

AN INTEGRATED FUZZY MULTI CRITERIA GROUP DECISION MAKING MODEL FOR HANDLING EQUIPMENT SELECTION

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Abstract. The problem of handling equipment selection plays a significant role in the total cost of a mining project; so that it can affect the activity and continuity of the project and is a strategic problem. In this study, an integrated model based on two fuzzy multi-criteria decision making techniques for handling equipment selection is proposed. The proposed evaluation model is derived from group decision making, fuzzy set theory, analytical hierarchy process (AHP), and Technique to Order Preference by Similarity to Ideal Solution (TOPSIS) methods. The fuzzy AHP (FAHP) method is utilized to calculate the relative importance of the evaluation criteria, then, fuzzy TOPSIS (FTOPSIS) is applied for evaluating the feasible handling equipment in order to select the best handling system among a pool of the possible alternatives. The model is applied for a real world case study to demonstrate the capability and effectiveness of the proposed model. To investigate the result sensitiveness to the changes of the criteria weights, a sensitivity analysis is finally conducted.

Keywords: handling equipment selection, group decision making, FAHP, FTOPSIS.

Introduction

Equipment selection plays a key role in mining design due to the fact that an inappropriate selection can negatively affect the overall cost and continuity of a mine. Loading and handling equipment are among the most crucial operation impacting production in surface and underground mines and have a substantial share of a total mine costs (Sayadi *et al.* 2012). Material handling can account for 30–75% of the total cost, and efficient material handling can be primarily responsible for reducing the operating cost by 15–30% (Sule 1994; Kulak 2005). Therefore, the outputs of the project depend on the type of selected equipment for handling. Since a wider range of equipment are available today, determination of the best equipment for a given production environment is not an easy task (Paramasivam *et al.* 2011).

The problem of handling equipment selection is a multi criteria decision making (MCDM) issue because it comprises a set of effective criteria that are often in conflict with each other. There are many ways to classify the existing MCDM methods (Zavadskas, Turskis 2011). Belton and Stewart (2002) grouped the MCDM methods into three main categories: (1) value measurement model such as analytical hierarchy process (AHP); (2) outranking models such as Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE); and (3) goal aspiration and reference level models such as Technique to Order Preference by Similarity to Ideal Solution (TOPSIS).

TOPSIS is one of the most popular methods for solving the MCDM problems (Liu 2009; Tupenaite *et al.* 2010; Han, Liu 2011; Kalibatas *et al.* 2011). This method takes into account the ideal and the anti-ideal solutions simultaneously to select the best alternative among a pool of feasible alternatives. However, TOPSIS is often criticized for its inability to deal with vague and uncertain problems (Yu *et al.* 2011); so that, without considering the inherent uncertainty and/or imprecision of the elements could result in unreliable and unrealistic assessment. On the other hand, fuzzy logic is capable of handling the existing uncertainty. This technique uses linguistic variable instead of traditional quantitative expression, which is a very helpful concept for dealing with situations which are too complex or insufficiently defined (Zadeh 1965). According to Fouladgar *et al.* (2011), fuzzy TOPSIS (FTOPSIS) has different advantages, including logical concepts, simple and fast computations, and tolerating the uncertainty. Hence, FTOPSIS is recently employed in order to solve different aspects of priority problems, such as strategy management (Wu *et al.* 2010; Fouladgar *et al.* 2011), equipment selection (Lashgari *et al.* 2011; Yazdani-Chamzini, Yakhchali 2012), risk management (Wang, Elhag 2006; Kutlu, Ekmekçioğlu 2012; Fouladgar *et al.* 2012b), service quality (Awasthi *et al.* 2011b; Büyüközkan, Çifçi 2012), supply chain management (Boran *et al.* 2009; Liao, Kao 2011; Jolai *et al.* 2011), and sustainability evaluation (Awasthi *et al.* 2011a; Awasthi, Chauhan 2012).

Moreover, Fuzzy AHP (FAHP) is widely used for solving MCDM problems in real situations (Fouladgar *et al.* 2011). In this paper, FAHP is integrated with FTOPSIS under group decision making to select the optimum handling system among a set of the feasible alternatives. First FAHP is employed to determine the relative importance of the evaluation criteria. Then by applying the weight vector of the evaluation criteria obtained in previous stage, FTOPSIS is used to acquire the final ranking order of handling methods.

The rest of the paper is organized as follows: past researches effort to prioritize and select the handling equipment is summarized in Section 1. Section 2 presents the basic descriptions of fuzzy set theory, FAHP method, and FTOPSIS technique. Stages of the proposed evaluation model are explained in Section 3. Section 4 illustrates a real world case study of handling equipment selection in an open pit mine. Finally, conclusions and findings are discussed in the last section.

1. Literature review

According to the importance of handling, a large number of researchers have applied different approaches for solving the problem of the handling equipment selection. Chan *et al.* (2001) developed an intelligent material handling equipment selection system called Material Handling Equipment Selection Advisor (MHESA). The MHESA contains three parts: (1) a database to store equipment types with their specifications; (2) a knowledge-based expert system for assisting material handling equipment selection; and (3) an AHP (analytical hierarchy process) model to select the most favourable equipment type.

Park (1996) proposed an intelligent knowledge-based expert system called ICMESE for the selection and evaluation of material handling equipment suitable for movement and storage of materials in a manufacturing facility. Chakraborty and Banik (2006) developed an AHP for designing a material handling equipment selection model. They used pairwise comparison matrices to measure the relative importance of each criteria, subcriteria and sub-subcriteria and then determined the overall ranking of each alternative equipment.

Chu *et al.* (1995) developed a computer-assisted methodology for the selection of the suitable material handling equipment. Onut *et al.* (2009) proposed a combined MCDM methodology for evaluation and selection of material handling equipment (MHE) types for a company in the steel construction industry in Istanbul, Turkey. Mirhosseini and Webb (2009) proposed a hybrid fuzzy knowledge-based expert system and genetic algorithm for efficient selection and assignment of material handling equipment.

Poon *et al.* (2011) proposed a RFID-GA-based warehouse resource allocation system (RGWRAS) for handling stochastic production material demand problems and for allocating warehouse resources on the shop floor and in warehouse environments. Fisher *et al.* (1988) proposed a rule-based expert system called MATHES for material handling equipment selection. A systematic pro-

cedure for the selection of bulk material handling equipment is proposed by Velury and Kennedy (1992). This paper concentrates on the selection of relevant factors that need to be taken into account in the design of a bulk material handling system and on the selection of equipment once these factors have been considered. Fonseca *et al.* (2004) applied a knowledge-based system for conveyor equipment selection.

Bazzazi *et al.* (2011b) proposed a new method of MCDM that is applied to select the suitable loading-haulage equipment for the open pits mines. Bazzazi *et al.* (2011a) presented an evaluation model based on deterministic data, fuzzy numbers, interval numbers and linguistic terms to select loading-hauling system for an iron ore open pit mine. In this model, a combination of AHP and entropy method was applied for attribute weighting and VIKOR was employed to rank the feasible alternatives.

Lashgari *et al.* (2012) proposed a new integrated model based on ANP, fuzzy AHP, and TOPSIS to choose the best alternative among possible loading and hauling systems. Mahdavi *et al.* (2011) developed a bi-objective operation allocation and material handling equipment selection problem in flexible manufacturing system (FMS) with the aim of minimizing the machine operation, material handling and machine setup costs and maximizing the machine utilization. Anand *et al.* (2011) developed an AHP for the selection of material handling systems in the design of FMS. Tuzkaya *et al.* (2010) proposed an integrated fuzzy multi-criteria decision making methodology for material handling equipment selection problem (MHESP). In this paper, evaluation criteria for the MHESP is weighted by fuzzy-ANP (F-ANP) approach, then, alternative material handling equipments are evaluated by fuzzy-PROMETHEE (F-PROMETHEE) approach.

The selection of a loading-hauling system using an AHP-based model was evaluated by Bascetin (2004) for coal production in an open pit coal mine located Orhaneli, in western Turkey. Yaman (2001) proposed a knowledge-based approach for selection of material handling equipment and material handling system pre-design. Denby and Schofield (1990) developed the MINDER system (MINE Design using Expert Reasoning) for surface mining method selection and excavation and haulage equipment selection.

According to incomplete data, less or even lack of information, and inherent complexity, most of the above-mentioned studies have neglected this problem. Fuzzy set theory is a powerful tool to handle the inherent uncertainty. Moreover, knowledge-based expert systems have some disadvantages, such as the doubts left due to the difficulties in defining many rules.

On the one hand, based on the past researches, it is clear that FTOPSIS has demonstrated its capabilities and efficiencies as a practical engineering and problem-solving tool. On the other hand, FAHP is the most popular technique for solving the MCDM problems. Likewise, by using group decision making (social choice), different rating viewpoints and the tradeoffs among different criteria are taken into consideration in the aggregation procedure to ensure more accurate decision making (Karsak

2002). This makes that the group decision making is attracting more and more attention in management, and has received a great deal of attention from researchers (Yue 2011). In this paper, an integrated model based on FTOPSIS and FAHP methods under group decision making is proposed to select the most appropriate handling equipment. First, FAHP is utilized to obtain the weights of the evaluation criteria, then, by using the weight vector obtained in the first step, FTOPSIS is used to select the best handling system.

2. Mathematical background

2.1. Fuzzy set theory

Complexity is an important part of most real world decision problems that is due to the existing uncertainty, imprecise knowledge, and less of information. The use of the techniques and tools that allow the available information to be used with the adequate guaranty is desired for dealing with such complexity. Fuzzy set, introduced by Zadeh (1965), is a powerful tool for capturing the uncertainty and vagueness under the conditions of imprecise and incomplete information. Fuzzy theory reflects human reasoning in its use of approximate information and uncertainty to generate decisions (Wong, Lai 2011).

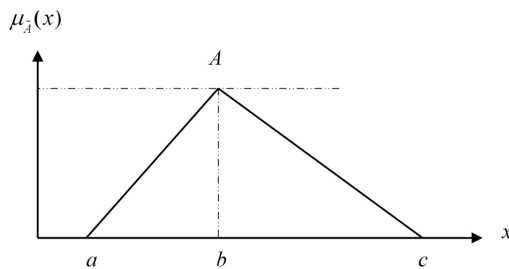


Fig. 1. Triangular fuzzy number

A triangular fuzzy number (TFN) is defined as $\tilde{A} = (a, b, c)$; which $a, b,$ and c are crisp numbers and $a \leq b \leq c$. A fuzzy number is defined by its membership function whose values can be any number in the interval $[0, 1]$, which 0 expresses do not belong to the set under consideration and 1 addresses full belong to the set. Assume that TFNs start rising from zero at $x = a$; reach a maximum of 1 at $x = b$; and decline to zero at $x = c$ as

shown in Figure 1. Then the membership function $\mu_{\tilde{A}}(x)$ of a TFN is given by:

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < a \\ (x - a) / (b - a), & a \leq x < b \\ (x - c) / (b - c), & b \leq x < c \\ 0, & x > c \end{cases} \quad (1)$$

Let $\tilde{a} = (a_1, b_1, c_1)$ and $\tilde{b} = (a_2, b_2, c_2)$ be two TFNs then the vertex method is defined to compute the distance between them by Eqn (2):

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3} [(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \quad (2)$$

The fuzzy linguistic term is a fuzzy number or a variable whose values are words or sentences in language terms (Fouladgar *et al.* 2012c). These terms can be divided into different linguistic criteria. A 9-point scale for defining the weights of criteria as presented in Table 1 has been deliberately selected. As well as, a 5-point scale for defining the preference ratings of alternatives is deliberately adopted as given in Table 2 and Figure 2.

Table 2. Linguistic terms for the preference rating of alternatives

Linguistic term	Corresponding triangular fuzzy number
Very poor (VP)	(0,1,3)
Poor (P)	(1,3,5)
Fair (F)	(3,5,7)
Good (G)	(5,7,9)
Very good (VG)	(7,9,10)

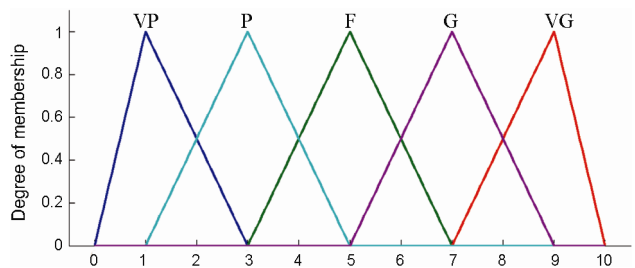


Fig. 2. Membership functions of linguistic values for preference rating

Table 1. Linguistic terms for the importance weights of the criteria

Linguistic term	Fuzzy number	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equal importance (EI)	$\tilde{1}$	(1,1,1)	(1,1,1)
Intermediate (IMI)	$\tilde{2}$	(1,2,3)	(1/3,1/2,1)
Moderate importance (MI)	$\tilde{3}$	(2,3,4)	(1/4,1/3,1/2)
Intermediate (ISI)	$\tilde{4}$	(3,4,5)	(1/5,1/4,1/3)
Strong importance (SI)	$\tilde{5}$	(4,5,6)	(1/6,1/5,1/4)
Intermediate (IVSI)	$\tilde{6}$	(5,6,7)	(1/7,1/6,1/5)
Very strong importance (VSI)	$\tilde{7}$	(6,7,8)	(1/8,1/7,1/6)
Intermediate (IEXI)	$\tilde{8}$	(7,8,9)	(1/9,1/8,1/7)
Extreme importance (EXI)	$\tilde{9}$	(8,9,10)	(1/10,1/9,1/8)

2.2. FAHP method

Analytical hierarchy process (AHP), developed by Saaty (1980), is a decision analysis method that takes into account both qualitative and quantitative information. AHP can decompose any complex problem into several sub-problems in terms of hierarchical levels where each level represents a set of criteria or attributes relative to each sub-problem. This method utilizes three principles to solve problems (Aydogan 2011): (1) structure of the hierarchy; (2) the matrix of pairwise comparison ratios; and (3) the method for calculating weights.

Despite the popularity of the AHP technique, it is not capable of handling the existing uncertainty and complexity in real world problems. The merit of using a fuzzy approach is to determine the relative importance of attributes using fuzzy numbers instead of precise numbers (Sun 2010; Kara 2011; Yazdani-Chamzini, Yakhchali 2012). There are many fuzzy AHP methods proposed on the basis of the concepts of the fuzzy set theory and hierarchical structure by various researchers to solve the selection problems in different fields of application (Van Laarhoven, Pedrycz 1983; Buckley 1985; Boender *et al.* 1989; Chang 1996; Cheng 1996).

In this paper, despite the fact Chang’s method is relatively easier to implement, Buckley’s method is applied for calculating the weights of the evaluation criteria because of some drawbacks of Chang’s method (Wang *et al.* 2008). The FAHP procedure can be defined as follows:

Step 1. Construct pairwise comparison matrices among all the criteria in the dimensions of the hierarchy system. Determine linguistic terms to the pairwise comparisons by asking which is the more important of each two dimensions based on Table 1, as following matrix \tilde{A} :

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{m1} & \tilde{a}_{m2} & \dots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \dots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{m1} & 1/\tilde{a}_{m2} & \dots & 1 \end{bmatrix}, \quad (3)$$

where:

$$\tilde{a}_{ij} = \begin{cases} \tilde{9}^{-1}, \dots, \tilde{2}^{-1}, \tilde{1}, \tilde{2}, \dots, \tilde{9}, & i \neq j \\ 1 & i = j \end{cases}. \quad (4)$$

Step 2. Calculate the aggregated fuzzy weights of each criterion by geometric mean technique (Buckley 1985) that is:

$$\tilde{r}_i = (\tilde{a}_{i1} \otimes \dots \otimes \tilde{a}_{ij} \otimes \dots \otimes \tilde{a}_{in})^{1/n}; \quad (5)$$

$$\tilde{w}_i = \tilde{r}_i \otimes [\tilde{r}_1 \oplus \dots \oplus \tilde{r}_i \oplus \dots \oplus \tilde{r}_n]^{-1}, \quad (6)$$

where: \tilde{a}_{ij} is fuzzy comparison value of dimension i to criterion j , thus, \tilde{r}_i is a geometric mean of fuzzy comparison value of criterion i to each criterion, \tilde{w}_i is the fuzzy weight of the i th criterion, can be indicated by a TFN, $\tilde{w}_i = (lw_i, mw_i, uw_i)$. The lw_i , mw_i and uw_i are the lower,

middle, and upper values of the fuzzy weight of the i th dimension.

2.3. FTOPSIS technique

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), introduced by Hwang and Yoon (1981), is based on the concept that the most appropriate alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest distance from the negative ideal solution (NIS). The PIS is a solution that maximizes the benefit criteria and minimizes the cost criteria simultaneously, whereas the NIS maximizes the cost criteria and minimizes the benefit criteria simultaneously (Yazdani-Chamzini, Yakhchali 2012). This technique was developed as fuzzy TOPSIS (FTOPSIS) to solve ranking and evaluating problems, because fuzzy allows the decision-makers to incomplete information, non-obtainable information into decision model (Kulak *et al.* 2005). The main steps of the FTOPSIS can be defined as follows:

Step 1. Choose the linguistic variables for the alternatives with respect to the evaluation criteria. The linguistic variables are linguistic terms that express the values by words or sentences. Each linguistic value can be represented by a TFN which can be assigned to a membership function. In this study, we employed TFNs be associated to the linguistic values and scales of five points for the ratings of alternatives (Table 2 and Fig. 2) and nine points for importance weights of the evaluation criteria (Table 1).

Step 2. Construct the fuzzy decision matrix.

To calculate the performance of a set of alternatives on a given set of criteria, the decision matrix of $m \times n$ dimension is formed, which m and n are the number of alternatives and criteria respectively.

$$\begin{matrix} & \text{C1} & \text{C2} & \dots & \text{Cn} & \\ \begin{bmatrix} \tilde{x}_{11k} & \tilde{x}_{12k} & \dots & \tilde{x}_{1nk} \\ \tilde{x}_{21k} & \tilde{x}_{22k} & \dots & \tilde{x}_{2nk} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1k} & \tilde{x}_{m2k} & & \tilde{x}_{mnk} \end{bmatrix} & A_1 \\ & & & & & A_2 \\ & & & & & \vdots \\ & & & & & A_m \end{matrix}, \quad (7)$$

where: \tilde{x}_{ijk} , $i = 1, 2, \dots, m; j = 1, 2, \dots, n; k$ is the number of decision makers, are linguistic triangular Fuzzy numbers, $\tilde{x}_{ijk} = (x_{ijk1}, x_{ijk2}, x_{ijk3})$.

Step 3. Aggregate the ratings of alternatives respect to each criterion (\tilde{x}_{ij}). In order to aggregate the ratings of alternatives versus each criterion, the arithmetic mean is applied.

Let the fuzzy ratings of all decision makers be TFNs $\tilde{x}_{ijk} = (x_{ijk1}, x_{ijk2}, x_{ijk3})$, $k = 1, 2, \dots, K$, which \tilde{x}_{ijk} represents the value of the i th alternative respect to the j th criterion by k th decision maker. Then the aggregated fuzzy rating can be defined as:

$$\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}), \quad k = 1, 2, \dots, K, \quad (8)$$

where:

$$\begin{aligned}x_{ij1} &= \frac{1}{K} \sum_{k=1}^k x_{ijk1}; \\x_{ij2} &= \frac{1}{K} \sum_{k=1}^k x_{ijk2}; \\x_{ij3} &= \frac{1}{K} \sum_{k=1}^k x_{ijk3}.\end{aligned}\quad (9)$$

Step 4. Calculate the normalized fuzzy decision matrix. In order to transform the various criteria scales into a comparable scale, the linear scale transformation is employed that the ranges of normalized TFNs belong to closed interval zero and one. The normalized fuzzy decision matrix can be computed by \tilde{R} :

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (10)$$

and

$$\begin{aligned}\tilde{r}_{ij} &= \left(\frac{x_{ij1}}{x_{j3}^*}, \frac{x_{ij2}}{x_{j3}^*}, \frac{x_{ij3}}{x_{j3}^*} \right), \quad x_{j3}^* = \max_i x_{ij3}, \\ \tilde{r}_{ij} &= \left(\frac{x_{j1}^*}{x_{ij3}}, \frac{x_{j1}^*}{x_{ij2}}, \frac{x_{j1}^*}{x_{ij1}} \right), \quad x_{j1}^* = \min_i x_{j1},\end{aligned}\quad (11)$$

where r_{ij} is the normalized value of x_{ij} .

Step 5. Calculate the weighted normalized fuzzy decision matrix. We can compute the weighted normalized fuzzy decision matrix by considering the relative importance of evaluation criteria as:

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n} \quad (12)$$

and

$$\tilde{v}_{ij} = \tilde{r}_{ij} \times \tilde{w}_j, \quad (13)$$

where \tilde{w}_j is the weights of the criteria that are obtained by FAHP in this paper.

Step 6. Identify positive ideal (A^*) and negative ideal (A^-) solutions. The fuzzy positive – ideal solution and the fuzzy negative-ideal solution are shown in Eqns (14), (15):

$$A^* = (\tilde{v}_1^+, \tilde{v}_2^+, \tilde{v}_3^+, \dots, \tilde{v}_n^+) = \left\{ \max_i v_{ij} \mid (i = 1, 2, \dots, n) \right\}; \quad (14)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \tilde{v}_3^-, \dots, \tilde{v}_n^-) = \left\{ \min_i v_{ij} \mid (i = 1, 2, \dots, n) \right\}. \quad (15)$$

Step 7. Calculate separation measures. The distance of each alternative from A^* and A^- can be currently calculated using Eqns (16), (17):

$$d_i^+ = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^+), \quad i = 1, 2, \dots, m; \quad (16)$$

$$d_i^- = \sum_{j=1}^n d(\tilde{v}_{ij}, \tilde{v}_j^-), \quad i = 1, 2, \dots, m. \quad (17)$$

Step 8. Calculate the similarities to ideal solution. This step solves the similarities to an ideal solution by Eqn (18):

$$CC_i^* = \frac{d_i^-}{d_i^- + d_i^*}. \quad (18)$$

Step 9. Rank preference order. Choose an alternative with maximum CC_i^* or rank alternatives according to CC_i^* in descending order.

3. The proposed model

The proposed model for selecting the best handling equipment, integrated of FAHP and FTOPSIS techniques under group decision making, includes three main steps: (1) determine the evaluation criteria in the decision making process; (2) calculate the importance weights of the evaluation criteria by Buckley's FAHP; (3) measure the preference ratings of alternatives with FTOPSIS method and select the alternative with the highest score as the first choice. In the first step, alternatives and evaluation criteria are determined and the structure of hierarchy is constructed. In the second step, the importance weights of evaluation criteria are obtained by decision maker team in the template of FAHP questionnaire. The decision maker team contains of ten experts with high degree of knowledge in the field of mine design. In this step, the weights of criteria are calculated by pairwise comparison matrixes formed by decision maker team based on the scale given in Table 1. As shown in Table 1, linguistic values and the membership functions of these linguistic values are listed for evaluation of criteria. The values obtained from individual evaluations are converted into final pairwise comparison matrix by the arithmetic mean to find a consensus on weight of criteria.

In the last step, alternatives are ranked in descending order using FTOPSIS method. In the first phase of this step, experts with the help of scale given in Table 2 and Figure 2 determine the rating of alternatives with respect to each criterion. After forming decision making matrix, the computations of the FTOPSIS method for evaluating the existing alternatives with respect to the evaluation criteria under consideration is implemented. In the last phase of this step, final ranking of alternatives in descending order is obtained and the optimal handling equipment is chosen. Schematic diagram of the proposed model for handling equipment selection is depicted in Figure 3.

4. An illustrative example

The proposed model is applied to select the most appropriate handling equipment in an open pit mine. The Sangan mine is one of the largest iron deposits of Iran which is situated 308 km southeast of Mashhad city in the north-east of the country (Fig. 4). This mine is designed to have an initial annual production of 3.4 Mt iron ore concentrate (Monjezi *et al.* 2011). The deposit of this mine comprises of a magnetite skarn and it is known as iron-oxide-type deposit. The case is implemented by using a step-by-step procedure as follows:

Step 1. After reviewing the literatures and a lot of face-to-face interviews, solid information is developed on the evaluation criteria and alternatives. After preliminary screening, three alternatives have left in the list of feasible alternatives, including belt conveyor system (A1), truck (A2), and truck-in-pit crusher-belt conveyor system (A3). Some basic features of these three systems are listed in Table 3. Then, a group of decision makers contains of ten experts with minimum four years' experience in the field of mining design in an assembly process identified the effective criteria as Capital cost (C1), Operation cost (C2), Production (C3), Material size (C4), Ground condition (C5), Distance (C6), Weather condition (C7), Environment (C8), Risk (C9), Reliability (C10), Efficiency (C11), Availability (C12), Safety (C13), Flexibility (C14), and Useful life (C15). These fifteen criteria are classified into three main criteria, including Economic parameters (EP), Operating parameters (OP), and Technical parameters (TP).

Among the effective criteria, the first two criteria and the ninth criterion (i.e. C1, C2, and C9) are the cost

type criteria (the lower, the better). The rest of the evaluation criteria (i.e. C3, C4, C5, C6, C7, C8, C10, C11, C12, C13, C14, and C15) are the benefit type criteria (the higher, the better).

The hierarchy of handling equipment selection presented in Figure 5 can be divided into four levels: level 1 includes the goal of the decision hierarchy, which is selection the optimum handling equipment. The criteria are on the second level. The sub-criteria are located in the third level. Level 4 comprises the decision alternatives.

Step 2. After constructing the decision hierarchy, the importance weights of the criteria are obtained by using the computations of the FAHP method. For achieving the aim, the ten evaluators are asked to form individual pairwise comparison matrix based on the scale given in Table 1. For example, when comparing the Reliability and Efficiency, the responses of ten evaluators are EI, EI, EI, IMI, EI, IMI, (IMI)*, EI, MI, and EI, respectively.

* Triangular fuzzy reciprocal scale

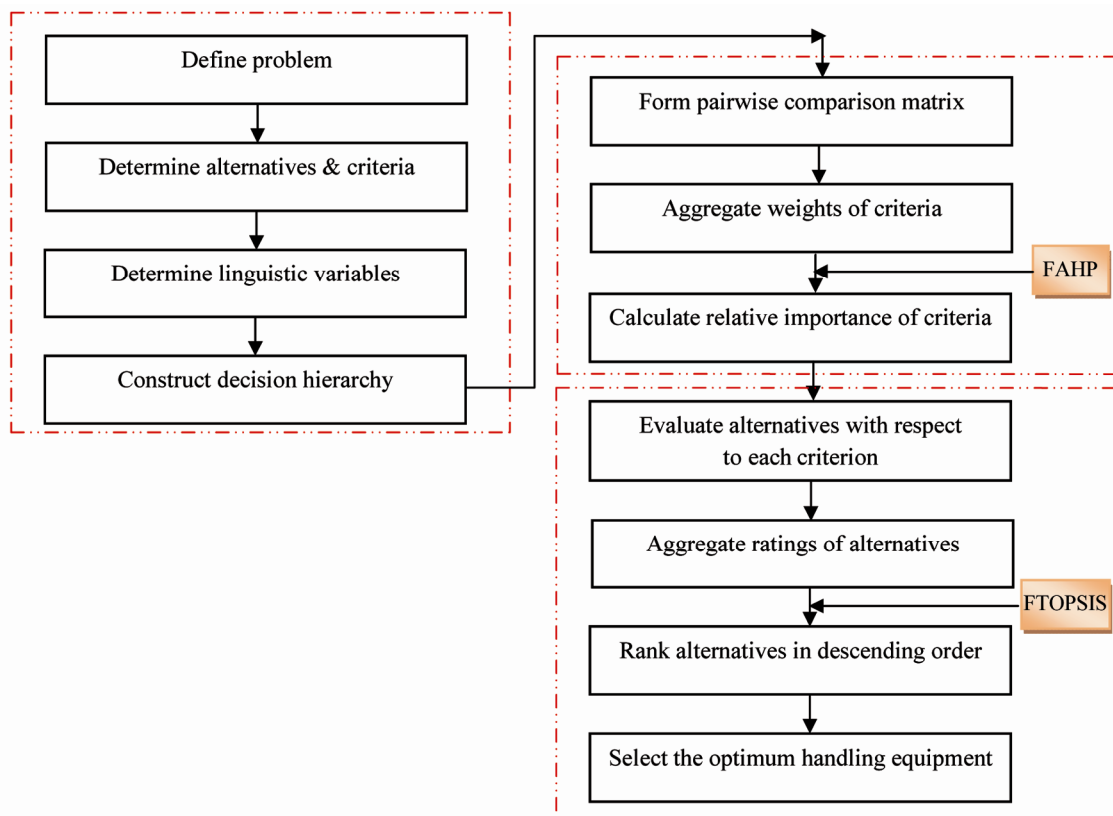


Fig. 3. Schematic diagram of the proposed model

Table 3. Some basic features of alternatives

	A1	A2	A3
Capital cast (\$)	2904100	2340000	2736000
Operation Cost (\$)	208.66	194.62	187.85
Useful life (year)	18	14	10



Fig. 4. Geography of Sangan iron mine (Naghizadeh *et al.* 2011)

The responses gathered from ten questionnaires filled by the experts are transferred into a final pairwise comparison matrix to the results be aggregated. In this paper, Buckley’s FAHP methodology that applies the geometric mean technique is used for calculating the elements of the synthetic pairwise comparison matrix in order to obtain a consensus as presented in Table 4.

As a sample, $\tilde{a}_{C10,C11}$ is calculated as follows:

$$\begin{aligned} \tilde{a}_{C10,C11} &= ((1,1,1) \otimes (1,1,1) \otimes (1,1,1) \otimes (1,2,3) \otimes (1,1,1) \otimes \\ &(1,2,3) \otimes (1/3,1/2,1) \otimes (1,1,1) \otimes (1,2,3) \otimes (1,1,1))^{1/10} = \\ &((1 \times 1 \times 1 \times 1 \times 1 \times 1/3 \times 1 \times 1 \times 1)^{1/10}, \\ &(1 \times 1 \times 1 \times 2 \times 1 \times 2 \times 1/2 \times 1 \times 2 \times 1)^{1/10}, \\ &(1 \times 1 \times 1 \times 3 \times 1 \times 3 \times 1 \times 1 \times 3 \times 1)^{1/10}) = \\ &(0.896, 1.149, 1.39). \end{aligned}$$

Similar calculations were carried out for the other elements and the results are listed in Table 4.

The fuzzy weights of the main and sub-criteria are computed by Eqn (5), the computations are presented as follows:

$$\begin{aligned} \tilde{r}_{EP} &= ((1 \times 0.77 \times 1.23)^{1/3}, (1 \times 0.96 \times 2.29)^{1/3}, \\ &(1 \times 1.29 \times \dots \times 3.37)^{1/3}) = (0.98, 1.3, 1.63). \end{aligned}$$

Similar calculations are conducted for the other main and sub-criteria and the results are summarized in the following part:

$$\begin{aligned} \tilde{r}_{OP} &= (0.95, 1.31, 1.61), \tilde{r}_{TP} = (0.45, 0.59, 0.9), \\ \tilde{r}_1 &= (0.6, 0.84, 1.08), \tilde{r}_2 = (0.93, 1.19, 1.66), \\ \tilde{r}_3 &= (1.55, 2.25, 2.83), \\ \tilde{r}_4 &= (0.46, 0.66, 0.96), \tilde{r}_5 = (0.79, 1.15, 1.75), \\ \tilde{r}_6 &= (1.62, 2.23, 2.94), \tilde{r}_7 = (0.31, 0.39, 0.57), \\ \tilde{r}_8 &= (0.45, 0.66, 0.96), \\ \tilde{r}_9 &= (0.68, 1.01, 1.57), \tilde{r}_{10} = (1.37, 1.9, 2.52), \\ \tilde{r}_{11} &= (1.04, 1.6, 2.1), \tilde{r}_{12} = (0.55, 0.79, 1.15), \\ \tilde{r}_{13} &= (1.33, 1.73, 2.36), \\ \tilde{r}_{14} &= (0.28, 0.36, 0.5), \tilde{r}_{15} = (0.5, 0.68, 0.96). \end{aligned}$$

The weight of each criterion can be calculated through Eqn (6):

$$\tilde{w}_{EP} = (0.98, 1.3, 1.63) \otimes (1 / (1.63 + 1.61 + 0.9), 1 / (1.3 + 1.31 + 0.59), 1 / (0.98 + 0.95 + 0.45)) = (0.24, 0.41, 0.68)$$

Similarly, the remaining \tilde{w}_i are obtained as follows:

$$\begin{aligned} \tilde{w}_{OP} &= (0.23, 0.41, 0.68), \tilde{w}_{TP} = (0.11, 0.18, 0.38), \\ \tilde{w}_1 &= (0.22, 0.41, 0.7), \tilde{w}_2 = (0.34, 0.59, 1.09), \\ \tilde{w}_3 &= (0.13, 0.27, 0.48), \tilde{w}_4 = (0.04, 0.08, 0.16), \\ \tilde{w}_5 &= (0.07, 0.14, 0.3), \tilde{w}_6 = (0.14, 0.27, 0.5), \\ \tilde{w}_7 &= (0.03, 0.05, 0.1), \tilde{w}_8 = (0.04, 0.08, 0.16), \\ \tilde{w}_9 &= (0.06, 0.12, 0.27), \tilde{w}_{10} = (0.14, 0.27, 0.5), \\ \tilde{w}_{11} &= (0.11, 0.23, 0.41), \tilde{w}_{12} = (0.06, 0.11, 0.23), \\ \tilde{w}_{13} &= (0.14, 0.26, 0.47), \tilde{w}_{14} = (0.03, 0.05, 0.1), \\ \tilde{w}_{15} &= (0.05, 0.1, 0.19). \end{aligned}$$

The output of fuzzy synthetic decisions obtained by each dimension is a fuzzy number. Therefore, it is necessary to convert fuzzy numbers into crisp numbers by defuzzification in order to compare the relative importance of dimensions. The procedure of defuzzification is to locate the Best Nonfuzzy Performance (BNP) value. Methods of such defuzzified fuzzy ranking generally include mean of maximal (MOM), center of area (COA), and α -cut (Chen *et al.* 2011).

This research for transforming the fuzzy weights into the crisp weights applies the centre of area (COA) method which is a simple and practical method (Fouladgar *et al.* 2012a) to compute the best nonfuzzy performance (BNP) value of the fuzzy weights of each criterion. The BNP value of the fuzzy number \tilde{R}_i can be found by using Eqn (19):

$$BNP_i = \frac{[(UR_i - LR_i) + (MR_i - LR_i)]}{3} + LR_i. \quad (19)$$

The relative weights of the main and sub-criteria and their ranks are shown in Table 5.

As seen in Table 5, the relative weights for the evaluation criterion are: Operation cost (0.355), Capital cost (0.234), Distance (0.161), Production (0.156), Ground condition (0.092), Reliability (0.084), Risk (0.081), Safety (0.079), Efficiency (0.07), Material size (0.051), Environment (0.051), Availability (0.037), Useful life (0.032), Weather condition (0.03), and Flexibility (0.017). Based on the weights obtained by FAHP, the most important criteria for the evaluation of handling equipment is Operation cost (0.355). Moreover, the less important criterion is Flexibility (0.017). The ranks of the evaluation criteria from the largest to smallest are schematically shown in Figure 6.

Table 4. Synthetic pairwise comparison matrices

	EP			OP			TP		
EP	1.00	1.00	1.00	0.77	0.96	1.29	1.23	2.29	3.37
OP	0.78	1.04	1.30	1.00	1.00	1.00	1.12	2.16	3.24
TP	0.30	0.44	0.81	0.31	0.46	0.89	1.00	1.00	1.00

Table 4. Continued

	C1			C2		
C1	1.00	1.00	1.00	0.36	0.71	1.16
C2	0.86	1.41	2.78	1.00	1.00	1.00

Table 4. Continued

	C3		C4		C5		C6		C7		C8		C9	
C3	1.00	1.00	1.00	2.43	3.56	4.71	1.32	2.47	3.57	0.69	0.92	1.16	3.24	4.35
C4	0.21	0.28	0.41	1.00	1.00	1.00	0.37	0.54	0.79	0.24	0.34	0.47	0.96	1.76
C5	0.28	0.40	0.76	1.27	1.85	2.70	1.00	1.00	1.00	0.34	0.53	0.87	2.21	3.27
C6	0.86	1.09	1.45	2.13	2.94	4.17	1.15	1.89	2.94	1.00	1.00	1.00	3.24	4.36
C7	0.22	0.23	0.31	0.35	0.57	1.04	0.23	0.31	0.45	0.18	0.23	0.31	1.00	1.00
C8	0.21	0.27	0.38	0.52	0.89	1.52	0.35	0.58	1.09	0.19	0.24	0.32	1.22	2.08
C9	0.29	0.45	0.89	1.09	1.79	2.94	0.44	0.83	1.28	0.27	0.41	0.72	1.96	2.94

Table 4. Continued

	C10		C11		C12		C13		C14		C15	
C10	1.00	1.00	1.00	0.87	1.12	2.15	1.46	2.52	3.67	0.57	0.96	1.16
C11	0.47	0.89	1.15	1.00	1.00	1.00	1.31	2.42	3.57	0.62	0.87	1.23
C12	0.27	0.40	0.68	0.28	0.41	0.76	1.00	1.00	1.00	0.38	0.63	0.94
C13	0.86	1.04	1.75	0.81	1.15	1.61	1.06	1.59	2.63	1.00	1.00	1.00
C14	0.16	0.19	0.25	0.19	0.24	0.34	0.29	0.43	0.81	0.19	0.24	0.32
C15	0.22	0.30	0.45	0.31	0.46	0.89	0.74	1.02	1.32	0.22	0.29	0.43

Table 5. Relative weight of the evaluation criteria

Main and sub-criteria	Local weights	Global weights	BNP	Rank
Economic parameters	(0.24,0.41,0.68)	–	–	
Capital cost	(0.22,0.42,0.70)	(0.052,0.169,0.482)	0.234	2
Operation cost	(0.34,0.58,1.09)	(0.080,0.238,0.746)	0.355	1
Operating parameters	(0.23,0.41,0.68)	–	–	
Production	(0.13,0.27,0.48)	(0.031,0.110,0.327)	0.156	4
Material size	(0.04,0.08,0.16)	(0.009,0.033,0.111)	0.051	10
Ground condition	(0.07,0.14,0.30)	(0.016,0.057,0.203)	0.092	5
Distance	(0.14,0.27,0.50)	(0.032,0.109,0.341)	0.161	3
Weather condition	(0.03,0.05,0.10)	(0.006,0.019,0.066)	0.030	14
Environment	(0.04,0.08,0.16)	(0.009,0.032,0.111)	0.051	11
Risk	(0.06,0.12,0.27)	(0.013,0.049,0.181)	0.081	7
Technical parameters	(0.11,0.18,0.38)	–	–	
Reliability	(0.14,0.27,0.50)	(0.016,0.049,0.188)	0.084	6
Efficiency	(0.11,0.23,0.41)	(0.012,0.042,0.156)	0.070	9
Availability	(0.06,0.11,0.23)	(0.006,0.020,0.086)	0.037	12
Safety	(0.14,0.25,0.47)	(0.015,0.045,0.176)	0.079	8
Flexibility	(0.03,0.05,0.10)	(0.003,0.009,0.037)	0.017	15
Useful life	(0.05,0.10,0.19)	(0.006,0.018,0.071)	0.032	13

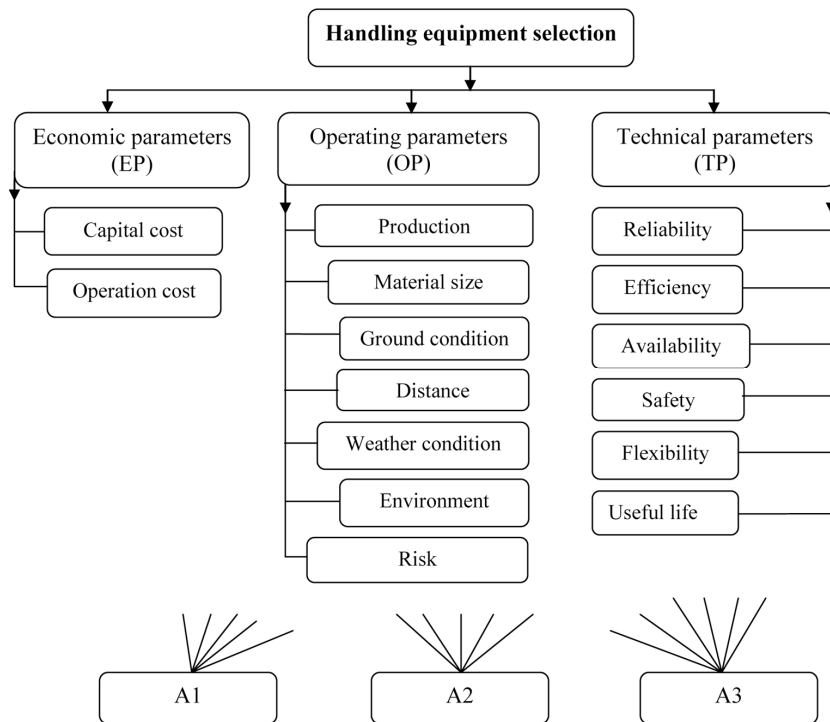


Fig. 5. Decision hierarchy

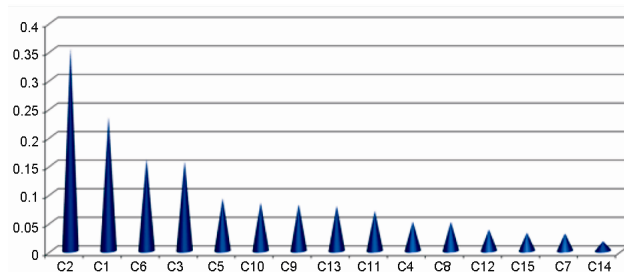


Fig. 6. Ranking of criteria

Step 3. In the last step, fuzzy evaluation matrices are established by ten evaluators for evaluating the handling equipment methods with respect to the criteria under consideration based on linguistic variables given in Table 2 and Figure 2. For example, the fuzzy decision matrix filled by one of the experts is shown in Table 6.

Then, the aggregated fuzzy performance ratings of handling methods with respect to each criterion are calculated by Eqn (9) and the results are presented in Table 7.

The second phase of this step is to normalize the aggregated fuzzy decision matrix using Eqn (11). After normalizing the decision matrix, by applying the relative importance of the evaluation criteria derived in previous step, the weighted decision matrix is resulted as shown in Table 8.

Table 6. A sample of filled questionnaire

	A1	A2	A3
C3	VG	G	VG
C4	VP	VG	G
C5	VP	G	G
C6	G	G	VG
C7	VP	G	P
C8	G	F	G
C9	VG	P	G
C10	F	G	G
C11	G	F	VG
C12	G	VG	P
C13	G	F	F
C14	VP	VG	F

Then, the fuzzy positive ideal solution (FPIS, A^+) and the fuzzy negative ideal solutions (FNIS, A^-) are calculated. Fuzzy preferences are normalized positive triangular fuzzy numbers, so the FPIS and the FNIS can be defined as $\tilde{v}_i^+ = w_j \otimes (1,1,1)$ and $\tilde{v}_i^- = (0,0,0)$. The distance of each alternative from A^+ and A^- is calculated by using Eqns (16) and (17).

In the last phase of this step, the alternatives are ranked in descending order as listed in Table 9. According to CC_i values, the final ranking of the alternatives in descending order are A2, A3, and A1. The proposed model shows that Truck (A2) is the most appropriate handling system with CC value of 0.642. Final rankings of the handling equipment based on CC_i values are depicted in Figure 7.

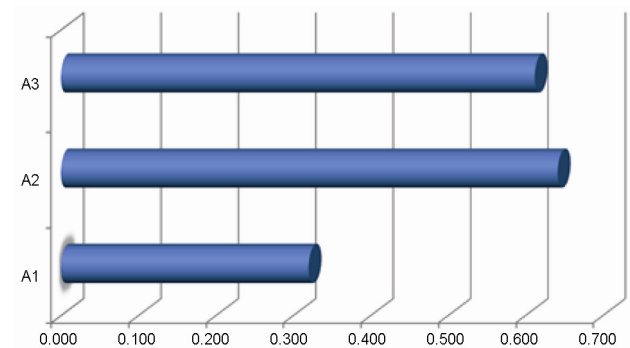


Fig. 7. Final rankings of alternatives

Table 7. Aggregated fuzzy performance ratings

	A1			A2			A3		
C1	2904100	2904100	2904100	2340000	2340000	2340000	2736000	2736000	2736000
C2	209	209	209	195	195	195	188	188	188
C3	5	7.43	10.00	3	6.53	9	5	7.23	10
C4	0	2.07	5.00	5	7.76	10	3	6.42	9
C5	0	2.12	5.00	3	6.59	9	3	6.89	10
C6	3	6.24	9.00	3	6.74	10	5	7.32	10
C7	0	1.87	5.00	3	6.34	9	0	3.17	7
C8	3	6.54	9.00	1	4.46	9	3	6.32	9
C9	5	7.87	10.00	1	3.12	7	3	6.94	10
C10	1	4.31	7.00	3	6.43	9	3	6.57	9
C11	3	6.45	9.00	1	4.57	7	5	7.12	10
C12	3	6.92	10.00	5	7.56	10	1	3.24	7
C13	1	6.21	9.00	1	4.23	7	1	4.36	7
C14	0	3.12	7.00	5	7.21	10	1	4.67	9
C15	18	18.00	18.00	14	14	14	10	10	10

Table 8. Weighted decision matrix

	A1			A2			A3		
C1	0.00	0.00	0.00	0.15	0.15	0.15	0.05	0.05	0.05
C2	0.00	0.00	0.00	0.16	0.16	0.16	0.23	0.23	0.23
C3	0.03	0.06	0.10	0.00	0.05	0.09	0.03	0.06	0.10
C4	0.00	0.01	0.02	0.02	0.03	0.03	0.01	0.02	0.03
C5	0.00	0.01	0.03	0.02	0.04	0.05	0.02	0.04	0.06
C6	0.00	0.05	0.09	0.00	0.06	0.11	0.03	0.06	0.11
C7	0.00	0.00	0.01	0.01	0.01	0.02	0.00	0.01	0.02
C8	0.01	0.02	0.03	0.00	0.01	0.03	0.01	0.02	0.03
C9	0.03	0.01	0.00	0.05	0.04	0.02	0.04	0.02	0.00
C10	0.00	0.02	0.04	0.01	0.04	0.06	0.01	0.04	0.06
C11	0.01	0.03	0.04	0.00	0.02	0.03	0.02	0.03	0.05
C12	0.01	0.02	0.02	0.01	0.02	0.02	0.00	0.01	0.02
C13	0.00	0.03	0.05	0.00	0.02	0.04	0.00	0.02	0.04
C14	0.00	0.00	0.01	0.01	0.01	0.01	0.00	0.01	0.01
C15	0.02	0.02	0.02	0.01	0.01	0.01	0.00	0.00	0.00

Table 9. FTOPSIS results

Alternatives	D_j^+	D_j^-	CC_j	Rank
A1	0.730	0.344	0.32	3
A2	0.391	0.701	0.642	1
A3	0.419	0.662	0.612	2

5. Sensitivity analysis

In order to identify the cause of the difference in the outcome of the proposed model, a sensitivity analysis is conducted. This technique generates different scenarios that may change the priority of alternatives and be needed to reach a consensus. If the ranking order is changed by increasing or decreasing the importance of the criteria, the results are expressed to be sensitive otherwise it is robust (Yazdani-Chamzini, Yakhchali 2012). In this study, sensitivity analysis is conducted to see how sensitive the alternatives change with the importance of the criteria. This tool graphical exposes the importance of criteria weights in selecting the optimal alternative among the feasible alternatives. The main goal of sensitivity analysis is to see which criteria is most significant in influencing the decision making process. For this reason, thirty experiments were conducted that each experiment is generated by an increase of 300% and 400% in the

amount of the weight of the criterion under consideration. Table 10 presents the details of these experiments.

It can be shown from Figure 8 that out of thirty experiments, alternative A2 has the highest score in twenty six experiments. In the rest of the experiments (experiment numbers 2, 17, 18, and 26), alternative A3 is located in the top level as the winner. Therefore, it can be resulted that the decision making process is rarely sensitive to the criteria weight with alternative A2 emerging as the winner (87% votes).

Conclusion

The problem of handling equipment selection plays a critical role in the process of mining design because it takes a great deal of the overall costs. For this reason, designers and managers should employ an efficient and capable method to select the most appropriate handling system among a pool of alternatives. The handling equipment selection problem is often influenced by uncertainty in real world, and in such circumstances fuzzy set theory is an appropriate tool to face with this type of problems and handle the existing uncertainty. In practice, it is difficult or even impossible for decision makers to express the precise numerical information on the weights and the ratings; for this reason, the linguistic terms are useful. Likewise, by applying group decision making

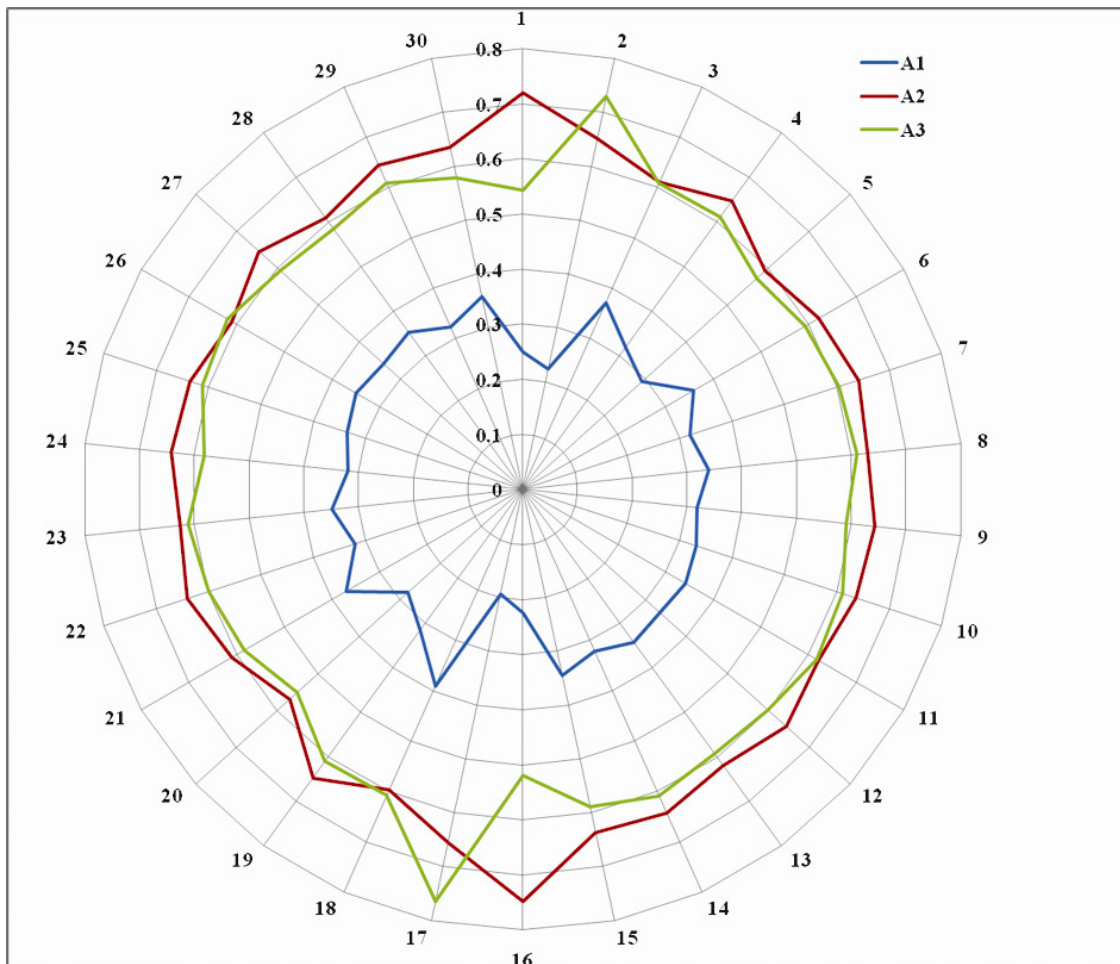


Fig. 8. Sensitivity analysis

Table 10. Changing the criteria weights for sensitivity analysis

No.	Weights of criteria	Ranking	No.	Weights of criteria	Ranking
1	$W_{C1(new)} = 3 \times W_{C1(old)}$	A2 > A3 > A1	16	$W_{C1(new)} = 4 \times W_{C1(old)}$	A2 > A3 > A1
2	$W_{C2(new)} = 3 \times W_{C2(old)}$	A3 > A2 > A1	17	$W_{C2(new)} = 4 \times W_{C2(old)}$	A3 > A2 > A1
3	$W_{C3(new)} = 3 \times W_{C3(old)}$	A2 > A3 > A1	18	$W_{C3(new)} = 4 \times W_{C3(old)}$	A3 > A2 > A1
4	$W_{C4(new)} = 3 \times W_{C4(old)}$	A2 > A3 > A1	19	$W_{C4(new)} = 4 \times W_{C4(old)}$	A2 > A3 > A1
5	$W_{C5(new)} = 3 \times W_{C5(old)}$	A2 > A3 > A1	20	$W_{C5(new)} = 4 \times W_{C5(old)}$	A2 > A3 > A1
6	$W_{C6(new)} = 3 \times W_{C6(old)}$	A2 > A3 > A1	21	$W_{C6(new)} = 4 \times W_{C6(old)}$	A2 > A3 > A1
7	$W_{C7(new)} = 3 \times W_{C7(old)}$	A2 > A3 > A1	22	$W_{C7(new)} = 4 \times W_{C7(old)}$	A2 > A3 > A1
8	$W_{C8(new)} = 3 \times W_{C8(old)}$	A2 > A3 > A1	23	$W_{C8(new)} = 4 \times W_{C8(old)}$	A2 > A3 > A1
9	$W_{C9(new)} = 3 \times W_{C9(old)}$	A2 > A3 > A1	24	$W_{C9(new)} = 4 \times W_{C9(old)}$	A2 > A3 > A1
10	$W_{C10(new)} = 3 \times W_{C10(old)}$	A2 > A3 > A1	25	$W_{C10(new)} = 4 \times W_{C10(old)}$	A2 > A3 > A1
11	$W_{C11(new)} = 3 \times W_{C11(old)}$	A2 > A3 > A1	26	$W_{C11(new)} = 4 \times W_{C11(old)}$	A3 > A2 > A1
12	$W_{C12(new)} = 3 \times W_{C12(old)}$	A2 > A3 > A1	27	$W_{C12(new)} = 4 \times W_{C12(old)}$	A2 > A3 > A1
13	$W_{C13(new)} = 3 \times W_{C13(old)}$	A2 > A3 > A1	28	$W_{C13(new)} = 4 \times W_{C13(old)}$	A2 > A3 > A1
14	$W_{C14(new)} = 3 \times W_{C14(old)}$	A2 > A3 > A1	29	$W_{C14(new)} = 4 \times W_{C14(old)}$	A2 > A3 > A1
15	$W_{C15(new)} = 3 \times W_{C15(old)}$	A2 > A3 > A1	30	$W_{C15(new)} = 4 \times W_{C15(old)}$	A2 > A3 > A1

(social choice), decision making will be more accurate because it can improve the results by reducing the effect of individual errors.

In this paper, an integrated group model based on FAHP and FTOPSIS is proposed that is able to consider both tangible and intangible criteria for evaluating the feasible alternatives in order to select the best handling equipment. FAHP is used to calculate the weights of the evaluation criteria, while FTOPSIS is utilized to prioritize alternatives. The weights obtained by FAHP are involved in the problem of the handling equipment selection by using them in FTOPSIS computations and ranking order is assigned based on these weights. Finally, the alternative with the highest score is selected. Also, sensitivity analysis was conducted to investigate the influence of criteria weights on the problem of the handling equipment selection. A real world case study is illustrated to show the potential application of the proposed model. However, the proposed method can be applied for tackling MCDM problems in real issues, such as management and engineering problems when information are incomplete, inaccurate, and uncertain by nature.

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