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ORIGINAL PAPER

Optimizing post-mining land use for pit area in open-pit mining using fuzzy decision making method

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Abstract Open-pit mining method has severe environmental impacts which should be prevented, monitored, controlled, and reduced by mined-land reclamation process. After mine closure, a permanent post-mining land use should be implemented as an appropriate choice for using different sections of mined land. The most appropriate alternative of post-mining land use for each section of mined land is presented as the optimum post-mining land use. Pit area among different sections of mined land has more significant effects on the environment and also on defining the optimum post-mining land use for other sections of mined land. Though there are several alternatives and criteria for defining the optimum post-mining land use, the multi-attribute decision-making methods can be efficient techniques in this regard. The nature of the effective parameters used for defining the optimum post-mining land use is the same as Fuzzy numbers including incremental changes without definite limits. Thus, application of the Fuzzy multi-attribute decision-making modeling can produce more reliable results than that of other techniques. As well, pair-wise comparisons and judgments through Fuzzy numbers have proper consistency with the nature of the effective parameters; therefore, a model is developed to attain the optimum post-mining land use for pit area through Fuzzy analytical hierarchy processing. As a case study, the model was implemented in Sungun copper mine in the Northwest of Iran. Forestry–lumber production was defined as the optimum post-mining land use containing the greatest relative importance coefficient 3.019 for the pit area in this mine.

Keywords Environmental impacts · Fuzzy analytical hierarchy processing · Reclamation · Sustainable development

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. In Appendix, Table 11 presents a list of the acronyms used through the whole paper.

Block economic values 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).

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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) includes the act and policies forcing mining companies to rehabilitate mined land accurately, SMCRA (1977) details the act, guidelines and procedures to carry out mined-land reclamation accurately, BAOC (1977) includes the regulation relating to back to the original contour in mined-land restoration, BLM (1992) dictates several goals and standards for mined-land reclamation, AEPG (1995) includes three goals for reclamation planning, restoration, and replacing ecosystem, RCTSMR (2002) provides several directions for open-pit uranium and surface coal mines rehabilitation, NWT (2005) offers several directions and goals for reclamation planning, and AG (2007) 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, identification of the optimum post-mining land use (OPMLU) among different applicable PMLUs is a key point to accurately determine closure and reclamation costs.

Prior to the late 1960s the issue of environmental protection had received little attention and the response of Governments to “localized” pollution problems was generally to enact weak regulatory legislation that was poorly enforced (United Nations 1993). In the after years, the environment protection debate has become more focused on the depletion and degradation of the natural resources, in particular, water, air, and non-renewable resources. The term sustainable development was devised to reflect this growing concern with the interaction among economic growth and long-term environmental quality. Sustainable development has been defined as “development that meets the needs of the present without comprising the ability of future generations to meet their own needs” (Bruntland 1987).

Based on the World attention to sustainable development, various international guidelines and standards were issued in order to protect the environment at mining sites and to sustain development through different conferences, committees, and organizations such as: A guide for revegetating coal mine soils (Vogel 1981), guidelines for reclaiming mine soils and overburden in the western United States (Barth et al. 1987), guidelines for Abandonment and Restoration Planning for Mines in the Northwest Territories (Northwest Territories Water Board 1990), UNEP/IEO (1991) which include “Environmental Aspects of Selected Non-ferrous Metals (Cu, Ni, Pb, Zn, Au) Ore Mining”, ICME (1991a, b) Environmental Policy, UNESCAP (1992) which include “Environmental Impact Assessment Guidelines for Mining Development”, Guidelines for Cyanide Leaching Projects (CO/NRMLRD 1992), Technical Guide for the Environmental Management of Cyanide in Mining (Higgs 1992), UNRFNRE (1993) which include “Environmental Protection Guidelines”, National Sustainable Development Strategy—Zambian Mining Sector Perspective (Limpitlaw 2001, 2003), Mining and the Environment—Berlin Guidelines (United Nations 1992, 1994) which include the need to translate the rhetoric of sustainable development into operational standards, guidelines of “Development, Environment and Mining” (World Bank 1994) which highlighted the trends in environment protection policies and social impact issues associated with mining, Rio Declaration principals and the Berlin Guidelines (United Nations Department of Public Information 1992) which include to guide the international community in achieving global sustainable development in mining sector, UNDDSMS (1994) which include the guidelines titled “Environmental Guidelines for Mining Operations”, International Strategies for Implementing Sustainable Development (Boer 1994), Manual and standards for erosion and sediment control measures (ABAG 1995), guidelines for Hard Rock Mining: State Approaches to Environmental Protection (Mcefish 1996), practical guidelines and interpretation for Static-test methods most commonly used to predict acid-mine drainage (White et al. 1999; Rashidinejad et al. 2008), An Environmental Management guide for cyanide mining (Mudder and Botz 2001), Mine Reclamation Guidelines for the Northwest Territories and Nunavut (INAC 2002a, b), Mine Site Reclamation Policy for the Northwest Territories (INAC 2002a, b).

In the recent decades different mandatory environment protection regulations have also been issued by different countries in order to control and treat environmental impacts of mining activities. These regulations contain several views such as: to protect and to prevent propagation and also immigration of the generated pollutions by mining activities, to control and to prevent increase of the rate of generation of pollution, to treat the generated contamination, to identify the type and rate of contamination generation, etc. Also several regulations have been issued in order to restore, reclaim and rehabilitate mined-land area in the recent decades. These regulations define the different aspects to recognize applicable alternatives for PMLU and also the effective criteria and attributes for selecting the most prior alternative.

UNEP/IEO (1991) with regard to Mining and Environment Protection Legislation declared that countries with a mining sector will usually incorporate environment protection requirements, such as waste disposal, water quality controls, rehabilitation and occupational health and safety within their relevant mining laws.

The World Bank (1994) announced Government roles in Environment Protection are gradually evolving in response to changing perceptions of their involvement in mining operations themselves, and as experience with earlier control systems are re-evaluated. UNDDSMS (1994) issued a guide in with respect to importance of environmental impact assessment (EIA) of mining projects which included to ensure that environmental issues are addressed adequately and that any potential adverse environmental impacts are foreseen at the appropriate stage of project design. Environmental impact assessment process (Abaza 1993) should always be envisaged as an integral part of the planning process, which is initiated at the project level from commencement of the project's design. Environmental Quality Standards and Criteria (UNDDSMS 1994) which provide the numerical limits to which industrial operations must be designed and managed, have been issued by different organizations during the last couple of decades. Enforcement Mechanisms (UNDDSMS 1994) which include regulatory frameworks for protection of the environment from adverse effects of mining and mineral processing are increasing in number and complexity, have been arranged by many countries during the last two decades. Zambian National Legislative Framework (ICME 1991a, b) prior to 1990 included Natural Resources Conservation Act in 1970, Water Act in 1964, Forest Act in 1973, National Parks and Wildlife Act in 1968, Town and country Planning Act in 1962, Industrial Development Act in 1974, in the after years the Zambian Government has become increasingly concerned about the effect on the environment of mining and other industrial activities, and of the effect of a rapidly growing population on the use of land, water, and forest resources. This concern led to the Environmental Protection and Pollution Control Act No. 12 (EPPCA 1990) being formulated in 1990, and subsequently enacted in 1992.

According to the above-mentioned standards, guidelines, and regulations, it is deduced that selecting the applicable alternatives, effective criteria and attributes can be carried out based on the specific situation of a project. Therefore, to develop multi-attribute decision-making (MADM) modeling to attain OPMLU, the applicable alternatives and the effective criteria and attributes are judged by Experts and the group of consensus based on the relevant aspects through pair-wise comparisons.

In the literature on the subject during the last few decades, several researchers have presented different approaches to recognize OPMLU according to Table 1. Nevertheless, all of these approaches were developed for mined land in strip mining methods or in a general situation without any description of different sections of mined land in open-pit mining. Due to the fact that 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 have different specifications, none of the previous approaches have specifically recognized OPMLU for a definite section of mined land. Also the approaches presented through creating MADM structures, have not been considered based on the fuzzy quality of the effective parameters. These approaches have limitedly presented the alternatives and the effective criteria for recognizing the OPMLU.

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 and 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 fuzzy analytical hierarchy processing (FAHP) method should be able to tolerate vagueness or ambiguity (Mikhailov and Tsvetinov 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 et al. 2006). Accordingly, FAHP was applied in many sciences through different applications (Buyukozkan et al. 2004; Cheng and Tang 2009; Huang and Wu 2005; Naghadehi et al. 2009; Safari et al. 2010). Fuzzy sets theory provides a wider frame than classic sets theory. It has been contributing to capability of reflecting real world (Ertugrul and 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 and Bojadziev 1998).

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

Table 1 A brief literature on the approaches to define PMLU during the last few decades

Author (year)	Approach	Advantages
Cairns (1972)	Using ecological considerations to recognize the most suitable reclamation procedure and PMLU	Presenting ecological criteria to classify mined-land uses
Bandopadhyay and Chattopadhyay (1986)	Using a Fuzzy algorithm to select PMLU	Presenting an Fuzzy algorithm based on the previous experimental considerations
Alexander (1998)	Using the effectiveness of small-scale irrigated agriculture in the reclamation of mine land soils	Presenting different procedures to successfully apply small-scale irrigated agriculture as PMLU
Chen et al. (1999)	Using a limiting factor for defining restoration procedure of soil fertility in a newly reclaimed coal mined site in Xuzhou	Presenting some criteria to define reclamation procedure for a specific case of coal mined land
Joerin et al. (2001)	Using GIS and outranking multi criteria analysis for assessing suitability of PMLU	Presenting a multi criteria structure to outrank suitability of PMLU by using GIS
Mchaina (2001)	Using environmental planning considerations for the decommissioning, closure and reclamation of mined land	Presenting environmental considerations to select suitable PMLU
Uberman and Ostrêga (2005)	Using Analytical Hierarchy Processing (AHP) in the revitalization of post-mining regions	Presenting an analytical hierarchy process to select PMLU
Osanloo et al. (2006)	Using AHP to select PMLU through consideration of the primary and secondary factors	Presenting an AHP structure to select PMLU by introducing and considering the primary and secondary factors
Mu (2006)	Using developing a suitability index for residential land use	Presenting suitability indexes to implement residential land use
Bascetin (2007)	Using AHP to create a decision support system to define the PMLU	Presenting an AHP structure to recognize PMLU
Cao (2007)	Using to regulate mined-land reclamation in developing countries: the case of China	Presenting a classification for issued regulations to analyze suitability of PMLUs
Soltanmohammadi et al. (2008a, b, 2009a, b)	Using multi criteria decision-making methods to rank suitability of PMLUs	Presenting a MCDM structure to outrank suitability of PMLU, developing effective criteria

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 to create a model based on the variation among different sections of mined land, and to develop effective criteria to define OPMLU for each section of mined land. The second is due to the fuzzy 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 the 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, 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 among 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, five relevant effective criteria, 96 attributes, and sub-attributes. Sungun copper mine was considered by the developed model as a 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.

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. Among 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

Table 2 Alternatives of applicable types of PMLU for pit area in open-pit mining

No.	Overall PMLU	No.	Detailed PMLU	Alternative
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

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 e.g., when the defined OPMLU for a pit area is a water reservoir, arable farmland is an appropriate PMLU for other sections, but, when land-fill 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 2004).

Five categories of PMLU for pit area included 17 applicable alternatives are presented in Table 2. The alternatives have been suggested based on their applicability within a pit area.

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 and Isabell 2004), Soil condition (Knabe 1964; Song and Yang 2006), cultural, social, and economical criterion (Ramani et al. 1990; Hill 2003; Mu 2006). Osanloo (2001) has categorized the relevant criteria in two groups of natural and cultural factors containing several attributes.

In this paper, the effective criteria to define OPMLU for pit area are presented more extensively than the previous approaches including five overall categories, 96 attributes, and sub-attributes. Fig. 1 shows the hierarchy of the developed MADM model. This hierarchy comprises five main columns consisting of the criteria description, the abbreviations of the attributes and sub-attributes. Description of the mentioned abbreviations is presented in the next paragraphs.

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 (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).

Executive criterion also includes several attributes as follows: authority of reclamation project execution (ARPE), executive managing experiences availability (EMEA), reclamation technique 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).

Social criterion includes several attributes as following: cultural (Cult.) included six sub-attributes: regional common economical activities (RCEA), regional social activities (RSA), regional morals customs (RMC), regional

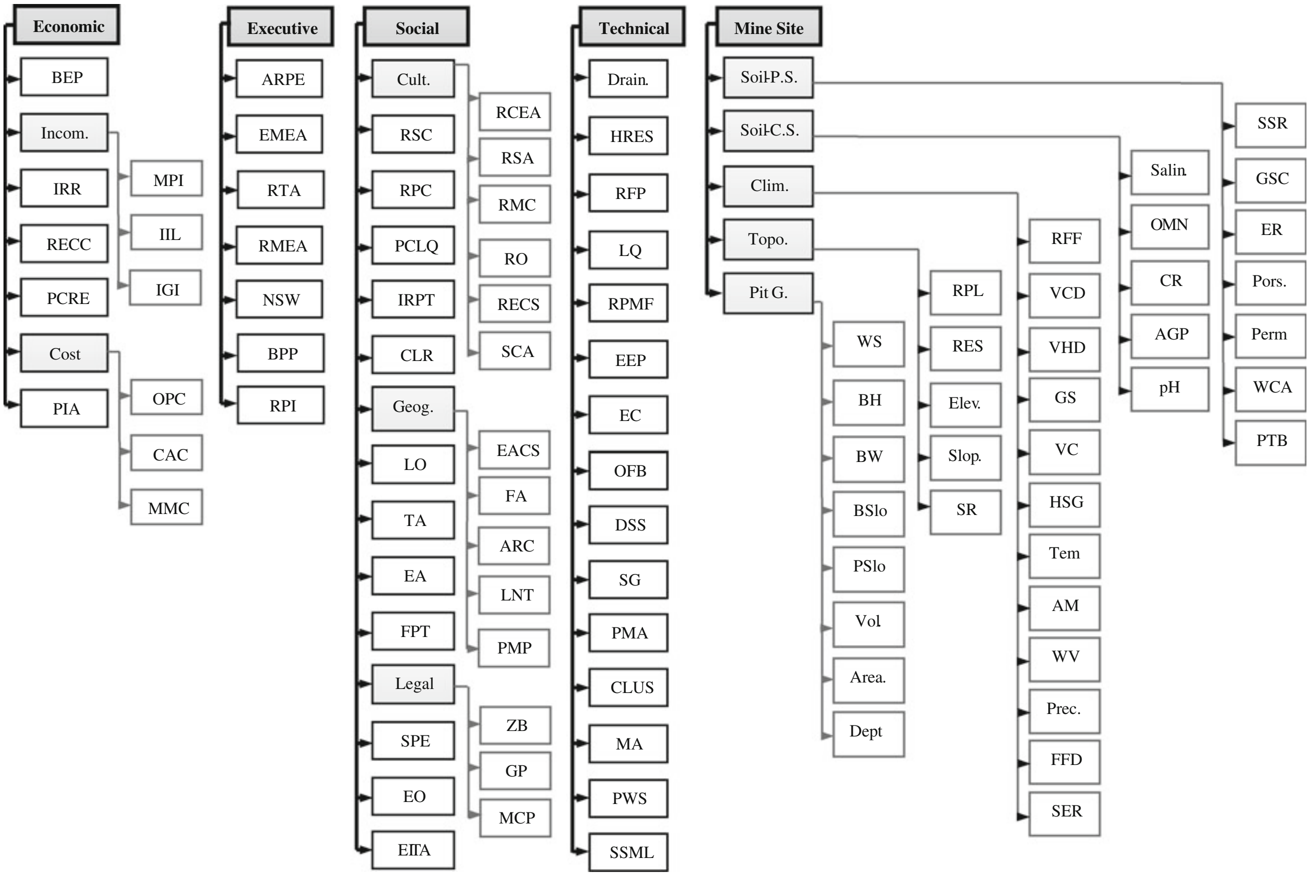

Fig. 1 The hierarchy of the developed MADM model comprises the criteria, attributes and sub-attributes to define OPMLU for pit area in open-pit mining

opponents (RO), regional ethnic customs specifications (RECS) and social and cultural condition of adjacent areas (SCA), regional safety condition (RSC), regional political condition (RPC), positive changes in livelihood quality (PCLQ), increase in regional public skills and technical knowledge (IRPT), consistency with local requirements (CLR), 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) and proximity of mine site to population centers (PMP), land ownership (LO), tourism attractions (TA), ecological acceptability (EA), frequency of passing through mine site (FPT), legal (Legal) included three sub-attributes: zoning by-laws (ZB), government policy (GP) and mining company policy (MCP), serving the public education (SPE), employment opportunity (EO) and effects on immigration to the area (EITA).

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).

Mine site criterion comprises the following five attributes: Soil physical specifications, Soil chemical specifications, climate, topography and pit geometry which consist of several sub-attributes.

Soil physical specifications (Soil-P.S.) 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 (Soil-C.S.) 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 (Clim.) 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 (Topo.) 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 (Pit G.) consists of the several following sub-attributes: wall 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 Fig. 1, 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 among 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, five main criteria in this approach have been considered in order to cover the most effective parameters in implementing different types of PMLU. Ninety-six 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 e.g., 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.

Use of FAHP to define OPMLU for pit area

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.

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) nine-point 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 Eq. (1).

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix},$$

$$a_{ij} = 1/a_{ji}, a_{ii} = 1, i, j = 1, 2, \ldots, n \tag{1}$$

where a_{ij} is the preference of element i to element j and vice versa for a_{ji}; 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 Eq. (2)

$$CI = (\lambda_{\max} - n)/(n - 1) \tag{2}$$

where, λ is an eigenvalue of matrix A. A consistency ratio (CR) is calculated by Eq. (3)

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

where, CR is consistency ratio, CI is consistency index, RI is random index and n is number of columns. If $CI/RI < 0.10$, then the degree of consistency is satisfactory. If $CI/RI > 0.10$, then 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 Eq. (4)

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

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.

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 FTN 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 Eq. (5).

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

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 FTNs, degree of possibility of M_i to M_j is shown according to Eq. (6)

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

where, $M_i = (l_i, m_i, n_i)$, $M_j = \left(l_j, m_j, n_j\right)$ and $V\left(M_i \geq M_j\right)$ is degree of possibility of M_i to M_j. Figure 2 illustrates the degree of possibility.

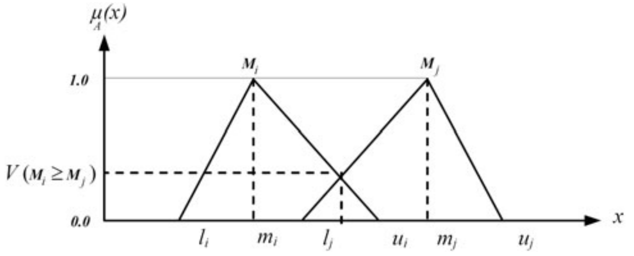

Fig. 2 The degree of possibility of $V\left(M_i \geq M_j\right)$

Degree of possibility of a FTN from another k FTNs is calculated according to Eq. (7)

$$V(M_1 \geq M_2,\ldots,M_k) = [V(M_1 \geq M_2),\ldots,V(M_1 \geq M_k)] \tag{7}$$

where, k is the index of the last FTN.

Forth step includes calculation of the weights. Weights are calculated as shown in Eq. (8)

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

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

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

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 Eq. (10) is applied

$$w_i = w'_i \Big/ \sum_{j=1}^{n} w'_j, \quad i,j = 1,2,\ldots,n \tag{10}$$

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. Figure 3 shows the steps comprising the FAHP procedure.

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 sq. km which will complete until the end of mining activities. There is the highest and the lowest elevation respecting free seas equal 2,460 and 1,700 m. For that reason there are big differences in the height of different point of mined-land area (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 2004a, b).

Firstly pair-wise comparison matrix for selection of the PMLUs of the pit area was made using AHP method. The

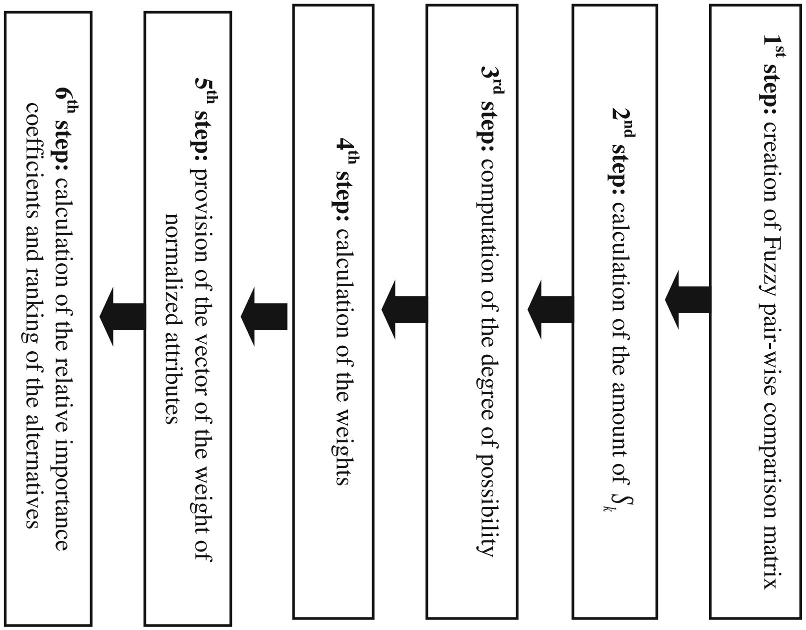

Fig. 3 The steps comprising the FAHP procedure

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 MPI attribute is shown in Table 3.

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 1,000 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 pair-wise comparison scores are entered into the program as the inputs of the model. Consequently FAHP Selector program provides the preferences of the PMLU alternatives 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, 5 with respect to MPI attribute.

Consequently all TFNs of the alternatives are added to each other based on each row from Table 3 and the result is

Table 3 Fuzzy pair-wise comparison matrix for the pit area with respect to MPI attribute

MPI	A-AF	A-G	A-P	A-N	F-LP	FW	F-SNF	L-L	L-A	L-AS	PB-WR	PB-GB	PB-L	MP	M-BTT	M-SRAC	M-MAT
A-AF	*(1,1,1)*	(1,1,1)	(1,1,1)	(2,3,4)	(1/5,1/4,1/3)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(1,1,1)	(3,4,5)	(3,4,5)	(3,4,5)	(2,3,4)	(4,5,6)	(1,2,3)	(5,6,7)
A-G	(1,1,1)	*(1,1,1)*	(1,1,1)	(2,3,4)	(1/5,1/4,1/3)	(2,3,4)	(2,3,4)	(2,3,4)	(1,1,1)	(1,1,1)	(3,4,5)	(3,4,5)	(3,4,5)	(2,3,4)	(4,5,6)	(1,2,3)	(5,6,7)
A-P	(1,1,1)	(1,1,1)	*(1,1,1)*	(1,2,3)	(1/6,1/5,1/4)	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)	(3,4,5)	(1,2,3)	(3,4,5)
A-N	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	*(1,1,1)*	(1/7,1/6,1/5)	(1,2,3)	(1,2,3)	(1,2,3)	(1,1,1)	(1,1,1)	(1,2,3)	(1,2,3)	(1,2,3)	(1,2,3)	(2,3,4)	(1,2,3)	(2,3,4)
F-LP	(3,4,5)	(3,4,5)	(4,5,6)	(5,6,7)	*(1,1,1)*	(5,6,7)	(5,6,7)	(5,6,7)	(2,3,4)	(3,4,5)	(6,7,8)	(5,6,7)	(5,6,7)	(5,6,7)	(5,6,7)	(2,3,4)	(6,7,8)
FW	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1/7,1/6,1/5)	*(1,1,1)*	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	(1,1,1)
F-SNF	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1/7,1/6,1/5)	(1,1,1)	*(1,1,1)*	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	(1,1,1)
L-L	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1/7,1/6,1/5)	(1,1,1)	(1,1,1)	*(1,1,1)*	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	(1,1,1)
L-A	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(4,5,6)	(4,5,6)	(4,5,6)	*(1,1,1)*	(1,1,1)	(3,4,5)	(3,4,5)	(3,4,5)	(3,4,5)	(4,5,6)	(1,1,1)	(4,5,6)
L-AS	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(4,5,6)	(4,5,6)	(4,5,6)	(1,1,1)	*(1,1,1)*	(3,4,5)	(3,4,5)	(3,4,5)	(3,4,5)	(4,5,6)	(1,1,1)	(4,5,6)
PB-WR	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/3,1/2,1)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	*(1,1,1)*	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)
PB-GB	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/3,1/2,1)	(1/7,1/6,1/5)	(1,1,1)	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	*(1,1,1)*	(1,1,1)	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)
PB-L	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/3,1/2,1)	(1/3,1/2,1)	(1/7,1/6,1/5)	(1,1,1)	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	*(1,1,1)*	(1,1,1)	(1,1,1)	(1/4,1/3,1/2)	(1,1,1)
MP	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(1/3,1/2,1)	(1/3,1/2,1)	(1/7,1/6,1/5)	(1,1,1)	(1,1,1)	(1,1,1)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1,1,1)	(1,1,1)	(1,1,1)	*(1,1,1)*	(1,1,1)	(1/5,1/4,1/3)	(1,1,1)
M-BTT	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/7,1/6,1/5)	(1,1,1)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	*(1,1,1)*	(1/5,1/4,1/3)	(1,1,1)
M-SRAC	(1/3,1/2,1)	(1/3,1/2,1)	(1/3,1/2,1)	(1/4,1/3,1/2)	(1/4,1/3,1/2)	(4,5,6)	(4,5,6)	(4,5,6)	(1,1,1)	(1,1,1)	(3,4,5)	(3,4,5)	(2,3,4)	(3,4,5)	(3,4,5)	*(1,1,1)*	(4,5,6)
M-MAT	(1/7,1/6,1/5)	(1/7,1/6,1/5)	(1/5,1/4,1/3)	(1/5,1/4,1/3)	(1/8,1/7,1/6)	(1,1,1)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	(1/6,1/5,1/4)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1/6,1/5,1/4)	*(1,1,1)*

Table 4 Sum of the TFNs of each row of the Fuzzy pair-wise comparison matrix with regards to MPI attribute to obtain the S_k

Row no.	$\sum_{j=1}^{n} M_{kl}$
1	(34.2, 45.25, 56.33)
2	(34.2, 45.25, 56.33)
3	(20.167, 31.25, 42.2)
4	(15.973, 26.327, 37.2)
5	(70.00, 86.00, 102.00)
6	(10.86, 11.427, 12.95)
7	(10.804, 11.427, 12.95)
8	(10.804, 11.427, 12.95)
9	(39.25, 48.33, 57.50)
10	(39.20, 48.25, 57.33)
11	(10.785, 11.393, 12.817)
12	(10.803, 11.417, 12.85)
13	(10.853, 11.497, 12.72)
14	(10.903, 11.577, 13.19)
15	(10.411, 10.717, 11.19)
16	(34.49, 44.16, 55.00)
17	(10.312, 10.577, 10.977)
$\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij}$	(384.015, 476.276, 576.484)
$\left[\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij}\right]^{-1}$	(0.0017, 0.0021, 0.0026)

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_ks are presented as shown in Table 5.

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

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

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.

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.

With reference to Table 9, it is concluded that lumber production has the highest rate of the relative importance coefficient among the different alternatives. It therefore is

Table 5 The achieved TFNs of S_ks for each row with respect to MPI attribute

Row no.	$\sum_{j=1}^{n} M_{kl} \times \left[\sum_{i=1}^{m} \sum_{j=1}^{n} M_{ij}\right]^{-1}$	S_k
1	(34.20, 45.25, 56.33) × (0.0017, 0.0021, 0.0026)	(0.058, 0.095, 0.146)
2	(34.20, 45.25, 56.33) × (0.0017, 0.0021, 0.0026)	(0.058, 0.095, 0.146)
3	(20.167, 31.25, 42.20) × (0.0017, 0.0021, 0.0026)	(0.034, 0.066, 0.110)
4	(15.973, 26.327, 37.20) × (0.0017, 0.0021, 0.0026)	(0.027, 0.055, 0.097)
5	(70.00, 86.00, 102.00) × (0.0017, 0.0021, 0.0026)	(0.119, 0.181, 0.265)
6	(10.86, 11.427, 12.95) × (0.0017, 0.0021, 0.0026)	(0.018, 0.024, 0.034)
7	(10.804, 11.427, 12.95) × (0.0017, 0.0021, 0.0026)	(0.018, 0.024, 0.034)
8	(10.804, 11.427, 12.95) × (0.0017, 0.0021, 0.0026)	(0.018, 0.024, 0.034)
9	(39.25, 48.33, 57.50) × (0.0017, 0.0021, 0.0026)	(0.067, 0.102, 0.149)
10	(39.20, 48.25, 57.33) × (0.0017, 0.0021, 0.0026)	(0.067, 0.102, 0.149)
11	(10.785, 11.393, 12.817) × (0.0017, 0.0021, 0.0026)	(0.018, 0.024, 0.033)
12	(10.803, 11.417, 12.85) × (0.0017, 0.0021, 0.0026)	(0.018, 0.024, 0.033)
13	(10.853, 11.497, 12.72) × (0.0017, 0.0021, 0.0026)	(0.018, 0.024, 0.033)
14	(10.903, 11.577, 13.19) × (0.0017, 0.0021, 0.0026)	(0.018, 0.024, 0.034)
15	(10.411, 10.717, 11.19) × (0.0017, 0.0021, 0.0026)	(0.018, 0.023, 0.029)
16	(34.49, 44.16, 55.00) × (0.0017, 0.0021, 0.0026)	(0.059, 0.093, 0.143)
17	(10.312, 10.577, 10.977) × (0.0017, 0.0021, 0.0026)	(0.017, 0.022, 0.028)

Table 6 The achieved amounts of S_ks using Eq. (6) are presented in this table based on to show the degrees of possibility among two S_ks by the index of a row to the index of a column

$V(M_1 \geq M_2)$	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}
$\rightarrow S_1$	–	1	1	1	0.24	1	1	1	0.92	0.92	1	1	1	1	1	1	1
$\rightarrow S_2$	1	–	1	1	0.24	1	1	1	0.92	0.92	1	1	1	1	1	1	1
$\rightarrow S_3$	0.64	0.64	–	1	0	1	1	1	0.54	0.54	1	1	1	1	1	0.65	1
$\rightarrow S_4$	0.49	0.49	0.85	–	0	1	1	1	0.39	0.39	1	1	1	1	1	0.50	1
$\rightarrow S_5$	1	1	1	1	–	1	1	1	1	1	1	1	1	1	1	1	1
$\rightarrow S_6$	0	0	0	0.18	0	–	1	1	0	0	1	1	1	1	1	0	1
$\rightarrow S_7$	0	0	0	0.18	0	1	–	1	0	0	1	1	1	1	1	0	1
$\rightarrow S_8$	0	0	0	0.18	0	1	1	–	0	0	1	1	1	1	1	0	1
$\rightarrow S_9$	1	1	1	1	0.27	1	1	1	–	1	1	1	1	1	1	1	1
$\rightarrow S_{10}$	1	1	1	1	0.27	1	1	1	1	–	1	1	1	1	1	1	1
$\rightarrow S_{11}$	0	0	0	0.16	0	1	1	1	0	0	–	1	1	1	1	0	1
$\rightarrow S_{12}$	0	0	0	0.16	0	1	1	1	0	0	1	–	1	1	1	0	1
$\rightarrow S_{13}$	0	0	0	0.16	0	1	1	1	0	0	1	1	–	1	1	0	1
$\rightarrow S_{14}$	0	0	0	0.18	0	1	1	1	0	0	1	1	1	–	1	0	1
$\rightarrow S_{15}$	0	0	0	0.06	0	0.92	0.92	0.92	0	0	0.92	0.92	0.92	0.92	–	0	1
$\rightarrow S_{16}$	0.98	0.98	1	1	0.21	1	1	1	0.89	0.89	1	1	1	1	1	–	1
$\rightarrow S_{17}$	0	0	0	0.03	0	0.83	0.83	0.83	0	0	0.83	0.83	0.83	0.83	0.91	0	–

Table 7 Normalized weights of the alternatives with regard to MPI attribute

$V(M_i \geq M_j, \ldots, M_k)$	$W'(x_i)$	w_i
$V(S_1 \geq S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.24	0.108
$V(S_2 \geq S_1, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.24	0.108
$V(S_3 \geq S_1, S_2, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_4 \geq S_1, S_2, S_3, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_5 \geq S_1, S_2, S_3, S_4, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	1	0.448
$V(S_6 \geq S_1, S_2, S_3, S_4, S_5, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_7 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_8 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_9 \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.27	0.121
$V(S_{10} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0.27	0.121
$V(S_{11} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_{12} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{13}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_{13} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{14}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_{14} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{15}, S_{16}, S_{17})$	0	0
$V(S_{15} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{16}, S_{17})$	0	0
$V(S_{16} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{17})$	0.21	0.094
$V(S_{17} \geq S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}, S_{16})$	0	0

Table 8 Some of the normalized weights of attributes and normalized weights of alternatives for the pit area

	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

Table 9 Relative importance coefficients of the alternatives of PMLUs for pit area of Sungun copper mine

Alternatives	Relative importance coefficients
A-AF	0.732
A-G	0.769
A-P	2.479
A-N	0
F-LP	3.019
F-W	2.998
F-SNF	2.653
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	0

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

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

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.

Figure 4 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. Among 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 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 F-LP as the PMLU and the specifications of the mine site.

Conclusion

Selection of PMLU 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 PMLU for the other sections of mined land. As there are several applicable alternatives, criteria, attributes and sub-attributes to define PMLU for pit area, multi-attribute decision-making methods are effective in this regard. Furthermore, the nature of the effective parameters for defining the OPMLU 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

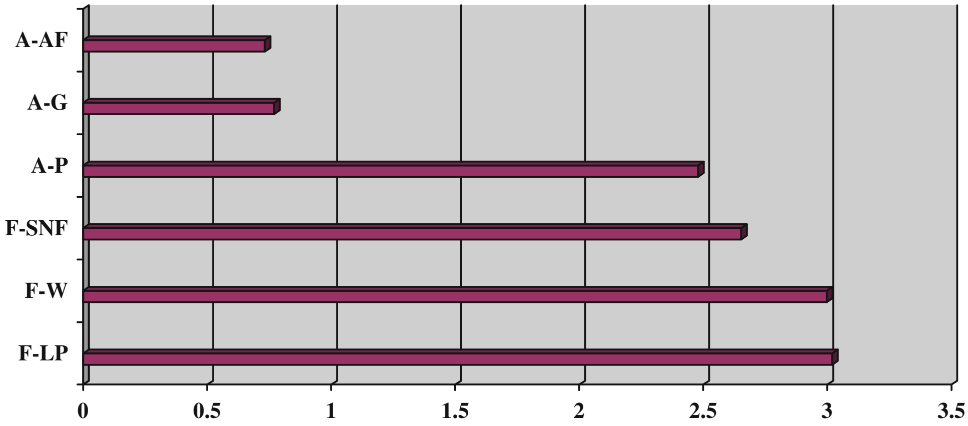

Fig. 4 Diagram of declining relative importance coefficients of the alternatives for the pit area

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 the OPMLU for pit area in open-pit mining. The developed model consists of 17 applicable PMLU alternatives, five relevant effective criteria, 96 attributes and sub-attributes for defining the OPMLU 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, F-LP has the greatest relative importance coefficient 3.019, F-W is the second choice with relative importance coefficient 2.998 and F-NSF is the third one with relative importance coefficient 2.653. Therefore, forestry is as overall PMLU with the highest priority for the pit area in this mine. Among three detailed PMLUs of forestry, F-LP is the OPMLU 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 OPMLU (F-LP) for pit area in Sungun copper mine, reclamation costs can be clarified in this project.

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Appendix

See Table 11.

Table 11 The acronyms used through the whole paper

No.	Acronym	Description
1	A-AF	Agriculture—arable farmland
2	AEPG	Australian Environment Protection Agency
3	AG	Alberta Government
4	A-G	Agriculture—garden
5	AGP	Acid generation potential
6	AHP	Analytical hierarchy processing
7	AM	Air moisture
8	A-N	Agriculture—nursery
9	A-P	Agriculture—pasture
10	ARC	Accessibility or road condition
11	Area.	Pit area
12	ARPE	Authority of reclamation project execution
13	BAOC	Back to original contour
14	BEP	Break even point
15	BEV	Block economic values
16	BH	Benches height
17	BLM	Bureau of Land Management
18	BPP	Budget providing potential
19	BSlop.	Benches slope
20	BW	Benches width
21	CAC	Capital costs
22	Clim.	Climate
23	CLR	Consistency with local requirements
24	CLUS	Current land use in surrounding area
25	CO/NRMLRD	Colorado Department of Natural Resources, Mined Land Reclamation Division
26	CR	Contamination rate
27	Cult.	Cultural
28	Depth.	Pit depth
29	Drain.	Drainage
30	DSS	Distance from special services
31	EA	Ecological acceptability
32	EACS	Easy accessibility in cold seasons
33	EC	Environmental contaminations
34	EEP	Extreme event potential
35	EIA	Environmental impact assessment
36	EITA	Effects on immigration to the area
37	Elev.	Overall regional elevation
38	EMEA	Executive managing experiences availability
39	EO	Employment opportunity
40	EPPCA	Environmental Protection and Pollution Control Act
41	FA	Facilities accessibility
42	FAHP	Fuzzy analytical hierarchy processing
43	FFD	Frost-free days
44	FLPMA	Federal Land Policy and Management Act
45	F-LP	Forestry—lumber production
46	FPT	Frequency of passing through mine site
47	F-SNF	Forestry—shrubs and native forestation
48	F-W	Forestry—woodland
49	Geog.	Geographical
50	GP	Government policy
51	GS	Geographical situation
52	HRES	High rate earthquake statistics
53	HSG	Hydrology of surface and groundwater
54	ICME	International Council on Metals and the Environment
55	IGI	Increase in governmental incomes
56	IIL	Increase in income of local community
57	INAC	Indian and Northern Affairs Canada
58	Incom.	Income
59	IRPT	Increase in regional public skills and technical knowledge
60	IRR	Internal rate of return
61	L-A	Lake—aquaculture
62	L-AS	Lake—aquatic sports
63	L-L	Lake—lagoon
64	LNT	Location towards nearest town
65	LO	Land ownership

Table 11 continued

No.	Acronym	Description
66	LQ	Landscape quality
67	MA	Market availability
68	MADM	Multi-attribute decision making
69	M-BTT	Miscellaneous—blasting techniques training
70	MCP	Mining company policy
71	M-MAT	Miscellaneous—military activity training
72	MMC	Maintenance and monitoring costs
73	M-P	Miscellaneous—Park
74	MPI	Mining project income
75	M-SRAC	Miscellaneous—ski and rock artificial climbing
76	NPV	Net present value
77	NSW	Need to specialist workforces
78	NWT	Mining reclamation regime in the northwest territories
79	OFB	Outlook of future businesses
80	OMNE	Organic material and nutrient elements
81	OPC	Operational costs
82	OPMLU	Optimum post-mining land use
83	PB-GB	Pit backfilling—garbage burying
84	PB-L	Pit backfilling—landfill
85	PB-WR	Pit backfilling—water reservoir
86	PCRE	Positive changes in real estate value
87	PCLQ	Positive changes in livelihood quality
90	PIA	Potential of investment absorption
91	Pit G.	Pit geometry
92	PMA	Prosperity in the mine area
93	PMLU	Post-mining land use
94	PMP	Proximity of mine site to population centers
95	PP	Production planning
96	Prec.	Precipitation
97	PSlop.	Pit slope
98	PWS	Proximity to water supply
99	RCEA	Regional common economical activities
100	RCTSMR	Railroad Commission of Texas Surface Mining and Reclamation Division
101	RECC	Regional economical condition coordination
102	RECS	Regional ethnic custom specifications
103	RES	Regional exposure to sunrise
104	RFF	Regional flora and fauna
105	RFP	Regional flood potential
106	RMC	Regional moral customs
107	RMEA	Required machines and equipment availability
108	RO	Regional opponents
109	RPC	Regional political condition
110	RPI	Regional potential for implementation the new land use
111	RPL	Regional pezometeric level
112	RPMF	Reusing potential of mine facilities
113	RSA	Regional social activities
114	RSC	Regional safety condition
115	RTA	Reclamation technique availability
116	Salin.	Salinity rate
117	SCA	Social and cultural condition of adjacent areas
118	SER	Surface evaporation rate
119	SG	Structural geology
120	Slop.	Overall regional slope
121	SMCRA	Surface Mining Control and Reclamation Act
122	Soil-P.S.	Soil physical specifications
123	SPE	Serving the public education
124	SSML	Shape and size of mined land
125	SR	Surface relief
126	TA	Tourism attractions
127	Temp.	Regional average temperature
128	Topo.	Topography
129	UNDDSMS	United Nations Department of Development Support and Management Services
130	UNEP/IEO	United Nations Environment Program / Industry and Environment Program Activity Center
131	UNESCAP	United Nations Economic and Social Commission for Asia and the Pacific
132	UNRFNRE	United Nations Revolving Fund for Natural Resources Exploration
133	UPL	Ultimate pit limit
134	VC	Vegetative coverage
135	VCD	Very cold days
136	VHD	Very hot days
137	Vol.	Pit volume
138	WS	Wall stability
139	WV	Wind velocity
140	ZB	Zoning by-laws

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