



Research Note

An integrated fuzzy QFD-MCDM framework for personnel selection problem

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Received 23 November 2018; received in revised form 26 September 2019; accepted 28 December 2019

KEYWORDS

Multi criteria
decision-making;
Personnel selection;
Fuzzy QFD;
Fuzzy DEMATEL;
Fuzzy GRA.

Abstract. In today's competitive and high technology world, companies are forced to differentiate themselves with continuous improvement. They need creative, well-educated, and self-confident human resources more than ever. Hiring the right person to the right job plays a significant role on firm growth. The goal of this paper is to propose a systematic approach to Personnel Selection Problem (PSP) of a textile company in Turkey by considering various performance requirements and criteria. The proposed framework consists of three phases. Initially, fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL) method is used to weight social criteria. Then, weights of technical requirements are calculated by applying fuzzy Quality Function Deployment (QFD) method allowing the evaluation of the interrelationship and relevance of social and technical criteria. Finally, by considering the criteria scores obtained in the previous stage, fuzzy Grey Relationship Analysis (GRA) method is applied to rank the alternatives. The method has been illustrated by a case study and compared to the current approach used in the company. The results show that the proposed method can effectively deal with PSP and help the company establish a systematic and unbiased approach to the problem.

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1. Introduction

Recruitment is one of the primary functions of organizations. Selection of the most appropriate candidate among alternatives that performs the requirement of the job is defined as Personnel Selection Problem (PSP) [1]. This problem is very important because correcting the consequences of a wrong decision to hire someone is very difficult, costly, and time-consuming [2]. As mentioned in [3], the main issues related to this problem are to determine the weight of the

criteria that affect the problem, use linguistic and/or numerical scales to evaluate applicants, and integrate the evaluation results, and rank applicants. To answer all these questions, a systematic and analytical method is needed. Since people working in an organization affect its performance, numerous researches have been conducted in this field. Considering different criteria and alternatives, the PSP is a typical example of a Multi-Criteria Decision-Making problem (MCDM) and several different MCDM approaches and their hybrids have been proposed to solve this problem.

However, there is an important gap regarding to the employer ideal personnel and employee selected for the job. Nearly all studies focusing on this subject have considered different criteria and used these defined criteria to evaluate alternatives. No attention has

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been given on the comparison between the employer ideal personnel and the employee selected. It is important that the employee selected should match employer requirements and this issue should be taken into consideration in the selection process. From this point of view, we are aiming to bridge this gap by providing an integrated framework. The most significant contribution of this study to the PSP literature is providing a systematical and analytical integrated method, considering social and technical criteria and their interactions in the recruitment process, simultaneously. Generally, in the recruitment process, multiple decision-makers are usually preferred instead of a single decision-maker to avoid bias. As we all know, decision-makers use qualitative and quantitative factors to evaluate candidates. For instance, the experience of a person can be defined with a crisp number however, for the evaluation of communication skills or creativity, linguistic variables are easier to use. In dealing with this kind of variable, the fuzzy set theory [4] has been accepted as a very useful decision framework that incorporates imprecise judgments inherent in the personnel selection process [5]. In the past decade, the number of papers addressing PSP in fuzzy environments has rapidly increased (see the comprehensive literature review provided by Afshari et al. [6]). There have been many applications of fuzzy Analytical Hierarchical Process (AHP) (see e.g. [7–11]) fuzzy Analytical Network Process (ANP) (see e.g. [3,12]), fuzzy TOPSIS (see e.g. [5,13–16]), and hybrid methods of those such as [3,17,18] in literature. The other contribution of this study is to help organizations overcome bias in the recruitment process.

The proposed approach consists of three different approaches, fuzzy Decision-Making Trial and Evaluation Laboratory (DEMATEL)-fuzzy Quality Function Deployment (QFD) and fuzzy Grey Relational Analysis (GRA). Although there are many methods for the recruitment process, to the best of our knowledge none of them has dealt with evaluating these criteria and their interactions simultaneously. In addition, the determination of the Social Attributes (SA) required by job candidates and the weighting of these criteria can sometimes be very complicated and time-consuming. At this stage, the fuzzy DEMATEL method is very useful and applicable. In the proposed method, the fuzzy QFD method is used to establish the relationship between SA and Technical Requirements (TR). Finally, in the evaluation and ranking stage, the fuzzy GRA method has been applied due to the efficiency in group decision making problems [19].

The rest of the paper is structured as follows: Section 2 reviews the related literature focusing on PSP. The method currently used by the company is explained in the Section 3, and the suggested method is explained in the Section 4. The results of the

case study are given in Section 5. Finally, the last section summarizes the findings and presents some future research directions.

2. Literature review

Considering the consequences of the wrong decision of recruitment, PSP has been extensively studied by many researchers and practitioners. The current articles in the literature related to personnel selection suggest integrated or hybrid methods since conventional MCDM methods cannot deal with the complexity of the PSP. Recently, many attempts have been made to combine or improve methods to find the most suitable personnel.

A contemporary study by Jasemi and Ahmadi [20] have proposed a novel fuzzy ELECTRE method to choose an industrial engineer for pipe manufacturing plant in Iran, and then the results have been compared to those of TOPSIS. Samanlıoğlu et al. [18] have utilized fuzzy TOPSIS and fuzzy AHP for the Information Technology (IT) personnel selection process of Turkish dairy company. Ji et al. [21] have proposed a fuzzy method based on Multi-Valued Neutrosophic Sets (MVNS) to select the sales supervisor for a manufacturing company. In order to select the personnel for assembly lines, Efe and Kurt [22] have integrated TOPSIS with interval type-2 trapezoidal fuzzy numbers and applied the method. Dahooie et al. [23] have selected the best IT personnel from five candidates by applying SWARA (Step-wise Weight Assessment Ratio Analysis) and grey ARAS (Additive Ratio Analysis). Deliktas and Ustun [24] have solved the assignment problem of students to the predetermined programs, namely Erasmus program, by using fuzzy MULTIMOORA and multichoice conic goal programming. Koutra et al. [25] have developed a multi criteria MCDM approach for personnel selection in the maritime industry, based on AHP and Correspondence Analysis (CA). Urosevic et al. [26] have proposed an approach based on the use of the SWARA and the WASPAS (the Weighted Aggregates Sum Product Assessment) methods and a numerical example is conducted to select the sales manager in the tourism sector. SWARA and ARAS methods are combined to select the sales manager by Karabasavic et al. [27]. Another integrated method consisting of GRA and IFWA (Intuitionistic Fuzzy Weighted Averaging) has been presented in Zhang and Liu [1] and an example is implemented to present the computational process of the proposed method. Alguliyev et al. [28] have proposed a hybrid algorithm including the worst-case method and fuzzy Vise Kriterijumska Optimizacija I Kompromisno Resenje (VIKOR). In the study, criteria weights have been calculated by the worst-case method and then by using fuzzy VIKOR candidates have been sorted. In addition, the results have been compared with those

obtained by modified fuzzy VIKOR. Chang [29] has successfully applied a method of fuzzy Delphi, ANP, and TOPSIS to select the best candidate of public relations personnel.

Chien and Chen [30] have developed an effective personnel selection mechanism to find the talents who are the most suitable to their own organizations by using a data-mining framework based on decision tree and association rules to generate useful rules for personnel selection. Chen and Cheng [31] have developed computer based decision support system to rank the candidates based on the metric distance method.

The research conducted by Sang et al. [16], Canós et al. [32], Kabak [33], Baležentis et al. [34], and Lin [3] are other good examples of the applications of fuzzy methods in the PSP literature. The interested reader can refer to Afshari et al. [6] for further applications of fuzzy logic in PSP.

The literature review shows that different MCDM approaches and their hybrid methods have been utilized to solve PSP. The most widely used ones are TOPSIS and AHP. This can be due to their simplicity. In recent years, new approaches such as TODIM and SWARA have also been applied to this problem (see Table 1). However, except for Chang [29] and Dağdeviren [35], nearly all these studies have not considered the interactions among criteria. Neglecting these interactions might lead to a wrong decision, which might affect the organization. Thus, the interactions should be taken into consideration in order to hire the right person. From this point of view, in this paper, the interactions between criteria have been handled using fuzzy DEMATEL and QFD, which have not been utilized to solve the problem in the previous literature. Table 1 briefly summarizes the studies on PSP under the headings of method and application area.

Before explaining the proposed method, the next section explains the current approach used by the company in the case study.

3. The current method

The first and most critical step in the recruitment process is identifying the hiring needs. The key point here is to understand the complete job description in order to clearly state the specifications and qualifications required for the job. This is very important since this document will generate the desired candidate profile and will strongly affect the evaluation and selection steps.

In our case study, the job description is written by the job analyst in the Human Resources (HR) department and Curriculum Vitae (CV) of applicants are evaluated. According to the evaluation of job analyst, the selected candidates are invited to the company for an interview. In the second step, the candidates

are interviewed by a group of experts. It should be noted that all experts in the interview (i.e. the decision-making group) have equal weights. These experts can change according to the vacant position. The predetermined questions are asked to the candidates and according to their responses, the decision-makers grade them from one to ten on consensus after the interview. In the end, the arithmetic average is calculated for each candidate and the one with the highest grade is hired for the job.

In our case study, a textile company located in Denizli needed to hire a senior Production Planning Engineer (PPE) and issue a recruitment announcement. This job announcement is based on a general job description and is prepared by a job analyst. So, the description does not consider some key technical skills such as six sigma, lean manufacturing and kaizen manufacturing knowledge and neglects the additional 3 year experience in garment industry. This is because the position requires professional knowledge in garment production and practical experience in quality standards. After preliminary screening by the HR department, ten candidates have been called for interview. A committee of three decision-makers:

- DM_1 : The supervisor of the production planning department;
- DM_2 : The human resource manager;
- DM_3 : The supply chain manager of the company has been formed to conduct the interview and ten different questions have been asked to the candidates.

The score of each candidate for each question after the interview is given in Table 2.

Based on the total scores, C_8 with the highest total score has been selected for the position. However, this method does not consider the SA of candidates and their interactions with TC. For example, a candidate could have excellent Technical Requirements (TR), but he could not get along with others and has the ability to work in a team. In this case, the person may not work for a long time in that position, and hiring such a person may be a waste of time.

Considering this example, the used current method can be said to be very simple, highly subjective and biased. Furthermore, it includes too much intuitiveness and lacks professionalism. In today system-oriented era, the HR department should create more analytical and robust methodologies for such an important process of companies. In order to deal with these disadvantages of the current method, we propose a more analytical approach in this study. The next section explains the details of the proposed method.

Table 1. The related literature on Personnel Selection Problem (PSP).

Reference	Method	Application area
Jasemi and Ahmadi [20]	Fuzzy ELECTRE	Industrial engineer
Samanlioglu et al. [18]	Fuzzy AHP and fuzzy TOPSIS	IT personnel
Ji et al. [21]	Fuzzy TODIM with MVNS	Sales supervisor
Efe and Kurt [22]	TOPSIS and interval type-2 trapezoidal fuzzy numbers	Personnel for assembly lines
Dahooie et al. [23]	SWARA and grey ARAS	IT expert
Deliktas and Ustun [24]	MULTIMOORA and multichoice conic goal programming	Erasmus student
Koutra et al. [25]	AHP and correspondence analysis	Managerial personnel in the maritime field
Urosevic et al. [26]	SWARA and WASPAS	Sales manager
Bayram and Sahin [36]	Monte Carlo simulation and TOPSIS	General empirical study
Kosareva et al. [37]	Kemeny Median Indicator Rank Accordance (KEMIRA)	Security personnel
Karabasevic et al. [27]	SWARA and ARAS	Sales manager
Liu et al. [38]	Interval 2-tuple and VIKOR	Healthcare personnel
Sang et al. [16]	Fuzzy TOPSIS and Karnik-Mendel algorithm	System analysis engineer
Alguliyev et al. [28]	Worst case method and fuzzy VIKOR	PhD student
Chang [29]	Fuzzy Delphi, ANP and TOPSIS	Public relations personnel
Kazan et al. [11]	AHP and PROMETHEE	Deputy candidate
Kusumawardani and Agintiara [17]	Fuzzy AHP and fuzzy TOPSIS	Human resources manager
Canós et al. [32]	Software: Staff designer and fuzzy theory	General empirical study
Bogdanovic and Miletic [39]	AHP and PROMETHEE	General empirical study
Keršulienė and Turskis [40]	AHP and ARAS	Chief accountant
Bali et al. [41]	Delphi and fuzzy sets	System analyzer
Rouyendegh and Erkan [42]	Fuzzy ELECTRE	Academic staff
Aggarwal [43]	AHP and fuzzy linear programming	IT personnel
Kabak [33]	Fuzzy DEMATEL and ANP	Military personnel
Kabak et al. [44]	Fuzzy ANP, fuzzy TOPSIS and fuzzy ELECTRE	Professional sniper
Baležentis et al. [34]	Computing with words and fuzzy MULTIMOORA	General empirical study
Safarzagdegan Gilan et al. [45]	Computing with words and interval type 2 fuzzy set	Construction personnel
Boran et al. [15]	Fuzzy TOPSIS	Sales manager
Kelemenis et al. [46]	Extended fuzzy TOPSIS	Support manager
Zhang and Liu [1]	GRA and fuzzy IFWA	System analysis engineer
Lin [3]	ANP and fuzzy DEA	Electrical engineer
Dağdeviren [35]	TOPSIS and ANP	Electronics engineer
Dursun and Karsak [5]	2-tuple linguistic representation model and TOPSIS	General empirical study
Kelemenis and Askounis [14]	Fuzzy TOPSIS	Management team member
Güngör et al. [9]	Fuzzy AHP	General empirical study
Chien and Chen [30]	Data mining (decision tree and association rules)	General empirical study
Chen and Cheng [31]	GDSS based on metric distance method	IT personnel

Table 2. Scores of each candidate for each question.

	Questions										Average score
	1	2	3	4	5	6	7	8	9	10	
1	1	10	1	6	5	5	4	3	3	3	4.1
2	2	4	8	1	2	3	8	7	9	1	4.5
3	6	7	2	8	6	5	6	7	7	0	5.4
4	3	8	1	8	8	5	1	2	9	1	4.6
5	2	2	3	2	5	2	9	7	9	6	4.7
6	8	1	5	7	4	6	2	9	3	8	5.3
7	2	5	1	3	5	3	6	8	10	8	5.1
8	9	4	9	6	10	6	8	8	10	2	7.2
9	3	2	2	1	7	5	7	7	1	5	4.0
10	8	2	2	1	9	1	8	2	6	4	4.3

4. The proposed method

The developed decision-making framework utilizes the methodologies of DEMATEL, QFD, and GRA for PSP. In order to capture the inherited vagueness, fuzzy set theory and group decision-making approaches have also been adopted. The proposed framework consists of five steps including fuzzy DEMATEL, fuzzy QFD and fuzzy GRA. In all steps, triangular fuzzy numbers, which generally considered an easy and effective way to quantify linguistic judgments of decision-makers, are utilized. In addition to vagueness and fuzziness, the group decision-making process, which enables the gradation of the criteria and the alternatives by three decision-makers, has been adopted. First, the fuzzy DEMATEL method has been used for weighting the SA which are then used as inputs for the following step. The weights of the TR are calculated by applying the fuzzy QFD method, which can evaluate the interrelationships and the correlation of social and technical criteria. Finally, the fuzzy GRA method has been applied to rank the alternatives. The stepwise schematic representation of the proposed integrated method is depicted in Figure 1.

Each step of the proposed method is explained in the following:

Step 1: Identifying the feature that the candi-

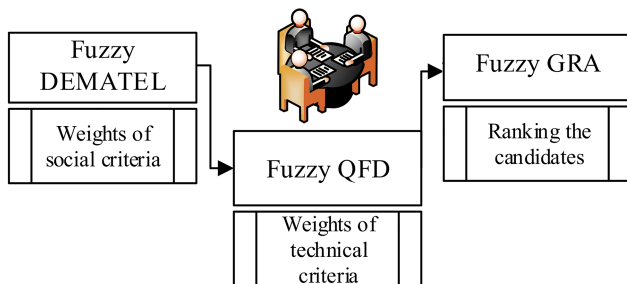


Figure 1. The schematic representation of the proposed method.

date should have internal variables “WHATs” in order to satisfy the company’s needs. The first step of the proposed method starts with identifying the features of the candidate in order to satisfy the company’s needs. These are the internal variables “WHATs”. It should be noted that these internal variables are Social Criteria (SC);

Step 2: Identifying the relevant TR (external variables “HOWs”). Regarding the position, TR should be defined. These are called external variables “HOWs”. It should be noted that these external variables are TC;

Step 3: Weighting the “WHATs”. The third step determines the weights of the internal variables using fuzzy DEMATEL. DEMATEL method derived from graph theory was developed by Gabus and Fontela at the Geneva Research Center of the Battelle Memorial Institute [47]. It has been widely recognized as an effective method to reveal inter-relationships between criteria and to identify the hierarchical structure of models. It is also considered to be an important tool to visualize the cause and effect relationships between complex factors [48]. To cope with the uncertainties, fuzzy DEMATEL has been widely preferred recently. There are a lot of applications of the fuzzy DEMATEL approach in various MCDM problems such as supplier selection [49], bidder evaluation [50], comparison of service quality improvement strategies [51], evaluation of critical operational hazards [48], project portfolio selection [52], resilience supplier selection [53]. In order to deal with the uncertainties, we also have utilized fuzzy DEMATEL. The outputs of this step have been used as inputs for the fourth step. The steps of fuzzy DEMATEL are given in Appendix A;

Step 4: Constructing the House Of Quality (HOQ). HOQ is a matrix that is commonly used in the evaluation and selection process in QFD. QFD is a method developed by Akao [54], which allows to systematically transform the qualitative needs of customers into quantitative quality characteristics in the decision-making stage of new product development. A well-structured, cross-functional technique that takes into account customer needs can ensure higher quality standards to meet expectations. Although the QFD method was introduced to deal with quality problems at each stage of the entire planning process, it has been widely used as an effective tool for evaluating various alternatives in recent years. QFD method used in product design process consists of four matrices, namely, the customer requirement-planning matrix, the product characteristics deployment matrix, process and quality control matrix and operative instruction matrix [55]. However, only the

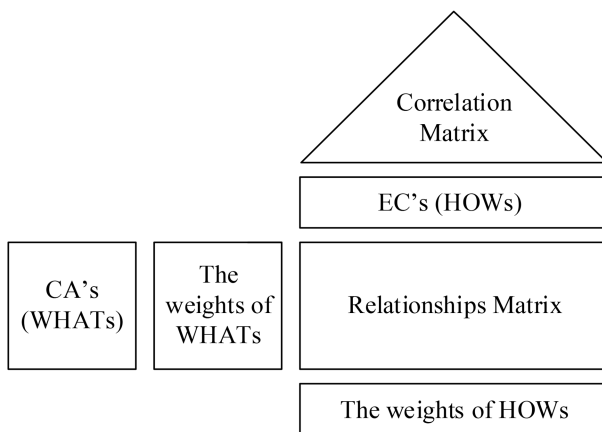


Figure 2. The general representation of House Of Quality (HOQ).

first matrix, also called HOQ, has been commonly practiced in the evaluation and selection process.

In this step, HOQ which translates customer needs and requirements (customer attributes-CA's-WHATs) into product design or TR, process planning, and production needs (engineering characteristics-EC's-HOWs), has been constructed. The key feature of the matrix is to take cognizance of the voice of the customer and to reveal the customer requirements in the end. A general HOQ model is illustrated in Figure 2 including the following:

- CA (WHATs), which are generally qualitative, includes requests and needs related to customer-defined product or service characteristics and known as the voice of the customer;
- EC (HOWs), which are generally quantitative, contain determining the technical requirements to meet customer requests and needs and are known as the voice of the company;
- The weights of WHATs show the importance of the related requirement and used to prioritize the CA's;
- Relationships between WHATs and HOWs; the relationships matrix indicates the degree of influence of each CA on each EC;
- The correlation matrix, which is used to show the inner dependence relations among ECs, is known as the roof matrix;
- The weights of HOWs, which are the major output of the HOQ, show the final importance scores of HOWs and are known as the ratings of EC.

In this study, the conceptual approach of the HOQ remained unchanged, while the components have been translated: in the conventional method, the company has to conceive its customers' needs and their importance degrees (CA) to determine which EC should be allocated the most resources [56]; on the other hand, in MCDM context, specifically

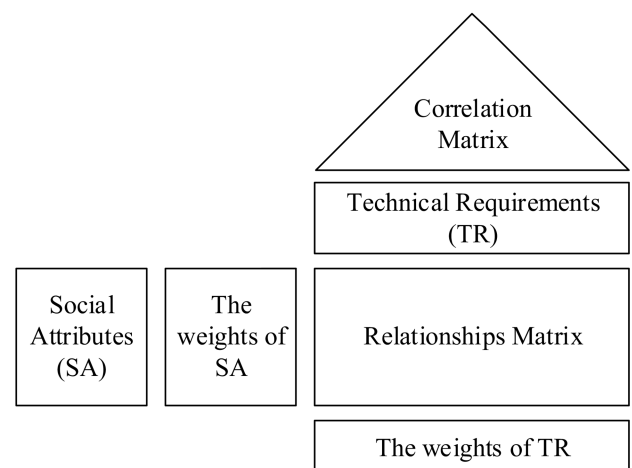


Figure 3. The House Of Quality (HOQ) representation of the proposed Quality Function Deployment (QFD) method.

PSP, the company defines the SA required for the candidate to obtain the weights of the TR. Within this scope, the components of the HOQ, namely SC, TC, relationships matrix, correlation matrix, and weights of the criteria, are shown in Figure 3.

The details of the fuzzy QFD can be found in Appendix B.

Step 5: Ranking the candidates. After obtaining the weights of the criteria considered in the problem, the candidates are ranked using fuzzy GRA. GRA is a MCDM method, which is evolved from the grey system theory proposed by Liu et al. [57]. The starting point of this method is to visualize the level of knowledge in any situation through a color scale, ranging between white and black. Black represents absolute uncertainty, while white represents the highest level of knowledge without any ambiguity. The most suitable color to represent real-world cases is considered grey. In this content, GRA allows the relationship between different factors to be expressed mathematically, and the interactions between factors are complicated [58]. The advantages of this method include ease of use, the possibility of using qualitative and quantitative data, and the applicability of the solution to small data sets. In recent years, GRA has been widely used in different applications such as green supplier selection in the agri-food industry [59], personnel selection [1], service quality evaluation of airports [58], and optimization of bone drilling process parameters [60], crew scheduling [61]. The steps of fuzzy GRA are explained in Appendix C in detail.

5. The case study

In this section, the application of the proposed approach is illustrated by the same case study that has already been explained in Section 3. However, here

the job description and weights of decision-makers have changed. Since the position is to hire a PPE, the weight of DM_1 (the supervisor of the production planning department) has been assigned to 0.5, while the weights of other decision-makers, DM_2 (human resources manager) and DM_3 (supply chain manager), have been set to 0.25 for final evaluation. The job description has been reprepared with the supervisor of the production planning manager and now considers some key technical skills such as six sigma, lean manufacturing, and kaizen manufacturing knowledge, and quality standards. Based on the new job description, the committee has decided to evaluate five candidates ($C_3, C_4, C_5, C_6,$ and C_8). It should be noted that $C_1, C_2, C_7, C_9,$ and C_{10} have not been evaluated in the proposed approach since they do not satisfy the requirements of the new job description.

5.1. Defining WHATs and HOWs

As a result of discussions with the committee members and the assessment gathered through the literature review, the SC and TC of the required personnel have been identified. We classify SC as WHATs, i.e. the features that the candidate should have to satisfy the company needs, and TC as HOWs, i.e. the features that each candidate has. These selection criteria are listed in Tables 3 and 4, respectively.

5.2. Determining the weights of WHATs

After determining the WHATs and HOWs, the fuzzy DEMATEL method has been employed to determine the weights of the WHATs, i.e. the weights of SC.

Each decision-maker has been asked to compare the SC. According to feedbacks, the decision matrix has been constructed using linguistic terms such as very low

Table 3. Social criteria (WHATs).

SC_1	Oral communication skills
SC_2	References
SC_3	Team work
SC_4	Self-confidence and leadership
SC_5	Emotional steadiness
SC_6	Responsibility
SC_7	Self-motivation

Table 4. Technical criteria (HOWs).

TC_1	Educational background
TC_2	Foreign language skills
TC_3	Basic computer skills
TC_4	Work experience
TC_5	Decision-making skills
TC_6	Risk management skills

Table 5. The linguistic scale [62].

Description (effect)	Triangular fuzzy number
No (N)	(0,0,0.25)
Very Low (VL)	(0,0.25,0.5)
Low (L)	(0.25,0.5,0.75)
High (H)	(0.5,0.75,1)
Very High (VH)	(0.75,1,1)

and low. Then it is transferred to the fuzzy number. Transformation of linguistic terms into fuzzy numbers is carried out by using the widely accepted linguistic scale for the DEMATEL method introduced by Li [62]. The linguistic scale is shown in Table 5.

The decision matrix, which consists of pairwise comparison values of decision-makers, DM_1 to DM_3 in sequence, is shown in Table 6.

After constructing the decision matrix for each decision-maker, linguistic expressions have been transformed into triangular fuzzy numbers. In the following step, the aggregate decision matrix has been obtained by multiplying the weights of decision-makers by fuzzy expressions. The normalized aggregate decision matrix and the total relation matrix have been obtained from the aggregate decision matrix. The next step includes transforming fuzzy triangular numbers into crisp values by adopting the defuzzification process proposed by Opricovic and Tzeng [63]. D_i and R_i values are calculated by summation values of rows and columns. The data set of causal diagrams that represents the influence levels via $D_i, R_i, D_i + R_i,$ and $D_i - R_i$ values is shown in Table 7. The weights of the SC are given in Table 8.

From Table 8, SC_7 self-motivation criteria are considered as the most important criterion followed by SC_5 emotional steadiness and SC_4 self-confidence and leadership, respectively.

5.3. Determining the weights of HOWs

In the next step, QFD has been utilized to obtain the weights of HOWs, i.e. TC. QFD method allows the use of HOQ to consider the relationships between SC and TC and interrelationships between TC. The weights of the SC obtained in the previous step have been incorporated into TC of the decision-making process in this step.

Firstly, the relationships and correlation matrices are constructed through an interview with the decision-makers. For the assessment of relationships and correlation matrices, the linguistic scales introduced by Bottani and Rizzi [55] given in Tables 9 and 10, respectively, have been adopted.

The relationships and correlation matrices are shown in Figure 4.

Table 6. The decision matrix regarding the criteria.

	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7
SC_1	0	L,L,VL	VH,VL,H	H,VL,L	L,VL,VL	N,N,N	N,VL,N
SC_2	N,N,N	0	N,N,N	N,VL,VL	N,N,N	N,N,N	VL,VL,VL
SC_3	N,VL,L	N,L,L	0	L,VL,VL	L,VL,VL	L,VL,L	L,VL,VL
SC_4	N,L,VL	N,L,VL	L,VL,L	0	L,VL,L	L,L,N	H,VL,H
SC_5	H,L,H	L,N,L	H,N,VL	H,VL,VL	0	H,N,VL	H,H,H
SC_6	L,N,VL	H,L,H	H,H,VL	L,L,VL	L,VL,N	0	H,VL,L
SC_7	H,VL,VL	H,H,H	H,L,L	H,L,L	H,VL,L	L,VL,L	0

Table 7. The influence levels among criteria.

Criteria	D_i	R_i	$D_i + R_i$	$D_i - R_i$	Group
SC_1	5.143	4.868	10.011	0.275	Cause
SC_2	2.342	6.201	8.543	-3.858	Effect
SC_3	5.269	6.318	11.587	-1.049	Effect
SC_4	5.878	6.007	11.886	-0.129	Effect
SC_5	7.174	5.205	12.379	1.970	Cause
SC_6	6.380	4.715	11.096	1.665	Cause
SC_7	7.189	6.062	13.252	1.127	Cause

Since there are three decision-makers, the importance (i.e. weights) of these decision-makers has been considered in obtaining the aggregate relationships and correlation matrices using a weighted average. By adding the aggregate correlation values of the criteria, the weights of the TC are acquired. After the defuzzification process proposed by Yager [64], the weights of TC are shown in Table 11.

5.4. Ranking the candidates

In the last step of the proposed integrated method, fuzzy GRA has been employed to determine the most appropriate candidate for the job. It should be noted that with the proposed approach five candidates (i.e. $C_3, C_4, C_5, C_6,$ and C_8) have been evaluated.

Initially, the decision matrix showing the evaluation scores of candidates based on TC has been constructed by each decision-maker. Since it is easier to use linguistic terms in comparisons and evaluations, the

Table 8. The weights of social criteria.

Criteria	SC_1	SC_2	SC_3	SC_4	SC_5	SC_6	SC_7
Weight	10.015	9.374	11.635	11.886	12.535	11.220	13.299
Normalized weight	0.125	0.117	0.146	0.149	0.157	0.140	0.166

Table 9. The linguistic scale for relationships matrix [55].

Degree of relationship	Fuzzy triangular number
Strong (S)	(0.7,1,1)
Medium (M)	(0.3,0.5,0.7)
Weak (W)	(0,0,0.3)
No (N)	(0,0,0)

Table 10. The linguistic scale for correlation matrix [55].

Degree of correlation	Fuzzy triangular number
Strong Positive (SP)	(0.7,1,1)
Positive (P)	(0.5,0.7,1)
Negative (N)	(0,0.3,0.5)
Strong Negative (SN)	(0,0,0.3)
No (-)	(0,0,0)

Table 11. The weights of technical criteria.

Criteria	TC_1	TC_2	TC_3	TC_4	TC_5	TC_6
Weight	0.483	0.191	0.454	1.047	1.007	0.933
Normalized weight	0.117	0.046	0.110	0.255	0.245	0.227

decision matrix has been constructed using linguistic terms and then converted to triangular fuzzy numbers using the linguistic scale proposed by Kulak and Kahraman [65] shown in Table 12.

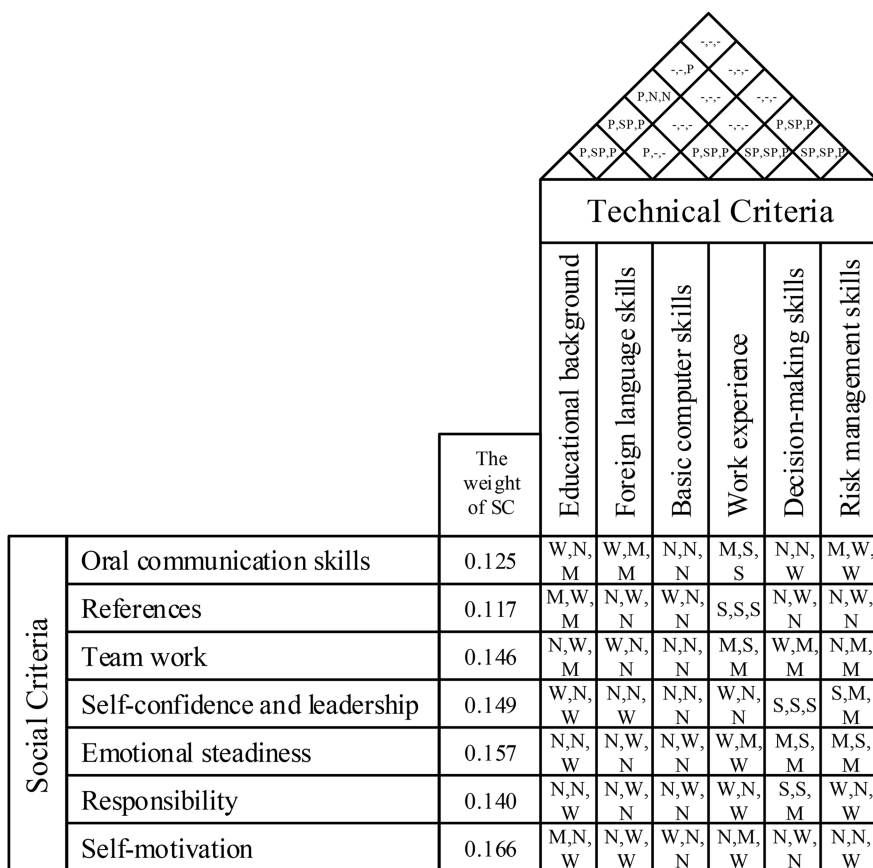


Figure 4. The relationships and correlation matrices.

Table 12. The linguistic scale [65].

Alternative ratings	Triangular fuzzy number
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)

The aggregate decision matrix that represents the assessment scores of the candidates is shown in Table 13.

Once the aggregate decision matrix is formed, the normalized aggregate decision matrix has been obtained based on the objective. The values closest to the most ideal score establish the reference series. Then, by using reference series, the distance matrix is formed. By using grey relational coefficients as the elements of the grey relational grades matrix, the final evaluation scores of the candidates are calculated and shown in Table 14.

As shown in Table 13, the person most suitable for the position is the fourth person with the highest evaluation score. A comparative ranking of the alternative

candidates is obtained as $C_3 > C_4 > C_8 > C_6 > C_5$ when scores are arranged in descending order.

6. Discussion

As we compared the results of the current method used by the company and the proposed method, two different results have been obtained. The proposed approach states that the third candidate should be hired for the position although the eighth has been selected in the current approach. This could be the interactions among criteria considered in the evaluation phase and the detailed job description. The main drawback of the current method used by the company is that the description of a job has been defined by a job analyst. Although the job analyst can perfectly define the job, he/she cannot define all technical details. For some positions that do not require special expertise, this may be acceptable, but it may cause serious problems in key positions in the company. Therefore, it would be a big mistake to completely exclude the supervisor/manager from the job description, because the supervisor/manager has a wealth of knowledge and understands the key responsibilities and skills of the job. The incomplete definition of a job could lead to hiring a wrong person which could affect the

Table 13. The aggregate decision matrix.

	TC_1	TC_2	TC_3	TC_4	TC_5	TC_6
C_3	F,F,P	F,F,F	G,G,F	VG,E,VG	VG,G,E	VG,VG,E
C_4	VG,E,VG	VG,E,VG	E,VG,VG	F,F,G	G,G,VG	G,G,VG
C_5	G,VG,G	E,E,VG	VG,VG,VG	F,F,P	G,G,VG	F,G,F
C_6	E,VG,E	VG,VG,G	VG,G,VG	F,G,F	F,G,G	F,F,G
C_8	G,G,F	G,VG,G	G,G,G	G,G,G	VG,G,VG	G,G,F

Table 14. The final evaluation scores.

Candidates	C_3	C_4	C_5	C_6	C_8
Score	0.833	0.634	0.534	0.538	0.586
Ranking	1	2	5	4	3

organization. Therefore, the group decision-making method should consider the opinions of the department manager at the end and in the initial steps of the recruitment process.

To overcome this shortcoming, in this paper, we suggest that the job description should be jointly developed by the HR department and the technical supervisor/manager. This would also let us considering both technical and SC of candidates in the selection process. Taking into account the interactions and opinions of different people, the proposed approach is a robust analytical method for the HR department. Moreover, since the proposed approach considers the TR of the job, the number of candidates that should be evaluated decreases which saves the amount of time needed.

7. Conclusions

Selecting the most appropriate person for the job is a serious and important challenge in human resource systems. There are many attempts in the literature to help practitioners to select the right person for the right job and we believe that further applications of new methodologies in this field will be developed.

The method proposed in this paper is mainly distinguished from other methods by combining two Multi-Criteria Decision-Making (MCDM) methods with Quality Function Deployment (QFD). The motivation behind this procedure is to help the human resources department to form and prioritize internal and external parameters, a robust decision structure to select the most appropriate candidate for the defined job. To better understand and to compare the proposed method with the method currently used by the company, it has been simulated through real case studies. In view of this, the applications of the production planning engineer are evaluated by a group of decision makers. Social criteria and technical criteria are determined to predict the job performance

of the candidates. Every decision-maker has their own opinion and sometimes there may be conflicts between them, as shown in the table above. First of all, social criteria and their complex inter-relational structure have been analyzed by Decision-Making Trial and Evaluation Laboratory (DEMATEL) and then the technical criteria of the job have been considered and integrated with social criteria so that the ideal candidate that satisfies not only social but also technical criteria, can be selected. Human intuition prefers to use language variables instead of numbers, so fuzzy logic has been integrated into the model. In the ranking of outputs, fuzzy Gray Relationship Analysis (GRA) method has been chosen since it is very efficient in this field.

Finally, it is expected that this comprehensive approach will become a useful tool for human resource management, reducing employee turnover and recruitment, and making the organization more competitive and efficient.

In the future, to incorporate uncertainty into decision-making process, some new aggregation operators under the uncertain environment can be added to the decision framework [66–70].

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Appendix A: The main steps of fuzzy DEMATEL

The main steps of the fuzzy DEMATEL method are described as follows:

Step 1: Generating the direct relation matrix.

The first step consists of writing the pairwise comparison values of the criteria throughout columns and rows based on a predetermined linguistic scale according to decision-maker assessments using Eq. (A.1). In this step, a group of experts is asked to obtain direct

relation matrices \tilde{A} , by linguistic terms to measure the relationship between criteria.

$$\tilde{A} = \begin{bmatrix} 0 & (l, m, u)_{12} & \cdots & (l, m, u)_{1n} \\ (l, m, u)_{21} & 0 & \cdots & (l, m, u)_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ (l, m, u)_{n1} & (l, m, u)_{n2} & \cdots & 0 \end{bmatrix} \quad (A.1)$$

Step 2: Normalizing the direct relation matrix. The criteria through which the evaluation or selection take place contain various scales and unit of measure. Therefore, in this step, these different data should be transformed into equally spaced data. The equation to transform the data is given in Eq. (A.2). All elements in the normalized direct relation matrix are between 0–1, and all diagonal elements are equal to zero.

$$\tilde{x}_{ij} = \frac{X}{r} = \left(\frac{l_{ij}}{r_1} \quad \frac{m_{ij}}{r_2} \quad \frac{u_{ij}}{r_3} \right) \quad 1 \leq j \leq n,$$

$$r_1 = \max \left(\sum_{j=1}^n l_{ij} \right), \quad r_2 = \max \left(\sum_{j=1}^n m_{ij} \right),$$

$$r_3 = \max \left(\sum_{j=1}^n u_{ij} \right). \quad (A.2)$$

Step 3: Attaining the total relation matrix.

Once the normalized direct relation matrix is obtained, the total relation matrix is constituted using Eq. (A.3). To deal with this step total relation matrix can be divided into sub-matrices. These sub-matrices indicate the lower, middle, and upper numbers of the fuzzy set to simplify the calculation.

$$\tilde{T} = \tilde{X} + \tilde{X}^2 + \cdots = \sum_{i=1}^{\infty} \tilde{X}^i = \tilde{X} (I - \tilde{X})^{-1},$$

$$X_l = \begin{bmatrix} 0 & l_{12} & \cdots & l_{1n} \\ l_{21} & 0 & \cdots & l_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ l_{n1} & l_{n2} & \cdots & 0 \end{bmatrix},$$

$$X_m = \begin{bmatrix} 0 & m_{12} & \cdots & m_{1n} \\ m_{21} & 0 & \cdots & m_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ m_{n1} & m_{n2} & \cdots & 0 \end{bmatrix},$$

$$X_u = \begin{bmatrix} 0 & u_{12} & \cdots & u_{1n} \\ u_{21} & 0 & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1} & u_{n2} & \cdots & 0 \end{bmatrix}. \quad (A.3)$$

Step 4: Defuzzification. This step is used to obtain the criteria crisp value after multiple calculations. The adopted defuzzification process CFCS, which was introduced by Opricovic and Tzeng [63], includes four stages, namely normalization, right, and left hand side normalized values, total normalized value, and crisp values. The crisp values are calculated according to Eqs. (A.4)–(A7).

Normalization:

$$\begin{aligned} xl_{ij} &= (l_{ij} - \min l_{ij}) / \Delta_{\min}^{\max}, \\ xm_{ij} &= (m_{ij} - \min m_{ij}) / \Delta_{\min}^{\max}, \\ xu_{ij} &= (u_{ij} - \min u_{ij}) / \Delta_{\min}^{\max}, \\ \Delta_{\min}^{\max} &= \max u_{ij} - \min l_{ij}. \end{aligned} \tag{A.4}$$

Right and left hand side normalized values:

$$\begin{aligned} xls_{ij} &= xm_{ij} / (1 + xm_{ij} - xl_{ij}), \\ xrs_{ij} &= xu_{ij} / (1 + xu_{ij} - xm_{ij}). \end{aligned} \tag{A.5}$$

Total normalized values:

$$\begin{aligned} x_{ij} &= [xls_{ij}(1 - xls_{ij}) + xrs_{ij} \times xrs_{ij}] \\ & / [1 - xls_{ij} + xrs_{ij}]. \end{aligned} \tag{A.6}$$

Crisp values:

$$z_{ij} = \min l_{ij} + x_{ij} \Delta_{\min}^{\max}. \tag{A.7}$$

Step 5: Obtaining $(D_i + R_i)(D_i - R_i)$ values through calculating the weights. The sum of rows and columns elements z_{ij} give D_i and R_i values of the related criterion, respectively. By using Eq. (A.8), the weights of the criteria w_i are obtained. $(D_i - R_i)$ indicates the net effect that criterion has on the system. In particular, if the value of $(D_i - R_i)$ is positive, the factor will be a net cause. When $(D_i - R_i)$ is negative, the factor will be a net result clustered into effect group [48].

$$\begin{aligned} w_i &= \sqrt{(D_i + R_i)^2 + (D_i - R_i)^2}, \\ W_i &= \frac{w_i}{\sum_{i=1}^n w_i}, \quad i = 1, 2, \dots, n. \end{aligned} \tag{A.8}$$

Appendix B: The main steps of fuzzy QFD

The basic steps of the QFD method are as follows:

Step 1: Generate relations and correlation matrices. According to the assessment expressed by the decision maker, the paired comparison values based on the social and technical criteria of the pre-determined language scale constitute the relationship matrix. Similarly, the correlation matrix is obtained by calculating the correlation between the technical requirements;

Step 2: Obtaining relative importance values of technical requirements. This step includes calculating the weight of the technical standards using the social standards and their weights according to the relationship matrix, without considering the correlation values between the technical criteria;

Step 3: Calculating the weights of technical requirements. However, in the previous step, the calculations include importance values of technical requirements by using social attributes, however, in this step the inner dependencies between the TR are not considered. Once relative importance values of technical criteria are obtained, the weights of technical criteria are calculated by adding correlation matrix values and the relative importance value of the criteria;

Step 4: Defuzzification of the weights of technical requirements. To attain crisp values of the weights of technical criteria, the method introduced by Yager [64] shown in Eq. (B.1) is utilized:

$$wTR_j = \frac{l + 2m + u}{4}. \tag{B.1}$$

Appendix C: The main steps of fuzzy GRA

The basic steps of the fuzzy GRA method are explained below:

Step 1: Constituting the decision matrix. The method starts with constituting the decision matrix, which includes the evaluation of the alternatives based on the selected criteria according to a pre-determined linguistic scale. The decision matrix represents the assessment scores of m alternatives based on n criteria specified by the decision-makers and is shown in Eq. (C.1).

$$\tilde{X} = \begin{bmatrix} (l, m, u)_{11} & (l, m, u)_{12} & \dots & (l, m, u)_{1n} \\ (l, m, u)_{21} & (l, m, u)_{22} & \dots & (l, m, u)_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ (l, m, u)_{m1} & (l, m, u)_{m2} & \dots & (l, m, u)_{mn} \end{bmatrix}. \tag{C.1}$$

Step 2: Normalizing the decision matrix. The process of normalization is different from the purpose of the problem. For maximization objective Eq. (C.2) is used, whereas for minimization objective Eq. (C.3) is adopted. The normalized decision matrix

\tilde{R} consists of the elements \tilde{r}_{ij} that are obtained using Eqs. (C.2) and (C.3).

$$\tilde{r}_{ij} = \left(\frac{l_{ij}}{u_j^+}, \frac{m_{ij}}{u_j^+}, \frac{u_{ij}}{u_j^+} \right),$$

$$i = 1, 2, \dots, m \quad j = 1, 2, \dots, n,$$

$$u_j^+ = \max\{u_{ij}\} \tag{C.2}$$

$$\tilde{r}_{ij} = \left(\frac{l_j^-}{u_{ij}}, \frac{l_j^-}{m_{ij}}, \frac{l_j^-}{l_{ij}} \right),$$

$$i = 1, 2, \dots, m, \quad j = 1, 2, \dots, n$$

$$l_j^- = \min\{l_{ij}\}. \tag{C.3}$$

Step 3: Determining the reference series. The desired values according to objective function type and using Eqs. (C.4) and (C.5) for maximization and minimization, are determined. Reference series \tilde{R}_0 contain maximum or minimum assessment values based on n criteria:

$$\tilde{R}_0 = [\tilde{r}_{01}, \tilde{r}_{02}, \dots, \tilde{r}_{0n} = \max(\tilde{r}_{ij})],$$

$$j = 1, 2, \dots, n, \tag{C.4}$$

$$\tilde{R}_0 = [\tilde{r}_{01}, \tilde{r}_{02}, \dots, \tilde{r}_{0n} = \min(\tilde{r}_{ij})],$$

$$j = 1, 2, \dots, n. \tag{C.5}$$

Step 4: Constructing the distance matrix. The distance matrix Δ_{0m} shows the variation of the alternative values from the reference series and is depicted in Eq. (C.6). Each element of the distance matrix $\Delta_{0m}(n)$ is calculated using Eq. (C.7) where \tilde{A} and \tilde{B} show \tilde{r}_{ij} and \tilde{R}_0 .

$$\Delta_{0m} = \begin{bmatrix} \Delta_{01}(1) & \Delta_{01}(2) & \Delta_{01}(n) \\ \Delta_{02}(1) & \Delta_{02}(2) & \Delta_{02}(n) \\ \Delta_{0m}(1) & \Delta_{0m}(2) & \Delta_{0m}(n) \end{bmatrix}, \tag{C.6}$$

$$d(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{3} [(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2]}. \tag{C.7}$$

Step 5: Constituting the grey relational coefficient matrix. The constituting elements $\gamma_{0m}(n)$ of grey relational coefficient matrix γ_{0m} , which can be seen in Eq. (C.8), is calculated by Eq. (C.9) where ξ

is resolving coefficient and in the range of $[0, 1]$:

$$\gamma_{0m} = \begin{bmatrix} \gamma_{01}(1) & \gamma_{01}(2) & \dots & \gamma_{01}(n) \\ \gamma_{02}(1) & \gamma_{02}(2) & \dots & \gamma_{02}(n) \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{0m}(1) & \gamma_{0m}(2) & \dots & \gamma_{0m}(n) \end{bmatrix}, \tag{C.8}$$

$$\gamma_{0m}(n) = \frac{\Delta_{\min} + \xi \Delta_{\max}}{\Delta_{0i}(j) + \xi \Delta_{\max}}. \tag{C.9}$$

Step 6: Calculating the grey relational grades
The importance values Γ_{0i} of each alternative are calculated using Eq. (C.10):

$$\Gamma_{0i} = \sum_{j=1}^n [wTR_j \gamma_{0i}(j)],$$

$$i = 1, 2, \dots, m, \quad j = 1, 2, \dots, n. \tag{C.10}$$

Biographies

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