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A HIERARCHICAL PREFERENCE VOTING SYSTEM FOR MINING METHOD SELECTION PROBLEM

WYKORZYSTANIE SYSTEMU GŁOSOWANIA ZAKŁADAJĄCY HIERARCHIĘ PREFERENCJI PRZY WYBORZE ODPOWIEDNIEJ METODY WYBIERANIA

To apply decision making theory for Mining Method Selection (MMS) problem, researchers have faced two difficulties in recent years: (i) calculation of relative weight for each criterion, (ii) uncertainty in judgment for decision makers. In order to avoid these difficulties, we apply a Hierarchical Preference Voting System (HPVS) for MMS problem that uses a Data Envelopment Analysis (DEA) model to produce weights associated with each ranking place. The presented method solves the problem in two stages. In the first stage, weights of criteria are calculated and at the second stage, alternatives are ranked with respect to all criteria. A simple case study has also been presented to illustrate the competence of this method. The results show that this approach reduces some difficulties of previous methods and could be applied simply in group decision making with too many decision makers and criteria. Also, regarding to application of a mathematical model, subjectivity is reduced and outcomes are more reliable.

Keywords: Mining Method Selection; Multi Attribute Decision Making; Preference Voting System; Data Envelopment Analysis

Przy wykorzystywaniu teorii decyzyjnych do zagadnień związanych z wyborem właściwej metody wybierania, badacze na przestrzeni lat napotykali na dwie zasadnicze trudności: (i) obliczenie odpowiedniego współczynnika wagi dla poszczególnych kryteriów oraz (ii) niepewność osądów dokonywanych przez decydentów. W celu uniknięcia tych trudności, zastosowaliśmy system głosowania zakładający hierarchię preferencji przy podejmowaniu decyzji odnośnie wyboru metody wybierania. W tym celu wykorzystano model DEA (metoda obwiedni danych) dla wygenerowania wag związanych z poszczególnymi pozycjami w rankingu. Proponowana metoda zakłada rozwiązanie problemu w dwóch etapach. W pierwszym etapie

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obliczane są wagi przyporządkowane poszczególnym kryteriom, w etapie drugim przeprowadzany jest ranking rozwiązań alternatywnych w odniesieniu do wszystkich kryteriów. Przedstawiono proste studium przypadku dla zilustrowania działania metody. Wyniki wskazują, że zastosowane podejście redukuje pewne niedogodności związane z poprzednio stosowanymi metodami i może być z powodzeniem wykorzystane do podejmowania decyzji grupowych, w sytuacjach gdy mamy do czynienia z wieloma decydentami i wieloma kryteriami. Ponadto, zastosowanie modelu matematycznego pozwala na ograniczenie subiektywizmu w ocenie, dzięki temu wyniki są bardziej wiarygodne.

Słowa kluczowe: wybór metody wybierania, procesy decyzyjne, preferencyjny system głosowania, metoda obwiedni danych

1. Introduction

Mining Method Selection (MMS) problem is one of the most critical and vital steps in designing an ore extraction system. The MMS problem has been widely studied in recent years. The approach to MMS problem can be classified into three divisions: qualitative methods such as Boshkov and Wright (1973), numerical ranking methods such as Nicholas (1993) and decision making methods. A comprehensive survey of literature on the first two groups can be found in Namin et al.(2009).

Decision making methods have been widely used to solve MMS problem. Ataei et al. (2008b) used the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method with 13 criteria to develop a suitable mining method for Golbini.No.8 of Jajarm bauxite mine in Iran. Also, Ataei et al. (2008a) used AHP (Analytic Hierarchy Process) method to select mining method for the same mine. Namin et al. (2008) developed a Fuzzy TOPSIS based model for mining method selection problem. Moreover, Namin et al. (2009) used three MADM (Multi Attribute Decision Making) methods (AHP, TOPSIS and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation)) to solve mining method selection problem. Jamshidi et al. (2009) used AHP approach to select optimum underground mining method. Mikaeil et al. (2009) developed a decision support system (DSS) using Fuzzy AHP and TOPSIS approaches to select the optimum underground mining method. In their DSS, Fuzzy AHP is used to determine the weight of each criterion by decision makers and then the methods are ranked via TOPSIS. Azadeh et al. (2010) modified the well-known MMS technique of Nicholas. They solved the MMS problem using Fuzzy AHP within 2 steps: in the first step mining alternatives were ranked according to technical and operational criteria while in the second step, the most profitable among them was selected based on economic criteria. Naghadehi et al. (2009) proposed application of Group Fuzzy AHP approach to select optimum underground mining method for Jajarm bauxite mine. Alpay and Yavuz (2009) used Yager's method and Fuzzy AHP approach to develop a computer program to select the best underground mining method.

The process of solving MMS problem by decision making models can be divided into two stages:

Stage 1: Determining relative weight associated with each criterion.

Stage 2: Selecting the most suitable mining method with respect to all criteria.

Considering the above mentioned literature, we realized that researchers have faced two difficulties in process of solving MMS problem: (i) calculation of relative weight associated with each criterion in the first stage, (ii) uncertainty in judgment for decision makers in both stages.

According to previous studies, for the first stage, AHP had been a common approach to calculate weights of criteria. There are too many factors related to MMS problem such as geological and geotechnical properties, economic parameters and geographical factors; so it is very difficult to make pairwise comparisons in AHP. Moreover, the process of solving the problem is time-consuming and eventually may lead to unrealistic outcomes because of inconsistency in comparison matrix. Dealing with this difficulty, some researchers tried to reduce the dimensions of pairwise comparisons matrix. In this way, Naghadehi et al. (2009) selected the most important criteria among all criteria. It is obvious that in this approach, some criteria which are involved in MMS problem are eliminated. Also, some other researchers divided criteria into subgroups. (Azadeh et al., 2010; Alpay & Yavuz, 2009; Namin et al., 2009; Mikaeil et al., 2009). It is clear that this approach prevents comparison of individual criteria belonging to different subgroups and comparisons are limited among subgroups and members of each group. Furthermore, too computational effort remained a significant difficulty. Although AHP method has been widely used in the first step, some researchers developed a preference voting system to determine the weights of criteria (Ataei et al., 2008a, 2008b; Mohsen et al., 2009). In such systems the weight associated with each ranking place was predefined in a subjective way. The rest of approaches used linguistic terms to determine the weights of criteria (Namin et al., 2009). Such choices are also subjective. In this paper to calculate the weights of criteria, we applied a preference voting system (PVS). The main difference between this PVS with those which proposed in previous research, is in procedure of determining relative weight associated with each ranking place. This PVS uses a DEA model to determine the weights associated with ranking places which maximizes the lower bound of relative score of each candidate. This approach decreases the subjectivity in determining weights of ranking places and the results are more reliable. In addition, dealing with the second difficulty (i.e. uncertainty in judgment), researchers mainly used fuzzy approach which itself requires much computational effort. Since applying PVS leads to prioritizing criteria without the need to determine priority levels, uncertainty in judgment is reduced in more simple way than Fuzzy approach.

Considering the 2nd stage, several decision making methods have been applied by researchers for MMS problem, such as AHP, TOPSIS and PROMETHEE. In this paper, to overcome the second difficulty (i.e. uncertainty in judgment), again we applied a PVS for alternatives according to each criterion. Then we aggregated all preferences with the weights that had been calculated in previous stage for each criterion. Finally, we computed an ultimate score for each alternative. Using these scores, we are able to rank alternatives and select the best one. In this approach decision makers only determine the priorities of alternatives with respect to each criterion. So, the subjectivity and uncertainty in judgment are decreased. Moreover, unlike previous methods, by means of this approach, we are able to use all criteria involved in MMS problem as a result of its less computational effort. Furthermore, this PVS enables us to perform a group decision making with many decision makers in a more simple way.

The paper is organized as follows. In section 2 Preference Voting System (PVS) is introduced. In section 3 we applied a HPVS for mining method selection problem. In section 4 we investigated a case study and finally a conclusion has been made.

2. Preference Voting System

In preference voting systems, each voter selects m candidates from among n candidates ($n \geq m$) and ranks them from the most to the least preferred. Each candidate may receive some votes in different ranking places. The total score of each candidate is the weighted sum of the votes he/she receives in different places (Wang et al., 2007) that is defined as follow:

$$z_i = \sum_{j=1}^{m} v_{ij} w_j \qquad i = 1, \ldots, n \tag{1}$$

Let w_j be the importance weight of j^{th} ranking place ($j = 1, \ldots, m$) and v_{ij} be the vote of candidate i being ranked in the j^{th} place. The structure of PVS is shown in Table 1.

In this structure, the winner is the one with the highest total score. So, the key issue of the preference aggregation in a PVS is how to determine the weights associated with different ranking places (i.e. (w_j)).

TABLE 1

Structure of preference voting system

Candidates	Ranking Places					Total Scores
	p_1	…	p_j	…	p_m	
	Weights of ranking places					
	w_1	…	w_j	…	w_m	
	Vote of each candidate in each ranking place					
candidate$_1$	v_{11}	…	v_{1j}	…	v_{1m}	$z_1 = \sum_{j=1}^{m} v_{1j} w_j$
⋮	⋮	⋮	⋮	⋮	⋮	⋮
candidate$_i$	v_{i1}	…	v_{ij}	…	v_{im}	$z_i = \sum_{j=1}^{m} v_{ij} w_j$
⋮	⋮	⋮	⋮	⋮	⋮	⋮
candidate$_n$	v_{n1}	…	v_{nj}	…	v_{nm}	$z_n = \sum_{j=1}^{m} v_{nj} w_j$

Broda-Kendall (BK) method (Cook & Kress, 1990) is a well-known approach to identify the weights. This approach assigns weights m, $m - 1$, $m - 2$, ..., 1 to m ranking places, from the highest ranking place to the lowest respectively. These weights are produced in a simple way, but their production process is quite subjective. To reduce subjectivity in generating weights, Cook and Kress (1990) proposed the application of Data Envelopment Analysis (DEA) in this problem, which considered candidates as Decision Making Units (DMUs). Their proposed model calculates weights for each candidate that maximizes its total score. Thereafter, the model is solved once for each candidate and the total score is computed. The candidate with the highest total score is considered as DEA efficient. This model is shown below:

$$\text{Maximize} \qquad z_i = \sum_{j=1}^{m} v_{ij} w_j \tag{2}$$

Subject to $\sum_{j=1}^{m} v_{ij} w_j \leq 1 \qquad i = 1, ..., n$

$w_j - w_{j+1} \geq d(j,\varepsilon) \qquad j = 1, ..., m-1$

$w_m \geq d(m,\varepsilon)$

where $d(.,\varepsilon)$ is referred to as a discrimination intensity function. This model led to reduction of subjectivity, however often more than one DEA efficient is derived from calculations. So Cook and Kress (1990) suggested maximizing the gap between the weights so that only one candidate is considered to be DEA efficient. Green et al. (1996) utilized cross-efficiency evaluation in DEA to select only one winner candidate. Noguchi et al. (2002) used the same technique, but they suggested a strong ordering constraint for weights which is shown below:

$$\text{Maximize} \quad z_i = \sum_{j=1}^{m} v_{ij} w_j \tag{3}$$

$$\text{Subject to} \quad \sum_{j=1}^{m} v_{ij} w_j \leq 1 \qquad i = 1, ..., n$$

$$w_1 \geq 2w_2 \geq ... \geq m w_m$$

$$w_m \geq \varepsilon = \frac{2}{Nm(m+1)}$$

where N is the number of voters.

Wang et al. (2007) proposed three models to produce the weights, without the need to predetermine any parameters such as ε. These models are given as follows:

$$\text{Maximize} \quad \alpha \tag{4}$$

$$\text{Subject to} \quad z_i = \sum_{j=1}^{m} v_{ij} w_j \geq \alpha \qquad i = 1, ..., n$$

$$w_1 \geq 2w_2 \geq ... \geq m w_m \geq 0$$

$$\sum_{j=1}^{m} w_j = 1$$

Model (4) determines weights for all candidates using a linear DEA model which maximizes the common lower bound of total scores (i.e. α). Also the sum of weights is equal to 1.

$$\text{Maximize} \quad \alpha \tag{5}$$

$$\text{Subject to} \quad \alpha \leq z_i = \sum_{j=1}^{m} v_{ij} w_j \leq 1 \qquad i = 1, ..., n$$

$$w_1 \geq 2w_2 \geq ... \geq m w_m \geq 0$$

Model (5) determines weights in a same way, but the common upper bound of total scores are equal to 1. Also there is no constraint for sum of weights.

$$\text{Maximize} \qquad z_i = \sum_{j=1}^{m} v_{ij} w_j \tag{6}$$

$$\text{Subject to} \qquad w_1 \geq 2w_2 \geq \ldots \geq mw_m \geq 0$$

$$\sum_{j=1}^{m} w_j^2 = 1$$

Model (6) specifies weights for each candidate using a nonlinear DEA model which maximizes the total score of it. This model should be solved for each candidate and candidate obtaining the highest total score could be considered as the winner.

Since, this study deals with too many candidates, we use model (4) to determine the weights associated with different ranking places due to its less computational effort.

3. Developing a HPVS for MMS problem

We considered MMS problem to have a hierarchical structure, as shown in Figure 1. The figure includes objective of the problem in the upper level, *m* criteria in the intermediate level and *n* decision alternatives in the lower level. Considering this structure, MMS problem is divided into 2 stages. (I) Ranking criteria and calculating their relative weights. (II) Ranking alternatives with respect to each criterion and selecting the most suitable alternative according to all criteria.

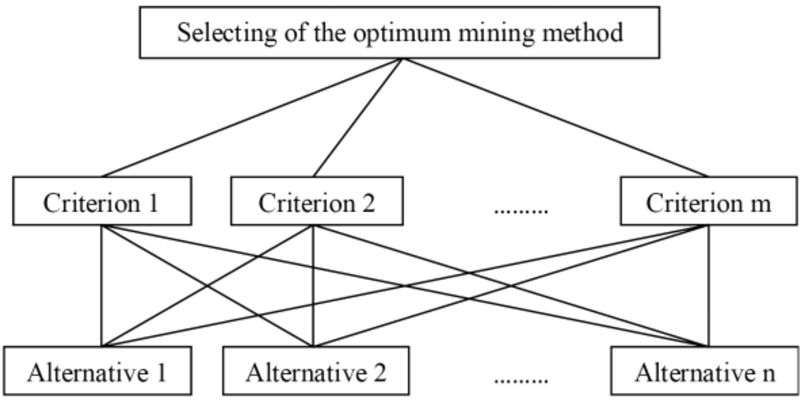

Fig. 1. Hierarchical structure of problem

4. Ranking criteria and calculating their relative weights

According to the reasons mentioned in section 1, we applied a preference voting system to calculate relative weight of each criterion. Applying Group decision making in methods which mentioned in literature, requires much computational effort, while PVS needs less calculations. The structure of PVS for criteria is shown in Table 2.

TABLE 2

Structure of preference voting system for criteria

Criteria	Importance Levels					Total Scores	Weights
	IL_1	…	IL_k	…	IL_p		
	Weights of importance levels						
	w_1	…	w_k	…	w_p		
	Vote of each criterion in each ranking place						
C_1	v_{11}	…	v_{1k}	…	v_{1p}	$TC_1 = \sum_{k=1}^{p} v_{1k} w_k$	W_1
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C_j	v_{j1}	…	v_{jk}	…	v_{jp}	$TC_j = \sum_{k=1}^{p} v_{jk} w_k$	W_j
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
C_m	v_{m1}	…	v_{mk}	…	v_{mp}	$TC_m = \sum_{k=1}^{p} v_{mk} w_k$	W_m

To characterize the relative importance of each criterion, we defined a set of importance levels as ranking places: $\{IL_1, ..., IL_k, ..., IL_p\}$, where $IL_1, ..., IL_k, ..., IL_p$ represent the importance from the most to the least and p is the number of importance levels. We asked decision makers from different domains to assess criteria in p importance levels. v_{jk} s are the numbers of the decision makers who assess criterion j (C_j) in importance level IL_k ($k = 1, ..., p$).

Let w_k be the weights associated with importance levels IL_k ($k = 1, ..., p$). Using model (4) we calculated weights for each importance level. The total score of each criterion could be obtained by following equation:

$$TC_j = \sum_{k=1}^{p} v_{jk} w_k \tag{7}$$

where TC_j is the total score obtained by criterion j. Using these scores we are able to rank the criteria. After normalizing these scores, the weights associated with each criterion (W_j) could be calculated.

4.1. Ranking alternatives with respect to each criterion and selecting most suitable alternative associated with all criteria

To deal with uncertainty of decisions on MMS problem, researchers mainly used Fuzzy theory. The fuzzy approach could be very helpful in situations dealing with uncertainty in decision making; however, as the number of decision makers rise, computational effort increases too. In this paper we applied a PVS to rank alternatives with respect to each criterion. Since, with the application of this approach, decision makers only need to determine the priority of alternatives (rather than amount of priority) according to each criterion, uncertainty in judgment will be decreased. Moreover, it simplifies group decision making with too many decision makers. The structure of this approach is shown in Table 3.

TABLE 3

Structure of preference voting system for alternatives

Alternatives	Criteria											Ultimate Scores
	C_1			…	C_j			…	C_m			
	Weights of each criterion											
	W_1			…	W_j			…	W_m			
	Ranking Places			…	Ranking Places			…	Ranking Places			
	RP_{11}	…	RP_{1h_1}	…	RP_{j1}	…	RP_{jh_j}	…	RP_{m1}	…	RP_{mh_m}	
	Weights of each ranking place											
	w_{11}	…	w_{1h_1}	…	w_{j1}	…	w_{jh_j}	…	w_{m1}	…	w_{mh_m}	
	Vote of each alternative in each ranking place											
A_1	v_{111}	…	v_{11h_1}	…	v_{1j1}	…	v_{1jh_j}	…	v_{1m1}	…	v_{1mh_m}	$UT_1 = \sum_{j=1}^{m}(\sum_{h=1}^{h_j} v_{1jh} w_{jh})W_j$
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
A_i	v_{i11}	…	v_{i1h_1}	…	v_{ij1}	…	v_{ijh_j}	…	v_{im1}	…	v_{imh_m}	$UT_i = \sum_{j=1}^{m}(\sum_{h=1}^{h_j} v_{ijh} w_{jh})W_j$
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
A_n	v_{n11}	…	v_{n1h_1}	…	v_{nj1}	…	v_{njh_j}	…	v_{nm1}	…	v_{nmh_m}	$UT_n = \sum_{j=1}^{m}(\sum_{h=1}^{h_j} v_{njh} w_{jh})W_j$

To distinguish the priorities of alternatives with respect to each criterion, we define a set of ranking places: $\{RP_{j1}, ..., RP_{jh_j}\}$ $(j = 1, ..., m)$ for each criterion, where $RP_{j1}, ..., RP_{jh_j}$ represent priority from the most to the least and h_j is the number of ranking places for criterion j. By this definition, we can use different numbers of ranking places for different criteria to assess. Note that if two or more alternatives have no priority over each other, they can be assigned to a similar ranking place. To evaluate alternatives, we conduct a preference voting among decision makers who were selected from different functional areas. The priorities of alternatives over each other with respect to each criterion are characterized based on their utility. In other words, if a criterion represents benefit, then the alternative which has more benefit will be located in an upper ranking place. Likewise, if a criterion represents cost, then the alternative which has less cost, will be located in an upper ranking place. Using this approach, after voting, we are able to assume all criteria as benefit. Let v_{ijh} be the vote of alternative i $(i = 1, ..., n)$ being ranked in the h^{th} ranking place associated with j^{th} criterion and w_{jh} be the importance weight of h^{th} ranking place with respect to j^{th} criterion. As mentioned earlier we can calculate w_{jh} by applying model (4). Then the total score of each alternative with respect to each criterion could be obtained just like equation (7). To aggregate preferences for all criteria we can exploit the following equation:

$$UT_i = \sum_{j=1}^{m}\left(\sum_{h=1}^{h_j} v_{ijh} w_{jh}\right)W_j \qquad i = 1, ..., n \tag{8}$$

where UT_i is the ultimate score for alternative i. Finally the most suitable mining method is the one with the highest ultimate score.

5. Case Study

In order to investigate the competence of this technique for MMS problem, we chose central mine of Tabas coal mine to conduct a case study. It is located in Parvadeh district in east of central Iran, west of the Yazd state, northwest of Lout Desert and southeast of Tabas city. It is in longitudes of 56°46'30" to 56°51'40" N and latitudes 33°02'15" to 33°59'48" E. The coal-bearing sediments are within the Iranian structural facies region from a part of the Shemshak Group, which is of Lower-Triassic to Mid-Jurassic era. Physical parameters such as deposit geometry (Ore body dip, thickness, volume and depth) rock mechanics characteristics have been shown in Table. 4.

TABLE 4

Some information about Central Mine of Tabas Coal Mine

Ore body	Ore body dip	12°
	Ore body thickness	1.95 m
	Ore body depth	50 to 150 m
	Ore body volume	400000 m^3
	Mineable reserve	1.1 Million Tonnes
	Production rate	250000 Annual
	Existence of strata gases	5 to 15 m^3/tonne
Geomechanical data	Ore body RMR	30
	Hanging wall RMR	10 to 24
	Footwall RMR	10 to 24
Hydrogeology	Hydrogeology conditions	Dry

Also some characteristics of primary non-coal lithology could be found in Table. 5. In this study, six feasible alternative methods (Traditional Longwall , Traditional Longwall with filling, Mechanized Longwall, Traditional Room & Pillar, Mechanized Room & Pillar and Shortwall), which obtained based on thoughts of experts, were evaluated with respect to 32 criteria. The list of criteria has been shown in Table. 6. Also 5 decision makers participated in decision making process.

TABLE 5

Average of the results for three primary non-coal lithologies

Lithology	**SG**	**Porosity**	**Comp. strength (MN/m^2)**	**Shear Strength (MN/m^2)**	**Slake%**	**RQD**
Sandstone	2.70	5.70	72.79	19.62	93	36
Siltstone	2.72	6.87	37.38	12.46	89	22
Mudstone	2.61	8.95	24.82	9.03	64	4

TABLE 6

Criteria for MMS problem

Criteria		Criteria		Criteria	
C1	Ore body dip	C12	Production rate	C23	Technology availability
C2	Ore body thickness	C13	Recovery	C24	Ability to mechanize and automate
C3	Ore body depth	C14	Development production	C25	Labor availability
C4	Grade distribution	C15	Production per man shift	C26	Environmental aspects
C5	Ore body volume	C16	Selectivity mining	C27	Surface subsidence
C6	Ore body uniformity	C17	Flexibility (Ability of changing a mining method to another similar methods)	C28	Safety
C7	Ore body RMR	C18	Dilution	C29	Occupational interests
C8	Hanging wall RMR	C19	Development rate (Rate of achieving to ore body since start of the project)	C30	Capital costs
C9	Footwall RMR	C20	Mineable reserve	C31	Operating costs
C10	Hydrogeology conditions	C21	Existence of strata gases	C32	Reclamation/rehabilitation costs
C11	Climate of area	C22	Ventilation		

Based on previous section, at first stage we calculated weight of each criterion. We defined 4 importance levels: {Really Important, Quite Important, Not Very Important, Not Important}, where these importance levels represent the importance from the most to the least. It is clear that the votes in the last importance level (i.e. Not Important) should not influence the total score of each criterion. Because, from the perspective of decision makers, such criteria are known as not important criterion in decision making process. So, we considered the weight of this importance level equal to zero and applied model (4) based on 3 importance levels as ranking places to calculate the weights. Then we calculated score and normalized weight of each criterion according to previous section. The results could be found in Table. 7.

TABLE 7

Preference voting for criteria related to their importance levels and weights obtained at the first stage of HPVS

Criteria	Weights of importance levels				Total score for each criterion	Normalized weight for each criterion
	0.545	0.273	0.182	0		
	Importance levels					
	Really important	Quite important	Not very important	Not important		
	Vote of each criterion in each importance level					
1	2	3	4	5	6	7
C1	4	1	0	0	2.454543	0.058315
C2	1	4	0	0	1.636362	0.038877
C3	1	2	1	1	1.272726	0.030238
C4	0	0	3	2	0.545454	0.012959
C5	0	3	1	1	0.999999	0.023758

1	2	3	4	5	6	7
C6	0	3	1	1	0.999999	0.023758
C7	1	3	1	0	1.545453	0.036717
C8	5	0	0	0	2.72727	0.064795
C9	0	4	1	0	1.272726	0.030238
C10	0	0	4	1	0.727272	0.017279
C11	0	0	1	4	0.181818	0.00432
C12	1	4	0	0	1.636362	0.038877
C13	0	5	0	0	1.363635	0.032397
C14	0	1	4	0	0.999999	0.023758
C15	0	5	0	0	1.363635	0.032397
C16	0	2	3	0	1.090908	0.025918
C17	0	3	2	0	1.181817	0.028078
C18	0	1	3	1	0.818181	0.019438
C19	0	5	0	0	1.363635	0.032397
C20	2	3	0	0	1.909089	0.045356
C21	1	2	2	0	1.454544	0.034557
C22	0	3	2	0	1.181817	0.028078
C23	3	2	0	0	2.181816	0.051836
C24	0	5	0	0	1.363635	0.032397
C25	0	2	3	0	1.090908	0.025918
C26	0	2	3	0	1.090908	0.025918
C27	0	5	0	0	1.363635	0.032397
C28	1	3	1	0	1.545453	0.036717
C29	0	0	2	3	0.363636	0.008639
C30	2	3	0	0	1.909089	0.045356
C31	1	4	0	0	1.636362	0.038877
C32	0	1	3	1	0.818181	0.019438
SUM					42.09087	1

In the second stage, we conducted a preference voting among decision makers about the priorities of alternatives over each other with respect to each criterion. Also, we applied model (4) to produce weights of ranking places. An example of this procedure for *Surface subsidence* criterion could be found in Table 8.

Also, scores of each alternative with respect to each criterion are shown in Table. 9. Finally we calculated ultimate scores of alternatives and ranked them according to their scores. The result of the second stage has been shown in Table 10. According to Table 10, „Mechanized Longwall“ was selected as the most suitable mining method from the perspective of all decision makers.

TABLE 8

Preference voting for alternatives with respect to "Surface subsidence" criterion at the second stage of HPVS

Alternatives	Weight of criterion 0.0323974						Score
	Ranking Places						
	RP_{27-1}	RP_{27-2}	RP_{27-3}	RP_{27-4}	RP_{27-5}	RP_{27-6}	
	Weights of Ranking Places						
	0.444444	0.222222	0.148148	0.111111	0.074074	0	
	Vote of each alternative in each ranking place						
Traditional Longwall		1	2	1	1		0.0227982
Traditional Longwall with filling	4	1					0.0647948
Mechanized Longwall		1	2	1	1		0.0647948
Traditional Room& Pillar	1	4					0.0647948
Mechanized Room & Pillar	1	3	1				0.0407967
Shortwall			4	1			0.0227982

TABLE 9

Scores of alternatives with respect to criteria

Criteria \ Alternatives	Traditional Longwall	Traditional Longwall with filling	Mechanized Longwall	Traditional Room& Pillar	Mechanized Room & Pillar	Shortwall
1	2	3	4	5	6	7
Ore body dip	0.1166307	0.174946	0.2332613	0.2332613	0.2915767	0.174946
Ore body thickness	0.0777538	0.1166307	0.1166307	0.1166307	0.1555075	0.1166307
Ore body depth	0.050396	0.0403168	0.050396	0.1007919	0.0907127	0.0604752
Grade distribution	0.0388769	0.0388769	0.0388769	0.0647948	0.0647948	0.0388769
Ore body volume	0.0345572	0.0280778	0.0388769	0.0431965	0.0453564	0.0583153
Ore body uniformity	0.1187905	0.1187905	0.1187905	0.1187905	0.1187905	0.1187905
Ore body RMR	0.0467308	0.0634204	0.0901237	0.0433929	0.0333791	0.0600825
Hanging wall RMR	0.0647948	0.1943844	0.2591792	0.0647948	0.0647948	0.1295896
Footwall RMR	0.063224	0.0714706	0.0467308	0.0467308	0.0467308	0.0439819
Hydrogeology conditions	0.0863931	0.0863931	0.0863931	0.0863931	0.0863931	0.0863931
Climate of area	0.0215983	0.0215983	0.0215983	0.0215983	0.0215983	0.0215983
Production rate	0.0334098	0.0297651	0.0911177	0.0297651	0.0637824	0.0607451
Recovery	0.0518358	0.0673866	0.0518358	0.0323974	0.0440605	0.0440605
Development production	0.0395968	0.0395968	0.0712743	0.0554356	0.0633549	0.0475162
Production per man shift	0.0260125	0.0234113	0.0709432	0.0234113	0.0567546	0.0378364
Selectivity mining	0.019527	0.021302	0.014912	0.053256	0.023965	0.014912
Flexibility (Ability of changing a mining method to another similar methods)	0.0314471	0.0336933	0.0280778	0.0539093	0.0471706	0.0606479
Dilution	0.0583153	0.0583153	0.0971922	0.0583153	0.0583153	0.0777538
Development rate (Rate of achieving to ore body since start of the project)	0.0647948	0.0971922	0.0323974	0.0647948	0.0647948	0.0647948

1	2	3	4	5	6	7
Mineable reserve	0.0907127	0.0453564	0.1360691	0.0453564	0.0907127	0.0453564
Existence of strata gases	0.0534066	0.072256	0.0439819	0.0314157	0.0471235	0.0502651
Ventilation	0.0430394	0.0532873	0.0348415	0.0151661	0.015371	0.0327918
Technology availability	0.1151908	0.0652748	0.0364771	0.0921526	0.0364771	0.0383969
Ability to mechanize and automate	0.0323974	0.0323974	0.1079914	0.0323974	0.0863931	0.0863931
Labor availability	0.0528937	0.0352625	0.0153392	0.02821	0.0162207	0.0167497
Environmental aspects	0.0518358	0.1295896	0.0518358	0.0518358	0.0518358	0.0518358
Surface subsidence	0.0227982	0.0647948	0.0647948	0.0647948	0.0407967	0.0227982
Safety	0.0249676	0.032311	0.0881209	0.0381857	0.0528726	0.0528726
Occupational interests	0.0042881	0.0050449	0.0189182	0.0075673	0.0170264	0.0100897
Capital costs	0.092564	0.0401111	0.0222154	0.0555384	0.0243752	0.0262265
Operating costs	0.0269584	0.0204317	0.0851319	0.0269584	0.0510791	0.0425659
Reclamation/rehabilitation costs	0.0171058	0.0466523	0.0186609	0.0373218	0.0279914	0.0279914

TABLE 10

Scores for alternatives and ranking

Alternatives	Ultimate Score	Ranking
Traditional Longwall	1.6728437	6
Traditional Longwall with filling	1.9683379	3
Mechanized Longwall	2.2829859	1
Traditional Room& Pillar	1.8385608	4
Mechanized Room & Pillar	2.0001081	2
Shortwall	1.8222798	5

6. Conclusion

In this paper we applied a HPVS for mining method selection problem. This PVS uses a DEA model to produce weights associated with each ranking place. The process of solving the problem consists of two stages. At the first stage, criteria are ranked and relative weight according to each one is calculated. Then in the second stage, mining methods are ranked by their scores. A case study was also investigated to illustrate the competence of presented method.

We showed that by application of HPVS for MMS problem, some difficulties related to the previous methods could be reduced. Also, regarding to application of a mathematical model, outcomes are more reliable. Moreover, this approach could be applied simply in group decision making with too many decision makers. It is expected that in the near future this method will be applied to various aspects of mining engineering.

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