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A grey analytic hierarchy process approach to project manager selection

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Abstract

Purpose – Evaluations of grey systems and systems with subjective judgements are always like an impasse for science and companies. Especially, calculations of the problems which include various units are really difficult situations. The purpose of this paper is to propose a grey analytic hierarchy process (G-AHP) for engineering and managerial problems with grey systems to make more clear and objective decisions.
Design/methodology/approach – Proposed G-AHP approach is applied to project manager selection for a software project of an energy company. The application includes three different units as year, score and assessment. Six engineers are evaluated with 25 criteria in the application. Weights of the factors and assessments are done by three top managers of the company as pairwise comparisons. Other data in the decision matrix are obtained from the personal information and exam results of engineers.
Findings – Final weights of the criteria and evaluations of engineers are all done with the proposed G-AHP. Obtained results of G-AHP are also compared with grey "VlseKriterijumska Optimizacija I Kompromisno Resenje" results as a validation of the calculations and proposed approach. Final results of the applications are ranked for the evaluations and comparison. All results of the case study are concluded with the effectiveness and applicability of the proposed G-AHP method both for this study and other fields of science, engineering and management.
Originality/value – This study provides to evaluate and interpret grey systems with different units and subjective judgements for science, engineering and management more clearly and objectively in an easier way.

Keywords Grey systems, Human resources management, Personnel selection, Engineer selection, Grey analytic hierarchy process, Project manager selection

Paper type Research paper

1. Introduction

Personnel selection is one of the most important functions of human resources management (HRM). Especially with the globalising world and rising unemployment rates, lots of applications are receiving to international companies and projects. These applications can sometimes leave HRM departments dysfunctional and some of highly qualified applicants also can be eliminated due to a large number of applications. Evaluating the applications can be easy for standard vacancies. But, vacancies, which are of highly qualified employees such as engineers, project managers, top managers, etc., require very careful evaluation processes.

The other part of personnel selection processes is subjectivity of decision makers of HRM department. One of the major fields which causes difficulties for both researchers and practitioners relates to the fairness and adverse impact of personnel selection methods (Robertson and Smith, 2001). In countries with diversity groups, this fairness and adverse impact is the most important issues of HRM. In today's world, almost all of the companies have diversity agreements for new and existing employees. But, when people are included to the processes, subjectivity is always an issue whether minor or major.

There are different methods in the literature for personnel selection given in Section 2. Almost all of them consider small number of criteria and there is little literature about engineer selection processes. All of the personnel selection methods in the literature given in Section 2 use fuzzy and crisp multi-criteria decision making (MCDM) methods with empirical examples. Most of the studies applies technique for order preference by similarity

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to ideal solution (TOPSIS) method which is criticised in the literature for its calculation processes. There is no grey-based MCDM method for personnel selection processes within our knowledge. Especially because of these, a grey analytic hierarchy process (G-AHP) is proposed and applied for an engineer selection of a real case study with detailed subjective criteria in this study. Besides, the main goal of performing this study is taking into account subjective judgements for unmeasurable criteria together with the other measurable criteria without any alteration or deformation on information for the best and unbiased results for both companies and candidates. Because, considering crisp numbers or measurable criteria with fuzzy numbers by transforming it always causes a loss of information. Considering this loss in further steps is almost impossible because of the complication of calculations or fuzziness, and also sum of these errors can cause really big unpredictable and non-measurable problems depending on the size of projects.

In Section 2, a detailed literature review of personnel selection studies is provided. In Section 3, the foundations of grey systems are briefly provided. The proposed G-AHP is given in Section 4. A real case study with the proposed G-AHP is given in Section 5 and finally, conclusions and discussions are given in Section 6.

2. Literature review

In this section, a detailed literature review is given chronologically, especially about personnel selection studies with MCDM techniques, in order to explore criteria for the project manager selection, and lacks of the literature. At the end of the section, a critique about the literature and their lacks is given.

Dursun and Karsak (2010) presented a fuzzy MCDM approach with using 2-tuple linguistic representations. In the proposed approach, they used TOPSIS. A hybrid MCDM model for personnel selection in manufacturing systems was introduced by Dağdeviren (2010). The author combined analytic network process (ANP) and TOPSIS methods in the hybrid MCDM model. The ANP was used to obtain the network structure and then TOPSIS was used to evaluate the final rank of personnel. The selection done in the study is a real case study in a company. The author used crisp values for the evaluations. Another TOPSIS-based MCDM approach was presented by Kelemenis and Askounis (2010) with fuzzy numbers. They also applied his approach to a real case study as a top management team member selection. In the study, they evaluate the alternatives for each criterion, too.

A grey relational analysis (GRA)-based intuitionistic fuzzy MCDM approach was proposed by Zhang and Liu (2011). They applied their study as a group decision making by using GRA. In the study, intuitionistic fuzzy entropy was used to obtain the weights and GRA was used to evaluate alternatives. Another intuitionistic fuzzy sets-based MCDM method was introduced by Boran *et al.* (2011) with using TOPSIS. They applied the proposed method for the sales manager selection of a manufacturing company. They specified that subjectivity, imprecision and vagueness of group decision-making problems were reduced by using fuzzy data. Chen *et al.* (2011) presented a linguistic VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and knowledge map for the application of a personnel selection. They mentioned that personnel selection has a great importance for companies because most of companies' activities need the right person to handle it. They also mentioned that there are lots of factors which influence the personnel selection like language ability, work experience, communication ability, etc.

Baležentis *et al.* (2012) applied fuzzy MULTIMOORA to select the best candidate. They used fuzzy MULTIMOORA to aggregate the subjective judgements of decision makers. A fuzzy analytic hierarchy process (AHP) was proposed by Rouyendegh and Erkan (2012) for the selection of academic staff. They used triangular fuzzy numbers (TFN) to evaluate five academic candidates. They applied F-AHP with three main factors and 11 sub-factors for the academic staff selection. An integrated AHP and complex proportional assessment of alternatives with grey relations (COPRAS-G) method was presented by Zolfani *et al.* (2012). The method was applied to select the best candidate for the position of quality control manager. They emphasised the globalising world and technological improvements for the needs of professional human resources of companies. AHP was used to obtain the weights, and then COPRAS-G was used to evaluate the candidates. Perez *et al.* (2012) introduced a new fuzzy TOPSIS approach to select the most suitable candidate. TFN were used in fuzzy TOPSIS calculations. They applied the proposed approach for a case study with specific criteria for the case. An integrated decision-making trial and evaluation laboratory (DEMATEL) and AHP approach was presented by Roy *et al.* (2012) with crisp number representations. They applied the proposed method with seven criteria and four alternatives. The DEMATEL method was used to prioritise the importance of criteria and AHP was used to evaluate the alternatives. Afshari *et al.* (2012) was introduced an application of Delphi method for personnel selection problems. Four main factors and 14 sub-factors were specified in the study according to literature review and studies.

Afshari *et al.* (2013) applied the linguistic extension of classic fuzzy measure and fuzzy integral model for personnel selection model according to the criteria obtained by their previous study (Afshari *et al.*, 2012). They ignored the dependencies of criteria in the study. A grey-based MCDM method was proposed by Kose *et al.* (2013) for sniper selection problem. They used grey ANP to obtain the selection criteria weights, and then grey possibility degrees were used to select the best candidate. They applied the proposed method with six candidates under ten selection criteria. Bali *et al.* (2013) presented a hybrid method which contains the Delphi method and intuitionistic fuzzy sets. They applied the method as a multi attribute decision making model. TFN were used during the calculations and to obtain the weights to select the best candidate.

Dodangeh *et al.* (2014) used linguistic extensions for the project manager selection. They applied the proposed fuzzy MCDM method with the criteria used in their other studies (Afshari *et al.*, 2012; Afshari *et al.*, 2013). An integrated MCDM method which contains TOPSIS and Hungary assignment was proposed by Safari *et al.* (2014). They applied the proposed integrated method with crisp numbers through a multidimensional perspective. As a personnel selection study, they evaluated four candidates for four different departments according to five selection criteria. Mammadova and Jabrayilova (2014) introduced a fuzzy TOPSIS method for personnel selection problems. TFN were used through all calculations till the end of the TOPSIS processes. An AHP application for personnel selection was applied by Chaghooshi *et al.* (2014). They integrate the AHP method with similarity techniques using crisp numbers. Five criteria were used to evaluate five alternatives in the study.

Alguliyev *et al.* (2015) presented a modified fuzzy VIKOR with using TFN. The worst-case method was used to obtain the weights of criteria for the modified fuzzy VIKOR method. Five alternatives were evaluated by five criteria like other studies as an empirical study. Another fuzzy TOPSIS application was generated by Sang *et al.* (2015). TFN were used during the all calculation processes to select the best candidate as a system analyst engineer for a software company. Only three candidates were evaluated by five criteria in the study. Liu *et al.* (2015) introduced an interval 2-tuple linguistic VIKOR method. Numerical example of the study was applied to select the best candidate as a head nurse for a tertiary hospital.

Ji *et al.* (2016) proposed a projection-based TODIM (an acronym in Portuguese of interactive and multi-criteria decision-making) method which takes advantage of distances between two fuzzy sets. They also considered the risk preferences of decision makers and overcome the defect of the extant fuzzy TODIM method. Salehi (2016) presented an integrated fuzzy AHP and fuzzy VIKOR method for personnel selection. TFN were used during the all evaluation processes both fuzzy AHP and fuzzy VIKOR. “Step-wise weight assessment ratio analysis” (SWARA) and “weighted aggregates sum product assessment”

(WASPAS) methods were used to evaluate candidates as a personnel selection by Karabašević *et al.* (2016). They evaluated four candidates with seven criteria using crisp numbers. Afshari *et al.* (2016) introduced a Preference Ranking Organisation Method for Enrichment Evaluation (PROMETHEE) model to evaluate the selection criteria for personnel selection process. They applied the proposed model with crisp numbers in a project based organisation. Detailed results of the PROMETHEE model application were also given in the study step by step.

An integrated fuzzy AHP and fuzzy COPRAS method was proposed by Fathi *et al.* (2017) as an MCDM model for personnel selection. The weights of criteria were obtained by using fuzzy AHP and fuzzy COPRAS method was used to evaluate the candidates according to criteria weights. TFN were used in the calculations till the final part of the fuzzy COPRAS method.

A brief comparison of the literature is given in tabular form in Table I for better capture the review studies before the critique. In the last row of the table, the proposed approach in this study and application process is also evaluated, which allows to compare it with the other studies in the literature. It is clearly seen in Table I, and also the application process in Section 5, that this study ensures all of the situations listed in the table including validation of the approach.

Most of the literature applied their studies to empirical studies with a small number of criteria and alternatives, and also with fuzzy numbers. This also means that none of them studied on different units in the same system. Herewith, the existing literature has following deficiencies and important points:

- Subjective and objective units are not contained in the same analysis.
- Most of the studies does not concern about the validation or robustness of the methodologies.
- The studies with fuzzy numbers study only subjective judgements. They evaluate the other data with subjective judgements to adapt them to the studies by ignoring their real values.
- Almost all of the studies obtain results in crisp numbers after fuzzy calculations.
- None of the studies concerns about loss of information beside fuzziness.
- Half of the studies are interested in fuzzy TOPSIS, whose crisp methodology is also questioned in the literature about its correctness.
- Some of the studies do not apply group decision making which is one of the most important part of problems with subjective judgement.

The proposed G-AHP to project manager selection deals with most of these deficiencies and important points. The main goal of the proposed G-AHP is taking into account the subjective judgements for unmeasurable criteria together with the other measurable criteria without any alteration or deformation on information to select the best candidate for the project and the company. In order to carry out this goal, grey numbers are used to represent subjective judgements, decrease the deviation of evaluations among decision makers and be applied objective criteria with interval and crisp numbers without any alteration on them and combine them with subjective judgements easier. Obtaining the results in grey number with the proposed approach also allows to observe the similarities and common aspects among the alternatives, which is very important for the sensitive and important criteria especially with subjective judgements. This critical situation is ignored in previous studies by focusing only ranking of alternatives. Therewithal, this study also aims to give a lead to other studies about HRM by compensating for these deficiencies.

Reference	Technique	Results			Evaluations				
		Validation	Fuzzy/grey numbers	Crisp numbers	Subjective	Objective	Fuzzy/grey numbers	Crisp numbers	Group decision making
Dursun and Karsak (2010)	Fuzzy TOPSIS			✓	✓	✓	✓	✓	✓
Dağdeviren (2010)	ANP + TOPSIS			✓	✓			✓	
Kelemenis and Askounis (2010)	Fuzzy TOPSIS	✓		✓	✓		✓		✓
Zhang and Liu (2011)	IFS + GRA			✓	✓		✓		✓
Boran *et al.* (2011)	IFS			✓	✓		✓		✓
Chen *et al.*, 2011	Fuzzy VIKOR			✓	✓		✓		✓
Baležentis *et al.* (2012)	Fuzzy MULTIMOORA			✓	✓		✓		✓
Rouyendegh and Erkan (2012)	Fuzzy AHP			✓	✓		✓		
Zolfani *et al.* (2012)	AHP + COPRAS-G			✓	✓		✓		
Perez *et al.* (2012)	Fuzzy TOPSIS			✓	✓		✓		✓
Roy *et al.* (2012)	DEMATEL + AHP			✓	✓			✓	
Afshari *et al.* (2013)	Fuzzy Integral			✓	✓		✓		✓
Kose *et al.* (2013)	Grey ANP			✓	✓		✓		
Bali *et al.* (2013)	IFS + Delphi			✓	✓		✓		✓
Dodangeh *et al.* (2014)	Fuzzy MCDM			✓	✓		✓		
Mammadova and Jabrayilova (2014)	Fuzzy TOPSIS			✓	✓		✓		✓
Chaghooshi *et al.* (2014)	AHP			✓	✓			✓	✓
Alguliyev *et al.* (2015)	Fuzzy VIKOR			✓	✓		✓		✓
Sang *et al.* (2015)	Fuzzy TOPSIS		✓		✓		✓		✓
Liu *et al.* (2015)	Fuzzy VIKOR			✓	✓		✓		✓
Ji *et al.* (2016)	Fuzzy TODIM	✓		✓	✓		✓		
Salehi (2016)	F-AHP + F-VIKOR			✓	✓		✓		
Karabašević *et al.* (2016)	SWARA + WASPAS			✓	✓			✓	✓
Afshari *et al.* (2016)	PROMETHEE			✓	✓			✓	✓
Fathi *et al.* (2017)	F-AHP + F-COPRAS			✓	✓		✓		✓
This study	Grey AHP	✓	✓	✓	✓	✓	✓	✓	✓

Table I.
A brief comparison of the literature

3. Grey systems

Theoretically, systems which do not include any information are represented with black and systems which include all information are represented with white. Systems between these two situations, which mean that systems include partial information, are represented with grey. Grey systems also explain the degree of information and relations between black and white systems. In grey system theory, numbers whose exact value is not known shown with grey numbers (Kaleli *et al.*, 2014). Partial and missing information can be in different forms. In this study, we use grey numbers to represent subjective judgements and decrease the deviation of evaluations among decision makers. Comparisons of black, grey and white systems are shown in Table II which is performed by Liu and Lin (2010).

Numbers instead of their range whose exact value are unknown are referred to as grey numbers (Liu *et al.*, 2016). So, it can be said that grey numbers represent uncertain and unclear numbers and information. Grey numbers are generally represented with $\otimes$ symbol in the literature and $\otimes a$ grey number is as follows:

$$\otimes a = \left[a,\ \overline{\otimes} a\right] = \left[a' \in \otimes a \middle| a \leqslant a' \leqslant \overline{\otimes} a\ \right] \tag{1}$$

where a represents the lower bound and $\overline{\otimes} a$ represents the upper bound of $\otimes a$. Let $c \in \mathbb{R}$ and $\otimes a = [\underline{a}, \overline{a}]$ and $\otimes b = [\underline{b}, \overline{b}]$ are two grey numbers. The basic operations between these two numbers are as follows:

$$\otimes a + \otimes b = \left[\underline{a} + \underline{b}, \overline{a} + \overline{b}\right] \tag{2}$$

$$\otimes a - \otimes b = \left[\underline{a} - \overline{b}, \overline{a} - \underline{b}\right] \tag{3}$$

$$\otimes a \cdot \otimes b = \left[\min\left(\underline{ab}, \overline{ab}, \overline{a}\underline{b}, \underline{a}\overline{b}\right),\ \max\left(\underline{ab}, \overline{ab}, \overline{a}\underline{b}, \underline{a}\overline{b}\right)\right] \tag{4}$$

$$\otimes a \cdot \otimes b^{-1} = \left[\min\left(\frac{\underline{a}}{\underline{b}}, \frac{\overline{a}}{\overline{b}}, \frac{\overline{a}}{\underline{b}}, \frac{\underline{a}}{\overline{b}}\right),\ \max\left(\frac{\underline{a}}{\underline{b}}, \frac{\overline{a}}{\overline{b}}, \frac{\overline{a}}{\underline{b}}, \frac{\underline{a}}{\overline{b}}\right)\right] \tag{5}$$

$$c \cdot \otimes a = \left[c \cdot \underline{a}, c \cdot \overline{a}\right] \tag{6}$$

$$\otimes a^{c} = \left[\underline{a}^{c}, \overline{a}^{c}\right] \tag{7}$$

Table II. Comparisons of black, grey and white systems

	Black	Grey	White
Information	Unknown	Incomplete	Completely known
Appearance	Dark	Blurred	Clear
Processes	New	Changing	Old
Properties	Chaotic	Multivariate	Order
Methods	Negation	Change for better	Confirmation
Attitude	Letting go	Tolerant	Rigorous
Outcomes	No solution	Multi-solutions	Unique solution

Source: Liu and Lin (2010)

4. The proposed G-AHP

G-AHP is basically similar with AHP first introduced by Saaty (1980). In G-AHP, grey numbers are used instead of crisp sets and crisp numbers. Pairwise comparisons are applied with linguistic scales and grey numbers in G-AHP method. Grey numbers are used for pairwise comparisons and calculations in this study and the linguistic scale and grey number representations are given in Table III.

The computational steps of proposed G-AHP approach are given as follows.

Step 1: defining the problem

First, a goal, criteria and alternatives in the problem set are defined in this step.

Step 2: constructing the hierarchical structure

After defining the goal, criteria and alternatives, the hierarchical structure is constructed.

Step 3: making the pairwise comparisons

Depending on the problem, decision makers or experts make the pairwise comparisons both among the criteria and among the alternatives if there is no decision matrix for the alternatives. All of the pairwise comparisons are done according to Table II. The grey pairwise comparison matrix done by decision maker d is shown in Equation (8) with grey number representations:

$$A_g^d = \begin{bmatrix} \otimes a_{11}^d & \otimes a_{12}^d & \cdots & \otimes a_{1j}^d & \cdots & \otimes a_{1n}^d \\ \otimes a_{21}^d & \otimes a_{22}^d & \cdots & \otimes a_{2j}^d & \cdots & \otimes a_{2n}^d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes a_{i1}^d & \otimes a_{i2}^d & \cdots & \otimes a_{ij}^d & \cdots & \otimes a_{in}^d \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ \otimes a_{n1}^d & \otimes a_{n2}^d & \cdots & \otimes a_{nj}^d & \cdots & \otimes a_{nn}^d \end{bmatrix} \tag{8}$$

where $\otimes a_{ij}^d = [\underline{a}_{ij}^d, \overline{a}_{ij}^d]$ and $d \in \{1, 2, 3, \ldots, D\}$. All of the pairwise comparisons are done for the upper part of principal diagonals like crisp AHP. Lower parts of the pairwise comparison matrices are calculated by using Equation (9) and the elements on the principal diagonal are equal to 1 which is shown in Equation (10) as grey number representation:

$$\otimes a_{ij}^k = \left[\frac{1}{\overline{a}_{ij}^k}, \frac{1}{\underline{a}_{ij}^k}\right] \tag{9}$$

$$\otimes a_{ii}^k = [1, 1] \tag{10}$$

Crisp Value	Linguistic term	Fuzzy number
1	Equally important (EI)	[1, 2]
3	Weakly important (WI)	[2, 4]
5	Important (I)	[4, 6]
7	Strongly important (SI)	[6, 8]
9	Absolutely important (AI)	[8, 9]

Table III. Linguistic scale and grey number representation for grey AHP

Step 4: aggregating the pairwise comparison matrices

Pairwise comparison matrices which are done by decision makers or experts are aggregated by using the geometric mean formulation like AHP but with grey numbers shown in the following equation:

$$\otimes a_{ij} = \sqrt[K]{\prod_{i=1}^{K} \otimes a_{ij}^{k}} \tag{11}$$

where $A_g = [\otimes a_{ij}]_{nxn}$ represents the aggregated pairwise comparison matrix.

Step 5: normalizations of the columns

Normalisation for grey numbers are obtained by using modified "converting fuzzy data into crisp scores" (CFCS) method which was proposed by Wu and Lee (2007) given in the following equations:

$$\otimes \underline{a_{ij}} = \left(\otimes \underline{a_{ij}} - min_j \otimes \underline{a_{ij}}\right) / \Delta_{min}^{max} \tag{12}$$

$$\otimes \overline{a_{ij}} = \left(\otimes \overline{a_{ij}} - min_j \otimes \underline{a_{ij}}\right) / \Delta_{min}^{max} \tag{13}$$

where $\Delta_{min}^{max} = max \otimes \overline{a_{ij}} - min \otimes \underline{a_{ij}}$.

Step 6: calculating the grey weights

Grey weights are obtained by calculating the mean of the rows and calculation of the weights will be applied by using Equation (14) shown for criteria set $c = \{1, 2, 3, \ldots, C\}$:

$$\frac{\sum_{j=1}^{C} \otimes a_{ij}}{C} \tag{14}$$

Step 7: priority weights

After calculating the weights of the criteria and the weights vector of the alternatives for each criterion, priority weights for the alternatives are obtained by using the following equation:

$$\sum_{j=1}^{C} w_j \otimes a_{ij} \tag{15}$$

Step 8: whitenization of the results

The Results of grey priority weights are whitened by using modified CFCS method (Wu and Lee, 2007) given in Equations (16)-(17).

The first step of the whitenization is normalisation given in Equations (12)-(13):

$$Y_i = \frac{\otimes \underline{a_i}\left(1 - \otimes \underline{a_i}\right) + \otimes \overline{a_i} \times \otimes \overline{a_i}}{1 - \otimes \underline{a_i} + \otimes \overline{a_i}} \tag{16}$$

$$a_i = min \otimes \underline{a_i} + Y_i\, \Delta_{min}^{max} \tag{17}$$

where $A = [1, 2, 3, \ldots a_i, \ldots]$ vector represents the final weights of the alternatives.

5. The application of engineer selection

In this section, the application of engineer selection is provided in detail. The application is an engineer selection as a project manager for a software project of an energy company.

5.1 Obtaining the weights

Criteria used in the application are obtained from both literature and decision makers in the company. There are five main criteria and 25 sub-criteria related to these main criteria. The evaluation criteria are given in Table IV and the hierarchical structure of the problem with these criteria is given in Figure 1. All of the pairwise comparisons and assessments are done by three top managers of the company.

Chosen five main criteria are basic criteria (C1), character criteria (C2), software criteria (C3), project criteria (C4) and energy criteria (C5). Basic criteria represent the basic criteria for personnel selection of international companies. Character criteria represent the personal characteristics of personnel. Software Criteria represent software related skills of personnel. Project criteria represent the team–focused project skills of personnel. Energy criteria represent energy knowledge and energy sector related experiences of personnel.

In Figure 1, the detailed hierarchical structure of the engineer selection problem as a project manager is given. Selection process is calculated in two steps. First step is sub-criteria calculations and second step is calculations with main criteria for the evaluations of personnel. Basic criteria include education level (CB1), general experience level (CB2), computer skills (CB3), communication skills (CB4) and language skills (CB5). Character criteria include leadership skills (CC1), innovation ability (CC2), creativity skills (CC3), risk-taking ability (CC4), problem-solving skills (CC5), decision-making skills (CC6) and analytical thinking ability (CC7). Software Criteria include software experience level (CS1), coding skills (CS2), technical skills (CS3) and software project experience level (CS4).

Symbol	Criteria	Symbol	Sub-criteria
C1	Basic criteria	CB1	Education
		CB2	General experience
		CB3	Computer skills
		CB4	Communication skills
		CB5	Language
C2	Character criteria	CC1	Leadership
		CC2	Innovation
		CC3	Creativity
		CC4	Risk taking
		CC5	Problem solving
		CC6	Decision making
		CC7	Analytical thinking
C3	Software criteria	CS1	Software experience
		CS2	Coding skills
		CS3	Technical skills
		CS4	Software project experience
C4	Project criteria	CP1	Project experience
		CP2	Strategic management
		CP3	Crisis management
		CP4	Time management
		CP5	Team management
C5	Energy criteria	CE1	Energy experience
		CE2	Energy project experience
		CE3	Energy software experience
		CE4	Energy policies knowledge

Table IV. Evaluation criteria for the engineer selection problem

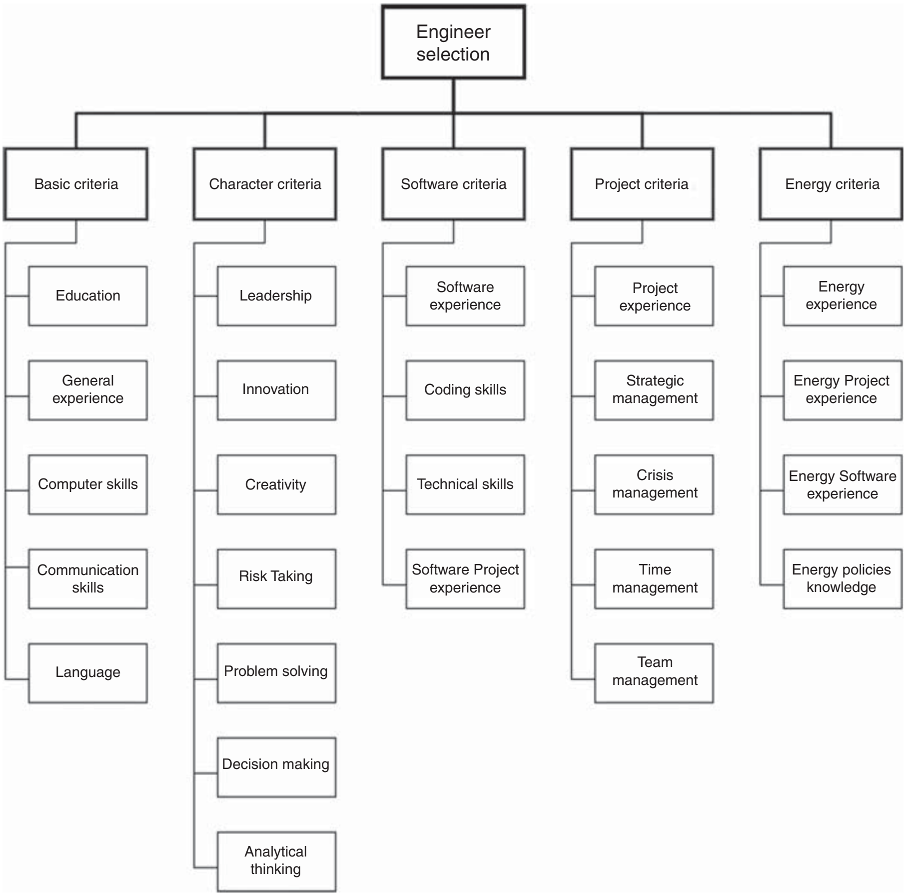

Figure 1.
Hierarchical structure of the problem

Project criteria include project experience level (CP1), strategic management skills (CP2), crisis management skills (CP3), time management skills (CP4) and team management skills (CP5). Energy Criteria include energy experience level (CE1), energy project experience level (CE2), energy software experience level (CE3) and energy policies knowledge level (CE4).

Normalised grey and crisp weight results of main criteria calculated with the proposed G-AHP is given in Table V. According to the table, energy criteria is the most important selection criteria and software criteria is following it as a second most important selection criteria. Sum of these two most important criteria have more than 60 per cent of total effect. Basic criteria is the least important selection criterion.

Table V.
Normalised grey and crisp weights of criteria

Symbol	Criteria	Grey weights	Whitened weights
C1	Basic criteria	[0.000, 0.322]	0.0981
C2	Character criteria	[0.007, 0.386]	0.1106
C3	Software criteria	[0.238, 0.953]	0.2975
C4	Project criteria	[0.100, 0.608]	0.1791
C5	Energy criteria	[0.256, 1.000]	0.3147

Normalised grey and crisp weight results of sub-criteria calculated with the proposed G-AHP is given with main weights in Table VI. According to the table, computer skills (CB3) is the most important sub-criterion of basic criteria, risk taking (CC4) is the most important sub-criterion of character criteria, software project experience (CS4) is the most important sub-criterion of software criteria, project experience (CP1) is the most important sub-criterion of project criteria and energy software experience (CE3) is the most important sub-criterion of energy criteria.

5.2 *Evaluation of engineer candidates*

Evaluations of the candidates are calculated with the weights obtained in Section 5.1. Three units, which are year, score (1-10) and assessment (1-9), used in decision tables while evaluating the candidates according to criteria. CB1, CB2, CC1, CC2, CC3, CC4, CS1, CS4, CP1, CE1, CE2 and CE3 are shown as years. CB3, CB5, CC5, CC6, CC7, CS2, CS3 and CE4 are shown as score which are in the range of 1-10. CB4, CC1, CC2, CC3, CC4, CP2, CP3, CP4 and CP5 are shown as assessment scores done by three top managers of the company. Top managers done their assessments independently, and then all of these assessments aggregated according to grey AHP calculations. In the second rows of the tables between Tables VII and XI, units of criteria are shown as Y for years, S for scores and A for assessments. Last columns of the tables are the final weight vectors of each criterion calculated with using G-AHP. These grey vectors will be used to obtain the global weights, final scores of the candidates for the evaluations.

Symbol	Grey weights	Final weights	Symbol	Grey weights	Final weights
C1	Basic criteria		C3	Software criteria	
CB1	[0.016, 0.452]	0.1440	CS1	[0.227, 0.681]	0.2574
CB2	[0.085, 0.719]	0.2218	CS2	[0.259, 0.732]	0.2867
CB3	[0.214, 1.000]	0.3291	CS3	[0.000, 0.052]	0.0244
CB4	[0.000, 0.453]	0.1394	CS4	[0.385, 1.000]	0.4315
CB5	[0.038, 0.529]	0.1657	C4	Project criteria	
C2	Character criteria		CP1	[0.229, 1.000]	0.3248
CC1	[0.189, 0.773]	0.1942	CP2	[0.001, 0.529]	0.1632
CC2	[0.049, 0.355]	0.0854	CP3	[0.007, 0.625]	0.1842
CC3	[0.000, 0.246]	0.0588	CP4	[0.010, 0.559]	0.1715
CC4	[0.249, 1.000]	0.2591	CP5	[0.000, 0.494]	0.1563
CC5	[0.158, 0.558]	0.1446	C5	Energy criteria	
CC6	[0.113, 0.604]	0.1427	CE1	[0.165, 0.420]	0.1642
CC7	[0.095, 0.475]	0.1152	CE2	[0.322, 0.805]	0.3553
			CE3	[0.385, 1.000]	0.4589
			CE4	[0.000, 0.038]	0.0216

Table VI. Normalised grey and crisp weights of sub-criteria

Unit	CB1 Year (Y)	CB2 Year (Y)	CB3 Score (S)	CB4 Assessment (A)	CB5 Score (S)	Final weights
E1	[3, 5]	[2, 4]	[9, 10]	[4.579, 6.604]	[6, 7]	[0.361, 0.573]
E2	[5, 7]	[0, 2]	[6, 7]	[4.160, 6.350]	[5, 6]	[0.122, 0.339]
E3	[3, 5]	[6, 8]	[5, 6]	[6.604, 8.320]	[7, 8]	[0.242, 0.446]
E4	[5, 7]	[6, 8]	[9, 10]	[7.268, 8.653]	[7, 8]	[0.554, 0.750]
E5	[5, 7]	[8, 10]	[7, 8]	[3.175, 5.241]	[8, 9]	[0.381, 0.594]
E6	[7, 12]	[10, 15]	[9, 10]	[5.769, 7.560]	[9, 10]	[0.673, 0.972]

Table VII. Evaluation of engineers for basic criteria

Grey decision matrix of basic criteria is shown in Table VII. All of the criteria vectors are shown in their real values normalised while using to calculate the final weight vector for basic criteria. The final weight vector of basic criteria shown in the last column is the first column of final decision matrix shown in Table XII as the first criterion weights for the evaluation of the candidates.

Grey decision matrix of character criteria is shown in Table VIII. All of the criteria vectors are shown in their real values normalised while using to calculate the final weight vector for character criteria. The final weight vector of character criteria shown in the last column is the second column of final decision matrix shown in Table XII as the second criterion weights for the evaluation of the candidates.

The grey decision matrix of software criteria is shown in Table IX. All of the criteria vectors are shown in their real values normalised while using to calculate the final weight vector for software criteria. The final weight vector of software criteria shown in the last column is the third column of final decision matrix shown in Table XII as the third criterion weights for the evaluation of the candidates.

The grey decision matrix of project criteria is shown in Table X. All of the criteria vectors are shown in their real values normalised while using to calculate the final weight vector for project criteria. The final weight vector of project criteria shown in the last column is the

Table VIII. Evaluation of engineers for character criteria

Unit	CC1 A	CC2 A	CC3 A	CC4 A	CC5 S	CC6 S	CC7 S	Final weights
E1	[1.58, 3.17]	[5.51, 7.11]	[6.07, 7.55]	[6.54, 7.95]	[9, 10]	[7, 8]	[5, 6]	[0.367, 0.625]
E2	[2.51, 4.57]	[6.95, 8.32]	[6.54, 7.95]	[7.65, 8.65]	[7, 8]	[7, 8]	[8, 9]	[0.516, 0.754]
E3	[3.63, 5.76]	[4.37, 6.34]	[5.51, 7.26]	[5.19, 6.95]	[4, 5]	[6, 7]	[8, 9]	[0.228, 0.533]
E4	[7.26, 8.65]	[5.24, 7.11]	[6.95, 8.32]	[4.82, 6.00]	[8, 9]	[9, 10]	[6, 7]	[0.470, 0.709]
E5	[4.82, 6.60]	[4.61, 6.34]	[3.82, 5.76]	[5.51, 7.11]	[9, 10]	[8, 9]	[9, 10]	[0.465, 0.748]
E6	[5.03, 6.86]	[2.51, 4.57]	[5.19, 6.95]	[5.59, 7.31]	[7, 8]	[5, 6]	[7, 8]	[0.283, 0.579]

Table IX. Evaluation of engineers for software criteria

Unit	CS1 Y	CS2 S	CS3 S	CS4 Y	Final weights
E1	[0, 2]	[6, 7]	[9, 10]	[0, 2]	[0.115, 0.363]
E2	[0, 2]	[4, 5]	[7, 8]	[0, 2]	[0.012, 0.259]
E3	[2, 4]	[8, 9]	[6, 7]	[0, 2]	[0.250, 0.497]
E4	[6, 8]	[9, 10]	[4, 5]	[4, 6]	[0.681, 0.928]
E5	[4, 6]	[7, 8]	[6, 7]	[4, 6]	[0.542, 0.789]
E6	[8, 10]	[8, 9]	[6, 7]	[2, 4]	[0.549, 0.796]

Table X. Evaluation of engineers for project criteria

Unit	CP1 Y	CP2 A	CP3 A	CP4 A	CP5 A	Final weights
E1	[2, 4]	[2.519, 3.779]	[3.476, 4.932]	[5.428, 7.230]	[2.410, 3.634]	[0.173, 0.386]
E2	[0, 2]	[1.587, 2.620]	[1.817, 3.107]	[5.517, 7.113]	[4.121, 6.073]	[0.107, 0.321]
E3	[2, 4]	[5.768, 7.398]	[5.768, 7.398]	[4.121, 5.517]	[3.036, 4.160]	[0.279, 0.488]
E4	[6, 8]	[6.952, 8.320]	[4.932, 6.952]	[6.073, 7.559]	[7.651, 8.653]	[0.559, 0.773]
E5	[6, 8]	[6.952, 8.320]	[6.073, 7.559]	[3.825, 5.241]	[5.277, 6.839]	[0.446, 0.657]
E6	[10, 15]	[7.651, 8.653]	[6.839, 8.276]	[7.318, 8.320]	[6.952, 8.320]	[0.746, 0.991]

fourth column of final decision matrix shown in Table XII as the fourth criterion weights for the evaluation of the candidates.

The grey decision matrix of energy criteria is shown in Table XI. All of the criteria vectors are shown in their real values normalised while using to calculate the final weight vector for energy criteria. The final weight vector of energy criteria shown in the last column is the fifth column of final decision matrix shown in Table XII as the fifth criterion weights for the evaluation of the candidates.

The grey decision matrix for final evaluation of the candidates is shown in Table XII. The Column vectors of the matrix are obtained by profiles of the candidates shown between Tables VII and XI. The weights of each criterion are also shown at the top row of the table.

All of the final weights (global weights) are shown in Table XIII. The grey results of final weights are obtained by using Equation (15) with the decision matrix shown in Table XII and then whitened. The best candidate for the project manager position is Engineer 4 with the highest whitened G-AHP result of 0.918. Candidates are ranked as decreasing values and the last preferable candidate for project manager position is Engineer 2 with the lowest whitened G-AHP result of 0.083.

As a validation of the approach, the grey VIKOR method (Çelikbilek and Tüysüz, 2016) was also applied to same data. Grey results, whitened results and rankings of grey VIKOR method were also shown in Table XIII. The VIKOR results are ranked as increasing values

Unit	CE1 Y	CE2 Y	CE3 Y	CE4 S	Final weights
E1	[2, 4]	[2, 4]	[0, 2]	[7, 8]	[0.170, 0.486]
E2	[0, 2]	[0, 2]	[0, 2]	[4, 5]	[0.000, 0.316]
E3	[6, 8]	[2, 4]	[2, 4]	[8, 9]	[0.408, 0.725]
E4	[4, 6]	[4, 6]	[4, 6]	[9, 10]	[0.642, 0.958]
E5	[4, 6]	[2, 4]	[2, 4]	[6, 7]	[0.360, 0.676]
E6	[4, 6]	[2, 4]	[4, 6]	[8, 9]	[0.520, 0.836]

Table XI. Evaluation of engineers for energy criteria

Weights	0.0981 Basic criteria	0.1106 Character criteria	0.2975 Software criteria	0.1791 Project criteria	0.3147 Energy criteria
E1	[0.361, 0.573]	[0.367, 0.625]	[0.115, 0.363]	[0.173, 0.386]	[0.170, 0.486]
E2	[0.122, 0.339]	[0.516, 0.754]	[0.012, 0.259]	[0.107, 0.321]	[0.000, 0.316]
E3	[0.242, 0.446]	[0.228, 0.533]	[0.250, 0.497]	[0.279, 0.488]	[0.408, 0.725]
E4	[0.554, 0.750]	[0.470, 0.709]	[0.681, 0.928]	[0.559, 0.773]	[0.642, 0.958]
E5	[0.381, 0.594]	[0.465, 0.748]	[0.542, 0.789]	[0.446, 0.657]	[0.360, 0.676]
E6	[0.673, 0.972]	[0.283, 0.579]	[0.549, 0.796]	[0.746, 0.991]	[0.520, 0.836]

Table XII. Grey decision matrix

	Grey analytic hierarchy process			Grey VIKOR		
	Grey results	Whitened results	Ranking	Grey results	Whitened results	Ranking
E1	[0.132, 0.468]	0.251	5	[0.538, 0.875]	0.759	5
E2	[0.000, 0.333]	0.083	6	[0.664, 1.000]	0.916	6
E3	[0.270, 0.611]	0.426	4	[0.390, 0.732]	0.577	4
E4	[0.669, 1.000]	0.918	1	[0.000, 0.151]	0.020	1
E5	[0.452, 0.791]	0.653	3	[0.195, 0.578]	0.356	3
E6	[0.600, 0.959]	0.854	2	[0.022, 0.361]	0.114	2

Table XIII. Results and rankings of project manager candidates for the software project of the energy company and all of the rankings are same for both methods. The ranking of the candidates for both G-AHP and grey VIKOR methods is as E4, E6, E5, E3, E1 and E2 starting from the best candidate engineer as the project manager.

5.3 Interpretation of the results

This section is allocated to interpretation of the results for better understanding of the study and its application. In Figure 2, the whitened results of final weights are expanded to 100 according to the highest value of each column. This allows to compare the candidates easier under each main criteria and final results of candidates.

In Figure 2, the overall ranking is E6, E4, E5, E1, E3 and E2 for basic criteria; E2, E5, E4, E1, E6 and E3 for character criteria; E4, E6, E5, E3, E1 and E2 for software criteria; E6, E4, E5, E3, E1 and E2 for project criteria; and E4, E6, E3, E5, E1 and E2 for energy criteria with descending orders. The lowest candidate scores of criteria are Engineer 2 with 31, Engineer 3 with 71, Engineer 2 with 8, Engineer 2 with 26 and Engineer 2 with 8 for each main criterion, respectively. Overall scores of candidates for project manager selection are 100, 93, 71, 46, 27 and 9, respectively.

The total weight of software criteria and energy criteria for project manager selection is more than 60 per cent which is also the most effective criteria for the selection of Engineer 4 as the best candidate because, Engineer 4 has the highest scores for software criteria and energy criteria. On the other hand, Engineer 6 also has the highest scores for basic criteria and project criteria, but the total weight of these two main criteria is only 27.7 per cent which is not as effective as the others.

Additionally, the results can be also interpreted for all candidates or only for selected candidate individually. These interpretations can contribute to the improvement of the selected candidate. As an example, deficiencies of Engineer 4 according to other candidates are basic criteria and project criteria. If Engineer 4 can fulfil these deficiencies, s/he can be perfect for the position for now or his/her future career. This means Engineer 4 has to improve his/her education and language for basic criteria, and also crisis management, time management and team management skills for Project Criteria. If necessary, company can also fund the selected candidate at possible and reasonable rates to improve his/her deficiencies better and faster.

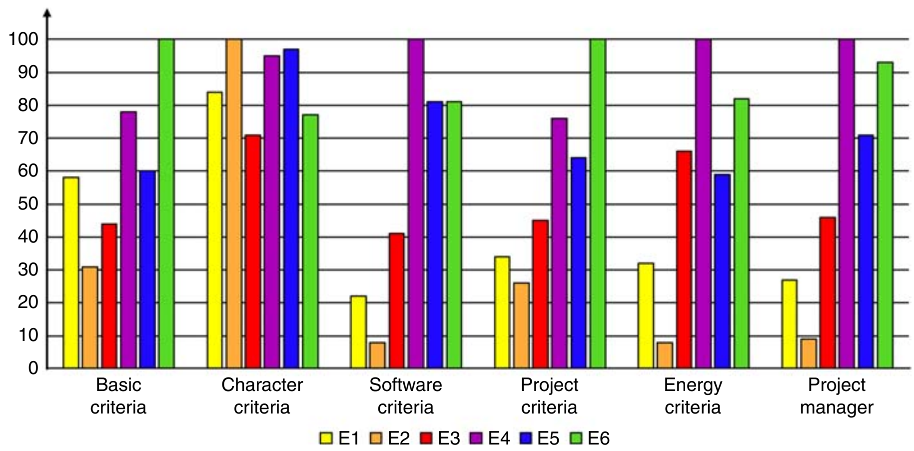

Figure 2. Graphical representation of results

6. Conclusion and discussions

In this study, a G-AHP approach is proposed to evaluate engineers as a project manager for a software project of an energy company. The proposed approach is applied to evaluate six candidate engineers with 25 sub-criteria under five criteria. Three different units are used in the application as year, score and assessment. The results of the study show the applicability of the proposed approach to grey and fuzzy systems which include various units and data. Especially, systems with missing information which have only a range without other information can easily be interpreted by using the proposed G-AHP.

Everything in the business starts with the selection of the most appropriate personnel. Hence, personnel selection is one of the most important and complex decision-making problem of HRM. Depending on the needs of projects and works, it handles big data with various units from different sources which have to be included in the selection process. There are different heuristic and MCDM methods in the literature for personnel selection process. But, almost all of these methods are applying simple data with basic methods or complex data with complex methods and usage which are not always suitable for HRM. The root of complexity of personnel selection process is considering group decision making, subjective judgements, various units from different sources and big data together without any bias or error. Other important problems, such as time, resource usage, being user friendly, ease of application, logical and interpretable results, have to be also taken into account while considering these problems. The proposed G-AHP approach to project manager selection is designed uniquely without any alteration, deformation or restriction on data to consider all these problems which have not been reported in the existing literature. Briefly, the proposed G-AHP approach to project manager selection has following advantages and novelties:

- it evaluates subjective and objective criteria together without any alteration;
- it obtains the results with both crisp and grey numbers;
- loss of information for objective criteria is eliminated;
- group decision making process is considered for subjective judgements; and
- it is easy to be used and interpreted by HRM.

The results of the study demonstrate that the proposed approach can be applied to other fields of science, engineering and management easily through advantages of the approach. For HRM departments, it can also be applied to observe current situations and advancements of current personnel for promotions and trainings needed according to lack of them. According to these statements, there are two practice study fields for further research works; first, applying the proposed approach to other problems of the fields which include decision making, evaluation and planning, such as personnel selection, artisan selection in a special field, evaluation of management technique, and also supplier selection, equipment selection, software selection, etc. Second, if the proposed approach is applied to the current personnel, it gives them chance to improve their skills and expertise, and make them perfect for both companies and their career.

Managers evaluating personnel can have different weights on companies or projects. In this situation, equally weighted evaluations can never represent the real results, and weighted evaluations are needed to be applied for the decisions of managers. This also gives a lead for two other further research topics; first, decisions of decision makers can be weighted according to their importance in the company or project. Second, the proposed approach can also be integrated with the other MCDM methods and theories of science and management, especially according to the application field, to improve solutions of the problems and the approach.

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