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A DECISION SUPPORT SYSTEM FOR OPTIMAL EQUIPMENT SELECTION IN OPEN PIT MINING: ANALYTICAL HIERARCHY PROCESS

AÇIK OCAK MADENCİLİĞİNDE OPTİMUM EKİPMAN SEÇİMİ İÇİN BİR KARAR DESTEK SİSTEMİ : ANALİTİK HİYERARŞİ PROSESİ

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ABSTRACT : This study has been directed to the research of an optimal loading-hauling system in an open pit mine. There are many factors that affect the equipment selection processes. These factors are both qualitative and quantitative according to structure of the selection. Decision-makers need a decision support system that evaluate the factors in a complex structure for optimal decision making. In this paper, Analytical Hierarchy Process (AHP) is used for equipment selection in open pit mining. For this purpose, this study involves with the selection of an optimal loading-hauling system from mine to a power station to be established in an open pit coal mine located Orhaneli, western part of Turkey. The optimum alternative has been found as shovel-in-pit crusher-belt conveyor, consequently.

Keywords : Equipment selection, decision making, multiple attribute decision making, analytical hierarchy process

ÖZ : Bu çalışma, açık ocak madenciliğinde optimum yükleme-taşıma sisteminin seçimine yöneliktir. Ekipman seçimi birçok etmene bağlı olarak yapılmaktadır. Bu seçimin yapısı gereği, bu etmenler hem nicel hem de nitel özellikler taşıdığı görülmektedir. Karar vericinin; bu kararlarını sağlıklı bir biçimde verebilmesi için sözü edilen bu çok karmaşık yapıda ve sayıda olan etmenleri irdeleyecek bir karar destek sistemine gerek duyarlar. Bu çalışmada, açık ocak madenciliği ekipman seçiminde bu karar destek sistemini oluşturmak için Analitik Hiyerarşi Prosesi (AHP) kullanılmıştır. Bu amaçla Türkiye Kömür İşletmeleri (TKİ) Orhaneli Linyitleri İşletmesi dekapaj kazısı için yükleme-taşıma sisteminin seçimi incelenmiş ve optimum çözüm elde edilmeye çalışılmıştır. Çalışanın sonucunda, ekskavatör-ocak içi kırıcı ve bant konveyör sistemi optimum sonuç olarak bulunmuştur.

Anahtar Kelimeler : Ekipman seçimi, karar verme, çok kriterli karar verme, analitik hiyerarşi prosesi.

INTRODUCTION

Equipment selection is one of the most important factor that affect open-pit design (pit slopes, bench high, block sizes and geometries, ramp layout as well as excavation sequences and open-pit layout) and production planning. Further, equipment selection also effects economic considerations in open-pit design, specifically overburden, waste rock and ore mining costs and cost escalation parameters as a function of plan location and depth. Mining costs are a function of site conditions, operating scale and equipment. The purpose of equipment selection is to select optimum equipment with minimum cost (Lizotte, 1988). We have used Analytical Hierarchy Process (AHP) approach for the equipment selection in final decision.

Multiple attribute decision making (MADM) deals with the problem of choosing an alternative from a set of alternatives which are characterised in terms of their attributes. Usually MADM consists of a single goal, but this may be of two different type. The first is where the goal is to select an alternative from a set of scored ones based on the values and importance of the attributes of each alternative. The second type of goal is to classify alternatives, using a kind of role model or similar cases. The use of past cases to deduce answers or explanations is a recent field of research, termed Case-Based Reasoning. Both type of goals require information about the preferences among the instances of an attribute and the preferences across the existing attributes. The assessment of these preferences is either provided directly by the decision maker or based on past choices. The geneal formalisation is:

Let A_1, A_2, ...A_n be set of alternatives to be assessed by criteria C_1, C_2, ...C_n .

Let R_{ij} be the numerical rating of alternative A_i for criteria C_j, i j.

Then the general decision function is:

$D(A) = (R_{i1} o\ R_{i2} o\ R_{i3} o \ldots\ldots\ R_{ij} o)$ for j = 1, 2, ...,n and o represents the aggregation.

Further, the decision maker might express or define a ranking for the criteria as importance/weights. There are many forms for expressing these importance, but the most common are: (a) utility preference functions; (b) the analytical hierarchy process and (c) a fuzzy version of the classical linear weighted average. In this paper, it is proposed developing the decision support system that is possible to evaluate all parameters together and assess the weights of criteria and objectives for equipment selection problem. The Analytical Hierarchy Process is used to devolope the decision support system. The method measures relative “fuzziness” by tructuring the criteria and objectives of a system, hierarchical in a multiple attribute framework (Riberio 1996).

THE ANALYTICAL HIERARCHY PROCESS

This method has been developed by Saaty [1980]. The AHP structures the decision problem in levels which correspond to one’s understanding of the situation: goals, criteria, sub-criteria, and alternatives. By breaking the problem into levels, the decision-maker can focus on smaller sets of decisions. The AHP is based on 4 main axioms:

1) Given any two alternatives (or sub-criteria), the decision-maker is able to provide a pairwise comparison of these alternatives under any criterion on a reciprocal ratio scale.
2) When comparing any two alternatives, the decision-maker never judges one to be infinitely better than another under any criterion.
3) One can formulate the decision problem as a hierarchy.
4) All criteria and alternatives which impact a decision-problem are represented in the hierarchy.

The above axioms describe the two basic tasks in the AHP: formulating and solving problem as a hierarchy, and eliciting judgements in the form of pairwise comparisons. The alicitation of priorities for a given set of alternatives under a given criterion involves the completion of a nxn matrix, where n is the number of alternatives under consideration. Since the comparisons are assumed to be reciprocal, one needs to answer only n(n-1)/2 of the comparisons. Saaty proposed an eigenvector approach for the estimation of the weights from a matrix of pairwise comparisons. The eigenvector approach is a theoretically and pratically proven method for estimating the weights. The eigenvector also has an intuitive interpretation in that it is an averaging of all possible ways of thinking about a given set of alternatives. After estimating the weights, the decision-maker is also provided with a measure of the inconsistency of the given pairwise comparisons. It is important to note that the AHP does not require decision-makers to be consistent but, rather, provides a measure of inconsistency as well as a method to reduce this measure if it is deemed to be too high. After generating a set of weights for each alternative under any criterion, the overall priority of the alternatives is computed by means of a linear, additive function (Munda, 1995, Albayrak et al. 1997).

The method measures relative “fuzziness” by structuring the criteria and objectives of a system, hierarchicaly in a multiple attribute framework. In order to rate the alternatives Saaty (1978a; 1978b) uses a hierarchical pair-wise comparison between attributes and/or objectives and then solves them with eigenvectors of the reciprocal matrices. Instead of presenting the approach in mathematical form, an example is developed to facilitate understanding. The importance of this approach is mainly used to calculate the criteria weights, since it has a non-fuzzy set nature. Consider the problem of selecting a site from the set $\{A, B, C\}$ to be located of a new in-pit crusher in an open-pit mine, with the goal, G, of spending the minimum investment possible and for criteria evaluation to be located near the pit and plant, respectively C_1 and C_2. The analytical hierarchy for this example is given in Figure 1.

The judgement scale used is the one proposed by Saaty (Saaty 1978a, 1978b): 1. Equally important, 3 weakly more important, 5 strongly more important, 7 demonstrably more important and 9-absolutely more important. In the hierarchy, the matrix of the upper nodes corresponds to level zero (the comparison of criteria) while the other correspond level one. The construction of the square reciprocal matrices is performed by asking the decision maker to compare element **i** with element **j**, the value $\mathbf{a_{ij}}$, with respect to a particular criteria or objective. The other values are assigned as follows : (a) $a_{ji} = 1/a_{ij}$; (b) $a_{ii} = 1$. For the example described, Saaty’s reciprocal matrices are:

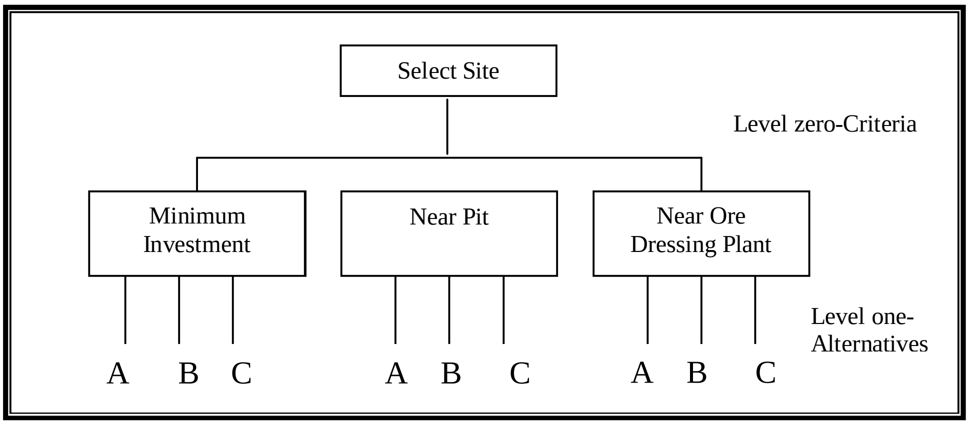

Figure 1. The Hierarchy Structure of The Example
Şekil 1. Örnek Problemin Hiyerarşik Yapısı

Criteria Comparison · Minimum Investment · Near Pit · Near Ore Dressing Plant

$$\begin{array}{c|ccc} & G & C1 & C2 \\ \hline G & 1 & 1/7 & 1/7 \\ C1 & 7 & 1 & 1 \\ C2 & 7 & 1 & 1 \end{array} \qquad \begin{array}{c|ccc} & A & B & C \\ \hline A & 1 & 1/5 & 1/5 \\ B & 5 & 1 & 1 \\ C & 5 & 1 & 1 \end{array} \qquad \begin{array}{c|ccc} & A & B & C \\ \hline A & 1 & 3 & 3 \\ B & 1/3 & 1 & 1 \\ C & 1/3 & 1 & 1 \end{array} \qquad \begin{array}{c|ccc} & A & B & C \\ \hline A & 1 & 1 & 7 \\ B & 1 & 1 & 5 \\ C & 1/7 & 1/5 & 1 \end{array}$$

The values in the reciprocal matrices are given by the decision maker. For example, criteria C_1 and C_2 are "demonstrably more important" (grade 7 on first matrix) than goal G (assumed as another criterion) and alternatives B and C are both "strongly more important" (grade 5 in second matrix) than A (cheaper since the criteria under evaluation is minimum investment). The other comparison are easily observed in the reciprocal matrices.

To solve the reciprocal matrices Saaty uses the maximum eigenvalue and eigenvectors. The eigenvector corresponding to the maximum eigenvalue is a cardinal ratio scale for the elements compared. The eigenvectors are then normalised to ensure consistency. After obtaining the normalised eigenvectors for each matrix, the vectors of the upper level become the members of the full matrix of weights of alternatives for each criteria. This last matrix of vectors is then multiplied by the matrix of weights of the criteria comparison (the eigenvector of the criteria comparison). The intermediate results are:

$$\text{Criteria}\begin{bmatrix}.1005\\.7035\\.7035\end{bmatrix}\ \text{normalised}\begin{bmatrix}.080\\.460\\.460\end{bmatrix}\quad \text{Minimum Inv.}\begin{bmatrix}.1400\\.7000\\.7000\end{bmatrix}\ \text{normalised}\begin{bmatrix}.090\\.455\\.455\end{bmatrix}$$

$$\text{Near Pit}\begin{bmatrix}.9045\\.3015\\.3015\end{bmatrix}\ \text{normalised}\begin{bmatrix}.600\\.200\\.200\end{bmatrix}\quad \text{N. Ore Dre. Pl.}\begin{bmatrix}.7403\\.6618\\.1183\end{bmatrix}\ \text{normalised}\begin{bmatrix}.490\\.430\\.080\end{bmatrix}$$

The final result is obtained by considering the normalised vectors for criteria comparisons, for each alternative (level 1 of hierarchy) as belonging to the same matrix and then multiplying it by the criterion weights (level zero of hierarchy), which are given by the criteria comparison normalised vector.

$$\begin{array}{c} \begin{array}{ccc} \text{Inv.} & \text{N.P.} & \text{N.O.} \end{array} \\ \begin{bmatrix} .09 & .6 & .49 \\ .455 & .2 & .43 \\ .455 & .2 & .08 \end{bmatrix} \end{array} \text{X} \begin{bmatrix} .08 \\ .46 \\ .46 \end{bmatrix} = \begin{bmatrix} .51 \\ .33 \\ .16 \end{bmatrix} \qquad \begin{array}{l} A = .51 \\ B = .33 \\ C = .16 \end{array}$$

Inv (min. invest); N.P. (Near Pit; N.O. (Near Ore Dressing Plant).

The best alternative is thus A.

The results show that since alternative A is more important than B and C, for the criteria “Near Pit” (3, 3), much more important than C, for the criteria “Near Ore Dressing Plant” (7), and since criteria “Near Pit” and “Near Ore Dressing Plant” (7, 7) are much more important than criteria “Minimum Investment”, Alternative A is the best choice. In summary, this approach is quite consistent, structured and intuitive.

APPLICATIONS OF AHP MODEL IN MINING

In spite of many advantages of the approach, only few applications of AHP model to mining industry problems have been reported in the literature. Some of these applications are briefly reviewed here:

Bandopadhyay (1987) indicated partial ranking of primary stripping equipment in surface mine planning and fuzzy algorithm. It deals with the process of ranking alternatives after determining their rating. Determining the optimal decision alternatives, when the results are crisp, is straightforward (just select the alternative with the highest support). It also considers that the supports for each alternative are themselves fuzzy sets. Therefore, in order to select the 'best' alternative more sophisticated methods of comparison are needed.

Gershon *et al* (1993) studied mining method selection: a decision support system integrating multi-attribute utility theory and expert systems.

Herzog, D. and Bandopadhyay, S (1996) indicated ranking of optimum beneficiation methods via the analytical hierarchy process. This process measures relative 'fuzziness' by structuring the criteria and objectives of a system, hierarchically, in a multiple attribute framework.

Bascetin, A., and Kesimal, A.(1999a) handled the study of a fuzzy set theory for the selection of an optimum coal transportation system from pit to the power plant. This project has comprised variety of criteria related to the coal transportation systems.

Bascetin, A., and Kesimal, A., (1999b) handled Application of Fuzzy Logic in Mining. It deals with the AHP and Fuzzy Logic Applications in Multiple Attribute Decision Environment.

Kesimal, A. and Bascetin, A., (2002) handled application of fuzzy multiple attribute decision making in mining operations. In this project, the AHP model was used together with fuzzy set theory for equipment selection.

CASE STUDY

In this case study it has been carried out some researches on loading-hauling systems for coal production to be established in an open pit coal mine located Orhaneli, western part of Turkey. The coal mine is situated about 65 km north of Bursa located west of Turkey. The mine has been in continuous operation since 1979. Currently the mine supplies Orhaneli power plant unit (1x210 MW) and some for domestic use only. The lowest calorific value lignite (2704 kcal/kg) will be mined for electricity generation. In this case, the overall measurements of the mine should be designed again in terms of transporting system, equipment fleet, etc. Technical parameters of working site, which affect the systems, have been searched thoroughly and summarized below in detail.

The present extent of the open pit is 1200 m long by 400 m wide and a total of 75 m of overburden being removed in three 15 m high benches and an average thickness of 7 m coal being mined at one bench only. The last 25 meters of overburden from surface is mined using dragline. The face inclination on individual benches is 75 degrees while overall pit slopes are 45 degrees. The average temperatures are varying between 30°C and minus 6°C. The average temperatures yearly is 14°C.

The mine will be worked over 18 years at the rate of one shift (12 h/d) per day, seven days a week for 300 days per year, the scheduled operating time being 3600 h/year. The average coal production is planned to be 1,300,000 t/year, (100,000 t/year upper 3,500 kcal/kg for domestic use, 1,200,000 t/year 2700 kcal/kg for power plant) which implies an average annual overburden removal of 15,000,000 m^3-i.e. the economic mine life is based on the first tenth year 11.43 m^3/ton and between tenth and eighteenth year 11 m^3/ton stripping ratio.

The equipments in the inventory reported are summarized as follow. Three drilling units are employed for overburden, four being 9 inch DM50. Coal bench has an easy diggibility. Sometimes blasting is applied for getting big size coal. Two rope shovels (Marion 191 MII) fitted with 15.3 m^3 buckets, four PH 1900 AL shovels with 7.64 m^3 buckets, one dragline (1260-W Bucyrus-Erie) with 25 m^3 bucket in waste and one as front shovel with 7.64 m^3 buckets in coal are used for loading. A fleet of totally forty-four off-highway trucks undertakes haulage. Twenty-seven (Caterpillar 777-77 ton), thirteen (Komatsu 785-2, 77 ton), four (Komatsu 785-2, 50 ton) are equipped as carrying waste and six (Komatsu HD 465-3) as coal trucks with 50 tonnes capacity. Average haul distances are 2,500 m with coal, 2,000 m with waste.

Supporting equipment in the mine includes five Komatsu D355A bulldozer of 410 hp; three Caterpillar 81 bulldozer; one Caterpillar Cat 824 wheeled dozer; four Caterpillar front-end loader; one

Volvo front-end loader with 5.5-6 m^3 buckets; two Champion of 120 hp: one Caterpillar grader of 275 hp.

The equipments in the inventory reported are given, berafly, in Table 1.

Table 1. Equipments In The Mine
Tablo 1. İşletmedeki Mevcut Ekipmanlar

Equipment	**Number**	**Explanation**
Drilling Units	3	9” DM50
Rope Shovels	2	Marion 191 MII -15.3 m^3 buckets,
Front Shovels	4	PH 1900 AL-7.64 m^3 buckets
Dragline	1	1260-W Bucyrus-Erie-25 m^3 bucket
Trucks	50	Caterpillar 777-77 ton-(27) Komatsu 785-2, 77 ton-(13) Komatsu 785-2, 50 ton-(4) Komatsu HD 465-3-(6, coal trucks)
Bulldozer	9	Komatsu D355A-410 hp-(5) Caterpillar 81-(3) Cat 824 wheeled dozer-(1)
Loader	7	Caterpillar front-end loader-(4) Volvo front-end loader with 5.5-6 m^3 buckets-(1) Champion-120 hp-(2)
Grader	1	Caterpillar-(275 hp)

The proper transportation system has been seen that it would be selected among the shovel-truck (A_1), shovel-truck-in-pit crusher-belt conveyor (A_2), shovel-in-pit crusher-belt conveyor (A_3) and loader-truck (A_4) systems. The other methods that is used in open pit mining have been eliminated because of may not be applied for the Orhaneli Coal Mine according to previous investigations with the experts decisions. The characteristic of the mine-site and the equipment technical features are given in Table 2. The some parameters are taken from inventory reported and the others like usefull life, loading time cycle time, etc. were calculated for this study. The structure of the problem according to Saaty Hierarchy is given in Figure 2.

Table 2. Technical Parameters Calculated For Each System
Tablo 2. Her Bir Sistem İçin Hesaplanan Teknik Parametreler

Reserve	23,000,000 ton
Coal Production	1,200,000 ton/year (for power plant), 100.000 ton/year (for domestic uses)
Active workday	1 shift/day, 300 days/year, 12 h/day, 3600 h/year
Coal	Lignite, intermediate: clay
Coal density	1.5 ton/m^3
Average Coal thickness	7 m
Coal size	Max. 50 cm (run-of-mine), 10 cm (belt conveyor)
Coal Analyse	Moisture: % 26.6, Ash: % 26, Low Calorific Value: 2097 kcal/kg, Sulfide: % 2
Swell Factor (coal)	1,2 (conveying)
Blasting	Exist
Haulage distance	2.5 km. (A_1), 2 km belt conveying - 0.5 km truck haulage (A_2), 2.5 km (A_3), 2.5 km (A_4)
Average grade resistance	%3 (assumed)
Average rolling resistance	%2 (assumed)
Max. inverse grade	+%4
Dump level	Front Shovel: 7.5m. Truck (Loading Height: 3.78m.).
Bucket capacity	Hydraulic Excavator : 7,64 m^3,
Bucket fill factor	%90
Operating weight	Front Shovel: 83800 kg, Truck : 40188 kg
Useful life	Front Shovel : 25000 h. Loader : 20000 h. Truck : 15000 h. Conveyor : 24000 h
Loading time	Hydraulic Excavator : 26 sec
Cycle time	17.85 min for 2.5 km (A_1), 7.2 min for 0.5 km (truck-conveyor)
Belt Conveyor	2 m/sec, 900 mm width, 2.5 km length (out of pit) 0.5 km (in-pit)
In-pit Crusher	350 ton/h
Capital cost	Truck : $400.000 Crusher: $700.000, Conveyor: 2.670.000 (2.5 km)
Operating cost	A_1= $12/ton, A_2= $6.80/ton, A_3= $6.12/ton, A_4=$11.72/ton

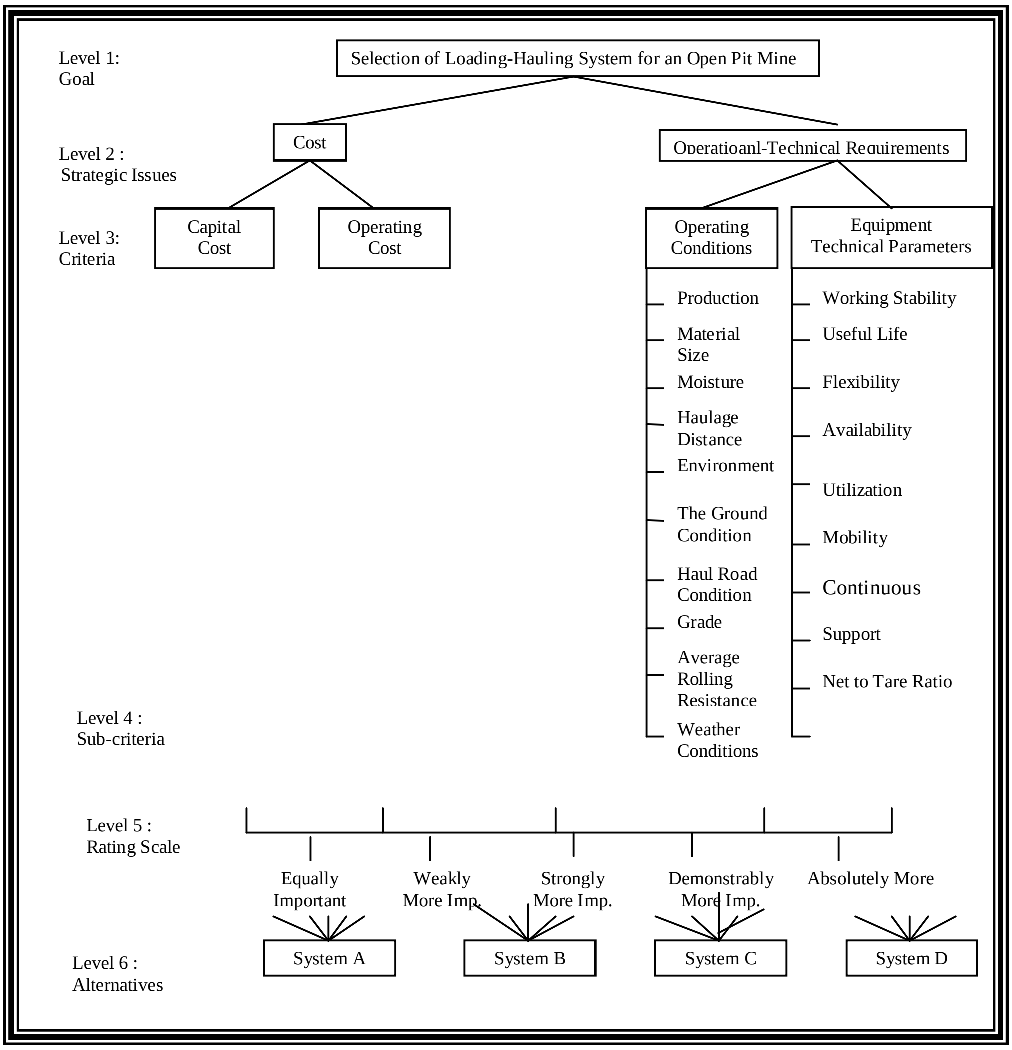

Figure 2. AHP Model For Loading-Hauling System Selection
Şekil 2. Yükleme-Taşıma Sistem Seçimi için AHP Modeli

Criteria of each operation is summarized in Table 3, and next, an optimum transportation system selection procedure is given below. These criteria have been determined according to mine site properties (geological, geotechnical parameters, etc.) and equipment technical parameters. To obtain these criteria, some measurements and observations were applied in mine site.

Table 3. Criteria of Each Operation
Tablo 3. İşlem Kriterleri

Criterion	**Operation**	**Criterion**	**Operation**
C1	Production	C12	Useful Life
C2	Material Size	C13	Flexibility
C3	Material Moisture	C14	Availability
C4	Haulage Distance	C15	Utilization
C5	The Ground Condition (for loading)	C16	Mobility
C6	Haul Road Condition	C17	Continuous
C7	Environment (dust, noisy, etc)	C18	Support
C8	Grade (haul road)	C19	Net to Tare Ratio
C9	Average Rolling Resistance (for equipments)	C20	Capital Cost
C10	Weather Conditions	C21	Operating Cost

C11	Working Stability		

Let $A = \{A_1, A_2, A_3, A_4\}$ be the set of alternative systems and $C = \{C_1, C_2, C_3, \ldots, C_m\}$ be the set of criteria. The judgement scale used is given as: 1. Equally important; 1.5 weakly more important; 2. Strongly more important; 2.5 demonstrably more important, 3. Absolutely more important (Fig. 2). For the example described, Saaty's reciprocal matrices are in below. These matrices are constructed by expert team. Using this approach, an evaluation team of five members who are frequently involved in equipment selection of the open pit coal mine in this case study. Of these five evaluators, two are mine planning engineers from the Production Department. Each one of them has more than six years of experience in open pit mine planning. Two evaluators are product managers from the same department. The last evaluator is general manager of this mine. Thus, the evaluators have sufficient experience in equipment selection and, hence, are qualified to assign pairwise comparison judgements for the proposed AHP model. The opinions expressed by them in ther judgements are considered to be representative of the company in evaluating the equipment selection criteria and the selection requirements. Before apply this, the following linquistic results are produced and therefore presented by the experts to questions posed (what if ..? or if..?, etc.) Each system has shown its own advantages. In this case, it did not appear that an easy solution to the problem could be obtained. From the solution point of view, application of the AHP would be a proper choice, and therefore used in this paper.

- The overburden thickness is thin, so A_1 is better to choose.
- Diggibility is not being difficult so the front-shovel can be selected unhesitatingly.
- The front-shovel as regards to the ground condition has more advantage (it is very wet and marshy especially in winter)
- All combinations (systems) are suitable in regard to the height of dump but the front-shovel can make much more safe loading, etc.

Criteria comparison.

$$
\begin{array}{c|ccccccccccccccccccccc|}
 & C_1 & C_2 & C_3 & C_4 & C_5 & C_6 & C_7 & C_8 & C_9 & C_{10} & C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} & C_{17} & C_{18} & C_{19} & C_{20} & C_{21} \\
C_1 & 1 & 1/1.5 & 1.5 & 1/2 & 1/3 & 1/2 & 1/2 & 1/1.5 & 1/1.5 & 1 & 1/2.5 & 1 & 1/2.5 & 1/2.5 & 1/3 & 1/3 & 1/2 & 1/2 & 1/3 & 1/2.5 & 1/3 \\
C_2 & 1.5 & 1 & 1 & 1/1.5 & 1/2.5 & 1/1.5 & 1/2 & 1 & 1/1.5 & 1/1.5 & 1/3 & 1/2 & 1/2.5 & 1/2.5 & 1/3 & 1/3 & 1/2 & 1/1.5 & 1/2.5 & 1/2.5 & 1/3 \\
C_3 & 1/1.5 & 1 & 1 & 1/2 & 1/3 & 1 & 1/2 & 1/1.5 & 1/1.5 & 1.5 & 1/3 & 1/1.5 & 1/3 & 1/2.5 & 1/3 & 1/3 & 1/2 & 1/1.5 & 1/3 & 1/2.5 & 1/3 \\
C_4 & 2 & 1.5 & 2 & 1 & 2 & 2 & 1.5 & 1.5 & 1.5 & 2.5 & 1/2 & 2.5 & 1 & 1 & 1/1.5 & 1/2 & 1 & 2 & 1/2 & 1/2 & 1/2.5 \\
C_5 & 3 & 2.5 & 3 & 1/2 & 1 & 3 & 2 & 3 & 2 & 3 & 1 & 2 & 1.5 & 1.5 & 1 & 1 & 2.5 & 2.5 & 1 & 1 & 1/2.5 \\
C_6 & 2 & 1.5 & 1 & 1/2 & 1/3 & 1 & 1/2 & 1 & 1/1.5 & 1 & 1/2.5 & 1/1.5 & 1/2 & 1/2 & 1/2.5 & 1/2.5 & 1 & 1 & 1/2 & 1/2 & 1/2.5 \\
C_7 & 2 & 2 & 2 & 1/1.5 & 1/2 & 2 & 1 & 1.5 & 1 & 1.5 & 1/2 & 1 & 1/2 & 1/2 & 1/2.5 & 1/2.5 & 1 & 1 & 1/2 & 1/2 & 1/2.5 \\
C_8 & 1.5 & 1 & 1.5 & 1/1.5 & 1/3 & 1 & 1/1.5 & 1 & 1/1.5 & 1 & 1/2.5 & 1/1.5 & 1/2.5 & 1/2.5 & 1/3 & 1/3 & 1 & 1 & 1/3 & 1/2.5 & 1/3 \\
C_9 & 1.5 & 1.5 & 1.5 & 1/1.5 & 1/2 & 1.5 & 1 & 1.5 & 1 & 1.5 & 1/2 & 1 & 1/2 & 1/2 & 1/2.5 & 1/2.5 & 1 & 1 & 1/2 & 1/2 & 1/2.5 \\
C_{10} & 1 & 1.5 & 1/1.5 & 1/2.5 & 1/3 & 1 & 1/1.5 & 1 & 1/1.5 & 1 & 1/2.5 & 1 & 1/2 & 1/2 & 1/2.5 & 1/2.5 & 1 & 1 & 1/2.5 & 1/2 & 1/2.5 \\
C_{11} & 2.5 & 3 & 3 & 2 & 1 & 2.5 & 2 & 2.5 & 2 & 2.5 & 1 & 3 & 1 & 1 & 1/1.5 & 1/1.5 & 2.5 & 2.5 & 1 & 1 & 1/1.5 \\
C_{12} & 1 & 2 & 1.5 & 1/2.5 & 1/2 & 1.5 & 1 & 1.5 & 1 & 1 & 1/3 & 1 & 1/2 & 1/2 & 1/2.5 & 1/2.5 & 1 & 1 & 1/2 & 1/2 & 1/2.5 \\
C_{13} & 2.5 & 2.5 & 3 & 1 & 1/1.5 & 2 & 2 & 2.5 & 2 & 2 & 1 & 2 & 1 & 1 & 1/1.5 & 1/1.5 & 2.5 & 2.5 & 1 & 1 & 1/1.5 \\
C_{14} & 2.5 & 2.5 & 2.5 & 1 & 1/1.5 & 2 & 2 & 2.5 & 2 & 2 & 1 & 2 & 1 & 1 & 1/1.5 & 1/1.5 & 2 & 2 & 1/1.5 & 1 & 1/1.5 \\
C_{15} & 3 & 3 & 3 & 1.5 & 1 & 2.5 & 2.5 & 3 & 2.5 & 2.5 & 1.5 & 2.5 & 1.5 & 1.5 & 1 & 1 & 3 & 3 & 1 & 1.5 & 1 \\
C_{16} & 3 & 3 & 3 & 2 & 1 & 2.5 & 2.5 & 3 & 2.5 & 2.5 & 1.5 & 2.5 & 1.5 & 1.5 & 1 & 1 & 2.5 & 3 & 1 & 1 & 1/1.5 \\
C_{17} & 2 & 2 & 2 & 1 & 1/2.5 & 1 & 1 & 1 & 1 & 1 & 1/2.5 & 1 & 1/2.5 & 1/2 & 1/3 & 1/2.5 & 1 & 1 & 1/2 & 1/2 & 1/2.5 \\
C_{18} & 2 & 1.5 & 1.5 & 1/2 & 1/2.5 & 1 & 1 & 1 & 1 & 1 & 1/2.5 & 1 & 1/2.5 & 1/2 & 1/3 & 1/3 & 1 & 1 & 1/2 & 1/2 & 1/2.5 \\
C_{19} & 3 & 2.5 & 3 & 2 & 1 & 2 & 2 & 3 & 2 & 2.5 & 1 & 2 & 1 & 1.5 & 1 & 1 & 2 & 2 & 1 & 1 & 1/1.5 \\
C_{20} & 2.5 & 2.5 & 2.5 & 2 & 1 & 2 & 2 & 2.5 & 2 & 2 & 1 & 2 & 1 & 1 & 1/1.5 & 1 & 2 & 2 & 1 & 1 & 1/1.5 \\
C_{21} & 3 & 3 & 3 & 2.5 & 1.5 & 2.5 & 2.5 & 3 & 2.5 & 2.5 & 1.5 & 2.5 & 1.5 & 1.5 & 1 & 1.5 & 2.5 & 2.5 & 1.5 & 1.5 & 1
\end{array}
$$

C_1 Criterion

$$
\begin{array}{c|cccc|}
 & A_1 & A_2 & A_3 & A_4 \\
A_1 & 1 & 1/1{,}5 & 2{,}5 & 2 \\
A_2 & 1{,}5 & 1 & 3 & 2 \\
A_3 & 1/2{,}5 & 1/3 & 1 & 1/2 \\
A_4 & 1/2 & 1/2 & 2 & 1
\end{array}
$$

C_2 Criterion

$$
\begin{array}{c|cccc|}
 & A_1 & A_2 & A_3 & A_4 \\
A_1 & 1 & 2{,}5 & 2{,}5 & 1/2 \\
A_2 & 1/2{,}5 & 1 & 1 & 1/3 \\
A_3 & 1/2{,}5 & 1 & 1 & 1/3 \\
A_4 & 2 & 3 & 3 & 1
\end{array}
$$

C_3 Criterion

$$
\begin{array}{c|cccc|}
 & A_1 & A_2 & A_3 & A_4 \\
A_1 & 1 & 2 & 2 & 1/2 \\
A_2 & 1/2 & 1 & 1 & 1/2{,}5 \\
A_3 & 1/2 & 1 & 1 & 1/2{,}5 \\
A_4 & 2 & 2{,}5 & 2{,}5 & 1
\end{array}
$$

C_4 Criterion

$$
\begin{array}{c|cccc|}
 & A_1 & A_2 & A_3 & A_4 \\
A_1 & 1 & 1/2 & 1/2{,}5 & 1 \\
A_2 & 2 & 1 & 1/2 & 2 \\
A_3 & 2{,}5 & 2 & 1 & 2{,}5 \\
A_4 & 1 & 1/2 & 1/2{,}5 & 1
\end{array}
$$

C_5 Criterion

$A_1 \quad A_2 \quad A_3 \quad A_4$

C_6 Criterion

$A_1 \quad A_2 \quad A_3 \quad A_4$

C_7 Criterion

$A_1 \quad A_2 \quad A_3 \quad A_4$

A_1
A_2
A_3
A_4

C_8 Criterion

$A_1 \quad A_2 \quad A_3 \quad A_4$

A_1
A_2
A_3
A_4

$$\begin{array}{cc} \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/1{,}5 & 1/2{,}5 & 1 \\ 1{,}5 & 1 & 3 & 1{,}5 \\ 2{,}5 & 1/3 & 1 & 2{,}5 \\ 1 & 1/1{,}5 & 1/2{,}5 & 1 \end{bmatrix} \end{array} \quad \begin{array}{cc} \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/1{,}5 & 1/2 & 1 \\ 1{,}5 & 1 & 1/2 & 1{,}5 \\ 2 & 2 & 1 & 2 \\ 1 & 1/1{,}5 & 1/2 & 1 \end{bmatrix} \end{array} \quad \begin{bmatrix} 1 & 1/2 & 1/2{,}5 & 1{,}5 \\ 2 & 1 & 1/1{,}5 & 2 \\ 2{,}5 & 1{,}5 & 1 & 2{,}5 \\ 1/1{,}5 & 1/2 & 1/2{,}5 & 1 \end{bmatrix} \quad \begin{bmatrix} 1 & 1/2 & 1/2{,}5 & 1 \\ 2 & 1 & 1/1{,}5 & 2 \\ 2{,}5 & 1{,}5 & 1 & 2{,}5 \\ 1 & 1/2 & 1/2{,}5 & 1 \end{bmatrix}$$

C_9 Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/2 & 1/3 & 1 \\ 2 & 1 & 1{,}5 & 2 \\ 3 & 1/1{,}5 & 1 & 3 \\ 1 & 1/2 & 1/3 & 1 \end{bmatrix} \end{array}$$

C_{10} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/1{,}5 & 1/2{,}5 & 1{,}5 \\ 1{,}5 & 1 & 1/1{,}5 & 1{,}5 \\ 2{,}5 & 1{,}5 & 1 & 2{,}5 \\ 1/1{,}5 & 1/1{,}5 & 1/2{,}5 & 1 \end{bmatrix} \end{array}$$

C_{11} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/1{,}5 & 2 & 1{,}5 \\ 1{,}5 & 1 & 2{,}5 & 1{,}5 \\ 1/2 & 1/2{,}5 & 1 & 1/2 \\ 1/1{,}5 & 1/1{,}5 & 2 & 1 \end{bmatrix} \end{array}$$

C_{12} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/1{,}5 & 1/2{,}5 & 2 \\ 1{,}5 & 1 & 1/1{,}5 & 1{,}5 \\ 2{,}5 & 1{,}5 & 1 & 2{,}5 \\ 1/2 & 1/1{,}5 & 1/2{,}5 & 1 \end{bmatrix} \end{array}$$

C_{13} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1 & 3 & 1 \\ 1 & 1 & 2{,}5 & 1/1{,}5 \\ 1/3 & 1/2{,}5 & 1 & 1/3 \\ 1 & 1{,}5 & 3 & 1 \end{bmatrix} \end{array}$$

C_{14}Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/2 & 1/2{,}5 & 1 \\ 2 & 1 & 1/1{,}5 & 2 \\ 2{,}5 & 1{,}5 & 1 & 2{,}5 \\ 1 & 1/2 & 1/2{,}5 & 1 \end{bmatrix} \end{array}$$

C_{15} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/2{,}5 & 1/3 & 1 \\ 2{,}5 & 1 & 1/1{,}5 & 2{,}5 \\ 3 & 1{,}5 & 1 & 3 \\ 1 & 1/2{,}5 & 1/3 & 1 \end{bmatrix} \end{array}$$

C_{16} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 2 & 3 & 1/1{,}5 \\ 1/2 & 1 & 2{,}5 & 1/2{,}5 \\ 1/3 & 1/2{,}5 & 1 & 1/3 \\ 1{,}5 & 2{,}5 & 3 & 1 \end{bmatrix} \end{array}$$

C_{17} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/2 & 1/3 & 1 \\ 2 & 1 & 1/1{,}5 & 2 \\ 3 & 1{,}5 & 1 & 3 \\ 1 & 1/2 & 1/3 & 1 \end{bmatrix} \end{array}$$

C_{18} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1{,}5 & 2 & 1 \\ 1/1{,}5 & 1 & 1{,}5 & 1/1{,}5 \\ 1/2 & 1/1{,}5 & 1 & 1/2 \\ 1 & 1{,}5 & 2 & 1 \end{bmatrix} \end{array}$$

C_{19} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/2{,}5 & 1/3 & 1 \\ 2{,}5 & 1 & 1/1{,}5 & 2{,}5 \\ 3 & 1{,}5 & 1 & 3 \\ 1 & 1/2{,}5 & 1/3 & 1 \end{bmatrix} \end{array}$$

C_{20} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 2 & 2{,}5 & 1/1{,}5 \\ 1/2 & 1 & 2 & 1/2{,}5 \\ 1/2{,}5 & 1/2 & 1 & 1/3 \\ 1{,}5 & 2{,}5 & 3 & 1 \end{bmatrix} \end{array}$$

C_{21} Criterion

$$\begin{array}{cc} & \begin{matrix} A_1 & A_2 & A_3 & A_4 \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ A_3 \\ A_4 \end{matrix} & \begin{bmatrix} 1 & 1/2 & 1/2{,}5 & 1 \\ 2 & 1 & 1/1{,}5 & 2 \\ 2{,}5 & 1{,}5 & 1 & 2{,}5 \\ 1 & 1/2 & 1/2{,}5 & 1 \end{bmatrix} \end{array}$$

The maximum eigenvalue and eigenvector was used to solve the reciprocal matrices. The eigenvector corresponding to the maximum eigenvalue is a cardinal ratio scale for the elements compared. The eigenvectors are then normalised to ensure consistency. After obtaining the normalised eigenvectors for each matrix, the vectors of the upper level became the members of the full matrix of weights of alternatives for each criteria. This last matrix of vectors is then multiplied by the matrix of weights of the criteria comparison (the eigenvector of the criteria comparison). The intermediate results are:

$$\begin{bmatrix} 0,0960 \\ 0,0989 \\ 0,0965 \\ 0,2168 \\ 0,2885 \\ 0,1198 \\ 0,1506 \\ 0,1113 \\ 0,1410 \\ 0,1147 \\ 0,2844 \\ 0,1334 \\ 0,2557 \\ 0,2428 \\ 0,3346 \\ 0,3246 \\ 0,1381 \\ 0,1275 \\ 0,2877 \\ 0,2670 \\ 0,3596 \end{bmatrix} \text{Normalised} \begin{bmatrix} 0,0230 \\ 0,0240 \\ 0,0230 \\ 0,0520 \\ 0,1000 \\ 0,0300 \\ 0,0400 \\ 0,0300 \\ 0,0300 \\ 0,0270 \\ 0,0700 \\ 0,0300 \\ 0,0600 \\ 0,0500 \\ 0,0800 \\ 0,0700 \\ 0,0330 \\ 0,0300 \\ 0,0700 \\ 0,0600 \\ 0,0800 \end{bmatrix}$$

C_1 Criterion

$$\begin{bmatrix} 0,5629 \\ 0,7182 \\ 0,2110 \\ 0,3504 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,305 \\ 0,400 \\ 0,114 \\ 0,200 \end{bmatrix}$$

C_2 Criterion

$$\begin{bmatrix} 0,5628 \\ 0,2377 \\ 0,2377 \\ 0,7552 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,314 \\ 0,130 \\ 0,130 \\ 0,421 \end{bmatrix}$$

C_3 Criterion

$$\begin{bmatrix} 0,5406 \\ 0,2826 \\ 0,2826 \\ 0,7403 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,293 \\ 0,153 \\ 0,153 \\ 0,400 \end{bmatrix}$$

C_4 Criterion

$$\begin{bmatrix} 0,2750 \\ 0,4919 \\ 0,7790 \\ 0,2750 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,150 \\ 0,270 \\ 0,430 \\ 0,150 \end{bmatrix}$$

C_5 Criterion

$$\begin{bmatrix} 0,3306 \\ 0,7365 \\ 0,5228 \\ 0,2739 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,177 \\ 0,395 \\ 0,280 \\ 0,147 \end{bmatrix}$$

C_6 Criterion

$$\begin{bmatrix} 0,3369 \\ 0,4588 \\ 0,7500 \\ 0,3369 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,200 \\ 0,243 \\ 0,400 \\ 0,200 \end{bmatrix}$$

C_7 Critetrion

$$\begin{bmatrix} 0,2826 \\ 0,5406 \\ 0,7403 \\ 0,2826 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,153 \\ 0,300 \\ 0,400 \\ 0,153 \end{bmatrix}$$

C_8 Criterion

$$\begin{bmatrix} 0,2826 \\ 0,5406 \\ 0,7403 \\ 0,2826 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,153 \\ 0,300 \\ 0,400 \\ 0,153 \end{bmatrix}$$

C_9 Criterion

$$\begin{bmatrix} 0,2628 \\ 0,6590 \\ 0,6539 \\ 0,2628 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,143 \\ 0,360 \\ 0,355 \\ 0,143 \end{bmatrix}$$

C_{10} Criterion

$$\begin{bmatrix} 0,3115 \\ 0,4799 \\ 0,7587 \\ 0,3115 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,167 \\ 0,257 \\ 0,400 \\ 0,167 \end{bmatrix}$$

C_{11} Criterion

$$\begin{bmatrix} 0,6551 \\ 0,6153 \\ 0,2228 \\ 0,3776 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,350 \\ 0,330 \\ 0,120 \\ 0,200 \end{bmatrix}$$

C_{12} Criterion

$$\begin{bmatrix} 0,3733 \\ 0,4753 \\ 0,7521 \\ 0,2627 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,200 \\ 0,255 \\ 0,403 \\ 0,141 \end{bmatrix}$$

C_{13} Criterion

$$\begin{bmatrix} 0,5684 \\ 0,4915 \\ 0,1976 \\ 0,6296 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,300 \\ 0,260 \\ 0,104 \\ 0,333 \end{bmatrix}$$

C_{14} Criterion

$$\begin{bmatrix} 0,2826 \\ 0,5406 \\ 0,7403 \\ 0,2826 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,153 \\ 0,300 \\ 0,400 \\ 0,153 \end{bmatrix}$$

C_{15} Criterion

$$\begin{bmatrix} 0,2377 \\ 0,5628 \\ 0,7552 \\ 0,2377 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,132 \\ 0,314 \\ 0,420 \\ 0,132 \end{bmatrix}$$

C_{16} Criterion

$$\begin{bmatrix} 0,6949 \\ 0,3407 \\ 0,1847 \\ 0,6058 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,380 \\ 0,186 \\ 0,101 \\ 0,331 \end{bmatrix}$$

C_{17} Criterion

$$\begin{bmatrix} 0,2582 \\ 0,5164 \\ 0,7746 \\ 0,2582 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,143 \\ 0,300 \\ 0,430 \\ 0,143 \end{bmatrix}$$

C_{18} Criterion

$$\begin{bmatrix} 0,6077 \\ 0,4174 \\ 0,2952 \\ 0,6077 \end{bmatrix} \text{normalised} \begin{bmatrix} 0,315 \\ 0,216 \\ 0,153 \\ 0,315 \end{bmatrix}$$

C_{19} Criterion

C_{20} Criterion

C_{21} Criterion

$$\begin{bmatrix} 0{,}2377 \\ 0{,}5628 \\ 0{,}7552 \\ 0{,}2377 \end{bmatrix} \text{normalised} \begin{bmatrix} 0{,}132 \\ 0{,}314 \\ 0{,}420 \\ 0{,}132 \end{bmatrix} \begin{bmatrix} 0{,}5477 \\ 0{,}3246 \\ 0{,}2072 \\ 0{,}7428 \end{bmatrix} \text{normalised} \begin{bmatrix} 0{,}300 \\ 0{,}200 \\ 0{,}113 \\ 0{,}400 \end{bmatrix} \begin{bmatrix} 0{,}2826 \\ 0{,}5406 \\ 0{,}7403 \\ 0{,}2826 \end{bmatrix} \text{normalised} \begin{bmatrix} 0{,}153 \\ 0{,}300 \\ 0{,}400 \\ 0{,}153 \end{bmatrix}$$

The final result is obtained by considering the normalised vectors for criteria comparisons, for each alternative (level 1 of hierarchy) as belonging to the same matrix and then multiplying it by the criterion weights (level zero of hierarchy), which are given by the criteria comparison normalised vector.

Criteria Comparisons For Each Alternative (Matrice A)

$$\begin{bmatrix} 0{,}305 & 0{,}314 & 0{,}293 & 0{,}150 & 0{,}177 & 0{,}200 & 0{,}153 & 0{,}153 & 0{,}143 & 0{,}167 & 0{,}350 & 0{,}200 & 0{,}300 & 0{,}153 & 0{,}132 & 0{,}380 & 0{,}143 & 0{,}315 & 0{,}132 & 0{,}300 & 0{,}153 \\ 0{,}400 & 0{,}130 & 0{,}153 & 0{,}270 & 0{,}395 & 0{,}243 & 0{,}300 & 0{,}300 & 0{,}360 & 0{,}257 & 0{,}330 & 0{,}255 & 0{,}260 & 0{,}300 & 0{,}314 & 0{,}186 & 0{,}300 & 0{,}216 & 0{,}314 & 0{,}200 & 0{,}300 \\ 0{,}114 & 0{,}130 & 0{,}153 & 0{,}430 & 0{,}280 & 0{,}400 & 0{,}400 & 0{,}400 & 0{,}355 & 0{,}400 & 0{,}120 & 0{,}403 & 0{,}104 & 0{,}400 & 0{,}420 & 0{,}101 & 0{,}430 & 0{,}153 & 0{,}420 & 0{,}113 & 0{,}400 \\ 0{,}200 & 0{,}421 & 0{,}400 & 0{,}150 & 0{,}147 & 0{,}200 & 0{,}153 & 0{,}153 & 0{,}143 & 0{,}167 & 0{,}200 & 0{,}141 & 0{,}333 & 0{,}153 & 0{,}132 & 0{,}331 & 0{,}143 & 0{,}315 & 0{,}132 & 0{,}400 & 0{,}153 \end{bmatrix}$$

Criterion Weights (Matrice B)

$$\begin{bmatrix} 0{,}0230 \\ 0{,}0240 \\ 0{,}0230 \\ 0{,}0520 \\ 0{,}1000 \\ 0{,}0300 \\ 0{,}0400 \\ 0{,}0300 \\ 0{,}0300 \\ 0{,}0270 \\ 0{,}0700 \\ 0{,}0300 \\ 0{,}0600 \\ 0{,}0500 \\ 0{,}0800 \\ 0{,}0700 \\ 0{,}0330 \\ 0{,}0300 \\ 0{,}0700 \\ 0{,}0600 \\ 0{,}0800 \end{bmatrix}$$

$$A \times B = \begin{bmatrix} 0{,}1990 \\ 0{,}2915 \\ 0{,}3326 \\ 0{,}2306 \end{bmatrix} \quad \begin{matrix} A_1 = 0.1990 \\ A_2 = 0.2915 \\ A_3 = 0.3326 \\ A_4 = 0.2306 \end{matrix}$$

The best alternative is thus A_3 (shovel-in-pit crusher-belt conveyor).

The analytic hierarchy process that is studied in this paper is quite consistent, structured and intuitive. The main problem lies in the fact that since all comparisons are done by importance comparisons. Another drawback is that the exhaustive pair-wise comparison, required to ensure consistency, is time consuming if there are many criteria. However, the analytical hierarchy process really represents an alternative to other approaches like fuzzy sets and etc., for obtaining alternative ratings in multiple attribute problems dealing with uncertainty. In addition to this, when the applications of similar mines are examined, the best alternative (A_3) obtained from this study is proper to the mine, fairly.

CONCLUSIONS

As explained in Section 1. equipment selection is one of the most important factor that affect open-pit design and production planning. We first identified strategic factors and the defining criteria. and then formulated an AHP- based model, to select the optimal equipment. The proposed AHP model is generally applicable to any equipment selection problem in mining operations. The decisions reached by using the model agreed with those obtained by using the pre-existing equipment selection process. However, using the AHP model, the criteria for equipment selection are clearly identified and the problem is structured systematically. This enables decision-makers to examine the strength and weakness of loading-hauling systems by comparing them with respect to appropriate criteria. 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 application of the AHP in equipment selection of a loading-hauling system to improve the team decision making process is desirable. The AHP model developed in this paper can be used as a basis for implementing equipment selections of loading-hauling systems. The suggested rating system of assessing the loading-hauling systems helps decision-makers in avoiding time consuming pair-wise comparision judgements. If new critical success factors. and. hence. new criteria emerge to satify changing business needs. then they can be included in the AHP model to select a equipment. Similarly. any new member can be included in the evaluation team to consider his or her input. Also. the equipment selection could be made in a more routine fashion.

ÖZET

Ekipman seçimi, açık ocak dizaynı ve üretim planlamasının çok önemli bir aşamasıdır. Ayrıca, dekapaj ve üretim maliyetleri gibi ekonomik düşünceleri de etkilemektedir. Buradaki maliyetler, alan koşullarının, işletme ölçeğinin ve ekipmanlarının bir fonksiyonudur. Dolayısı ile karar aşamasında yapılacak ufak bir hata büyük ekonomik kayıplara neden olacaktır. Ekipman seçiminin amacı, minimum maliyetle en uygun ekipmanı seçmektir. Bu çalışmanın amacı ise Türkiye Kömür İşletmeleri, Orhaneli Linyit İşletmesinde ocaktan termik santrale en uygun kömür yükleme –taşıma sisteminin belirlenmesidir.

Ekipman seçimi birçok etmene bağlı olarak yapılmaktadır. Bu seçimin yapısı gereği, bu etmenlerin hem nicel hem de nitel özellikler taşıdığı görülmektedir. Karar vericinin; bu kararlarını sağlıklı bir biçimde verebilmesi için sözü edilen bu çok karmaşık yapıda ve sayıda olan etmenleri irdeleyecek bir karar destek sistemine gerek duyarlar. Bu çalışmada, açık ocak madenciliği ekipman seçiminde bu karar destek sistemini oluşturmak için Analitik Hiyerarşi Prosesi (AHP) kullanılmıştır. Söz konusu proses gereği öncelikle problemin hiyerarşik yapısı ortaya konmuştur. Yapılan arazi ölçüm ve gözlemleri ile laboratuvar deneyleri sonucunda elde veriler bu hiyerarşik yapının elemanlarını oluşturmuştur. Bu aşamada işletme verilerinden de yararlanılmıştır. Bu aşamanın tamamlanmasından sonra literatürde yer alan ve işletmenin kendine özgü yapısı da dikkate alınarak ekipman seçiminde etkili olan kriterler bir uzman ekip tarafından belirlenmiştir. Bu iki önemli aşamadan sonra ise karar verici uzman grubun belirlediği ölçek üzerinde kriter ve çözüm alternatiflerinin ağırlıkları belirlenerek prosese uygulanmıştır. Çalışmanın sonucunda, ekskavatör-ocak içi kırıcı ve bant konveyör sistemi optimum sonuç olarak bulunmuştur. AHP modeli, söz konusu problemi hiyerarşik bir yapıda çözdüğü için çözüm alternatiflerinin kriterlerle daha kolay değerlendirilmesini sağlamaktadır. Ayrıca, karar verme sürecindeki zaman ve efor önemli ölçüde azaltılmış ve kriterlerin tümü değerlendirelebildiği ve tüm alternatiflere göre önem dereceleri belirlenebildiği için optimum çözüm elde edilmesi sağlanmıştır.

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