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Supplier selection using AHP methodology extended by D numbers

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ABSTRACT

Supplier selection is an important issue in supply chain management (SCM), and essentially is a multi-criteria decision-making problem. Supplier selection highly depends on experts' assessments. In the process of that, it inevitably involves various types of uncertainty such as imprecision, fuzziness and incompleteness due to the inability of human being's subjective judgment. However, the existing methods cannot adequately handle these types of uncertainties. In this paper, based on a new effective and feasible representation of uncertain information, called D numbers, a D-AHP method is proposed for the supplier selection problem, which extends the classical analytic hierarchy process (AHP) method. Within the proposed method, D numbers extended fuzzy preference relation has been involved to represent the decision matrix of pairwise comparisons given by experts. An illustrative example is presented to demonstrate the effectiveness of the proposed method.

1. Introduction

Supply chain management (SCM) has emerged as an important element in improving the global competitiveness of companies in the highly competitive global economy (Othman & Ghani, 2008; Gunasekaran & Ngai, 2005). One of the key problems in SCM is supplier selection (Wu and Barnes, 2011; Huang and Keskar, 2007, i.e., find the best supplier among several alternatives according to various criteria, such as cost, service, risk and others. This is a complicated multi-criteria decision-making problem (Chai, Liu, & Ngai, 2013). The identification of criteria and integration of experts' assessments are two components of the supplier selection problem.

With respect to the identification of criteria, selection of criteria and calculation of priority weights both should be considered. Lee, Kang, Hsu, and Hung (2009) investigated the green supplier selection problem for high-tech industry, and identified six criteria, namely quality, technology capability, pollution control, environmental management, green production and green competency. In the automobile industry, Govindan, Kannan, and Haq (2010) developed a framework to identify and rank the associated criteria, for instance asset specificity and supplier performance. Aksoy and Ozturk (2011) explored the problem of supplier selection in just-in-time (JIT) production environments. It is worth noting that environmental criteria have gradually begun to attract increasing attention in supplier selection. Humphreys, Wong, and Chan (2003) identified seven environmental categories, including environmental costs (pollutant effects), environmental costs (improvement), management competencies, "green" image, design for environment, environmental management systems, and environmental competencies.

Generally speaking, the criteria for supplier selection highly depend on individual companies and industries. On the one hand, different companies have different organizational structure, management strategy, enterprise culture and others. All of these influence the determination of supplier selection criteria. On the other hand, industry background causes huge difference and greatly impacts the selection of suppliers. Therefore, the identification of supplier selection criteria are on the basis of specific environments, and largely requires domain experts' assessment and judgement.

After identifying the criteria, a methodology is needed to integrate experts' assessments in order to find the best supplier. At present, various methods have been applied to supplier selection, such as the analytic hierarchy process (AHP) (Chan, 2003; Wang, Chin, & Leung, 2009), fuzzy set theory (Ordoobadi, 2009; Labib, 2011), fuzzy extended AHP method (Chan & Kumar, 2007; Chan, Kumar, Tiwari, Lau, & Choy, 2008; Kilincci & Onal, 2011), TOPSIS method (Boran, Genc, Kurt, & Akay, 2009; Deng, 2006; Wang, Cheng, & Kun-Cheng, 2009; Zouggari & Benyoucef, 2012), Dempster–Shafer evidence theory (Deng & Chan, 2011) and others (Chen & Chao, 2012; Ferreira & Borenstein, 2012; Ng, 2008; Sanayei, Mousavi, & Yazdankhah, 2010). Among these methods, AHP

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(Ngai & Chan, 2005; Saaty, 1980) is popular and extensively used to deal with complex decision problem due to its simplicity in concept and convenience in operation. Even so, its inability to adequately handle the inherent uncertainty and imprecision in the data is also often criticized. The fuzzy extended AHP method (Buyukozkan, Cifci, & Guleryuz, 2011; Chan & Kumar, 2007; Chan et al., 2008; Sadiq & Tesfamariam, 2009; Wang, Luo, & Hua, 2007) provides the ability to handle the fuzziness in the experts' subjective judgment with the aid of fuzzy set theory. However, the inconsistency of the fuzzy evaluation comparison matrix is still an open issue (Leung & Cao, 2000; Wang & Chen, 2008). Some researchers have studied the concept of fuzzy preference relation (Chen & Chao, 2012; Garcia, del Moral, Martinez, & Herrera-Viedma, 2012; Herrera-Viedma, Herrera, Chiclana, & Luque, 2004; Herrera-Viedma, Alonso, Chiclana, & Herrera, 2007; Lee, 2012; Tanino, 1984; Wang & Fan, 2007; Xu, 2007) which directly enables the fuzziness of preference relation to be represented in the form of membership function. Yet the method of fuzzy preference relation is still unable to handle situations when the information is incomplete.

Supplier selection highly depends on large amounts of domain knowledge, where experts' assessments play an important role. However, various uncertainties are present in domain experts' subjective and qualitative judgment, such as imprecision, fuzziness, incompleteness and so on. Therefore it is necessary to develop a more effective method for supplier selection, which should be able to handle various types of uncertainties (Kara, 2011; Li & Zabinskys, 2011; Wu, 2009).

In order to effectively handle various uncertainties involved in the supplier selection problem, a new representation of uncertain information, called D numbers (Deng, 2012), is presented in this paper. The concept of D numbers extends the Dempster–Shafer evidence theory (Dempster, 1967; Shafer, 1976), and is more effective in representing uncertain information, as discussed later. Secondly, a D numbers-based preference relation is proposed by extending the fuzzy preference relation approach. The proposed D numbers preference relation overcomes the deficiency of fuzzy preference relation. Finally, the AHP method is extended using the D numbers-based preference relation, leading to the proposed D-AHP method for decision-making under uncertain information.

The rest of this paper is organized as follows. Section 2 gives a brief introduction to the classical AHP method. Section 3 develops the proposed D-AHP method for supplier selection. It contains the introduction of D numbers and fuzzy preference relation, the concept of D numbers preference relation, the calculation of priority weights and inconsistency degree in D numbers preference relation, and the D-AHP method. After that, an illustrative example of supplier selection is given to show the effectiveness of the proposed D-AHP method in Section 4. Finally, Section 5 concludes the paper.

2. Analytic hierarchy process (AHP)

AHP Saaty (1980) is a structured technique for handling complex decision problems. Both qualitative and quantitative factors are combined by using AHP in the decision-making process.

Generally, the process of applying AHP can be divided into three steps. First, establish a hierarchical structure by recursively decomposing the decision problem. Second, construct the pairwise comparison matrix to indicate the relative importance of alternatives. A numerical rating including nine rank scales is suggested, as shown in Table 1. Third, calculate the priority weights of alternatives according to the pairwise comparison matrix by the following equation:

$$Aw = \lambda_{\max} w, \quad w = (w_1, w_2, \ldots, w_n)^T \tag{1}$$

Table 1
Numerical rating in the AHP method.

Scale	Meaning
1	Equal importance
3	Moderate importance
5	Strong importance
7	Demonstrated importance
9	Extreme importance
2,4,6,8	Intermediate values

where A is a n dimensional comparison matrix, $\lambda_{\max}$ is the largest eigenvalue of A and w is the eigenvector corresponding to $\lambda_{\max}$.

In AHP, a consistency index ($C.I.$) is defined to measure the inconsistency within the pairwise comparison matrix A.

$$C.I. = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

Accordingly, the consistency ratio $C.R.$ is used to measure the degree of $C.I.$ by the following equation:

$$C.R. = \frac{C.I.}{R.I.} \tag{3}$$

where $R.I.$ is the random consistency index, its value is related to the dimension of the matrix, listed in Table 2.

If $C.R. < 0.10$, the inconsistency degree of the comparison matrix A is consider acceptable and the eigenvector w is used as the weighting vector after normalization. Otherwise, the comparison matrix needs to be adjusted.

3. D-AHP for supplier selection

3.1. D numbers

Information about the real world is affected by many sources of uncertainty. Many existing theories, such as probability theory, fuzzy set theory (Zadeh, 1965), Dempster–Shafer evidence theory (Dempster, 1967; Shafer, 1976), have been developed to model various types of uncertainty, and provide some desirable properties. But these theories, however, still contain deficiencies that cannot be ignored. Take Dempster–Shafer evidence theory as an example. Due to its inherent advantages in the representation and handling of uncertain information, the Dempster–Shafer evidence theory is being studied for use in many fields, such as decision analysis, pattern recognition, risk assessment, supplier selection and others (Dempster, 1967; Deng, Shi, Zhu, & Liu, 2004; Deng, Su, Wang, & Li, 2010; Deng, Chan, Wu, & Wang, 2011; Deng, Sadiq, Jiang, & Tesfamariam, 2011; Deng, Jiang, & Sadiq, 2011; Deng, Liu, Hu, & Deng, 2013; Kang, Deng, Sadiq, & Mahadevan, 2012; Liu, Chan, Li, Zhang, & Deng, 2012; Sadiq, Kleiner, & Rajani, 2006; Sadiq, Najjaran, & Kleiner, 2006; Sadiq, Kleiner, & Rajani, 2007; Shafer, 1976; Zhang, Deng, Wei, & Deng, 2012; Wei, Deng, Zhang, Deng, & Mahadevan, 2013). In the mathematical framework of Dempster–Shafer theory, the basic probability assignment (BPA) defined on the frame of discernment is used to express the uncertainty in judgement. A problem domain indicated by a finite non-empty set Ω of mutually exclusive and exhaustive hypotheses is called a frame of discernment. Let 2^Ω denote the power set of Ω, a BPA is a mapping $m: 2^\Omega \to [0,1]$, satisfying

$$m(\emptyset) = 0 \quad \text{and} \quad \sum_{A \in 2^\Omega} m(A) = 1 \tag{4}$$

Table 2
Random consistency index $R.I.$

n	1	2	3	4	5	6	7	8	9	10
$R.I.$	0	0	0.52	0.89	1.12	1.26	1.36	1.41	1.46	1.49