_{n-1n}\}$ can be derived by comparing $n-1$ and constructing a consistent reciprocal fuzzy preference relations P'. This method is similar to that for conventional AHP characteristics, which is a transitivity property satisfied by preference relations.

Several researchers have applied consistent fuzzy preference relations to many different fields in recent years. For example, Wang and Chang (2007a, 2007b) applied this method to forecast the probability of successful knowledge management, and to predict the success of knowledge management implementation. Wang and Chen (2006) adopted this method to select a multimedia authoring system (MAS). Wang and Chen (2007) applied consistent fuzzy preference relations to partnership selection. Wang and Liang (2006) adopted this method to measure the user-perceived service quality of information-presenting web portals. Wang and Lin (2009a) applied consistent fuzzy preference relations to predict the success of B2B e-commerce in small and medium enterprises. Wang and Lin (2009b) adopted this method to select merger strategy for commercial banks in new financial environments. The consistent fuzzy preference relations approach has so far shown a good performance in many fields.