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A NOVEL APPROACH FOR GREEN SUPPLIER SELECTION PROBLEM: FUZZY AXIOMATIC DESIGN WITH RISK FACTORS

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ABSTRACT

Today's environmental conscious world forces companies to be more concerned with energy and water consumption. New trends in the world generally provide competitive advantage to the firms if they work on environmental issues. As a critical decision of companies, supplier selection problem needs to consider the environmental factors and economic factors simultaneously. This study proposes a novel solution methodology for green supplier selection problem: Fuzzy axiomatic design with risk factors. This method is applied in many decision-making problems in the literature successfully. A case study is presented to implement the method and the results are compared with traditional fuzzy axiomatic design and fuzzy TOPSIS. It has seen that the decision of the best supplier selection can be influenced by the risk factors such as the deviation in the economical conditions or the working conditions of the company.

Keywords: *Green Supplier Selection (GSS), Fuzzy Axiomatic Design with Risk Factors, Fuzzy TOPSIS.*

JEL Codes: C44, Q52, Q53, D20

YEŞİL TEDARİKÇİ SEÇİMİ PROBLEMİ İÇİN YENİ BİR YAKLAŞIM

ÖZET

Günümüzün çevreye duyarlı müşterileri, firmaları enerji ve su tüketimi konusunda daha dikkatli davranmaya zorlamaktadır. Dünyadaki yeni yönelimler, çevresel konulara değer veren firmaların rekabet avantajı sağladığını göstermektedir. Firmalar için kritik öneme sahip tedarikçi seçimi probleminde, yalnızca ekonomik faktörlerin değil, çevresel faktörlerin de dikkate alınması gerekmektedir. Bu çalışma yeşil tedarikçi seçimi problemi için yeni bir yöntem olan 'Risk Faktörlü Bulanık Aksiyomatik Tasarım' yöntemini önermektedir. Önerilen model ülkemizden bir örnek vaka üzerinde uygulanmış ve elde edilen sonuçlar Klasik Bulanık Aksiyomatik Tasarım ve Bulanık İdeal

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Çözüme Benzerliğe Göre Tercih Sıralama Tekniği (TOPSIS) kullanılarak ulaşılan sonuçlar ile karşılaştırılmıştır.

Anahtar Kelimeler: *Yeşil Tedarikçi Seçimi, Risk Faktörlü Bulanık Aksiyomatik Tasarım, Bulanık TOPSIS.*

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1. INTRODUCTION

Considering the huge effect of suppliers on the product's final costs, conventional Supplier Selection Problem (SSP) is widely studied by many researchers in the literature. However, these papers generally focus on economic factors and neglect the environmental factors. Today's customers are highly conscious and sensitive about protecting the environment. Furthermore, academics, industry partners and scientists get together to propose ways to maintain environmental sustainability (Tseng et al., 2019). Consequently, global trends in the world generally provide competitive advantage to the firms if they work on environmental issues. SSP is the first step of purchase and supply chain. So incorporating green factors to this process is essential to provide eco-friendly companies in this era. Researches in Green Supplier Selection (GSS) have been more popular in the era of clean energy and waste minimization. (see Govindan et al. for a comprehensive review of GSS and evaluation literature (Govindan et al., 2015). A very recent study by Tseng et al. 2019, reviewed the GSS published papers from 1998 to 2017 and find a sharp growth of publications on the topic after 2010 until now (Tseng et al, 2019). The main reason behind this outcome is the awareness of the importance of green factors in Supply Chain Management (SCM). GSS problem is assumed as Multi Criteria Decision Making problem since quantitative and qualitative factors should be taken into account in evaluation process simultaneously. Conventional supplier selection criteria for instance quality, cost and service are widely used in the literature but green criteria such as energy consumption, hazardous material usage and awareness of environmental responsibility are newly chosen as decision criteria by many researchers (Kannan et al.,2014). These new criteria and dimensions makes the decision models more complex; where the tradeoffs become more evident. Furthermore, the responses and evaluations of experts for selecting the supplier are generally in terms of words and linguistic, hence, inexact. This situation motivates us to use fuzzy logic and a MCDM method, Axiomatic Design (AD) to GSS problem. Furthermore, this paper presents a new tool based on fuzzy AD approach in decision process. This new approach considers risk factors during the evaluation and as far as our knowledge, this research is one of the pioneer studies considering risk factors in the selection of suppliers in terms of green design. The rest of the paper is organized as follows: Initially literature review is provided for GSS problem and methodologies used. Then the fuzzy AD and fuzzy AD with risk factors and fuzzy TOPSIS are described. A case study from Turkey is presented in the third section and finally, a conclusion and future studies are explained.

2. LITERATURE REVIEW

GSS discussion is a new research area and it emerges from the idea of greener companies (Marcus and Fremeth, 2009). Many researchers and practitioners started to pay attention to this today's hot topic. A number of literature reviews have been prepared for green supplier selection problem recently. As noted, GSS problem is a MCDM problem and there are many studies proposing support tools for analyzing and supporting organizational decisions (Govindan et al, 2015). These techniques are such as Analytical Hierarchy Process (AHP) (Handfield et al.,2002; Shaw et al., 2012) Analytic Network Process (ANP) (Hsu and Hu, 2007; Hsu and Hu, 2009) Data Envelopment Analysis (DEA) (Kumar and Jain,2010; Fallahpour et al.,2016); and (TOPSIS) methodology (Banaeian et al.,2018, Awasthi et al.,2010) Quality Function Development (QFD) (Babbar and Amin, 2018). Furthermore Govindan et al., 2015) and Chai et al. (2013) presents a good review of MCDM approaches and models for both conventional and GSS problem.

Suitable criteria selection is very important for companies in evaluation of suppliers. Nielsen et al. (2014) not only review the literature but also give a framework for GSS criteria. Carbon footprint and emissions, energy efficiency, water usage, and recycling initiatives have been the more common environmental measures in GSS literature (Chiou et al., 2008).

According to recent literature review of GSS and evaluation the most widely applied approaches are fuzzy analysis (Kannan et al.,2015). The main reason of this situation is crisp data are inadequate to simulate real-life decision problems. Since there is uncertainty and intangibility exist in managerial decisions, fuzzy approaches are proposed by many researchers to deal with this difficulty in the analysis. Fuzzy AHP (Kahraman et al.,2003; Chan et al.,2008; Kılınççı et al.,2011), fuzzy ANP (Vinodh et al.,2011; Dargi et al.,2014) and fuzzy TOPSIS (Wang et al.,2009; Roshandel et al.,2013; Wang and Chen,2013; Wood,2016) are the most popular approaches for supplier selection problem in the literature. These methodologies find promising solutions for many industries such as garment, automotive, chemical or agrıculture. Researchers also use the integration of these MCDM methods to evaluate and select the most suitable supplier in many published work recently. However, these methods are not without their critics. In Axiomatic Design (AD), there is no need of pairwise comparison where AHP, ANP and TOPSIS requires to evaluate. AD differentiates from other MCDM methods by choosing the most suitable one (Kannan et al.,2015). This method enables the evaluation of the alternatives and the definition of Functional Requirements with linguistic variables. There is only one study that proposes FAD to GSS problem in the literature. Kannan et al., (2015) applied FAD methodology in the selection of best supplier by considering green factors in a plastic company located in Singapore. They initially developed the economic and environmental criteria by considering the company requirements. Then, according to the experts' assessments, FRs are determined and the supplier with minimum information content that satisfies the design goals is selected.

Fuzzy Axiomatic Design with Risk Factors (RFAD) is a new method that considers the degree of risk in any decision making. RFAD was proposed by Gören and Kulak (2013) and applied to healthcare industry successfully in Kulak et al.,2015.

3. METHOD

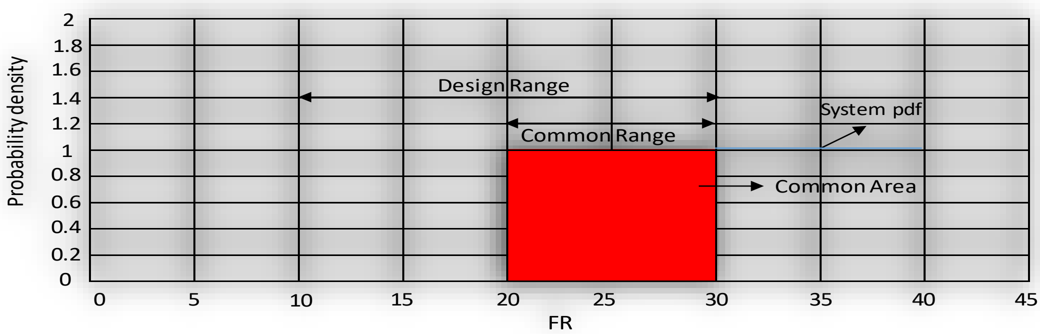
3.1. Fuzzy Axiomatic Design (FAD)

The two main axioms of design principles were proposed by Suh (1990) which are the independence axiom and information axiom respectively. These two axioms basically explain that the decision maker should identify the functional requirements which are our design goals and the best one is the design that has the smallest information content (Suh,2001). In this method, information content, I_i, can be calculated by the formula 1. In this formula, p_i represents the probability of achieving the Functional requirements.

$$I_i = \log_2\left(\frac{1}{p_i}\right) \quad (1)$$

According to design principles, the designer identifies the design range and the system range. Figure 1 shows the differences between "design range" and "system range" and "common range".

Figure 1. The Important Ranges of Probabilty of a Functional Requirement



By using the formula 2 and formula 3, the areas shown in Figure 1 (Kulak and Kahraman, 2005) can be easily calculated.

$$p_i = \left(\frac{common\ range}{system\ range}\right) \quad (2)$$

$$I_i = \left(\frac{system\ range}{common\ range}\right) \quad (3)$$

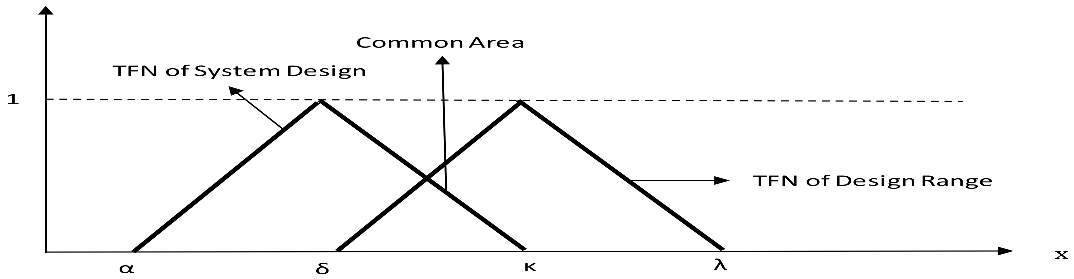
Since decision problems have some uncertainty, fuzzy logic is incorporated to the axiomatic principles by Kulak and Kahraman (2005a, 2005b)

When we have limited data about the ranges of system and design, it's better to use fuzzy logic. In this approach the linguistic terms such as "around a number" or "over a number", are preferred by decision makers. In the literature these verbal expressions are represented by Triangular Fuzzy Numbers (TFN). In Figure 2, the common area can be seen.

Information content is calculated by Formula 4:

$$I = \log_2\left(\frac{TFN\ of\ system\ design}{common\ area}\right) \quad (4)$$

Figure 2. The Illustration of Triangular Fuzzy Numbers



3.2. Fuzzy Axiomatic Design with Risk Factors (RFAD)

The most important advantage of this method is integrating risk factors in its methodology while the other methods in decision making problems generally threat risk factors separately.

As seen in Formula 5, *r* represents the risk factor of a criterion. It's mentioned that r value is between zero and one. If it is close to 1, this means there is a high level of risk for that specific criteria. The revised value of the information content is calculated as follows:

$$I = \log_2\left(\frac{system\ range}{common\ range\ (1-r)}\right) \quad (5)$$

Initially The design and system ranges must be determined for each alternative under each criterion. The features of alternatives are the system ranges and FR_s are the design ranges. Then the information contents are calculated according to the level of risks. Finally, the information content is compared and the smallest one is selected.

3.3. Fuzzy TOPSIS

After conventional TOPSIS is proposed by Hwang and Yoon [36], many researchers paid attention to this methodology in decision making problems. Since this method does not require pairwise comparisons and is especially good at huge number of alternatives and criteria, it is extended to fuzzy numbers to deal with linguistic assessment of the decision makers. The fuzzy TOPSIS method, according to Govindan et al. [37] and Kannan et al. [3] is summarized as follows:

Step 1: For k decision makers, containing m alternatives and n criteria, the decision matrix is represented as follows:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ . \\ . \\ A_m \end{array} \begin{array}{c} C_1 \; C_2 \; . \; . \; C_n \\ \begin{bmatrix} r_{11} & r_{12} & . & . & r_{1n} \\ r_{21} & r_{22} & . & . & r_{2n} \\ . & . & . & . & . \\ . & . & . & . & . \\ r_{m1} & r_{m2} & . & . & r_{mn} \end{bmatrix} \end{array}$$

Step 2: We generated a normalized decision matrix after the common sense of decision makers and determining the weights each criteria as shown in

$$R = \lfloor r_{ij} \rfloor_{m \times n} \tag{6}$$

The normalized values for benefit related criteria are calculated as As Eq. (7).

$$r_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right), j \in B \tag{7}$$

$$c_j^* = \max c_{ij}, \ j \in B$$

Step 3: Weighted normalized decision matrix is calculated by using Eq. (8):

$$V = \lfloor v_{ij} \rfloor_{m \times n} \tag{8}$$

$$v_{ij} = r_{ij} \times w_j$$

Step 4: The fuzzy positive-ideal solution (A*) and negative-ideal solution (A-) can be calculated as:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*) \tag{9}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) \tag{10}$$

Where;

$$v_j^* = \max_i \{v_{ij}\} \ and \ v_j^- = \min_i \{v_{ij}\}$$

Step 5: The positive and negative distance of each alternative to ideal solutions are calculated as follows:

$$d^* = \sum_{j=1}^{n} d_v(v_{ij}, v_j^*) \tag{11}$$

$$d^- = \sum_{j=1}^{n} d_v(v_{ij}, v_j^-) \tag{12}$$

where $d_v(v_{ij}, v_j^*)$ is the distance and the distance of two TFNs can be calculated by Eq. (13).

$$d(A,B) = \sqrt{\frac{1}{3}\left[(a-a_1)^2 + (a-b_1)^2 + (a-c_1)^2\right]} \tag{13}$$

Step 6: Closeness Coefficient (CC_i) is calculated by Eq. (14):

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, i = 1,2,\ldots,m \tag{14}$$

Step 7: Finally, alternatives are evaluated by comparing CC_i values. The descending order of CC_i of all alternatives is preferred by decision maker

4. CASE STUDY

A major textile company in Turkey would like to select the most suitable supplier due to the new legal environmental requirements. Because of the recent changes in the government regulations and pressures from customers, the company obliged to focus on production process. The company is working on a new carpet production. This new product will bold not only in domestic market but it is planned to be sold in the European countries and USA. So there are stricter regulations about green factors and sustainability. The raw material of the carpet is a special yarn and the team is expected to choose the best supplier. After a serious and time consuming investigation of the market, the team members consist of an environmental engineer, a textile engineer and a purchasing department director, they had a meeting on the functions of alternatives, selection criteria, and the definitions of functional requirements. To figure out the solution of the problem the methods explained previously are used and the results are compared.

4.1. Fuzzy Axiomatic Design (FAD)

Initially FAD is applied to company's GSS problem. The expert group checked the minimum and maximum price and defined the system ranges and design ranges of supplier selection criteria by using linguistic variables as seen in Table 1, Table 2 and Table 3. These variables are converted to fuzzy numbers by using the scale given in Table 7 and Table 8 which are also used in Fuzzy Axiomatic Design with Risk Factors and Fuzzy TOPSIS method in section 4.2 and 4.3, respectively.

Table 1. Fuzzy and Linguistic Variables Ratings of The Alternative

	Supplier selection criteria					
	Price ($) Min Max	Quality	Service	Awareness of Energy Consumption	Restriction on the use of Chemicals	Social and Environmental Responsibility
Design	2.50 4.20	G	E	VG	VG	VG

Table 2. Design Range

	Supplier selection criteria						
	Price ($) Min	Max	Quality	Service	Awareness of Energy Consumption	Restriction on the use of Chemicals	Social and Environmental Responsibility
Supplier 1	1.50	3.20	F	E	G	E	VG
Supplier 2	2.40	4.20	G	VG	VG	VG	E
Supplier 3	3.10	4.00	G	E	VG	E	VG
Supplier 4	3.20	5.60	VG	E	E	VG	VG

Table 3. System Range

	Supplier selection criteria							
	Price ($)	Quality	Service	Awareness of Energy Consumption	Restriction on the use of Chemicals	Social and Environmental Responsibility	Weighted FAD	FAD
Weight	0.17	0.19	0.13	0.16	0.16	0.19		
Supplier 1	1.28	3.17	0	3.17	2.80	0	1.77	1.74
Supplier 2	0.08	0	3.39	0	0	2.80	0.99	1.05
Supplier 3	0	0	0	0	2.80	0	0.45	0.47
Supplier 4	1.26	3.17	0	2.80	0	0	1.27	1.21

The total information content is calculated as illustrated in Table 4 and supplier 3 is selected as the most appropriate supplier according to these green criteria.

Table 4. Information Content

	Supplier selection criteria							
	Price ($)	Quality	Service	Awareness of Energy Consumption	Restriction on the use of Chemicals	Social and Environmental Responsibility	Weighted FAD	FAD
Weight	0.17	0.19	0.13	0.16	0.16	0.19		
Supplier 1	1.28	3.17	0	3.17	2.80	0	1.77	1.74
Supplier 2	0.08	0	3.39	0	0	2.80	0.99	1.05
Supplier 3	0	0	0	0	2.80	0	0.45	0.47
Supplier 4	1.26	3.17	0	2.80	0	0	1.27	1.21

4.2. Fuzzy Axiomatic Design with Risk Factors (RFAD)

Price has a risk of variation because of the economic conditions. For the quality criteria, with the effect of raw material or the process, there is a risk of lower quality. The energy consumption may be influenced from the working conditions and the specifications of the device in terms of order quantity. It is possible to carry risk for after-sales service criterion.

The use of restricted chemicals is a huge risk especially for textile industry to match the true color. And finally the budget of the company may affect the social and environmental responsibility of the supplier. RFAD considers these facts given in Table 5 and calculate the knowledge content given in Table 6 by considering these risk factors.

Table 5. Risk Factors

	Supplier selection criteria					
	Price ($)	Quality	Service	Awareness of Energy Consumption	Restriction on the use of Chemicals	Social and Environmental Responsibility
Supplier 1	1	0.2	0.15	0.2	0.15	0.2
Supplier 2	0.05	0.05	0.05	0.05	0.05	0.05
Supplier 3	0.5	0.35	0.4	0.5	0.35	0.3
Supplier 4	0.05	0.3	0.1	0.05	0.05	0.05

Table 6. Knowledge Content with Risk Factors

	Supplier selection criteria							
	Price ($)	Quality	Service	Awareness of Energy Consumption	Restriction on the use of Chemicals	Social and Environmental Responsibility	Weighted FAD	FAD
Weight	0.17	0.19	0.13	0.16	0.16	0.19		
Supplier 1	1.43	3.49	0.23	3.49	3.04	0.32	2.04	2.00
Supplier 2	0.05	0.07	3.46	0.07	0.07	2.88	1.04	1.10
Supplier 3	0.30	0.62	0.74	1.00	3.43	0.51	1.07	1.10
Supplier 4	0.40	3.68	0.15	2.88	0.07	0.07	1.27	1.21

Different than conventional FAD, the supplier 2 is the most appropriate supplier according to the RFAD.

4.3. Fuzzy TOPSIS

To make a better understanding and comparison, Fuzzy TOPSIS method is also applied to the case study. As we follow the steps of Fuzzy TOPSIS, The linguistic assessments of DMs about each criterion are converted to fuzzy numbers by using Table 7 and Table 8. Then, their evaluation of each supplier in terms of criteria are given in Table 9 and these values are normalized as seen in Table 10. The positive and negative distance of each alternative to ideal solutions are calculated by using the formula given section 3.3 and shown in Table 11 and Table 12. Finally the closeness coefficient is obtained to give the last decision and rank of the suppliers.

Table 7. Fuzzy Ratings Of Criteria In Terms of Linguistic Expressions [Wang and Elhag,2006]

Linguistic expression	Fuzzy numbers
Very Low (VL)	(0, 0.2, 0.4)
Low (L)	(0.2, 0.4, 0.5)
Medium (M) s	(0.4, 0.6, 0.8)
High (H)	(0.6, 0.8,1)
Very High (VH)	(0.8,0.9,1)

Table 8. Fuzzy Ratings of Alternatives In Term of Linguistic Expressions [Kulak et al.,2005]

Linguistic expression	Fuzzy numbers
Poor (P)	(0,0,6)
Fair (F)	(4,7,10)
Good (G)	(8,11,14)
Very Good (VG)	(12,15,18)
Excellent (E)	(16,20,20)

Table 9. Decision Makers Ratings of The Alternatives

	Supplier selection criteria					
	Price ($)	Quality	Service	Awareness Of Energy Consumption	Restriction On The Use Of Chemicals	Social And Environmental Responsibility
Supplier 1	E	F	E	G	E	VG
Supplier 2	VG	G	VG	VG	VG	E
Supplier 3	G	G	E	VG	E	VG
Supplier 4	F	VG	E	E	VG	VG

Table 10. Normalized Matrix

	Price	Quality	Service	Awareness Of Energy Consumption	Restriction On The Use Of Chemicals	Social And Environmental Responsibility
Supplier 1	0.8 1 1	0.2 0.35 0.5	0.8 1 1	0.4 0.55 0.7	0.8 1 1	0.6 0.75 0.9
Supplier 2	0.6 0.75 0.9	0.4 0.55 0.7	0.6 0.75 0.9	0.6 0.75 0.9	0.6 0.75 0.9	0.8 1 1
Supplier 3	0.4 0.55 0.7	0.4 0.55 0.7	0.8 1 1	0.6 0.75 0.9	0.8 1 1	0.6 0.75 0.9
Supplier 4	0.2 0.35 0.5	0.6 0.75 0.9	0.8 1 1	0.8 1 1	0.6 0.75 0.9	0.6 0.75 0.9

Table 11. d^* values

	Price	Quality	Service	Awareness of Energy Consumption	Restriction on the use of Chemicals	Social and Environmental Responsibility
Supplier 1	0.1035 0.3499		0.0901	0.3271	0.1035	0.1287
Supplier 2	0.1932 0.1801		0.1475	0.1932	0.1932	0.0465
Supplier 3	0.3271 0.1801		0.0901	0.1932	0.1035	0.1287
Supplier 4	0.5143 0.0757		0.0901	0.1035	0.1932	0.1287

Table 12. d^- values

	Price	Quality	Service	Awareness of Energy Consumption	Restriction on the use of Chemicals	Social and Environmental Responsibility
Supplier 1	0.5675 0.0465		0.1499	0.0839	0.2059	0.0715
Supplier 2	0.3948 0.1431		0.0915	0.1932	0.1164	0.1575
Supplier 3	0.2215 0.1431		0.1499	0.1932	0.2059	0.0715
Supplier 4	0.0919 0.3051		0.1499	0.3163	0.1164	0.0715

Table 13. Closeness Coefficient (CC_N)

Supplier 1	0.505
Supplier 2	0.535
Supplier 3	0.491
Supplier 4	0.487

Similar with RFAD, the decision maker should choose supplier 2 according to the calculations of fuzzy TOPSIS.

5. CONCLUSION

Selecting the most suitable supplier is a serious and important challenge in manufacturing industry. Although there are many approaches to solve this problem in the literature, there are still gap to solve the real life problems. In this paper, we initially applied conventional FAD approach for selecting the most appropriate yarn supplier for a textile company. In every real world problem there are many alternatives and risk factors. If a decision maker wants to select the best alternative he/she should consider the risk factors during the solution method. Unfortunately, the methods of MCDM in the literature generally neglect the risk level of alternatives or evaluate after the decision. The most powerful challenge of proposed method is integrating the risk factors during the selection process. By calculating the information content revised by risk levels, the rank of alternatives has changed which enable us to determine the real appropriate alternative. Finally, the results are compared with conventional fuzzy axiomatic design and fuzzy TOPSIS. Furthermore, the proposed method not only presents a systematic procedure for GSS problem can be solved with fuzzy AHP or other popular methods and the results can be compared.

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