

A decision support system using analytical hierarchy process (AHP) for the optimal environmental reclamation of an open-pit mine

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Abstract The selection of an optimal reclamation method is one of the most important factors in open-pit design and production planning. It also affects economic considerations in open-pit design as a function of plan location and depth. Furthermore, the selection is a complex multi-person, multi-criteria decision problem. The group decision-making process can be improved by applying a systematic and logical approach to assess the priorities based on the inputs of several specialists from different functional areas within the mine company. The analytical hierarchy process (AHP) can be very useful in involving several decision makers with different conflicting objectives to arrive at a consensus decision. In this paper, the selection of an optimal reclamation method using an AHP-based model was evaluated for coal production in an open-pit coal mine located at Seyitomer region in Turkey. The use of the proposed model indicates that it can be applied to improve the group decision making in selecting a reclamation method that satisfies optimal specifications. Also, it is found that the decision process is systematic and using the proposed model can reduce the time taken to select a optimal method.

Keywords Open-pit mining · Reclamation methods · Decision making · Analytic hierarchy process

Introduction

Environmental impacts of open-pit mining are numerous and diverse. Mining operations cause degradation of the land, the loss of forest, topsoil and agricultural land, change in topography and hydrologic conditions, and the pollution of usable surface and ground water. The damage to the environment is usually seen as an unavoidable consequence of maintaining national development. It is also desirable to optimize and minimize environmental impacts by adopting proper mining techniques, rapidly reclaiming the already damaged parts and identifying the areas vulnerable to environmental damage in the near future. All these need quickly accessible, synoptic, cost-effective, multi-temporal information regarding the research area's environmental status (Chatterjee et al. 1994; Toren 2002).

Over nearly the past three decades, the analytical hierarchy process (AHP) and fuzzy logic have been advanced as a formal means to deal with implicit imprecision in a wide range of problems, e.g. in industrial control, military operations, economics, engineering, medicine, reliability, and pattern recognition and classification. Among many existing references, see e.g. Karadogan et al. (2001), Bandopadhyay et al. (1986, 1987a, b), Gershon et al. (1993), Herzog and Bandopadhyay (1996), Bascetin (1999, 2004), Bascetin and Kesimal (1999a, b), and Kesimal and Bascetin (2002).

The AHP was applied to this study, mainly because of its inherent capability of handling qualitative and quantitative criteria used in reclamation method selection problems. Furthermore, it can easily be understood and applied to all mining decisions by

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operating managers (Saaty 1980, 1986, 1994). Also, the AHP can help to improve the decision-making process. The hierarchical structure used in formulating the AHP model can enable all members of the evaluation team to visualize the problem systematically in terms of relevant criteria and sub-criteria. The team can also provide input to revise the hierarchical structure, if necessary, with additional criteria. Furthermore, using the AHP, the evaluation team can systematically compare and determine the priorities of the criteria and sub-criteria. Based on this information, the team can compare several reclamation methods effectively and select the optimum method.

The AHP model

This method has been developed by Saaty (1980, 1986, 1994). The AHP structures the decision problem in levels which correspond to one’s understanding of the situation: objectives, criterion, sub-criterion, and alternatives. By breaking the problem into levels, the decision maker can focus on smaller sets of decisions. The use of AHP for decision making involves four steps. It will be assumed that candidate requirements will be evaluated by using the criterion of value.

Step 1. Set up the “*n*” requirements in the rows and columns of an “*n*×*n*” matrix. We will assume here that you have four candidate requirements: Req1, Req2, Req3, and Req4, and you want to know their relative value. Insert the “*n*” requirements into the rows and columns of a matrix of order “*n*” (in this case, we have a “4 × 4” matrix)

Step 2. Perform pairwise comparisons of all the requirements according to the criterion. The fundamental scale used for this purpose is shown in Table 1. For each pair of requirements (starting with Req1 and Req2, for example), insert their determined relative intensity of value in the position (Req1, Req2) where

the row of Req1 meets the column of Req2. In position (Req2, Req1) insert the reciprocal value, and in all positions in the main diagonal insert a “1”. Continue to perform pairwise comparisons of Req1–Req3, Req1–Req4, Req2–Req3, and so on. For a matrix of order “*n*”, *nx(n – 1)/2* comparisons are required. Thus, in this example, pairwise comparisons are required; they might look like this:

	Req1	Req2	Req3	Req4
Req1	1	1/3	2	4
Req2	3	1	5	3
Req3	1/2	1/5	1	1/3
Req4	1/4	1/3	3	1

Step 3. Use averaging over normalized columns to estimate the eigenvalues of the matrix (which represent the criterion distribution). Thomas Saaty proposes a simple method for this, known as averaging over normalized columns. First, calculate the sum of the “*n*” columns in the comparisons matrix. Next, divide each element in the matrix by the sum of the column the element is a member of, and calculate the sums of each row:

	Req1	Req2	Req3	Req4	Sum
Req1	0.21	0.18	0.18	0.48	1.05
Req2	0.63	0.54	0.45	0.36	1.98
Req3	0.11	0.11	0.09	0.09	0.34
Req4	0.05	0.18	0.27	0.27	0.62

Then, normalize the sum of the rows (divide each row sum with the number of requirements). The result of this computation is referred to as the criteria comparison normalized vector. The vector can be called as the priority matrix.

$$\frac{1}{4} \begin{bmatrix} 1.05 \\ 1.98 \\ 0.34 \\ 0.62 \end{bmatrix} = \begin{bmatrix} 0.26 \\ 0.50 \\ 0.09 \\ 0.16 \end{bmatrix}$$

Table 1 Scale for pairwise comparisons

Relative intensity	Definition	Explanation
1	Of equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over another
5	Essential or strong value	Experience strongly favors one requirement over another
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed

Reciprocals if requirement *i* has one of the above numbers assigned to it when compared with requirement *j*, then *j* has the reciprocal value when compared with *i*

Step 4. Assign each requirement to its relative value based on the estimated eigenvalues. From the resulting eigenvalues of the comparison matrix, the following information can be extracted:

- Req1 contains 26% of the requirements’ total value,
- Req2 contains 50%,
- Req3 contains 9%, and
- Req4 contains 16%.

If we are able to determine precisely the relative value of all requirements, the eigenvalues can be perfectly consistent. For instance, if we determine that Req1 is much more valuable than Req2, Req2, somewhat more valuable than Req3, and Req3 is slightly more valuable than Req1, an inconsistency has occurred and the result’s accuracy is decreased. The redundancy of the pairwise comparisons makes the AHP much less sensitive to judgment errors; it also lets you measure judgment errors by calculating the consistency index (CI) of the comparison matrix, and then calculating the consistency ratio.

The CI is a first indicator of result accuracy of the pairwise comparisons. You calculate it as $CI = (\lambda_{max} - n)/(n-1)$. λ_{max} denotes the maximum principal eigenvalue of the comparison matrix. The closer the value of λ_{max} is to “ n ” (the number of requirements), the smaller the judgmental errors and thus the more consistent the result. To estimate λ_{max} , you first multiply the comparison matrix by the priority vector:

$$\begin{bmatrix} 1 & 1/3 & 2 & 4 \\ 3 & 1 & 5 & 3 \\ 1/2 & 1/5 & 1 & 1/3 \\ 1/4 & 1/3 & 3 & 1 \end{bmatrix} \times \begin{bmatrix} 0.26 \\ 0.50 \\ 0.09 \\ 0.16 \end{bmatrix} = \begin{bmatrix} 1.22 \\ 2.18 \\ 0.37 \\ 0.64 \end{bmatrix}$$

Then you divide the first element of the resulting vector by the first element in the priority vector, the second element of the resulting vector by the second element in the priority vector, and so on:

$$\begin{bmatrix} 1.22/0.26 \\ 2.18/0.50 \\ 0.37/0.09 \\ 0.64/0.16 \end{bmatrix} = \begin{bmatrix} 4.66 \\ 4.40 \\ 4.29 \\ 4.13 \end{bmatrix}$$

To calculate λ_{max} , the average over the elements in the resulting vector:

$$\lambda_{max} = \frac{4.66 + 4.40 + 4.29 + 4.13}{4} = 4.37$$

Now the CI can be calculated as

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.37 - 4}{4 - 1} = 0.12$$

To find out if the resulting consistency index (CI = 0.12) is acceptable, you must calculate the consistency ratio.

The consistency indices of randomly generated reciprocal matrices from the scale 1 to 9 are called the random indices, RI. The ratio of “CI” to “RI” for the same-order matrix is called the consistency ratio (CR), which defines the accuracy of the pairwise comparisons. The RI for matrices of order “ n ” is given below. The first row shows the order of the matrix (n), and the second the corresponding “RI” value (Table 2).

According to Table 1, the “RI” for matrices of order 4 is 0.90. Thus, the CR for our example is

$$CR = \frac{CI}{RI} = \frac{0.12}{0.90} = 0.14.$$

As a general rule, a CR of 0.10 or less is considered acceptable. This means that the result here is less than ideal. In practice, however, consistency ratios exceeding 0.10 occur frequently.

Application of the AHP model in the selection of the optimal reclamation method

Mine information

The selection of a reclamation method in an open-pit coal mine located at Seyitomer region in the western part of Turkey was evaluated. The project is conducted by the Seyitomer Lignite Enterprise (SLE). In the enterprise, a large amount of produced coal has been fed to the power plant with the capacity of 4×150 MW.

Total coal reserves of Turkey are estimated to be in the order of 8.4 Gt low-rank coals (lignite and sub-bituminous coal) and 1.1 Gt bituminous coal, and total annual low-rank coal production reaches about 65 Mt. The Seyitomer lignite basin which is one of the most productive lignite basins in western Anatolia, Turkey, has a lignite reserve of about 200 Mt. The basin includes two lignite seams, lower and upper, in the Lower-Middle Miocene lacustrine Seyitomer Formation. While the former seam is minable, the later has no economic value. The thickness of lower seam reaches 36.75 m thickness in some boreholes, but it averages 15 m in the basin. The lower seam is currently

Table 2 RI values versus “*n*”

<i>n</i>	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

operated in open-cast mines with a dragline, excavator and truck system in the Seyitomer field.

The coal-bearing Seyitomer Formation in the basin has bedding dips between 5° and 15°. A significant normal fault is developed within the Seyitomer Formation and Egrioz Formation. The current dimension of the open pit is approximately 8,500 m long by 4,200 m wide and an average of 35–60 m of overburden being removed in three or six 10 m high benches, and the average thickness of the coal being mined at only one bench is 12 m. The last 25 m. of overburden from surface is mined by a dragline. The face inclination on individual benches is 60° while overall pit slopes are 45°. For a few years, the pit was expanded down to a further depth of 35 m, over an area larger than 450 m lengthways and 100 m in width, while the waste dumps, which were rich in sulphide, Zn and Fe ores, disposed in the periphery, occupied a surface of 90,000 m².

Geological setting

A generalized stratigraphic sequence of the Seyitomer Basin and a simplified geologic map showing also coal sample locations are presented in Figs. 1 and 2, respectively (Celik and Karayigit 2004). The metamorphic and ophiolitic rocks and granites of Pre-Neogene age form the basement of the basin. The Miocene–Pliocene-aged basin fill rests unconformably on the basement rocks (Fig. 1).

The first sedimentary system in the basin begins with fluvial regime of the Egrioz Formation (Fig. 1), which consists of conglomerate, trough cross-bedded conglomerate, sandstone, mudstone, and thin coal seam. The conglomerates are much more abundant near the basin margin. The conglomerate, trough cross-bedded conglomerate and pebbly sandstone units are channel deposits, which incised into a floodplain and horizontally bedded siltstone and mudstone, which are interpreted as overbank deposits.

The coal-bearing Seyitomer Formation of Lower-Middle Miocene age in the basin was conformably underlain by fluvial deposits of the Egrioz Formation and conformably overlain by the Kepez Formation of Miocene–Pliocene age. The coal-bearing Seyitomer Formation in the lateral-vertical direction was developed in lacustrine facies, and is represented, from the base to the upward, by green claystone, lower coal

seam, bituminous marl with mudstone and sapropelic coal lenses, upper coal seam, diatomite interbedded with carbonaceous claystone and fossiliferous marl. However, field studies show that fluvial inputs with trough cross-bedded sandstone and tuffaceous sandstone are increasing to the southwest of the Seyitomer Basin, around Arslanli and Kepez villages (Fig. 2).

Case study

Five potential reclamation alternatives, including the agriculture (A), tree planting/forest land (B), recreational development (C), large acreage residential development (D), and new community residential development (E) systems have been evaluated for the mine site. The certain characteristics of the mine site are given in Table 3. Some of the parameters in the table have been taken from inventory reported and the other parameters of the soil material such as porosity, pH, carbonate, nitrogen, etc., have been measured for this study. The estimates of the total reclaimed land

Age	Formation	Thickness (m)	Lithology	Explanations
Quaternary		0–50		Gravel, silt and clay <i>UNCONFORMITY</i>
Miocene–Pliocene	Kepez	150–300		Clayey limestone-conglomerate-tuffite
				Tuffite
Lower-Middle Miocene	Seyitomer	100–150		Carbonaceous claystone
				Diatomite interbedded with carbonaceous claystone
				Upper coal seam (Ucs): alternations of coal and claystone
Lower-Middle Miocene	Egrioz	0–100		Bituminous marl with mudstone and coal lenses
				Lower coal seam (Lcs)
Pre-Neogene	Basement	?		Green claystone
				Fluvial deposits: conglomerate, sandstone and mudstone
				<i>UNCONFORMITY</i>
				Granite
				Ophiolitic and metamorphic rocks

Fig. 1 Generalized stratigraphic column section of the Seyitomer Basin

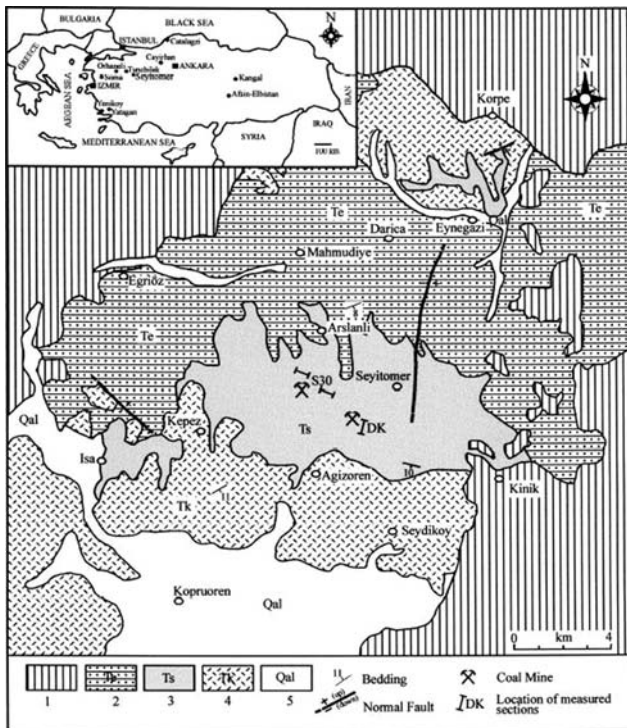


Fig. 2 Location map showing Turkish coal-fired power plants and simplified geological map of the Seyitomer Basin

values based on the various land use plans for economic criteria evaluation have been made. The unit prices for each land usage were determined with the aid of experienced realtors operating in Seyitomer. Alternatives C, D, and E are presumed to be infeasible due to the marketing conditions. Considering the economic analysis and the assumption that the current ownership presents no barrier to such a development, alternatives A and B would be selected.

The structure of the problem defined according to Saaty Hierarchy is given in Fig. 3. The goal of our study is to select the most appropriate reclamation method to meet optimal requirements and increase company profitability. This goal is placed on the first level of the hierarchy. Two strategic factors, namely, cost and operational requirements, are identified to achieve this goal, which form the second level of the hierarchy. The criteria defining the two strategic factors of cost and operational requirement of the second level occupy the third level. There are two criteria related to cost, capital, and operating expenditures. On the other hand, the criteria associated with operational requirements are natural and cultural parameters. These criteria are subdivided into 18 sub-criteria at the fourth level as shown in Fig. 1. The parameters dealing with the selection of the environmental reclamation method may change according to mine sites. These

parameters were analyzed in detail in the project study, but only some important parameters were given briefly in this case study.

After building the AHP hierarchy, the next step is the measurement and data collection, which involves forming a team of evaluators and, as explained above, assigning pairwise comparisons to the strategic factors, criteria and sub-criteria used in the AHP hierarchy. The nine-point scale as suggested by Saaty (1980) is used to assign pairwise comparisons of all elements in each level of the hierarchy. In general, every member assigns his or her pairwise comparisons, which will be converted into the corresponding pairwise comparison judgment matrices (PCJMs). As suggested by Saaty (1980), the geometric mean approach, instead of the arithmetic approach, is used to combine the individual PCJMs to obtain the consensus PCJMs for the entire team. As explained earlier, the pairwise comparison judgment matrices obtained from five evaluators in the measurement and data collection phase are combined using the geometric mean approach at each hierarchy level to obtain the corresponding consensus pairwise comparison judgment matrices. Each of these matrices is then interpreted into the corresponding largest eigenvalue problem and is solved to find the normalized and unique priority weights for each criterion.

For the case study described, Saaty’s reciprocal matrix is given in Table 4. These matrices are constructed by expert team. Using this approach, an evaluation team of five members who are frequently involved in mine planning and equipment selection in the particular open-pit coal mine operation is engaged. While one of these five team members is the general manager of this mine, the other two evaluators are product managers from the Production Department besides the two evaluators who are the mine planning engineers from the same department. Each has more than 6 years of experience in open-pit mine planning. It is adjudged that the evaluators have sufficient experience in system selection and, hence, are qualified to assign to the pairwise comparison judgments for the proposed AHP model. The opinions expressed by them in their judgments are considered to be representative of the company in evaluating the reclamation method selection criteria and the selection requirements. The following are some of the given linguistic results derived from various solution methods (linear programming, expert systems, etc.) and therefore mentioned by the experts in replying the questions posed (what if...? or if..?, etc.). Each system has shown its own advantages (or characteristics of each system alternative). In this case, it did not appear that an easy solution to the problem could be obtained. From the

Table 3 Some parameters determined for reclamation

Parameters	Explanation
Reserve	391,730,278.83 ton (total)
Coal production	6,543,000 ton/year (2001)
Coal	Lignite, intermediate: clay, marl, topsoil (0.5–1 m)
Coal density	1.8 ton/m ³ (<1,000 Kcal/kg), 1.65 on/m ³ (1,001–1,500 Kcal/kg), 1.55 on/m ³ (1,501–2,000 Kcal/kg), 1.45 on/m ³ (2,001–2,500 Kcal/kg), 1.35 on/m ³ (>2,500 Kcal/kg)
Average coal thickness	Overburden 5–40 m, Seam A 8–10 m, interburden 20–25 m, Marn 2–6 m, Seam B 10–15 m
Coal analysis	Seam A: moisture: 33%, ash: 47% , low calorific value: 1,550 kcal/kg, sulfide: 1.75%. Seam B: moisture: 36%, ash: 42%, low calorific value: 1,776 kcal/kg, sulfide: 1.42%
Blasting	Exist
Climate	Average rain: 550 mm/year, the maximum daily rain fall is resulting in 67 mm, temperatures: 32°C (July–August)–15°C (December–February)
Elevation	+1,300 m (maximum point of the site)
Position according to sun	Average duration of sunshine 5.7 h/day (max. 9.9 h/day), average density of the sunshine 358.34 cal/cm ²
Soil	Deep of the soil <30 cm, pH:7.00–8.40
Waste dumps	Dry specific gravity: 1.65–1.92 g/cm ³ –2.58 g/cm ³ . The materials of the dumps: sand: 2–0.02 mm; dust: 0.02–0.002 mm; clay: < 0.002 mm; grain diameters: sand: 10–60%; dust: 20–51%; clay: 20–55%; salt: 2–4 mΩ/cm
Mining method	Dragline/excavator + truck for stripping, hydraulic excavator + truck for coal production
Dragline	8050-49-A, 1988, 70 yd ³ Unit: 1
Excavator	PH-1900-AL: 1986, 10 yd ³ , Unit: 10; DAEWOO: 1985, 2.5 yd ³ , Unit: 1; EKG-8 I: 1972, 8 yd ³ , Unit: 3; BENATI: 1985, 3/4 yd ³ , Unit: 2; KOMATSU: 1993, 8 yd ³ , Unit: 1; KOMATSU: 1998, 6.5 yd ³ , Unit: 1
Truck	WABCO 35/C: 1978, 35 ton, Unit: 6; WABCO 85/D: 1985, 85 ton, Unit: 18 (for coal); WABCO 85/D: 1985, 85 ton, Unit: 18 (for waste); WABCO 75/C: 1985, 110 ton, Unit: 2
Other equipments	Bulldozer (13 units), pay dozer (3 units), grader (6 units), drilling machine (6 units), Loader (6 units), etc.

Fig. 3 AHP model for selection of the environmental reclamation method

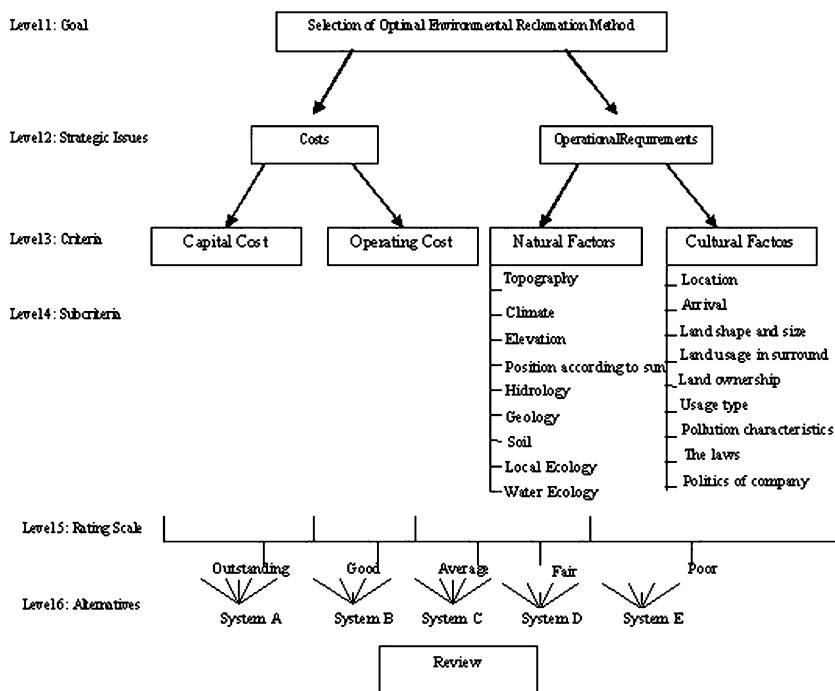


Table 4 Pairwise comparison judgment matrices of selection of land reclamation

Goal	Cost	Requirements	Priority							
Cost	1	1.3	0.565							
Requirements	0.8	1	0.435							
			CR = 0.0							
Cost	Capital cost	Operating cost	Priority							
Capital cost	1	0.6	0.524							
Operating cost	1.5	1	0.476							
			CR = 0.0							
Requirements	Natural factors	Cultural factors	Priority							
Natural factors	1	1.3	0.565							
Cultural factors	0.8	1	0.435							
			CR = 0.0							
Natural factors	T	C	E	PS	H	G	S	LE	WE	Priority
Topography (T)	1	0.5	1.5	0.67	1.5	0.5	0.33	0.33	0.33	0.067
Climate (C)	2	1	2	1.5	1.5	0.5	0.67	0.4	0.5	0.100
Elevation (E)	0.67	0.51	1	0.67	1.5	0.5	0.4	0.33	0.4	0.060
Position according to sun (PS)	1.5	0.67	1.5	1	1	0.67	0.5	0.4	0.5	0.077
Hydrology (H)	0.67	0.67	0.67	1	1	0.5	0.4	0.4	0.5	0.060
Geology (G)	2	2	2	1.5	2	1	0.67	0.5	0.67	0.123
Soil (S)	3	1.5	2.5	2	2.5	1.5	1	0.67	2	0.167
Local ecology (LE)	3	2.5	3	2.5	2.5	2	1.5	1	1.5	0.194
Water ecology (WE)	3	2	2.5	2	2	1.5	0.5	0.67	1	0.152
										CR = 0.016
Cultural factors	L	LA	LS	LU	LO	UT	PC	LW	PC	Priority
Location (L)	1	0.5	1.5	0.5	0.5	0.4	0.67	0.5	1.5	0.073
Arrival (A)	2	1	2.5	0.5	0.5	0.67	0.5	0.67	2	0.106
Land shape and size (LS)	0.67	0.4	1	0.4	0.5	0.5	0.67	0.67	1	0.065
Land usage in surround (LU)	2	2	2.5	1	0.5	1	2.5	2	2	0.160
Land ownership (LO)	2	2	2	2	1	1.5	1.5	1	1.5	0.150
Usage type (UT)	2.5	1.5	2	1	0.67	1	1.5	2	3	0.156
Pollution characteristics (PC)	1.5	2	1.5	0.4	0.67	0.67	1	2	2.5	0.126
The laws (LW)	2	1.5	1.5	0.5	1	0.5	0.5	1	2.5	0.113
Politics of company (PC)	0.67	0.5	0.67	0.5	0.67	0.33	0.4	0.4	1	0.051
										CR = 0.016

solution point of view, application of the AHP would be a proper choice, and therefore used in this paper.

- The climate of the region is so suitable for agriculture and tree planting, so A and B are better to choose.
- The distance from the area to Kutahya city is not far away with approximately 2 km, so alternative C can be proper for this thought.
- The hydrological conditions may not be so suitable for agriculture, so alternative A can be eliminated according to this criterion, etc.

Liberatore’s (Liberatore et al. 1992) five-point rating scale of outstanding (O), good (G), average (A),

fair (F), and poor (P) was used to determine the pairwise comparison judgment matrix as shown in Table 5. It is assumed that the difference in relative importance between two adjacent scales with respect to a particular scale is constant at two times, and obtains the cor-

Table 5 Pairwise comparison judgment matrix for a five-point rating scale

	O	G	A	F	P
O	1	3	5	7	9
G	1/3	1	3	5	7
A	1/5	1/3	1	3	5
F	1/7	1/5	1/3	1	3
P	1/9	1/7	1/5	1/3	1

Table 6 Composite priority weights for critical factors

Strategic issues	Local weights	Criteria	Local weights	Success factors (sub-criteria)	Local weights	Global weights
Cost	0.565			Capital cost	0.524	0.190
				Operating cost	0.476	0.171
Requirements	0.435	Natural factors	0.565	Topography	0.067	0.024
				Climate	0.100	0.035
				Elevation	0.060	0.021
				Position according to sun	0.077	0.027
				Hydrology	0.060	0.021
				Geology	0.123	0.044
				Soil	0.167	0.063
				Local ecology	0.194	0.070
				Water ecology	0.152	0.054
		Cultural factors	0.435	Location	0.073	0.020
				Arrival	0.106	0.030
				Land shape and size	0.065	0.017
				Land usage in surround	0.160	0.044
				Land ownership	0.150	0.041
				Usage type	0.156	0.043
				Pollution characteristics	0.126	0.035
				The laws	0.113	0.032
				Politics of company	0.051	0.014

responding PCJM for the rating scales. The matrix is then translated into the largest eigenvalue problem and, by using (Expert Choice 2000), the resulting priority weights of outstanding, good, average, fair, and poor are found as 0.513, 0.261, 0.129, 0.063, and 0.034, respectively.

After computing the normalized priority weights for each PCJM of the AHP hierarchy, the next phase is to synthesize the solution for the reclamation method selection problem. The normalized local priority weights of strategic factors, criteria and sub-criteria obtained from the third phase are combined together with respect to all successive hierarchical levels to obtain the global composite priority weights of all sub-criteria used in the fourth level of the AHP model. The Expert Choice software system is used to determine the global priority weights as shown in Table 6.

After calculating the global weights, they are rearranged in the descending order of priority, as shown in Table 7. It can be seen that the capital cost occupies the top-most rankings in the list, followed by operating cost and local ecology.

The global priorities are determined for all 20 sub-criteria factors as shown in the last column of Table 6. Once we transfer the global priority weights of all sub-criteria and ratings of the alternative systems on a spreadsheet, we can find the global priority weight of each method by multiplying the global priority weight of each sub-criterion with the global priority weight of the five reclamation method rating, and adding the result values. Since the priority weights of each rating is already determined, we use them against each

sub-criterion on a spreadsheet format and determine the global priority weights of the five methods as shown in Table 8. After this stage, these global priority weights must be normalized as shown in Table 8.

Based on the global priority weights of the five reclamation methods shown in Table 8, it is determined that the tree planting/forest land method (B) had the highest score. Therefore, it is selected as the optimum method to satisfy the goals and objectives of the mine company.

Table 7 Ranking of critical factors

Rank	Critical success factors (sub-criteria)	Global weights
1	Capital cost	0.190
2	Operating cost	0.171
3	Local ecology	0.070
4	Soil	0.063
5	Water ecology	0.054
6	Geology	0.044
7	Land usage in surround	0.044
8	Usage type	0.043
9	Land ownership	0.041
10	Climate	0.035
11	Pollution characteristics	0.035
12	The laws	0.032
13	Arrival	0.030
14	Position according to sun	0.027
15	Topography	0.024
16	Elevation	0.021
17	Hydrology	0.021
18	Location	0.020
19	Land shape and size	0.017
20	Politics of company	0.014

Table 8 Application of the AHP model to reclamation method selection of the Seyitomer open-pit coal mine

Strategic criteria issues critical factors	Global weights	System A			System B			System C			System D			System E		
		Rating	Score	xGW	Rating	Score	xGW	Rating	Score	xGW	Rating	Score	xGW	Rating	Score	xGW
Cost																
Capital cost	0.190	P	0.034	0.0065	F	0.063	0.0119	A	0.129	0.0245	G	0.261	0.0496	A	0.129	0.0245
Operating cost	0.171	F	0.063	0.0108	F	0.063	0.0108	F	0.063	0.0108	F	0.063	0.0108	F	0.063	0.0108
Requirements																
Natural factors																
Topography	0.024	O	0.513	0.0123	G	0.261	0.0063	P	0.034	0.0082	A	0.129	0.0031	O	0.513	0.0123
Climate	0.035	O	0.513	0.0179	O	0.513	0.0179	A	0.129	0.0045	P	0.034	0.0012	A	0.129	0.0045
Elevation	0.021	A	0.129	0.0027	G	0.261	0.0055	P	0.034	0.0071	P	0.034	0.0071	F	0.063	0.0013
Position according to sun	0.027	A	0.129	0.0035	O	0.513	0.0140	P	0.034	0.0092	P	0.034	0.0092	P	0.034	0.0092
Hydrology	0.021	O	0.513	0.0108	O	0.513	0.0011	P	0.034	0.0071	O	0.513	0.0108	O	0.513	0.0108
Geology	0.044	O	0.513	0.0226	A	0.029	0.0057	A	0.129	0.0057	P	0.034	0.0015	P	0.034	0.0015
Soil	0.063	O	0.513	0.0323	O	0.513	0.0323	A	0.129	0.0081	P	0.034	0.0021	P	0.034	0.0021
Local ecology	0.070	O	0.513	0.0360	O	0.513	0.0360	O	0.513	0.0360	P	0.034	0.0024	P	0.034	0.0024
Water ecology	0.054	P	0.034	0.0018	G	0.261	0.0141	P	0.034	0.0018	P	0.034	0.0018	O	0.513	0.0277
Cultural factors																
Location	0.020	A	0.129	0.0026	A	0.129	0.0026	O	0.513	0.0103	O	0.513	0.0103	A	0.129	0.0026
Arrival	0.030	P	0.034	0.0010	A	0.129	0.0039	A	0.129	0.0039	O	0.513	0.0154	P	0.034	0.0010
Land shape and size	0.017	O	0.513	0.0087	A	0.129	0.0022	P	0.034	0.0058	A	0.129	0.0022	P	0.034	0.0058
Land usage in surround	0.044	P	0.034	0.0015	G	0.261	0.1740	A	0.129	0.0057	O	0.513	0.0226	P	0.034	0.0015
Land ownership	0.041	P	0.034	0.0014	P	0.034	0.0014	A	0.129	0.0053	A	0.129	0.0053	P	0.034	0.0014
Usage type	0.043	P	0.034	0.0015	P	0.034	0.0015	P	0.034	0.0015	O	0.513	0.0220	P	0.034	0.0015
Pollution characteristics	0.035	A	0.129	0.0045	P	0.034	0.0012	A	0.129	0.0045	O	0.513	0.0180	P	0.034	0.0012
The laws	0.032	A	0.129	0.0041	P	0.034	0.0011	A	0.129	0.0041	O	0.513	0.0164	P	0.034	0.0011
Politics of company	0.014	A	0.129	0.0018	G	0.261	0.0036	A	0.129	0.0018	O	0.513	0.0072	P	0.034	0.0048
Total scores																
							0.3471			0.1659			0.2190			0.1280
Renormalized scores							0.3324			0.1589			0.2097			0.1226

Conclusions

Reclamation method selection can be listed as one of the most important factors that affect open-pit design and production planning. Strategic factors and the defining criterion were identified and, then, an AHP-based model was formulated to select the optimal method. The proposed AHP model is generally applicable to any reclamation method selection problem in mining operations. Using the AHP model, the criterion for method selection is clearly identified and the problem is structured systematically. This enables decision makers to examine the strengths and weaknesses of the possible methods by comparing them with respect to appropriate criterion. Moreover, the use of the proposed AHP model can significantly reduce the time and effort in decision making. From the results of the case study, it can be concluded that the application of the AHP in the selection of the optimal reclamation method to improve the team decision-making process is plausible. The AHP model developed in this paper can be used as a basis for implementing selections of the reclamation methods. The suggested five-point rating system of assessing the reclamation methods helps decision makers in avoiding time consuming pairwise comparison judgments. If new critical success factors, and hence, new criteria emerge to satisfy changing business needs, then they can be included in the AHP model to select a method. Also, the reclamation method selection could be made in a more routine fashion.

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