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Group multi-criteria design concept evaluation using combined rough set theory and fuzzy set theory

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ABSTRACT

Design concept evaluation is a critical stage in the product development which has significant impact on the downstream process in product development thus on success of new product. Design concept evaluation is widely recognized as a complex multi-criteria decision-making (MCDM) problem involving various decision criteria and large amount of data which are usually imprecise and subjective. This paper proposes a new decision-making method to evaluate product design concepts based on the distance between interval vectors each alternative and positive and negative ideal reference vectors. Rank of design concepts is obtained by calculating interval-based relative closeness index for each alternative. In this method, to deal with uncertainty and vagueness of data in the primary phases of product design, performance of design concepts with respect to quantitative and qualitative criteria are concurrently evaluated using rough set and fuzzy set. The weights of criteria used in the evaluation are obtained using the extent analysis method on fuzzy AHP. The efficacy of the method is demonstrated with a numerical example and the results are compared to TOPSIS method. In final, the conclusions of our method are represented and some future directions are proposed to improve the model.

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1. Introduction

Customers are constantly seeking products with higher quality, lower price, shorter delivery time and higher satisfaction. In a highly competitive environment, many companies have focused product development process to respond customers' growing needs.

New product development (NPD) process is a set of all activities required, from identification of market opportunity, to delivery of a product (Ulrich & Eppinger, 2011). These stages mainly include customers' needs analysis, setting target specifications, concept generation, concept evaluation and selection, concept testing, and setting final specifications. The success of new products relies to a great extent on the performance of the product development team in dealing with these stages.

A good design process should guarantee both the fulfillment of customer needs and business goals. Therefore, the evaluation of new product concept has long been recognized as one of the most critical decisions for the success of product development because of significant effects on the downstream development activities. Although product architecture is normally set up during the early stages of the product development cycle, it influences decisions in the next processes in the domains of product, process and supply chain (Fixson, 2005). It is estimated that product and process design influences 80% of manufacturing costs, 50% of quality, 50% of order lead time, and 50% of business complexity (Child, Diederichs, Sanders, & Wisniowski, 1991; Shehab & Abdalla, 2001).

Design concept evaluation is a multi-criteria decision-making (MCDM) process which is recognized as an effective technique in solving the NPD selection problem. Each design concept evaluation problem should consider customer needs, factors involving in life cycle of product and business constraints.

In the early design stages, the evaluation of design concepts is difficult to precisely express by crisp data because the available information is usually imprecise, incomplete or subjective. In many cases in design concept evaluation problem, quantitative criteria (e.g. cost) and qualitative criteria (e.g. aesthetic) are needed to be simultaneously considered. Therefore, an effective method for the evaluation of design concepts which considers various criteria as well as uncertainty and vagueness in information in the early stages of design process is very necessary.

This paper develops a novel method to rank design concepts considering quantitative and qualitative criteria and uses theories of rough set and fuzzy set to deal with uncertainty and vagueness in the problem. The method develops an interval-based relative

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Table 1
Different categories for MDCM methods.

Mathematics	Statistics	Artificial intelligence
Analytic hierarchy process (AHP), Analytic network process (ANP), Analytic target cascading (ATC), Game theory, Data envelopment analysis (DEA), Costing, Grey theory, Technique for order of preference by similarity to ideal Solution (TOPSIS), VIKOR, Elimination and choice expressing reality (ELECTRE), The Preference Ranking Organization Method for Enrichment of Evaluations (Promethee)	Process capability index, Factor analysis, Data mining, Loss functions, Decision trees, Multivariate statistics, Structural equations	Fuzzy set theory, Expert systems, Vector machines, Simulation, Neural networks, Case based reasoning

closeness index to rank design concepts based on distance between performance of design concepts with respect to quantitative and qualitative criteria and positive and negative ideal reference vectors.

The remainder of this paper is organized as follows: Section 2 presents a brief literature about design concept evaluation. Section 3 provides a background of the concepts and methods used in the method proposed. Section 4 describes the different stages of the proposed method. A numerical example is expressed in Section 5 to show the efficiency of the method. This section compares the rank of alternatives obtained from our method with the TOPSIS method for this numerical example. Different analyzes on the model proposed and the TOPSIS method are carried out with respect to various parameters affecting the design concept evaluation such as weights of criteria and decision makers (DMs)' confidence level. Section 6 provides conclusions and future research directions.

2. Literature review

Many works based on MCDM approaches have been carried out to evaluate alternatives in different problems such as supplier evaluation (Dursun & Karsak, 2013; Lin, 2012), financial performance of companies (Seçme, Bayrakdaroglu, & Kahraman, 2009; Wang, 2008), innovation performance evaluation (Chen & Chen, 2010; Lu, Tzeng, & Tang, 2013) and Entrepreneurship (Nikfarjam, Kiani Mavi, & Fazli, 2013; Rezaei, Ortt, & Scholten, 2012; Rostamzadeh, Ismail, & Bodaghi Khajeh Noubar, 2014). The survey in the literature identifies different categories of MCDM methods shown in Table 1.

Research on the classification and sorting problems have major practical interest in several fields including NPD, innovation and entrepreneurship, finance, environmental and energy policy, planning, marketing, medical diagnosis, robotics (pattern recognition), etc. The multivariate statistical classification techniques have been used for decades to study such problems. However, their inability to provide a realistic and flexible approach to support real-world decision-making problems in situations where sorting is required, led to create different tools and methods to develop classification and sorting models within a realistic and flexible context (Zopounidis & Doumpos, 2002). Rezaei et al. (2012) carried out a good comparison based on four different methodologies of the traditional statistical methodology, a fuzzy-logic methodology, a DEA-like methodology and a naïve methodology for the construct of entrepreneurial orientation (EO).

In during decades, many researchers have proposed numerical and non-numerical methods to support the design concept evaluation. According Ayağ and Özdemir (2009), non-numerical methods such as concept screening (Ulrich & Eppinger, 2000) and concept selection (Pugh, 1996) are simple, fast, and suitable for the design concepts with simple applications. Numerical methods such as utility function analysis (Thurston & Carnahan, 1992), fuzzy sets (Tsai & Hsiao, 2004), analytic hierarchy process (Ayağ, 2005b), The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Davoodi et al., 2011) and PROMETHEE (Preference Ranking Organizational Method for Enrichment Evaluation) (Vinodh & Girubha, 2012) often follow a systematic approach in order to the accurate evaluation of design concepts (Zhai, Khoo, & Zhong, 2009). Analysis of these papers recognizes mainly two main difficulties associated with design evaluation; 1) various decision criteria, and 2) different reliability of data.

There are various objective and subjective criteria which should be considered when designing a product (Florez & Castro-Lacouture, 2013). The objective (or quantitative) criteria such as cost and lead time are characterized by quantitative measures and often quantified by numerical variable (Fine, Golany, & Naseraldin, 2005). The subjective (or qualitative) criteria such as the aesthetic are characterized by qualitative descriptions of experts and often evaluated in linguistic terms. In many cases, criteria affecting design concepts have a qualitative nature (e.g. Aesthetic). Therefore, it is important to investigate concurrently the effects of qualitative and quantitative criteria for the evaluation of design concepts (Tseng, 1998; Ulutas et al., 2012; Shidpour, Shahrokhi, & Bernard, 2013).

The evaluation of design concepts in new product development (NDP) process involves subjectivity and vagueness of information available at the early stages (Seo, Park, Jang, & Wallace, 2002). To reflect the subjectivity and imprecision involved in the evaluation process, hybrid methods have received more attention for the problem of design concept evaluation. Combining the methods in Table 1 builds the hybrid MCDM methods. Salhieh and Al-Harris (2014) introduced a new methodology for the evaluation and selection of new product concepts using Data Envelopment Analysis (DEA) and Conjoint Analysis (CA). Among integrated evaluation methods, fuzzy set theory and AHP method are often integrated with other methods in this area due to their abilities in handling uncertainty and vagueness (Kuo, Tzeng, & Huang, 2007; Saridakis & Dentsoras, 2008). Sii and Wang (2003) integrated both the Delphi method and fuzzy logic with AHP method to evaluate alternatives under a subjective and uncertain environment. Ayağ (2005a) proposed a Fuzzy AHP method to reduce the number of conceptual design alternatives and evaluated the remaining alternatives with integration of simulation analysis with the fuzzy AHP method. Ayağ (2005b) used AHP method to reduce the number of conceptual design alternatives and integrated simulation analysis with the AHP method to help decision makers to perform economic analyses. Huang, Bo, and Chen (2006) proposed an approach for design concept generation and evaluation with integration fuzzy sets with genetic algorithms and neural networks. Akay and Kulak (2007) proposed a combined method including grey theory, fuzzy sets and information. Zhang and Chu (2009) proposed an integrated approach based on QFD and group decision-making. Fuzzy set theory is also incorporated to handle the vagueness and uncertainty in the selection process. To capture imprecise and subjective information in the process of concept selection, Akay, Kulak, and Henson (2011) proposed a methodology that uses the fuzzy information axiom approach to incorporate interval type-2 fuzzy sets.

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