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Fuzzy analytical hierarchy processing to define optimum post mining land use for pit area to clarify reclamation costs

Introduction

Open pit mining is an efficient method for exploitation of a wide range of ore bodies especially for massive reserves of shallow metallic substances. In this mining method Production Planning (PP) is carried out based on the defined Ultimate Pit Limit (UPL). On the other hand, UPL is defined based on Block Economic Values (BEVs). Therefore, BEVs should be accurately calculated to attain an accurate UPL and consequently to plan an accurate PP in order to achieve maximum Net Present Value (NPV) of a project.

BEV is currently calculated on the basis of the return obtainable from any ore in the block, less the cost of mining and processing the block (Whittle 1988). The costs which are entered in BEV calculation consist of relevant direct costs of mining and processing of each block and any overhead expense which would stop if mining stopped (Whittle 1989, 1990).

Nowadays closure and reclamation stage in a mining project is emphatically enforced by the relevant environmental protection regulations in many countries. For Instance, FLPMA (1976) which includes the act and policies forcing mining companies to rehabilitate mined land accurately; SMCRA (1977) which details the act, guidelines and procedures to carry out

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mined land reclamation accurately; BAOC (1977) which includes the regulation relating to back to the original contour in mined land restoration; BLM (1992) dictating several goals and standards for mined land reclamation; AEPG (1995) which includes three goals for reclamation planning, restoration and replacing ecosystem; RCTSMR (2002) which provides several directions for open pit uranium and surface coal mines rehabilitation; NWT (2005) which offers several directions and goals for reclamation planning; AG (2007) which includes several criteria for mined land reclamation etc. Therefore, this indicates that the direct and dependent variable overhead costs of closure and reclamation should be included in the calculation of BEV as it is necessary for other stages of open pit mining.

Post Mining Land Use (PMLU) is the most effective indicator which defines the costs of closure and reclamation processes with respect to the specifications of a mine site. Therefore, the identification of Optimum Post Mining Land Use (OPMLU) amongst different applicable PMLUs is a key point to accurately determine closure and reclamation costs.

In the literature on the subject during last two decades, several researchers have presented different approaches to recognize OPMLU such as Cairns (1972), Bandopadhyay et al. (1986) using Fuzzy method, Alexander (1998), Chen et al. (1999), Joerin et al. (2001), Mchaina (2001), Uberman et al. (2005) using Analytical Hierarch Processing (AHP), Osanloo et al.(2006) using AHP, Mu (2006), Bascetin (2007) using AHP, Cao (2007) and Soltanmohammadi et al. (2008, 2009) using different Multi Attribute Decision Making techniques. Nevertheless, all of these approaches were developed for mined land in strip mining methods or in a situation without any description of different sections of mined land in open pit mining consist of pit(s), waste dump(s), tailing pond(s), roads, areas for on site facilities and free land zones which are not mined. Due to the fact that different sections of mined land have different specifications, none of the previous approaches have specifically recognized OPMLU for a definite section of mined land.

The major difference among defining OPMLU in strip mining methods and open pit mining is due to the difference among their reclamation procedures. Continuous reclamation at the end of each cycle of strip mining methods is opposite to permanent reclamation after mine closure in open pit mining. Therefore, two major factors: 1) the specifications of each section of mined land, and 2) the desired objectives of the reclamation program after mine closure, are involved in defining OPMLU.

The approach of this paper is developed on the basis of two innovative ideas. The first is in order to create the model based on the variation amongst different sections of mined land, and the second is due to the nature of the effective parameters for defining OPMLU which is same as Fuzzy sets and numbers. Fuzzy sets use a spectrum of numbers instead of using absolute numbers, and Fuzzy numbers include incremental changes without definite limits. Thus, the approach is developed by use of Fuzzy MADM modeling for each section of mined land in open pit mining. As the pair-wise comparisons and judgments through Fuzzy numbers have a high rate of consistency with the nature of the effective parameters for defining OPMLU, Fuzzy Analytical Hierarchy Processing (FAHP) can produce more reliable results than the other techniques.

Pit area due to its shape and depth, affects the adjacent environment as well as effecting the selection of the OPMLU of the other sections of mined land. Therefore, pit area amongst different sections of mined land is the main focus of this paper. Defining OPMLU for other mined land sections will be focused in another paper. This approach is developed through a model based on the application of FAHP to recognize OPMLU for pit area with 17 applicable PMLU alternatives, 5 relevant effective criteria, 96 attributes and sub--attributes. Sungun copper mine was considered by the developed model as the case study. The steps of implementation of the model are presented through the case study to define OPMLU for the pit area of Sungun copper mine.

1. Relevant alternatives and criteria to define OPMLU for pit area

An open pit mine covers a large area of mined land consists of different sections as the above. Amongst these sections, pits are mostly the deepest area where pollutants generated through mining activities come into contact with surface and underground waters. Pit area mostly covers a more extended region than the other sections of mined land. The most severe effect of open pit mining on landscape quality is created by pit excavation. Thus, it is concluded that reclamation principles and PMLU alternatives, criteria and attributes for pit area should specifically develop on the basis of its specifications. Further, selected PMLU for pit area affects defining OPMLU for other sections. For example, when the defined OPMLU for a pit area is water reservoir, arable farmland is an appropriate PMLU for other sections. But, when Garbage burying is the defined OPMLU for a pit area, residential facilities cannot be an appropriate choice for the other sections. Therefore, it is concluded that OPMLU for the pit area acts as a criterion for defining OPMLU for other sections.

Uniformity of landscape quality is one of the effective parameters of mined land reclamation planning. Therefore, OPMLU for each section of mined land in any region should be selected based on its regional specifications (Stejskal 2000).

1.1. Relevant alternatives

Five categories of PMLU for pit area included 17 applicable alternatives are presented in Table 1. The alternatives have been suggested based on their applicability within a pit area.

1.2. Relevant Criteria

Defining OPMLU is carried out based on the relevant criteria. Several specialists have previously presented a number of criteria such as population, air and water condition (Burger 2004; Isabell 2004), Soil condition (Knabe 1964; Song 2006), cultural, social and economical criterion (Ramani 1990; Hill 2003; Mu 2006). Osanloo (2001) has categorized the relevant criteria in two groups of natural and cultural factors containing several attributes.

TABLE 1

Alternatives of applicable types of post mining land use for pit area in open pit mining

TABELA 1

Wersje możliwych do zastosowania sposobów pogórniczego użytkowania ziemi dla obszaru odkrywki w kopalni odkrywkowej

No.	Overall PMLU	No.	Detailed PMLU	Symbol
1	Agriculture	1	Arable farmland	A-AF
		2	Garden	A-G
		3	Pasture	A-P
		4	Nursery	A-N
2	Forestry	5	Lumber Production	F-LP
		6	Woodland	F-W
		7	Shrubs and native forestation	F-SNF
3	Lake	8	Lagoon	L-L
		9	Aquaculture	L-A
		10	Aquatic Sports	L-AS
4	Pit Backfilling	11	Water Reservoir	PB-WR
		12	Garbage burying	PB-GB
		13	Landfill	PB-L
5	Miscellaneous	14	Park	M-P
		15	Blasting Techniques Training	M-BTT
		16	Ski and Rock Artificial Climbing	M-SRAC
		17	Military Activities Training	M-MAT

In this paper, the effective criteria to define OPMLU for pit area are presented more extensive than the previous approaches included five overall categories, 96 attributes and sub-attributes. Table 2 shows the hierarchy of the developed MADM model. This hierarchy comprises six main rows consisting of goal description of the model, the alternatives descriptions, the detailed PMLUs as the sub-alternatives, the criteria descriptions, the attributes descriptions and the sub-attributes descriptions. Description of the abbreviations of the criteria, attributes and sub-attributes are presented in the next parts.

1.2.1. Economical Criterion

Economical criterion is the first category which includes several attributes as follows: Break Even Point (BEP), Income (Incom) which includes three sub-attributes: Mining Project Income (MPI), Increase in Income of Local Community (IIL) and Increase in Governmental Incomes (IGI), Internal Rate of Return (IRR), Regional Economical Condition Coordination

TABLE 2

The hierarchy of the MADM model comprises the criteria, attributes, sub-attributes, alternatives and detailed PMLU for pit in open pit mining

TABELA 2

Hierarchia metody wielokryterialnej podejmowania decyzji składająca się z kryteriów, atrybutów głównych, atrybutów pomocniczych, wariantów oraz szczegółowych sposobów pogórniczego użytkowania odkrywki w kopalni odkrywkowej

Goal	**Defining of Optimum Post Mining Land Use (OPMLU)**											
Alternat.	**Agriculture**			**Forestry**			**Lake**		**Pit Backfilling**		**Miscellaneous**	
Detailed PMLU	A-AF			F-LP			L-L		PB-WR		M-P	
	A-G			F-W			L-A		PB-GB		M-BTT	
	A-P			F-SNF			L-AS		PB-L		M-SRAC	
	A-N										M-MAT	
Criteria	**Economical**		**Executive**		**Social**			**Technical**		**Mine Site**		
Attri-butes	BEP		ARPE		RSC			Drain		**Soil-Physical Spec.** **Soil-Chemical Spec.** **Climate** **Topography** **Pit Geometry**		
	Incom		EMEA		RPC			HRES				
	IRR		RTA		PCLQ			RFP				
	RECC		RMEA		**Cult**			LQ				
	PCRE		NSW		IRPT			RPMF				
	Cost		BPP		CLR			EEP				
	PIA		RPI		LO			EC				
					TA			OFB				
					EA			DSS				
					Geog			SG				
					FPT			PMA				
					SPE			CLUS				
					EO			MA				
					Legal			PWS				
					EIA			SSML				
Sub-Attributes	**Incom.**	**Cost**		**Cult.**	**Geog.**	**Legal**		**Soil-P.**	**Soil-C.**	**Clim.**	**Topo.**	**Pit. G.**
	MPI	OPC		RCEA	EACS	ZB		SSR	Salin	RFF	RPL	WS
	IIL	CAC		RSA	FA	GP		GSC	OMNE	VCD	RES	BH
	IGI	MMC		RMC	ARC	MCP		ER	CR	VHD	Elev	BW
				RO	LNT			Pors	AGP	GS	Slop	BSlop
				RECS	PMP			Perm	pH	VC	SR	PSlop
				SCA				WCA		HSG		Vol
								PTB		Temp		Area
										AM		Depth
										WV		
										Prec		
										FFD		
										SER		

(RECC), Positive Changes in Real Estate Value (PCRE), Cost (Cost) which includes three sub-attributes: Operational Costs (OPC), Capital Costs (CAC) and Maintenance and Monitoring Costs (MMC) and Potential of Investment Absorption (PIA).

1.2.2. Executive Criterion

Executive criterion also includes several attributes as follows: Authority of Reclamation Project Execution (ARPE), Executive Managing Experiences Availability (EMEA), Reclamation Techniques Availability (RTA), Required Machines and Equipments Availability (RMEA), Need to Specialist Workforces (NSW), Budget Providing Potential (BPP), and Regional Potential for implementation the new land use (RPI).

1.2.3. Social Criterion

Social criterion is included several attributes as following: Regional Safety Condition (RSC), Regional Political Condition (RPC), Positive Changes in Livelihood Quality (PCLQ), Cultural (Cult.) included six sub-attributes: Regional Common Economical Activities (RCEA), Regional Social Activities (RSA), Regional Morals Customs (RMC), Regional Opponents (RO), Regional Ethnic Customs Specifications (RECS), Social and Cultural Condition of Adjacent Areas (SCA), Increase in Regional Public skills and Technical knowledge (IRPT), Consistency with Local Requirements (CLR), Land Ownership (LO), Tourism Attractions (TA), Ecological Acceptability (EA), Geographical (Geog.) included five sub-attributes: Easy Accessibility in Cold Seasons (EACS), Facilities Accessibility (FA), Accessibility or Road Condition (ARC), Location Towards Nearest Town (LNT), Proximity of Mine Site to Population Centers (PMP), Frequency of Passing through Mine Site (FPT), Serving the Public Education (SPE), Employment Opportunity (EO), Legal (Legal) included three sub-attributes; Zoning By-Laws (ZB), Government Policy (GP), Mining Company Policy (MCP) and Effects on Immigration to the Area (EIA).

1.2.4. Technical Criterion

Technical criterion includes several attributes as follows; Drainage (Drain), High Rate Earthquake Statistics (HRES), Regional Flood Potential (RFP), Landscape Quality (LQ), Reusing Potential of Mine Facilities (RPMF), Extreme Events Potential (EEP), Environmental Contaminations (EC), Outlook of Future Businesses (OFB), Distance from Special Services (DSS), Structural Geology (SG), Prosperity in the Mine Area (PMA), Current Land Use in Surrounding Area (CLUS), Market Availability (MA), Proximity to Water Supply (PWS) and Shape and Size of Mined land (SSML).

1.2.5. Mine Site Criterion

Mine site criterion comprises the following four attributes; Soil, Climate, Topography and Pit Geometry which consist of several sub-attributes. The sub-attributes of Soil are categorized in two physical and chemical groups.

Soil Physical specifications attribute consists of the sub-attributes, such as, Soil Stability Rate (SSR), General Soil Color (GSC), Erosion Rate (ER), Porosity (Pors.), Permeability (Perm.), Water Conduction Ability (WCA) and Petrologic Type of Bedrock (PTB).

Soil Chemical specifications attribute consists of the sub-attributes, such as, Salinity Rate (Salin.), Organic Material and Nutrient Elements (OMNE), Contamination Rate (CR), Acid Generation Potential (AGP) and pH (pH).

Climate consists of several sub-attributes: Regional Flora and Fauna (RFF), Very Cold days (VCD), Very Hot Days (VHD), Geographical Situation (GS), Vegetative Coverage (VC), Hydrology of Surface and Groundwater (HSG), Regional Average Temperature (Temp.), Air Moisture (AM), Wind Velocity (WV), Precipitation (Prec.), Frost Free Days (FFD) and Surface Evaporation Rate (SER).

Topography comprises several attributes as follows: Regional Pezometeric Level (RPL), Regional Exposure to Sunrise (RES), Overall Regional Elevation (Elev.), Overall Regional Slope (Slop.) and Surface Relief (SR).

Pit geometry consists of the several following sub-attributes: Walls Stability (WS), Benches Height (BH), Benches Width (BW), Benches Slope (BSlop.), Pit Slope (PSlop.), Pit Volume (Vol.), Pit Area (Area) and Pit Depth (Depth).

According to Table 2, the procedure includes 1 pair-wise comparison matrix 96×96 of the attributes and 96 pair-wise comparison matrixes 17×17 of the alternatives with regard to each attribute. In this approach extensive attributes and sub-attributes of the model result clearer and more reliable definition of the optimum choice of PMLU for pit area than the previous approaches. The first reason for considering more attributes in this approach is to consider some new applicable PMLUs for pit area. The Second is that of, differences amongst inherent specifications of different sections of mined land in open pit mining.

Furthermore, it is obvious that some types of PMLU are very rarely homogeneous relating to some of the effective parameters on their implementation. Therefore, 5 main criteria in this approach have been considered in order to cover the most effective parameters in implementing different types of PMLU. 96 attributes are the direct and also detailed effective parameters which demonstrate complete preferences in ranking of the alternatives of PMLU for pit area. Also they cover some overall effective parameters. For example, morphology and lithology are two overall parameters which are covered by the different attributes of mine site criterion as Topography attribute and its sub-attributes, Pit geometry attribute and its sub-attributes, Soil attribute and its physical and chemical sub-attributes.

2. Use of Fuzzy AHP to define OPMLU for pit area

AHP method facilitates judgments and calculation preferences using pair-wise comparisons. It also is the best procedure to carry out pair-wise judgment comparisons (Saaty 1977). Nonetheless, human judgments are commonly imprecise hence the priorities are not determined by precise numeric amount (Herrera 2000). Fuzzy theory was developed by Zadeh (1965) to overcome imprecise judgments and preferences. Many of the weighing methods of attributes and alternatives are intellectually carried out by qualitative scales, whereas logical determination of the priorities is difficult for decision makers in general (Warren 2004). Therefore, in order to carry out precise pair-wise judgment comparisons and decision making, Fuzzy sets theory and AHP method were combined by Buckley (1985). Afterwards other methods were presented through combining these two approaches (Cheng 1996). Since Fuzziness and vagueness are common characteristics in many decision-making problems, a FAHP method should be able to tolerate vagueness or ambiguity (Mikhailov 2004).

In other words, FAHP is capable of capturing a human's appraisal of ambiguity when complex multi-attribute decision making problems are considered (Erensal 2006). Accordingly, FAHP was applied in many sciences through different applications (Buyukozkan 2004; Cheng; Tang 2009; Huang 2005; Uberman, Ostrega 2008; Aghajani Bazzazi et al. 2008; Naghadehi et al. 2009). Fuzzy sets theory provides a wider frame than classic sets theory. It has been contributing to capability of reflecting real world (Ertugrul, Karakasoglu 2009). Fuzzy sets and logic are powerful mathematical tools for modeling. Their role is significant when applied to complex phenomena not easily described by traditional mathematical methods, especially when the goal is to find a good approximate solution (Bojadziev 1998).

In this paper using FAHP which is one of Fuzzy MADMs, OPMLU for pit area is worked out. First, using AHP, pair-wise judgment comparison matrixes are formed. Then through taking pair-wise judgment comparison matrixes to Fuzzy mode the data for FAHP is entered. Consequently, relative importance coefficients of the alternatives are obtained by the above procedure and then their priorities are determined. Finally the alternative with the highest priority is introduced as the OPMLU.

2.1. Analysis by Fuzzy Analytical Hierarchy Processing method

With reference to Fuzzy thought, analysis of the structure of the model to attain OPMLU, is carried out using FAHP. Fuzzy pair-wise comparison matrix is the entering data to FAHP algorithm. To produce the Fuzzy pair-wise comparison matrix, the pair-wise comparison matrix is made according to AHP algorithm. In this algorithm, firstly the hierarchy tree is established and then decision making matrix is generated based on Saaty (1990) 9 points scale.

At the next step, pair-wise comparisons are executed amongst the members of the decision making matrix. Pair-wise comparisons are carried out to determine relative preferences of attributes with reference to each other. The structure of a pair-wise comparison matrix for comparison amongst attributes is as shown in Equation 1.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix}, \quad a_{ij} = \frac{1}{a_{ij}}, \quad a_{ii} = 1, \quad i, j, = 1, 2, ..., n \tag{1}$$

where: a_{ij} is the preference of element i to element j and vice versa for a_{ij}. i, j vary at natural numbers set. Saaty showed that the largest eigenvalue λ, of a reciprocal matrix A is always greater than or equal to n (Saaty 1980). If pair-wise comparisons do not contain any inconsistencies, so λ equals n. Comparisons comprise of more consistent judgments, have closer values of λ to n. Consistency Index (CI) measures the inconsistencies of pair-wise comparisons according to Equation 2.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{2}$$

where λ is an eigenvalue of matrix A. A Consistency Ratio (CR) is calculated by Equation 3.

$$CR = 100(CI/RI) \tag{3}$$

where CR is consistency ratio, CI is consistency index, RI is random index and n is number of columns. If $CI/RI < 0.10$, so the degree of consistency is satisfactory. If $CI/RI > 0.10$, so the degree of consistency is not satisfactory consequently the AHP comparisons may not have reliable results (Liang 2003). If CI and CR are satisfactory, then the preferences are calculated based on normalized values; otherwise the procedure is repeated until the results will be lain in the desired range.

Also if two or more decision makers are involved in measuring the priorities of alternatives and/or attributes, Grouped AHP is applied (Altuzarra et al. 2004). In Grouped AHP numeral average is calculated for different preferences of the experts as x'_{ij} in Equation 4.

$$x'_{ij} = \left(\prod_{l=1}^{k} x_{ijl} \right)^{\frac{1}{k}}; \quad i, j = 1, 2, ..., n; \quad i \neq j; \quad l = 1, 2, ..., k \tag{4}$$

where l is the index of each decision maker, k is the total number of all decision makers, i, j are the indexes of the alternative and the attribute which are compared to each other.

The important point in this regard is to prevent creating a high inconsistency ratio. Therefore, the issued preferences from the decision-makers have to be relatively consistent with each other.

2.2. Steps of FAHP Algorithm

First step comprises creating of Fuzzy pair-wise comparison matrix. In this step pair-wise comparison matrixes are established through Fuzzy thought and TFN using AHP method.

Second step consists of calculation the amount of S_k. In this step, S_k amount which is a TFN and is calculated for each row of pair-wise comparison matrix according to Equation 5.

$$S_k = \sum_{j=1}^{n} M_{kl} \cdot \left[\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij} \right]^{-1}; \quad i = 1, 2, ..., m; \quad j = 1, 2, ..., n; \tag{5}$$

where k is the number of each row, i, j are the indexes of the alternative and attribute respectively.

Third step contains computation of the degree of possibility. In this step, degree of possibility of different S_k is calculated. If M_i and M_j are two TFNs, degree of possibility of M_i to M_j is shown according to Equation 6.

$$V(M_i \geq M_j) = \begin{cases} 1, m_i \geq m_j \\ \dfrac{u_i - l_j}{(u_i - l_j) + (m_j - m_i)}, & l_j \leq u_i, i, j = 1, 2, ..., n; \quad j \neq i \\ 0, otherwise \end{cases} \tag{6}$$

where $M_i = (l_i, m_i, n_i)$, $M_j = (l_j, m_j, n_j)$ and $V(M_i \geq M_j)$ is degree of possibility of M_i to M_j. Figure 1 illustrates the degree of possibility.

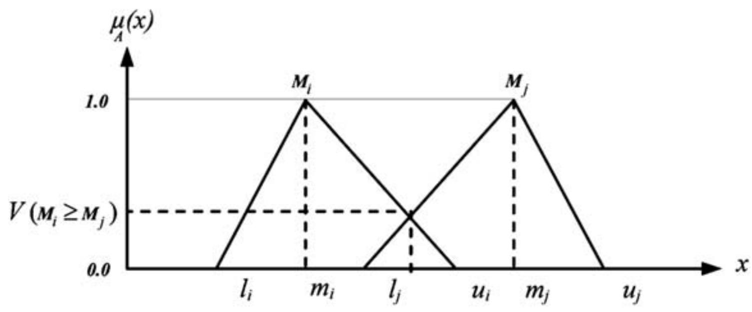

Fig. 1. The degree of possibility of $V(M_i \geq M_j)$

Rys. 1. Stopień prawdopodobieństwa wielkości $V(M_i \geq M_j)$

Degree of possibility of a FTN from another k FTNs is calculated according to Equation 7.

$$V(M_1 \geq M_2, ..., M_k) = [V(M_1 \geq M_2), ..., V(M_1 \geq M_k)] \quad (7)$$

where k is the index of the last TFN.

Forth step includes calculation of the weights. Weights are calculated as shown in Equation 8.

$$W'(x_i) = Min\{V(S_i \geq S_k)\}, \quad i = 1, 2, ..., k; \quad k = 1, 2, ..., n; \quad k \neq i \quad (8)$$

where $W'(x_i)$ is the desired weight. The vector of the weight is achieved according to Equation 9.

$$W' = [W'(c_1), W'(c_2), \ldots, W'(c_n)]^T \quad (9)$$

where W' is the vector of the weight of the attributes.

Fifth step is comprised of to obtain the vector of the weight of normalized attributes. The vector of the weight of normalized attributes is made when Equation 10 is applied.

$$w_i = \frac{w'_i}{\sum_{j=1}^{n} w'_j}, \quad i, j = 1, 2, ..., n \quad (10)$$

where i is the index of each attribute and n is the number of all attributes.

Sixth step contains calculation of the relative importance coefficients of the Alternatives and ranking of those. At six and the last step relative importance coefficients is produced using to multiply the weights of the attributes by achieved weights of the alternatives with respect to each attribute. In this step it is concluded that an alternative which has a greater relative importance coefficient, is more appropriate for implementing in the pit area.

3. Implementation of the model in Sungun copper mine

As a case study the model was implemented in Sungun copper mine in northwest of Iran. The mineable ore reserve of the mine is about 380 Mt. Average grade of the deposit is 0.67% and Overall Stripping Ratio (OSR) is 1.63. The estimation of mined land of Sungun copper mine is about 38 square kilometers which will complete until the end of mining activities. There is the highest and lowest elevation respecting free seas equal 2460 and 1700 m. For that reason there are big differences in the height of different point of mined land area

TABLE 3

Fuzzy pair-wise comparison matrix for the pit area with respect to MMC attribute

TABELA 3

Macierz porównania par o danych rozmytych dla odkrywki w odniesieniu do atrybutu MCC (kosztów utrzymania i monitorowania)

MMC	**AAF**	AG	AP	AN	FLP	FW	FSNF	LL	LA	LAS	PBWR	PBGB	PBL	MP	MBTT	MSRAC	MMAT
AAF	**(1,1,1)**	(1,1,1)	(4,5,6)	(2,3,4)	(1,2,3)	(3,4,5)	(2,3,4)	(4,5,6)	(1/3,1/2,1)	(1,2,3)	(4,5,6)	(5,6,7)	(5,6,7)	(1,1,1)	(2,3,4)	(2,3,4)	(2,3,4)
AG	(1,1,1)	**(1,1,1)**	(4,5,6)	(2,3,4)	(1,2,3)	(4,5,6)	(2,3,4)	(4,5,6)	(1,1,1)	(1,2,3)	(4,5,6)	(5,6,7)	(5,6,7)	(1,1,1)	(3,4,5)	(2,3,4)	(3,4,5)
AP	(1/6,1/5,1/4)	(1/6,1/5,1/4)	**(1,1,1)**	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(1,1,1)	(2,3,4)	(1/5,1/4,1/3)	(1/3,1/2,1)	(2,3,4)	(2,3,4)	(3,4,5)	(1/4,1/3,1/2)	(1,2,3)	(1,1,1)	(1,2,3)
AN	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)	**(1,1,1)**	(1,2,3)	(4,5,6)	(2,3,4)	(4,5,6)	(1,1,1)	(1,2,3)	(4,5,6)	(5,6,7)	(5,6,7)	(1,2,3)	(4,5,6)	(2,3,4)	(2,3,4)
FLP	(1/3,1/2,1)	(1/3,1/2,1)	(1,1,1)	(1/3,1/2,1)	**(1,1,1)**	(4,5,6)	(2,3,4)	(3,4,5)	(1/4,1/3,1/2)	(1,2,3)	(4,5,6)	(5,6,7)	(5,6,7)	(1,2,3)	(4,5,6)	(2,3,4)	(2,3,4)
FW	(1/5,1/4,1/3)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	**(1,1,1)**	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	(1/4,1/3,1/2)	(1,2,3)	(1,1,1)	(1,2,3)	(1/3,1/2,1)	(1,2,3)	(1/3,1/2,1)	(1,2,3)
FSNF	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(2,3,4)	**(1,1,1)**	(3,4,5)	(1/3,1/2,1)	(1,1,1)	(2,3,4)	(2,3,4)	(3,4,5)	(1/4,1/3,1/2)	(2,3,4)	(1,2,3)	(2,3,4)
LL	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(1/5,1/4,1/3)	**(1,1,1)**	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)
LA	(1,2,3)	(1,1,1)	(3,4,5)	(1,1,1)	(2,3,4)	(3,4,5)	(1,2,3)	(4,5,6)	**(1,1,1)**	(2,3,4)	(4,5,6)	(4,5,6)	(5,6,7)	(1,2,3)	(3,4,5)	(2,3,4)	(3,4,5)
LAS	(1/3,1/2,1)	(1/3,1/2,1)	(1,2,3)	(1/3,1/2,1)	(1/3,1/2,1)	(2,3,4)	(1,1,1)	(3,4,5)	(1/4,1/3,1/2)	**(1,1,1)**	(4,5,6)	(4,5,6)	(5,6,7)	(1,1,1)	(3,4,5)	(1,1,1)	(3,4,5)
PBWR	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	**(1,1,1)**	(2,3,4)	(3,4,5)	(1/5,1/4,1/3)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)
PBGB	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/4,1/3,1/2)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/4,1/3,1/2)	**(1,1,1)**	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)	(1/5,1/4,1/3)	(1/3,1/2,1)
PBL	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/3,1/2,1)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1,1,1)	**(1,1,1)**	(1/6,1/5,1/4)	(1,1,1)	(1/4,1/3,1/2)	(1/3,1/2,1)
MP	(1,1,1)	(1,1,1)	(2,3,4)	(1/3,1/2,1)	(1/3,1/2,1)	(1,2,3)	(2,3,4)	(3,4,5)	(1/3,1/2,1)	(1,1,1)	(3,4,5)	(3,4,5)	(4,5,6)	**(1,1,1)**	(4,5,6)	(1,2,3)	(3,4,5)
MBTT	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	**(1,1,1)**	(1/6,1/5,1/4)	(1,1,1)
MSRAC	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,1,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1,2,3)	(1/3,1/2,1)	(2,3,4)	(1/4,1/3,1/2)	(1,1,1)	(2,3,4)	(3,4,5)	(2,3,4)	(1/3,1/2,1)	(4,5,6)	**(1,1,1)**	(3,4,5)
MMAT	(1/4,1/3,1/2)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1,2,3)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,2,3)	(1,2,3)	(1,2,3)	(1/5,1/4,1/3)	(1,1,1)	(1/5,1/4,1/3)	**(1,1,1)**

(about 750 m) and topography. Sungun is an open pit mine with mountain climate. Temperature is cold till moderate with moderately humid condition. There are various flora and fairly compact natural vegetation (Rashidinejad 2004).

Firstly pair-wise comparison matrix for selection of the PMLUs of the pit area was made using AHP method. The entry is then prepared for FAHP algorithm through changing the pair-wise comparison matrix to Fuzzy condition. Fuzzy pair-wise comparison matrix to select PMLUs of the pit area with respect to MMC attribute is shown in Table 3.

TABLE 4

Sum of the TFNs of each row of the Fuzzy pair-wise comparison matrix with regards to MMC attribute to obtain the S_k

TABELA 4

Suma trójkątnych liczb rozmytych dla każdego rzędu macierzy porównania parami liczb rozmytych w odniesieniu do atrybutu MMC (koszty utrzymania i monitorowania) dla uzyskania S_k

Row No.	$\sum_{j=1}^{n} M_{kl}$
1	(40.33, 53.50, 67.00)
2	(44.00, 57.00, 70.00)
3	(18.45, 25.98, 34.33)
4	(38.50, 51.66, 65.00)
5	(36.24, 47.83, 60.50)
6	(9.32, 14.09, 19.91)
7	(21.58, 30.15, 39.50)
8	(8.31, 9.96, 12.32)
9	(41.00, 55.00, 69.00)
10	(30.57, 39.33, 49.50)
11	(10.63, 13.44, 17.33)
12	(7.38, 8.07, 09.46)
13	(5.85, 6.80, 8.94)
14	(30.99, 41.50, 53.00)
15	(8.44, 9.21, 10.99)
16	(21.91, 29.65, 38.50)
17	(8.66, 13.57, 19.65)
$\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij}$	(382.16, 506.74, 644.93)
$\left[\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij}\right]^{-1}$	(0.0016, 0.0020, 0.0026)

Calculations of FAHP algorithm including 17 alternatives and 96 attributes include enormous mathematical operations therefore it needs to be carried out use of a computer program. For this reason a program of more than 1000 lines of code was written by a skilled programming team using C++ language. The written program was called FAHP Selector. Hence to use FAHP Selector the pairwise comparison scores are entered in to the program as the inputs of the model. Consequently FAHP Selector program provides the preferences of the PMLU alternatives within a few seconds based on the entered scores.

In this step S_k amount for each row of a pair-wise comparison matrix is calculated. To calculate S_k, the TFNs of each row firstly are added with each other then the achieved result is multiplied to the invert amount of the sum of all TFNs of the matrix, final result of this step is also a TFN. Calculation of weights of the alternatives is presented in Tables 4 and 5 with respect to MMC attribute.

TABLE 5

The Achieved TFNs of S_k s for each row with respect to MMC attribute

TABELA 5

Uzyskane liczby rozmyte S_k dla każdego rzędu w odniesieniu do atrybutu MMC (koszty utrzymania i monitorowania)

Row No.	$\sum_{j=1}^{n} M_{kl} \cdot \left[\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij} \right]^{-1}$	S_k
1	(40.33, 53.50, 67.00) (0.0016, 0.0020, 0.0026)	(0.064, 0.107, 0.174)
2	(44.00, 57.00, 70.00) (0.0016, 0.0020, 0.0026)	(0.071, 0.114, 0.182)
3	(18.45, 25.98, 34.33) (0.0016, 0.0020, 0.0026)	(0.029, 0.052, 0.089)
4	(38.50, 51.66, 65.00) (0.0016, 0.0020, 0.0026)	(0.062, 0.103, 0.169)
5	(36.24, 47.83, 60.50) (0.0016, 0.0020, 0.0026)	(0.058, 0.096, 0.157)
6	(9.32, 14.09, 19.91) (0.0016, 0.0020, 0.0026)	(0.015, 0.028, 0.052)
7	(21.58, 30.15, 39.50) (0.0016, 0.0020, 0.0026)	(0.035, 0.060, 0.103)
8	(8.31, 9.96, 12.32) (0.0016, 0.0020, 0.0026)	(0.013, 0.020, 0.032)
9	(41.00, 55.00, 69.00) (0.0016, 0.0020, 0.0026)	(0.066, 0.110, 0.179)
10	(30.57, 39.33, 49.50) (0.0016, 0.0020, 0.0026)	(0.049, 0.079, 0.129)
11	(10.63, 13.44, 17.33) (0.0016, 0.0020, 0.0026)	(0.017, 0.027, 0.045)
12	(7.38, 8.07, 09.46) (0.0016, 0.0020, 0.0026)	(0.012, 0.016, 0.025)
13	(5.85, 6.80, 8.94) (0.0016, 0.0020, 0.0026)	(0.009, 0.014, 0.023)
14	(30.99, 41.50, 53.00) (0.0016, 0.0020, 0.0026)	(0.049, 0.083, 0.138)
15	(8.44, 9.21, 10.99) (0.0016, 0.0020, 0.0026)	(0.013, 0.018, 0.029)
16	(21.91, 29.65, 38.50) (0.0021, 0.0027, 0.0038)	(0.035, 0.059, 0.100)
17	(8.66, 13.57, 19.65) (0.0021, 0.0027, 0.0038)	(0.014, 0.027, 0.051)

Consequently all TFNs of the alternatives are added to each other based on each row from Table 3 and the result is obtained as a TFN. Finally by multiplying inverted TFNs from Table 4, $\left[\sum_{i=1}^{m}\sum_{j=1}^{n} M_{ij}\right]^{-1}$ to each obtained Fuzzy from each alternative $\sum_{j=1}^{n} M_{kl}$, the amount of S_k for each alternative is calculated. The amounts of S_k s are presented as shown in Table 5.

In the next step as the third step, degrees of possibility of the S_k s are calculated with respect to each other. Table 6 shows the achieved amounts of S_k s using Equation (5).

TABLE 6

The achieved amounts of S_k s using Equation (5) are presented in this table based on to show the degrees of possibility among two s by the index of a row to the index of a column

TABELA 6

Uzyskane wielkości S_k za pomocą równania (5) w celu pokazania prawdopodobieństwa pomiędzy dwiema wielkościami S_k poprzez indeks rzędu do indeksu kolumny

$V(M_1 \geq M_2)$	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	S_{13}	S_{14}	S_{15}	S_{16}	S_{17}
$\to S_1$	–	0.94	1	1	1	1	1	1	0.97	1	1	1	1	1	1	1	1
$\to S_2$	1	–	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
$\to S_3$	0.31	0.23	–	0.35	0.41	1	0.87	1	0.28	0.6	1	1	1	0.56	1	0.89	1
$\to S_4$	0.96	0.9	1	–	1	1	1	1	0.94	1	1	1	1	1	1	1	1
$\to S_5$	0.89	0.83	1	0.93	–	1	1	1	0.87	1	1	1	1	1	1	1	1
$\to S_6$	0	0	0.49	0	0	–	0.35	1	0	0.06	1	1	1	0.05	1	0.35	1
$\to S_7$	0.45	0.37	1	0.49	0.56	1	–	1	0.43	0.74	1	1	1	0.7	1	1	1
$\to S_8$	0	0	0.09	0	0	0.68	0	–	0	0	0.68	1	1	0	1	0	0.72
$\to S_9$	1	0.96	1	1	1	1	1	1	–	1	1	1	1	1	1	1	1
$\to S_{10}$	0.7	0.62	1	0.74	0.81	1	1	1	0.67	–	1	1	1	0.95	1	1	1
$\to S_{11}$	0	0	0.39	0	0	0.97	0.23	1	0	0	–	1	1	0	1	0.24	1
$\to S_{12}$	0	0	0	0	0	0.45	0	0.75	0	0	0.42	–	1	0	0.86	0	0.5
$\to S_{13}$	0	0	0	0	0	0.36	0	0.63	0	0	0.32	0.85	–	0	0.71	0	0.41
$\to S_{14}$	0.76	0.68	1	0.79	0.86	1	1	1	0.73	1	1	1	1	–	1	1	1
$\to S_{15}$	0	0	0	0	0	0.58	0	0.89	0	0	0.57	1	1	0	–	0	0.63
$\to S_{16}$	0.43	0.35	1	0.46	0.53	1	0.98	1	0.4	0.72	1	1	1	0.68	1	–	1
$\to S_{17}$	0	0	0.47	0	0	0.97	0.33	1	0	0.04	1	1	1	0.04	1	0.34	–

After that as the fourth step, degree of possibility for each S_k is calculated by Equation (7). The achieved degrees of possibility are as the scaled weights of each alternative with regard to MMC attribute. In the next step as the fifth step, weights and normalized weights of the alternatives with regard to MMC attribute are calculated using Equations (8) and (10). The achieved normalized weights of the mentioned step are shown in Table 7.

TABLE 7

Normalized weights of the alternatives with regard to MMC attribute

TABELA 7

Znormalizowane wagi różnych sposobów rekultywacji w odniesieniu do atrybutu MMC

$V(M_i \geq M_j, ..., M_k)$	$W'(x_i)$	w_i
$V(S_1 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.94	0.137
$V(S_2 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	1	0.145
$V(S_3 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.23	0.033
$V(S_4 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.9	0.131
$V(S_5 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.83	0.121
$V(S_6 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_7 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.37	0.054
$V(S_8 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_9 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.96	0.139
$V(S_{10} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.62	0.090
$V(S_{11} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_{12} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_{13} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_{14} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.68	0.099
$V(S_{15} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_{16} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.35	0.051
$V(S_{17} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0

The weights of the alternatives with regard to each attribute and also the weights of the attributes with regard to each other are achieved by the end of FAHP calculation. Lastly, to obtain relative importance coefficient for each alternative, normalized weights of the attributes are calculated. Then the weights of each alternative are defined with respect to the different attributes. By the above mentioned algorithm normalized weights of attributes and alternatives for the pit area are achieved. Some of these weights are as shown in Table 8.

TABLE 8

Some of the normalized weights of attributes and normalized weights of alternatives for the pit area

TABELA 8

Niektóre znormalizowane wagi atrybutów i znormalizowane wagi sposobów rekultywacji dla odkrywki

	Weight	A-AF	A-G	A-P	...	M-P	M-BTT	M-SRAC	M-MAT
MMC	0.127	0.367	0.391	0.092	...	0.268	0	0.136	0
CAC	0.114	0.336	0.347	0	...	0.462	0	0.351	0
OPC	0.111	0	0	0.197	...	0.026	0.047	0.040	0.009
…	...	...	...	...	...	...	...	...	...
BW	0	3.786	2.628	4.362	...	1.243	0	1.046	0
BH	0.039	0.102	0.102	0.230	...	0.086	0	0.080	0.165
WS	0.097	0.155	0.155	0.258	...	0.138	0	0.129	0

Finally, relative importance coefficients of the alternatives are calculated by multiplication of the weights of the attributes by achieved weights from the alternatives as shown in Table 9.

TABLE 9

Relative importance coefficients of the alternatives of PMLUs for pit area of Sungun copper mine

TABELA 9

Względna ważność współczynników sposobów rekultywacji w odkrywce w kopalni Sungun

Relative Importance Coefficients	Alternatives
0.732	A-AF
0.769	A-G
2.479	A-P
0	A-N
3.019	F-LP
2.998	F-W
2.653	F-SNF
0	L-L
0	L-A
0	L-AS
0	PB-WR
0	PB-GB
0	PB-L
0	M-P
0	M-BTT
0	M-SRAC
0	M-MAT

With reference to Table 9, it is concluded that lumber production has the highest rate of the relative importance coefficient amongst the different alternatives. It therefore is selected as the most appropriate alternative of PMLU for the pit area. Table 10 shows the obtained priorities of the PMLUs based on the achieved relative importance coefficients of the alternatives.

TABLE 10

Priorities of the PMLUs based on the achieved relative importance coefficients of the alternatives of PMLUs for pit area of Sungun copper mine

TABELA 10

Priorytety sposobów rekultywacji oparte na uzyskanej względnej ważności współczynników różnych sposobów rekultywacji w odkrywce w kopalni miedzi Sungun

Alternatives	A-AF	A-G	A-P	F-LP	F-W	F-SNF
Priorities	6	5	4	1	2	3

Figure 2 shows the diagram of declining relative importance coefficients of the alternatives for the pit area of Sungun copper mine. According to this diagram, forestry – lumber production (F-LP) has the biggest relative importance coefficient (3.019). Forestry – woodland (F-W) is the second alternative with the second relative importance coefficient (2.998) and forestry – shrubs and native forestation (F-SNF) is the third one with 2.653. Therefore, according to the diagram, forestry as the overall PMLU has the highest priority for pit area in this mine. Amongst three detailed PMLUs of forestry, F-LP has the highest priority so it is the OPMLU. F-W and F-SNF have the second and third priority respectively therefore they are as the second and third choices for the pit area Sungun copper mine. It therefore can

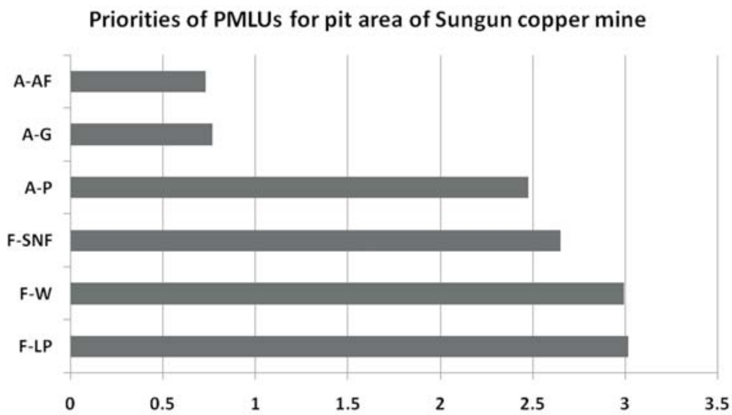

Fig 2. Diagram of increasing relative importance coefficients of the alternatives for the pit area

Rys. 2. Wykres w kolejności rosnącej współczynników względnej ważności różnych sposobów rekultywacji w odkrywce be concluded that according to the recognized OPMLU for the pit area in Sungun copper mine, reclamation costs of the pit area can be clarified. For clarification of the reclamation costs, costs will be estimated based on forestry – lumber production as the post mining land use and the specifications of the mine site.

Conclusion

Selection of post mining land use in open pit mining plays a significant role with regard to clarification of mine closure and reclamation costs. It therefore affects the ultimate pit limit and subsequently the production planning. Mined land in open pit mining comprises of the following sections; pit(s), waste dump(s), tailing pond(s), roads, areas for on site facilities and free land zones which are not mined. Pit area due to its shape and depth, has effectual effects on the adjacent environment and also on selection of the optimum post mining land use for the other sections of mined land. As there are several applicable alternatives, criteria, attributes and sub-attributes to define post mining land use for pit area, multi attribute decision making methods are effective in this regard. Furthermore, the nature of the effective parameters for defining optimum post mining land use includes incremental changes without definite limits same as Fuzzy numbers changes. Thus, pair-wise comparisons and judgments through Fuzzy numbers have an appropriate consistency and reliability rate in the obtained results. Therefore, Fuzzy analytical hierarchy processing was selected as the technique which can produce more reliable results than the other techniques. Accordingly, a model was developed to identify optimum post mining land use for pit area in open pit mining. The developed model consists of 17 applicable post mining land use alternatives, 5 relevant effective criteria, 96 attributes and sub-attributes for defining optimum post mining land use for pit area. The developed model was implemented in Sungun copper mine in northwest of Iran as the case study. According to the obtained results from the case study, forestry – lumber production (F-LP) has the greatest relative importance coefficient 3.019, forestry – woodland (F-W) is the second choice with relative importance coefficient 2.998 and forestry – shrubs and native forestation (F-NSF) is the third one with relative importance coefficient 2.653. Therefore, forestry is as overall post mining land use with the highest priority for the pit area in this mine. Amongst three detailed PMLUs of forestry, F-LP is the optimum post mining land use with the highest priority. F-W and F-SNF are the second and third choices for the pit area in Sungun copper mine. Due to the recognized optimum post mining land use (forestry – lumber production) for pit area in Sungun copper mine, reclamation costs can be clarified in this project.

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PROCES ANALIZY HIERARCHICZNEJ OPARTEJ NA DANYCH ROZMYTYCH DLA OKREŚLENIA OPTYMALNEGO SPOSOBU POGÓRNICZEGO UŻYTKOWANIA ODKRYWKI I OKREŚLENIA KOSZTÓW REKULTYWACJI

Słowa kluczowe

Górnictwo odkrywkowe, optymalny sposób pogórniczego użytkowania, AHP, liczby rozmyte, kształt wyrobiska, koszty rekultywacji

Streszczenie

Eksploatacja metodą odkrywkową niesie za sobą poważne obciążenie dla środowiska naturalnego w rejonie górniczym. Proces rekultywacji terenu wyeksploatowanego metodą odkrywkową składa się z szeregu działań mających na celu w ochronę, monitorowanie, kontrolę i ograniczenie wpływu na środowisko całego przedsięwzięcia od etapu robót poszukiwawczych poprzez eksploatację aż po proces likwidacji kopalni i dalej. Po likwidacji kopalni należy przeprowadzić rekultywację terenu pogórniczego, a sposób dalszego użytkowania terenu powinien być wybrany indywidualnie dla różnych części wyeksploatowanej kopalni odkrywkowej. Obszar taki składa się z różnych części, takich jak odkrywka, zwałowiska, stawy osadowe, drogi, obszary zajęte przez infrastrukturę kopalni oraz obszary, na których nie było eksploatacji. Sposoby dalszego użytkowania dla każdej takiej części, wybrane jako najlepsze przy uwzględnieniu wielu kryteriów, stanowią optymalny sposób pogórniczego użytkowania.

Optymalny sposób pogórniczego użytkowania dla każdej części byłej kopalni oraz specyfika obszaru górniczego to parametry, które w największym stopniu wpływają na jakość i zakres procesu likwidacji kopalni, rekultywację i jej koszty. Dla określenia ostatecznego kształtu wyrobiska w kopalni odkrywkowej, rozważania dotyczące kosztów likwidacji i rekultywacji są równie ważne jak inne koszty wynikające z projektu górniczego. Dlatego określenie optymalnego sposobu pogórniczego użytkowania dla każdej części eksploatowanego obszaru jest bardzo ważne na etapie projektowania eksploatacji odkrywkowej.

W tym artykule przedstawiono możliwe do zastosowania wersje sposobów pogórniczego użytkowania, zastosowane kryteria, atrybuty główne i pomocnicze, które służą do zdefiniowania optymalnego sposobu pogórniczego użytkowania dla obszaru odkrywki, będącej jednym z elementów obszaru zajętego przez eksploatację odkrywkową. Obszar odkrywki ma, spośród różnych części obszaru zajętego przez eksploatację odkrywkową, największy wpływ na środowisko, jak również na sposób zdefiniowania optymalnego sposobu pogórniczego użytkowania pozostałych części kopalni. Jako że możliwe jest określenie kilkunastu sposobów użytkowania pogórniczego, istnieje wiele kryteriów, atrybutów głównych i pomocniczych dla określenia optymalnego sposobu pogórniczego użytkowania, uznano, że wielokryterialne metody podejmowania decyzji są techniką efektywną do określenia optymalnego sposobu pogórniczego użytkowania odkrywek. Zbiory rozmyte operują przedziałami wielkości zamiast liczb ścisłe zdefiniowanych. Co więcej, specyfika parametrów mających wpływ na określenie optymalnego sposobu pogórniczego użytkowania ma charakter zbiorów rozmytych, w których ważny jest charakter zmian bez możliwości określenia wyraźnych granic, więc użycie rozmytych wielokryterialnych metod modelowania daje lepsze wyniki w porównaniu z innymi metodami. Ponieważ porównywanie parami i dokonywanie ocen za pomocą wielkości rozmytych daje większą zgodność z zastosowanymi parametrami, zbudowano model służący do wyboru optymalnego sposobu pogórniczego użytkowania z wykorzystaniem zbiorów rozmytych w procesie analizy hierarchicznej. Model został zastosowany jako analiza przypadku w kopalni odkrywkowej Sungun w północno-zachodnim Iranie. Dla tej kopalni optymalnym sposobem pogórniczego użytkowania okazała się rekultywacja leśna z pozyskiwaniem drewna. Końcowym wnioskiem jest stwierdzenie, że przy użyciu opracowanego modelu można określić optymalny sposób pogórniczego użytkowania dla odkrywki, co stanowi podstawowy parametr do określenia kosztów rekultywacji na etapie planowania eksploatacji odkrywkowej.

FUZZY ANALYTICAL HIERARCHY PROCESSING TO DEFINE OPTIMUM POST MINING LAND USE FOR PIT AREA TO CLARIFY RECLAMATION COSTS

Key words

Open pit mining, OPMLU, FAHP, UPL, reclamation cost

Abstract

Open pit mining has severe environmental impacts on the environment of mining region. Mined land reclamation procedure in open pit mining contains numerous activities in order to prevent, monitor, control reduce environmental impacts of a project from exploration stage to exploitation, to mine closure and beyond. After mine closure, a permanent Post Mining Land Use (PMLU) should be implemented as an appropriate choice for use of different sections of mined land in an open pit mine. Mined land in open pit mining comprise different sections as pit(s), waste dump(s), tailing pond(s), roads, areas for on site facilities and free land zones which are not mined. The selected PMLU for each section of mined land as the most appropriate alternative based on the different points of view is presented as Optimum Post Mining Land Use (OPMLU).

OPMLU for each section of mined land and the specifications of mine site are the most decisive parameters which affect the quality and volume of mine closure procedure, reclamation process and their costs. Furthermore, to define Ultimate Pit Limit (UPL) in open pit mining, consideration of mine closure and reclamation costs is essential as other costs of a mining project. Therefore, defining OPMLU for each section of mined land is essential within planning phase of an open pit mining project. In this paper the applicable alternatives of PMLU, the effective criteria, attributes and sub-attributes for defining OPMLU are presented for pit area amongst different sections of mined land. Pit area amongst different sections of mined land has more significant effects on the adjacent environment and also on defining OPMLU for the other sections of mined land. As there are several alternatives of PMLU, several criteria, attributes and sub-attributes for defining OPMLU, Multi Attribute Decision Making (MADM) methods are efficient techniques to define OPMLU for pit area. Fuzzy sets use a spectrum of numbers instead of using absolute numbers. As well, the nature of the effective parameters for defining OPMLU is same as Fuzzy numbers including incremental changes without definite limits thus the use of Fuzzy MADM modeling can produce more reliable results than the other techniques. As pair-wise comparisons and judgments through Fuzzy numbers have proper consistency with the nature of the effective parameters for defining OPMLU accordingly, a model is developed to attain OPMLU for pit area through Fuzzy Analytical Hierarchy Processing (FAHP). As a case study the model was implemented in Sungun copper mine in Northwest of Iran. Lumber production was defined as OPMLU for the pit area in this mine. It is finally concluded that using the developed model, OPMLU is defined for pit area as a key parameter to estimate reclamation costs in planning phase of an open pit mining project.