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A multi-criteria decision-making framework for risk ranking of energy performance contracting project under picture fuzzy environment

Le Wang [a], Juan-juan Peng [a, b], Jian-qiang Wang [a, *]

[a] School of Business, Central South University, Changsha, 410083, PR China
[b] School of Economics and Management, Hubei University of Automotive Technology, Shiyan, 442002, China

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ABSTRACT

Identifying the priority of risks as regards energy performance contracting (EPC) projects is one of the main issues faced by energy service companies. Considering the complexity and uncertainty of EPC mechanism, this study attempts to formulate a hybrid fuzzy multi-criteria decision-making framework with picture fuzzy information to rank the risk factors of EPC projects. The proposed framework not only considers the interrelationship among criteria but also considers the decision-maker's bounded rationality and behavioural psychology. First, to effectively express the uncertainty and fuzziness of risk and environment, risk evaluation is expressed as picture fuzzy numbers. Subsequently, the new distances of picture fuzzy sets are proposed to fully use picture fuzzy information. Meanwhile, considering the interrelationship among criteria, an optimisation model based on the maximizing deviation method and Bonferroni mean distance of picture fuzzy sets is established to determine the weight vector of criteria with incomplete weight information. Furthermore, a prospect theory-based multi-attributive border approximation area comparison (MABAC) method is proposed to rank the risks and identify the priority of risks by reflecting the decision-maker's bounded rationality and behaviour psychology. In addition, the proposed framework is successfully implemented in a case study of a hotel's energy efficiency retrofit. Results show that the proposed framework is an effective and practical decision tool for risk ranking problems under picture fuzzy environment. Finally, the detailed risk mitigation, energy-saving performance and implications are presented to provide a reference and suggestion for other projects.

1. Introduction

Given the rapid development of China's economy and fast-paced urbanisation, energy consumption and carbon emissions gradually increase. In 2015, China emitted 9,153,900,000 tons of CO_2, which accounted for 27.3% of the global emissions, exceeding the 5,485,700,00 tons of the United States (Deng et al., 2017). Meanwhile, buildings' energy consumption accounts for approximately 40% of total energy and the more than 97% buildings are categorised as high energy consumption (Carbonara et al., 2018; Rivalin et al., 2018). Thus, building energy efficiency indicates considerable potential. The attainment of building energy-saving targets not only requires government support but also the efforts of the building owner. To reduce energy consumption and improve energy efficiency, national strategic plans and policies have been published, such as the 11th Five-Year Plan, 12th Five-Year Plan, 13th Five-Year Plan, tax breaks and energy-saving subsidies. However, the building owner in energy efficiency retrofit faces economic and technical problems. For example, hotel owners wish to conduct energy efficiency retrofit, and they should transform and upgrade the overall structure of the hotel, such as the transformation and maintenance of facilities, and staff training. These initiatives represent considerable expenditure. Meanwhile, the development of energy efficiency retrofit for hotel buildings remains in the exploratory stage; the technology and management are not perfect. Thus, if hotel owners conduct energy efficiency retrofit blindly, they must bear the technological and economic risks.

To reduce the technology and economic risks for the building owners, energy performance contracting (EPC), an effective and important energy-efficiency retrofit mechanism, is becoming a key priority for building owners. Two main participants in the EPC project are energy service companies (ESCOs) and client (energy consumption units, such as building owners). ESCO is a type of specialised company that provides an energy-saving turnkey

* Corresponding author.
E-mail address: jqwang@csu.edu.cn (J.-q. Wang).

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service (energy audit, project design, financing, equipment installation and maintenance) to clients and shares the energy savings benefit with them (Zhou et al., 2017). The client uses the energy-saving benefit for the cost of ESCO during the contract and the total energy-saving benefit is obtained by the client at the end of contract (Liu et al., 2017). Thus, the client does not spend and gains energy-saving benefits. Generally, EPC can save 5%–40% of the total energy used in the past (Aasen et al., 2016). EPC can not only improve energy utilisation efficiency and reduce energy consumption for the client but also generate benefits for ESCO. Thus, EPC is significant for energy saving and economic development. Thus, the EPC mechanism has been widely used worldwide, and regions include Italy (Principi et al., 2016), the United Kingdom (Capelo et al., 2018), Germany (Polzin et al., 2016), Europe (Bertoldi and Boza-Kiss, 2017), and Russia (Garbuzova-Schlifter and Madlener, 2016).

The EPC project is a turnkey process by ESCO. Thus, ESCO undertakes almost all of the risks of the EPC project (Carbonara et al., 2018). In addition, EPC projects are characterised by complexity, large investment and long periodicity. Thus, risk management in EPC projects is necessary. Given the limited resources and numerous risk factors, ESCOs must identify the priority of risks by ranking the identified risk factors. Then, based on the priority of risk, ESCO can manage, mitigate and even eliminate the critical risks to guarantee project success. If improper risk management exists in ESCO, the profits will greatly decrease; losses may even occur. Thus, ESCO not only cannot recover the project investment but also cannot compensate the time investment. Therefore, the decision-makers (DMs) of ESCO must distinguish the priority of risks and adopt appropriate decisions accordingly. Identifying the priority of risk factors by risk ranking can be viewed as a multi-criteria decision-making (MCDM) problem (Papapostolou et al., 2017; Wang et al., 2018b).

Many researchers use crisp numbers to describe the risk evaluation in the MCDM method. However, project risk evaluation is an ex-ante estimate to predict the future value in the early stage of the project. Thus, the resulting value is uncertain and fuzzy. Meanwhile, the judgment of risk evaluation information generally depends on experts' experiences. However, experts cannot express their opinions as accurately as machines when describing a complex object, and vagueness always occurs in the thinking mode (Wu et al., 2018a). Thus, using fuzzy numbers to describe the risk evaluation information is more appropriate and superior than crisp numbers in the MCDM method. Picture fuzzy sets (PFSs) (Cuong and Kreinovich, 2014), as a type of fuzzy sets, are characterised by the following membership degrees: positive, neutral, negative and refusal. Thus, PFSs satisfy the situations in which DMs face opinions that involve various types of answers, such as yes, abstain, no and refusal. For example, three evaluation levels, namely, "high", "medium" and "low", are generally used by experts to evaluate risk factors under a criterion. Furthermore, experts can also refuse to provide the evaluation because of knowledge limitations. Thus, the degree of "high", "medium", "low" and "refuse" correspond to the positive membership degree, neutral membership degree, negative membership degree and refusal membership degree, respectively. Therefore, the risk evaluation information can be expressed as picture fuzzy numbers (PFNs). In addition, PFSs can be better applied to many practical problems such as decision-making problems (Wei, 2016; Wei et al., 2016b), shareholder voting (Nie et al., 2017), geographic data clustering (Hoa and Thong, 2017) and weather nowcasting (Son and Thong, 2016).

To describe the difference between two risk evaluations, distance is a useful tool in various fuzzy environments. However, the existing picture fuzzy distances (Peng and Dai, 2017; Son, 2016, 2017) only consider three parameters while ignoring the effect of the fourth parameter (refusal membership degree). To fully use the information of PFSs, new picture fuzzy distances with four parameters are necessary and significant. Meanwhile, interrelationships among criteria are universal in decision-making problems. Such as, support probability of risk occurrence, risk impact, exposure to risk and response capacity are four criteria in the risk evaluation problem. In this situation, the probability of risk occurrence and response capacity may affect the risk impact. The probability of risk occurrence may depend on the effect of exposure to risk and response capacity. Therefore, we must consider the interrelationship among criteria, and the Bonferroni mean distances represents one strategy to dealing such situation.

Determining the weight vector of criteria is important in the MCDM problem. Generally, the information of criteria weights possesses three types of information, namely, unknown, incomplete and complete known information. In the risk-ranking problem, considering the complexity of the risk, the information of criteria weight is not completely known. Meanwhile, the information of criteria weights is not completely unknown; it can be given by experts based on their experience and relevant research. Thus, the maximizing deviation method is used to obtain the criteria weights with the incomplete information. The maximizing deviation method proposed by Wang (1997) uses the concept of deviation to determine the criteria weights objectively. The basic principle of maximizing the deviation method is that the criterion is important when a greater difference occurs among the evaluations of all alternatives with regard to the criterion. Thus, the criterion should be assigned a greater weight. Recently, Mousavi et al. (2017) proposed an ELECTRE model for renewable energy policy selection with unknown information under a hesitant fuzzy environment. Wei (2015) proposed a method for interval intuitionistic trapezoidal fuzzy MCDM with incomplete weight information. However, the existing maximizing deviation method did not consider the interrelationship among criteria.

Many effective tools are used in solving the MCDM problem, such as aggregation operators (Wang et al., 2018a; Wei, 2017; Wei and Lu, 2018), distance measures (Peng et al., 2018; Wang. et al., 2017b), similarity measures (Wei and Wei, 2018), TOPSIS (technique for order performance by similarity to ideal solution) method (Ou et al., 2018), VIKOR (vlsekriterijumska optimizacija i kompromisno resenje) method (Xu et al., 2017), TODIM (an acronym in Portuguese of interactive and multi-criteria decision making) method (Yu et al., 2018; Ji et al., 2017) and SMAA (stochastic multi-criteria acceptability analysis) (Yang and Wang, 2018). Recently, a new reliable method was proposed by Pamučar and Ćirović (2015), namely, multi-attributive border approximation area comparison (MABAC) method. The method uses a straightforward and simple computation process, systematic procedure, and a sound logic that demonstrates the fundamental of DMs' decision making (Xue et al., 2016). Given its advantages, the MABAC method has been used to address MCDM problems under various fuzzy sets, such as interval-valued intuitionistic fuzzy set (Xue et al., 2016), Pythagorean fuzzy environment (Peng and Yang, 2016), interval type-2 fuzzy (Yu et al., 2017) and hesitant fuzzy linguistics (Sun et al., 2017). However, these methods are mainly based on the assumptions of DMs being fully rational. In fact, DMs are bounded rational in the decision-making process (Simon, 1947). For example, DMs are more sensitive to loss than gain. In other words, the joy of decreasing risk by 50% cannot easily compensate for the pain of increasing risk by 50%. Thus, people tend towards loss aversion. Considering the bounded rationality of DMs, Kahneman and Tversky (1979) proposed the prospect theory based on individual behaviour research by investigation and experiment. The behavioural principles of prospect theory include loss aversion, reference dependence and diminishing sensitivity. Therefore, the decision-making process considers