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EXPERT SYSTEM FOR OVERBURDEN REMOVAL,
EQUIPMENT SELECTION IN SURFACE COAL MINES

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ABSTRACT

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The selection of a suitable equipment for overburden removal in surface mines is a difficult task depending on geological, technological and economic conditions as well as the human judgement. Expert systems approach, which is relatively new approach attempting to handle imprecise and subjective information is very suitable for this problem.

In this study, an expert system is developed for the problem, using PCPLUS expert system shell. The system uses 85 parameters and 224 rules in decision process. It can be used for the following equipment types; dragline, bucket wheel excavator, hydraulic excavators (hydraulic excavator and backhoe), dozer, dozer-scraper combination and front-end loader. The rules were derived from the available literature, from case studies and from the consultation with experts. A number of sample

consultations were conducted and the equipments selected with highest certainty factors in each sample consultation seem to be proper choices when the conditions which led to this conclusion are investigated.

Key words: Expert systems, equipment selection, overburden removal, surface coal mines.

ÖZET

KÖMÜR AÇIK OCAKLARINDA DEKAPAJDA KULLANILAN EKİPMANLARIN SEÇİMİ İÇİN UZMAN SİSTEM

ERDEM, Bülent

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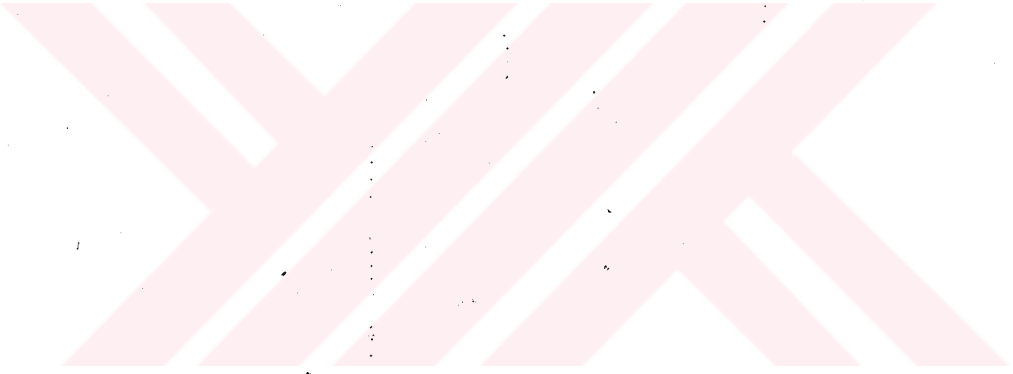
Şubat 1990, 95 Sayfa

Acık ocaklarda dekapaj için uygun ekipman seçimi jeolojik, teknolojik ve ekonomik koşullara olduğu kadar insan kararına da bağlı zor bir iştir. Göreceli olarak yeni bir yaklaşım olan, belirsiz ve subjektif bilgileri işleyen uzman sistem yaklaşımı bu problem için çok uygundur.

Bu çalışmada, PCPLUS adlı bir uzman sistem paket programıyla bir uzman sistem geliştirilmiştir. Sistem karar aşamasında 85 parametre ve 224 kural kullanmaktadır. Sistem draglayn, döner kepçeli ekskavatör, skrayper, dozer, elektrikli ekskavatör, hidrolik ekskavatörler, önden yükleyiciler ve dozer-skrayper kombinasyonu için kullanılabilir. Kurallar literatür'den, durum değerlendirmelerinden ve eksperlerle yapılan görüşmelerden çıkarılmıştır. Sistemle yapılan bir dizi konsültasyon, sistemin bulduğu uygun ekipmanların

aynı kořulların arařtırılmasıyla bulunacak sonuçlarla uyumlu olduđunu gstermektedir.

Anahtar Kelimeler : Uzman sistemler, Ekipman seęimi, dekapaj, kmr aık iřletmeciliđi.



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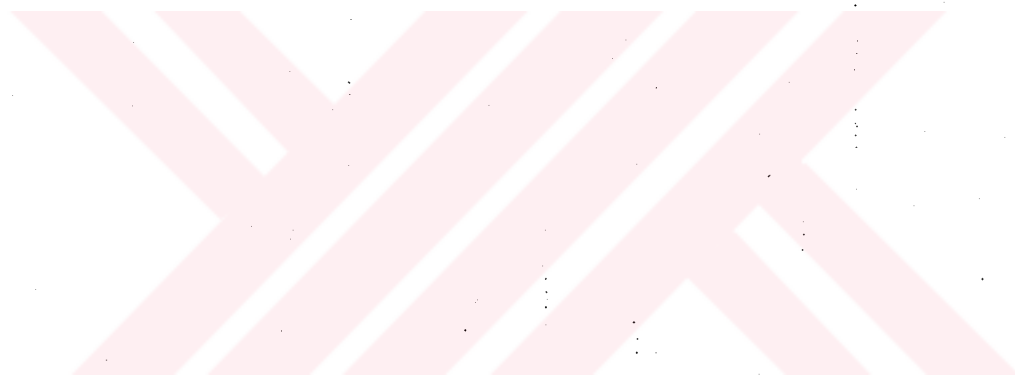
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1. INTRODUCTION

Selection of an overburden excavating equipment for a surface mine is always of the utmost importance; because overburden removal is one of the major items that should be performed in an open-pit mine. Another important point in this subject is the result of a misselected equipment. Since these equipments are extremely expensive and cannot be afforded easily, then the importance of correct equipment selection can be seen more clearly.

Approaches to solve this problem can be categorized into two; the classical approach of numerical methods classify the excavating equipments based on the productivity and the unit cost items of various equipments. However, nowadays, the work is growing in approaches which attempt to include uncertain and descriptive information into the equipment selection problem. It can be said that, this problem of suitable equipment selection in surface mines contain uncertainty in sub-disciplines it employs, such as the geotechnical considerations, excavability of the formations and the mining method to be applied. However, the history of the second approach, which is the expert system approach, does not go back more than a few years and examples of this approach are mostly unavailable due partly to some

of them are still under development and the rest handle the problem considering a specific part of it.

The purpose of this study is to develop an expert system which will model the equipment selection problem considering the conditions existing in a surface mine. In other words, this expert system does not deal with a specific area, but consists of many sub-problem areas which, when gathered together constitute the main problem of excavating equipment selection.

A review of the literature on the expert systems, their use, history and applications to earth sciences, mining and excavating equipment selection in surface mines are presented in Chapter 2. Chapter 3 is devoted to the explanation of parameters or conditions that are encountered in equipment selection problem and to the explanation about the selection and usage of the expert system tool. In Chapter 4, searching mechanism of the expert system is given and sample outputs of the system are presented and explained. Finally, conclusions and further recommendations for future research are included in Chapter 5.

2. EXPERT SYSTEMS IN MINING

2.1. Expert System Fundamentals

2.1.1. General Features

An expert system is a computer program equipped with artificial intelligence techniques to solve problems that are difficult enough to require significant human expertise for their solution.

The history of expert systems go back to sixties. Artificial intelligence scientists tried to simulate the method of human thinking and used these methods in general-purpose programs. During seventies they concentrated on techniques like representation and search. At the late seventies, they realized a very important thing: "The problem solving power of a program comes from the knowledge it possesses, not just from the formalisms and inference schemes it employs". This realization led to the development of special computer programs which were expert in a narrow domain, which were called Expert systems (Waterman, 1986).

The most useful feature of an expert system is the high-level expertise, which represents the best thinking of top-level experts leading to accurate, efficient and imaginative problem solving. The system is also flexible,

it can be grown incrementally to meet the user's needs.

Training facility is another feature since expert systems have their explanation abilities about their reasonings. This is important for new staff members and key personnel.

The final feature of expert systems is the predictive modeling power. The system can act as an information processing theory or model of problem solving in the given domain, providing the desired answers for a given problem situation and showing how they would change for new situations.

The advantages and disadvantages of expert systems are summarized in Table 2.1.

Table 2.1. Advantages and Disadvantages of Artificial Expertise Compared to Human Expertise
(Waterman, 1986)

Advantages of Artificial Expertise		Disadvantages of Artificial Expertise	
Human Expertise	Artificial Expertise	Human Expertise	Artificial Expertise
Perishable	Permanent	Creative	Uninspired
Difficult to transfer	Easy to transfer	Adaptive	Needs to be told
Difficult to document	Easy to document	Sensory experience	Symbolic input
Unpredictable	Consistent	Broad focus	Narrow focus
Expensive	Affordable	Commonsense knowledge	Technical knowledge

Figure 2.1. illustrates the structure of a general expert system. The system can be divided into two parts; knowledge base and inference engine. The knowledge base in an expert system contains facts (data) and rules that use facts to make decisions. The inference engine contains an interpreter that decides how to apply the rules to infer new knowledge and a scheduler that decides the order in which the rules should be applied.

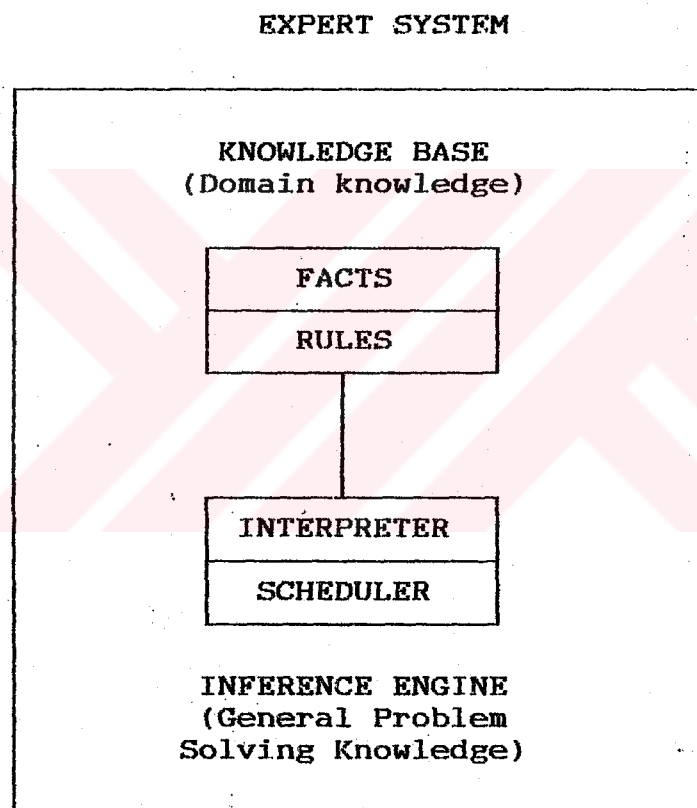


Figure 2.1. The Structure of an Expert System

Knowledge-based systems generally work with two searching methods which are forward-chaining and backward-chaining.

Forward-chaining is the search system which starts with the given facts and work towards the goal-facts. System selects a relevant rule, applies to the appropriate subset of facts, which are originally had in the facts list or derived during consultation, notes the substitutions of particular terms for general terms, puts the newly derived facts in the graph, tests whether any of them are goals, and if not, repeats the cycle. When working, system has certain amount of freedom in choosing which of several potential rule-applications it will construct next.

Backward-chaining is not opposite of forward-chaining but the scenario changes with additions to the search system. Typical specification is the query to backwards to prove a goal. The system tries to derive a fact that satisfies the specification. The system starts with what it wants to prove, and only executes rules that are relevant to establishing it (Management of Applications Software, 1989).

2.1.2. Expert System Building Tools

Expert system development is a long, iterative procedure. Choosing the correct problem scope and picking the right tool for building the expert system are two of the most difficult decisions to make in expert system development.

There are a number of expert system languages, tools and shells in which a knowledge-based system can be implemented. Primary languages of Artificial Intelligence are PROLOG and LISP. A list of selected expert system tools are given in Table 2.2.

Table 2.2. Selected Commercial Systems (Waterman, 1986)

COMMERCIAL SYSTEMS			
Tools	Use	Description	Hardware
EXPERT-EASE	Knowledge acquisition	Infers a decision tree from examples	IBM PC IBM XT
KEE	General-purpose	Rule-based Frame-based Procedure-oriented Object-oriented	CADR machines Symbolic 3600 IBM PC
SERIS	Diagnosis	Rule-based	IBM PC
PERSONAL CONSULTANT	Diagnosis	Rule-based	IBM PC
M.1	General-purpose	Rule-based English-like syntax	IBM PC
OPS5	General-purpose	Rule-based	WAX 11 Systems
LISP	General-purpose	Procedure-oriented	Lambda machines IBM PC
PROLOG	General-purpose	Logic-based Procedure-oriented	DEC 10 System DEC 20 System IBM PC

2.2 General Mining Applications of Expert Systems

Prospector was one of the first examples of a truly knowledge-based system developed in the late 70's at Stanford, USA (Denby and Atkinson, 1988). It acts as a consultant to aid exploration geologists in their search for ore deposits. Given field data about a geological region, it estimates the likelihood of finding particular types of mineral deposits there. The system can assess the potential for finding a variety of deposits, including massive sulfide, carbonate lead/zinc, porphyry copper, nickel sulfide, sandstone uranium and porphyry molybdenum deposits. It bases its inferences on the use of certainty factors.

Litho assists geologists in interpreting data from oil-well logs (Waterman, 1986). The system uses the log data plus knowledge of the region's geological environment to characterize the rock encountered in a well.

Dipmeter Advisor is an expert system which draw inferences about subsurface geological structure by interpreting dipmeter logs, measurements of the conductivity of rock in and around a borehole as related to depth below the surface (Waterman, 1986).

Drilling Advisor assists an oil-rig supervisor in resolving problems related to the drilling mechanism sticking within the borehole during drilling. The system

diagnoses the most likely causes of the sticking and recommends a set of treatments to alleviate the problem and lessen its chances of reoccurrence (Waterman, 1986).

Gridding Advisor is a recently available expert system which helps make a decision about which gridding algorithm to use for different distribution of data (Anon, 1987).

Mud helps engineers maintain optimal drilling fluid properties. It does this by diagnosing the causes of problems with drilling fluids and suggesting treatments (Waterman, 1986).

Hvdro helps a hydrologist use HSPF, a computer program that simulates the physical processes by which precipitation is distributed throughout a watershed. The system assists in describing watershed characteristics to HSPF in the form of numerical parameters (Waterman, 1986).

METHPRO, an acronym for METHane PROfessional, is an expert system developed by U.S. Bureau of Mines for use on personal computers. It is designed to aid mine operators in selecting the best methane control strategy to employ in their particular situation (King, 1986).

Another methane risk prediction expert system is UFEL, an acronym for Unexpected Firedamp Emission Level (Anon, 1987). It gives indications of possible risk areas

for methane emission based on a reasonable assessment from the data present, even if incomplete. UFEL uses statistical weightings to replies to specific questions and derives an overall weighting.

Shearer Fault diagnosis is an expert system programmed to reduce the time required to determine a fault or breakdown condition on an underground coal shearer (Anon, 1987).

One type of expert system for underground coal mining, now being used as an experimental decision-making tool for mine management, is called CHOOZ. While it is still experimental, it is being developed to automatically search and compile work crews, premium work lists and suggest strategy on deploying a workforce for its maximum productive effort (Britton, 1987).

Another expert system, although not complex for actual use, is described by Bandopadhyay and Venkatasubramanian (1987a). It is developed to help mine engineers in selecting mining methods for coal deposits mineable by underground methods. For the initial system, several geotechnical factors such as rock strength, groundwater, floor condition that influence the selection of a mining method were chosen. Values for the certainty factor in each production rule was obtained from expert opinion. These factors were considered of prime importance for a selected coal deposit mineable by

underground methods.

Two different works were carried out for slope stability analyses. One of these is ESDS (Expert Slope Design System) developed by the University of Nottingham for assessing slope stability over a mine site (Brown and Singh, 1987 and Brown, et al., 1988). To represent uncertainties about the instability of the slopes certainty values are assigned. Assigning certainty factor values is, however largely a matter of subjective judgement, assisted by having studied statistical analyses and descriptive accounts of the instability data.

The other expert system "Slope Safety Analyzer" developed by Sinha and Sengupta (1989), has three distinct modules, namely; identification of existing landslide class, identification of potential landslide class, possible remedial measures for identified potential landslide type. Furthermore, the expert system attempts to give suggestions about type of shear strength required for factor of safety calculations.

2.3. Expert Systems for Surface Mine Equipment Selection

One of the suitable application areas for the expert systems in mining is the surface mine equipment selection since it is a very complicated problem and subjective judgement based on experience is the most

important input of the decision making process. Hence, there are a few attempts to the problem.

The expert system developed by Bandopadhyay and Venkatasubramanian (1987b), is capable of aiding in the selection of equipment for topsoil removal, overburden preparation, primary stripping, coal loading and hauling and regrading and vegetation areas. The program is implemented on VAX 750 computers. In the program, the performance variable represents the overall utility of equipment in a surface mining system. The overall utility of a primary stripping equipment depends on other performance variables such as geological, technical, environmental. Each of these variables in turn depends on other characteristics, e.g. geological variable depends on thickness, fragmentation characteristics, etc. Similarly, technical variable depends on transport distance, production capability, equipment flexibility and mobility.

Another system described by Nenonen et al. (1987), although said prototype, uses geotechnical and equipment characteristics. The system uses rules which describe the feasibility and desirability of selecting various types of excavation equipment given values for geotechnical parameters such as block size, rock strength and degree of weathering. Confidence factors are used to represent any uncertainties inherent in the data provided by the user. Lastly, an experimental prototype system,

set up in the Universite Laval, to assist the scraper selection procedures for an earth moving application is explained by Fytas et al. (1987). Selection of an appropriate scraper for a particular earth-moving application requires two types of data; material characteristics (e.g. sizing, abrasiveness, etc.) and mine profile conditions (haul distance, grades, etc.). These data are asked from the user during the reasoning process. Typical material characteristics that SCRAPER takes into account are; presence and relative quantity of boulders and rocks, ground conditions, material moisture, underfoot conditions (rolling resistance); and material abrasiveness. Most of this data is descriptive, i.e. non-numerical. Mine profile conditions include haul distance, adverse grades, cycle time and availability of dozers (pusher). Only 12 rules are presently taken into account. The program in its present form allows selection of the best type of scrapers according to material conditions and mine profile. In its preliminary form SCRAPER does not take into account parameters such as capital and operating costs, service and parts availability, existing scraper types in the fleet and performance curves.

3. EXPERT SYSTEM CONSTRUCTION

3.1. Parameters Relating to Diggability of Formations

The parameters in this group are used to determine the diggability of formations in the mine area by various equipments. Determining the diggability at the beginning, an initial classification of equipments can be performed. A number of equipments can be eliminated from further consideration, if diggability of formations is found to be difficult. Because of these reasons, parameters of diggability group are the most important ones among others.

To determine the diggability of formations, the diggability classification table given in Table 3.1., which was developed by Paşamehmetoglu et. al., (1988) was used. This table was generated for electrical and hydraulic excavators, hydraulic backhoes and for front end loaders depending on rippability. The classification is based on a rating system depending on five parameters; Uniaxial Compressive Strength (or Point Load Strength) value, Average Joint Spacing, Seismic Wave Velocity, Degree of Weathering and Hardness.

But, in the expert system, classification is enlarged and dragline, bucket-wheel-excavator, scraper, dozer-scraper combination are included into the system.

Table 3.1 Diggability Classification Table (Paşamehmetoğlu et al., 1988)

Diggability Class	Diggability Description	Diggability Rating	Digging Type and Digging Equipment			If to be blasted	
			Electric Excavator	Hydraulic Excavator	Rippability	Av. Drilling Speed, m/min	Specific Charge, g/m ³
1	Easy	0-25	Direct Digging	Direct Digging	Rippable with D7	-	-
2	Medium	25-45	Digging with Blasting	Direct Digging	Marginal with D7 Rippable with D9	1.48	130-200
3	Medium-Hard	45-65	Digging with Blasting	Digging with Blasting	Marginal with D9 Rippable with D11	1.28	200-280
4	Hard	65-85	Digging with Blasting	Digging with Blasting	Blasting or poorly rippable with D11	0.47	280-350
5	Very-Hard	85-100	Digging with Blasting	Digging with Blasting	Digging with Blasting	less than 0.42	>350 or AL. added emulsion

The first parameter is the Uniaxial Compressive Strength of the formations. The value of this parameter can be conclusive for two types of equipments; namely dragline and bucket wheel excavator. If the value of uniaxial compressive strength exceeds 40 MPa, these equipments are neglected because;

i. For draglines; In surface lignite mines of Turkish Coal Enterprises (TKİ), the uniaxial compressive strengths of formations are less than 40 MPa limit where the draglines are the primary stripping equipments. Also, draglines work without blasting if uniaxial compressive strength is less than 5 MPa. Between 5 and 40 MPa range they work with blasting (Paşamehmetoglu, 1989).

ii. For bucket-wheel-excavators; the diggability ranges given by various researchers are below the 40 MPa limit.

According to Strazodka, as it is seen in Table 3.2., bucket-wheel excavators operating in rocks are not able to dig formations with uniaxial compressive strengths of more than 20 MPa (Wade et.al., 1987).

Table 3.2. Strazodka Criteria (Wade et al., 1987)

Class	Diggability Rating	Range of F_p^* (MPa)
1	Diggable	< 1.5
2	Difficult to dig	1.5 - 2.0
3	Not able to dig	> 2.0

* The term F_p is defined as (uniaxial compressive strength / 10).

In Monenco criteria, the upper limit of diggability is also lower than 40 MPa limit (Wade et al., 1987) as seen in Table 3.3.

Table 3.3. Monenco Criteria (Wade et al., 1987)

Class	Diggability Rating	St^1 ($\mu\text{sec/m}$)	Qu^2 (MPa)	Max Thick. ³ (m)	F_a^4 (MPa)	R_a^5 (MPa)
1	Easy diggable	>500	<2	No limit	<.15	<.17
2	Diggable	420-500	2-10	2.0	.15-.4	.17-.36
3	Difficult to dig without light blasting	320-420	10-20	.5	.4-1.25	.36-.54
4	Diggable only with light/med blasting	260-360	20-30	<.5	1.25-5.25	.54-.80
5	Frag. Blasting	<260	>30	0.0	>5.25	>0.8

where 1 is the seismic wave velocity,

2 is the uniaxial compressive strength,

3 is the maximum thickness of digging,

4 is the specific cutting force obtained in laboratory with wedge test,

5 is the specific digging force obtained in field on a bucket wheel excavator.

In another diggability chart for bucket wheel excavators, developed by Wade and Clark (1989), the upper limit of diggability is again below the 40 MPa limit and diggability range without blasting is about 5 MPa as Gorylewicz describes (Table 3.4.).

Table 3.4. Comparison of BWF Diggability Criteria
(Wade and Clark, 1989)

Class	Digging Resistance	Compressive Strength (MPa)				Estimated Productivity (%)
		Highvale	Goonyella	Gorylewicz	Wade & Clark	
1	Easy	0-8	-		0-8	100
2	Diggable	8-16	-	0-5	8-16	75-100
3	Hard	16-20	10	5-10	16-20	50-75
4	Marginal	20-25	15	10-45	20-25	50-
5	Undiggable	25+	-	45+	25+	-

In above criterias, the undiggability margin for bucket wheel excavators are below 40 MPa and diggability margin with high efficiency without blasting is 5 MPa. For this reason, the upper limit of diggability was selected to be 40 MPa and diggability margin without blasting as 5 MPa.

For the other equipment types, as seen in Table 3.1., remaining parameters of the classification table, in addition to the uniaxial compressive strength are asked and a rating is found, since in the classification table diggability classifications are given according to the rating of parameters.

If the diggability rating is between 0 and 25, then the diggability class is "Easy", all of the excavating equipments are assumed to excavate the formations.

If the diggability rating is between 25 and 45, the diggability class is "Medium" and the classification of equipments are as follows;

- Hydraulic excavators (Hydraulic shovel and Backhoe) can excavate the formation directly,
- Electric excavators can excavate the formation with blasting,
- Front end loader can work in this formation with ripping. Since the diggability power of front end loaders are less than other excavating equipments and it loads rather than digs as described by White (1973), Berg (1978), Chironis (1980),

Chironis (1983b), Pfleider (1972), Fung (1981).

If the diggability rating exceeds 25, then front end loaders will work with ripping to excavate the formation.

- Dozer alone can excavate the formation.
- Scraper is assumed not to be able to excavate the formation, because it is mostly employed in removing topsoil or soil-like formations due to its inability to excavate harder and largely-fragmented rock formations. Pfleider (1972), Fung (1981), Chironis (1983b), Pearse (1984), Chironis (1981) discuss the use of scrapers in relatively soft formations. Because of this reason, scrapers will be disqualified from the equipment list if the diggability rating exceeds 25.
- Dozer-scraper combination can excavate the formation, since dozer can rip and scraper loads and hauls the waste material.

If the diggability rating is between 45 and 65, the diggability class is "Medium-hard", and the classification of equipments are as follows;

- Hydraulic excavators need blasting to excavate the formation,
- Electric excavators need blasting to excavate the formation,
- Front end loader can excavate the formation with ripping,

- Dozer alone can excavate the formation,
- Scraper cannot excavate the formation,
- Dozer-scraper combination can excavate the formation.

If the diggability rating is between 65 and 85, then the diggability class is "Hard", the classification of equipments are as follows;

- Hydraulic excavators need blasting to excavate the formation,
- Electric excavators need blasting to excavate the formation,
- Front end loader cannot excavate the formation, since the available most powerful dozer can very poorly rip the formation,
- Dozer cannot excavate the formation since ripping cannot be performed,
- Dozer-scraper combination cannot excavate the formation, since again dozer cannot rip the formation.
- Scraper cannot excavate the formation,

If the diggability rating is between 85 and 100, the diggability class is "Very-hard", the classification of equipments are as follows;

- Hydraulic excavators need blasting to excavate the formation,
- Electric excavators need blasting to excavate the

formation,

- Front end loader cannot excavate the formation,
- Scraper cannot excavate the formation,
- Dozer cannot excavate the formation,
- Dozer-scraper combination cannot excavate the formation.

3.2. Basic Parameters to Select the Open-pit Excavation Equipment

Parameters listed below are thought to be among the major parameters to be determined to select the excavation equipment.

3.2.1. Annual Production

Annual production is one of the most important parameters in that as the annual production increases, then the larger excavation equipments should be considered. Since smaller equipments like front end loaders, dozers, scrapers are not capable to make huge amounts of stripping, they are favored if the annual production of overburden removal is low which may be less than 2-3 million cubic meters.

3.2.2. Life of the Mine

The projected life of the mine has a greater impact on the selection of open-pit excavation equipment. As Pearse (1984) states, equipments with high service lives

like draglines, bucket wheel excavators and shovels are disadvantageous in mines with short projected mine lives.

3.2.3. Overburden Thickness

Average thickness of overburden overlying coal seam(s) is one of the major parameters which should be considered with care. This parameter is especially important for equipments with limited reach capabilities like dozers or scrapers which can compete with thicknesses of up to 90 ft (27 m) as Wiebmer (1979) states. A huge dozer can remove overburden up to 70 ft (21 m) thickness as Chironis (1986) describes. If the thickness increases, then equipments working in benches or working with hauling units may be favorable.

3.2.4. Length of Haul Road

This is another important parameter in selection of a proper equipment. If the waste overburden should be moved to the waste area more than 150 meters, then the use of dozers and draglines may be inhibited due to shorter reach of them as discussed by Fung (1981), Ramani et. al., (1976). Requirements of longer haulage distances favor the use of equipments which work in combination with hauling units, e.g. shovels, scrapers, front end loaders as discussed by Pearse (1984).

3.2.5. General Topography

Because many of excavation equipments are capable to work in most of the topographically varying areas, there is a general rule of thumb that as topography gets steeper, use of smaller and mobile excavation equipments are favored. Stefanko et. al. (1973), Stefanko (1983), Ford et. al. (1975) give examples of equipment usage in varying places as related to differences in topography and equipments in accordance with the above rule of thumb.

3.3. Parameters Relating to Water Conditions in the Pit

Parameters of this group are used to get information about the water condition in the pit. These parameters are important, since the existence of water may change the selection of equipments.

Kumaraswamy and Mozumdar (1987) states that, if the coal seam(s) or part of the overburden lies beneath the ground water table, there will be water problem in the pit and huge amounts of water may be required to be pumped out of the pit. In such a situation, equipments working on coal seams or at the toe of the benches like dozers, shovels, scrapers are affected adversely while draglines and backhoes may be preferred.

Amount of rainfall is another important parameter for particular excavation machinery as described by

Kumaraswamy and Mozumdar (1987). If seasonal rainfall exceeds a certain amount, e.g. 100 mm/month, then bucket wheel excavator's performance is greatly affected.

The possibility of the floor of benches to be flooded would be disadvantageous for the equipments working at the toe of bench, on the other hand, equipments like dragline or backhoe are not affected (Anon., 1977).

In mountaneous or steeply sloping areas, spoil pile stability, if water is in contact with them, is a problem as Stefanko (1983) states. In such a case, equipments forming spoil piles will not be favored.

3.4. Parameters Relating to Topsoil

The condition of the topsoil affects equipments. If the topsoil is slushy, the water sweeps through tracks causing breakage of links between them as discussed by Kumaraswamy and Mozumdar (1987). In this case, equipments on crawlers like bucket wheel excavators, hydraulic and electric excavators, dozers will be affected adversely.

Heavy root systems of vegetation may cause clogging problems for bucket wheel excavators. Ford et. al. (1975) explain this situation, and if vegetation is not cleared off, this equipment cannot be preferred.

In case when reclamation will not be performed, because all the topsoil is not removed, the topsoil may not carry the weight of large excavation equipments. Pundari (1981) discusses this problem and states that this condition may be disadvantageous for larger equipments such as draglines and bucket wheel excavators.

3.5. Parameters Relating to Topography

The altitude is important for diesel-driven equipments in that a diesel engine loses 3% of the gross HP for every 1000 ft. (304.8 m) above sea level as described in (Anon., 1979). As the elevation increases, to use electric-driven equipments e.g. draglines, shovels, bucket wheel excavators become advantageous.

The use of mining area after mining operations are completed is important due to the fact that some equipment types are capable to regrade the area to its original position. If reclamation will be performed, then scrapers or shovel-truck combinations can be favored, because as they remove the waste, at the same time they perform the reclamation as Chironis (1983b) states.

3.6. Parameters Relating to Highwall and Spoil-pile Stability

The first parameter is the occurrence of outsized boulders within the formations. Existence of such boulders highly affects bucket wheel excavator

performance, however, hydraulic shovels are capable to selectively pick up oversized boulders as discussed by Merritt (1978).

Stability of highwalls is especially important for equipments working under highwalls. If there exists the possibility of highwall failure, then equipments working on highwalls like draglines, are preferable as Chironis (1983a) states, or equipments capable of working in benches can be preferred (Anon., 1979).

Landslides occurring in spoil piles favor use of excavation units with haul trucks or self-hauling equipments. This feature is important especially in mountaneous areas where spoil piles are located on the outsoles of the pit as explained by Stefanko (1983).

Material falling or rolling from benches or highwalls may cause injury or damage as Chironis (1983a) states. In this case machinery working at the toe of benches may be subject to falling rocks and spoil which can break and wear mechanical parts of equipments working at the toe of benches. Also lubrication of crawlers of these equipments may not be performed frequently as Ford et. al. (1975) explain.

Instability of spoil piles can sometimes cause low coal recoveries due to frequent covering up of coal seams resulting in low production rates and high mining costs as expressed by Hird (1980).

3.7. Parameters Relating to Mine Economics

When the economics of selection is concerned, available fund to purchase the mining machinery becomes a very important item as expressed by Chironis (1983b), White (1973) and Wiebmer (1979). In case where the available fund is limited, then large equipments will be affected adversely while smaller ones will not.

If the expansion and contraction of operations are likely to happen in the mine, then smaller equipments will be more adaptable to changing conditions than larger ones as Chironis (1983b) and Stefanko (1983) state.

Another consideration about these equipments is the delivery time of them. Wiebmer (1979) states that large equipments will take a number of years to be delivered and erected to start mining activities which can be a disadvantage of them if the mine owner wants to start mining quickly. In such a condition, smaller equipments are preferred.

3.8. Parameters Relating to Coal Seams

When coal seams are considered, one of the most important parameters is the number of coal seams present in the mine. This parameter is especially important for direct dumping systems in that if there are more than one coal seam, then due to reach problems or flexibility requirements of the operation, excavation equipments

working with hauling units may become advantageous over those with direct dumping systems (Anon., 1976).

Another parameter of this group is the support characteristics of coal seams. Varying support characteristics of coal seams affect large equipments more adversely than smaller ones if they are working on coal seam to remove the overburden. Coal seams can poorly support large excavation equipments as discussed by Fung (1981) and Ramani et. al. (1976). In this case shovels and bucket wheel excavators may not be preferable.

Among other parameters, the position of coal seams are also important. In case of dipping coal seams, because as mining progresses, amount of rehandle rate increases due to increase in overburden thickness, Chironis (1983a) state that to use direct dumping systems, like draglines, may be disadvantageous. Also if coal seams are pitching, then selective mining is required and equipments capable of this ability e.g. hydraulic shovels, are favored as discussed by Merritt (1978). Presence of stray seams is another point to be considered. If these seams are planned to be extracted, then the mining strategy can be changed. Finch and Fidler (1980) discuss this situation.

3.9. Parameters Relating to the Equipments

Parameters listed below are relating to expectations from the equipments and to their capabilities.

The first parameter to determine basic requirements of excavation equipments is the capability of the excavation equipment to construct access roads between pit and waste area. As described by Pfleider (1972), Fung (1981) and Ford et. al. (1975) only particular types of equipments, like front end loaders or dozers are capable to perform this job.

High availability is one of the major basic requirements expected from an excavation equipment. However, because of their natures, some equipments, like electric shovels are very robust and highly available even in most difficult digging conditions (Anon., 1979).

In very cold places, excavation equipments may face a number of problems. While diesel-driven engines have starting problems, draglines will have material sticking, heating and greasing problems with their buckets while bucket wheel excavators will have conveyor related problems as Ford et. al. (1975) discuss.

Operator fatigue is another parameter to be considered. This parameter, even has minor importance on equipments, can rank them according to fatigue since

operators of some equipments e.g. hydraulic backhoe, dragline are subject to less fatigue when working (White, 1973), (Anon., 1982).

When the hauling units are subject to severe loading impacts, then excavation equipments working with hauling units, like shovels, front end loaders, will be unfavorable when compared to direct dumping systems (Pfleider, 1972).

Due to some conditions, such as the existence of more than one coal seam, or irregularity of coal seams or the topographical location of the mine, the mobility feature may gain importance. In such a case, as their names imply, mobile equipments like scrapers, front end loaders become popular as White (1973) expresses.

Maintaining spoil piles is another important feature that particular equipment are capable to perform. If there exist water problem in the pit or if spoil piles are sliding and consequently preventing coal extraction covering coal seams, then equipments which are able to do this job may be preferred like dozers or front end loaders as Pfleider (1972) describes. When water is a problem in the pit and the primary excavation equipment will be employed also as a utility tool, then small equipments capable of moving pipes and pumps such as front end loaders, will be advantageous against others as Pfleider (1972) states.

Among others, loading overburden from left pockets is another parameter. Pfleider (1972) states that this is meaningful especially in geologically disturbed zones of coal seams where dilution is a big problem if mined with a large excavation machinery. A typical equipment can be a hydraulic shovel.

Service life of excavation equipments is another point to be considered by the mine owner. A number of researcher give service life of various excavation equipments, among them, White (1973), Pfleider (1972), Wiebmer (1979), Chironis (1983b) can be listed. If the life of the mine will be long, then mine owner is faced a number of choices of mining machinery with long or short service lives. However, if the life of the mine will be shorter, then large equipments will be disadvantageous due to their long service lives.

Utility is a dummy parameter in this group, however it directs the search mechanism according to the reply assigned to it. If the user or mine owner wants the excavating equipment to be employed as a utility tool, then a number of questions are asked to the user to determine which particular features an equipment should have. Towing disabled vehicles is one of the utility jobs that the excavation equipment perform, if it will be used as a backup tool. White (1973) and Pfleider (1972) state that only a few of excavation equipments can do this like dozers or front end loaders. Also the equipment may

perform moving pumps and pipes, digging ditches in the mine.

3.9.1. Parameters Relating to Haul Roads

In mines, if conditions of haul roads are poor, then these roads should be maintained to ensure good haulage of waste overburden. As Pearse (1984) discusses, a few number of equipments are capable to perform this activity, e.g. dozers, scrapers. If road surfaces are to be maintained, then these equipments will be favorable.

Construction of haul roads is another consideration of excavation equipments. If this property is desired, again, equipments like dozers, scrapers, front end loaders will become popular as Pfleider (1972) and Fung (1981) state.

Excavating equipments which work with hauling units to move the waste will be assumed slightly unfavorable if haul roads to be constructed will have sharp turns that work against them and cause cycle times to be increased as Stefanko (1983) describes.

Another parameter that works in the same way with the sharp turns is the existence of steep ramps. Since particular types of haulage equipments cannot negotiate steep grades, then this could be a disadvantage of equipments working with haulage units as Stefanko (1983) describes.

3.10. Parameters Relating to General Mining Activities

First parameter is the starting to mining with a box-cut or not. This parameter is important especially in areas of very gentle slopes or flat topography with flat-lying coal seams, in which to reach them an initial box-cut should be opened. In such a case, draglines are preferable (Anon., 1979).

Second is the construction of bridges across the mined-out pit. Since haulage of waste overburden is one of the major cost items in overburden removal, the means to shorten haul ways would favor or keep the excavation equipments working with hauling units from being unfavorable as discussed by Chironis (1983b).

Another parameter is the disturbance of adjacent land. This parameter gains importance in more hilly, mountaneous areas where probable spoil piles may cause landslide problems which can be said to be a disadvantage of direct dumping systems like a dragline as Stefanko (1983) mentions.

Installation of electricity gains importance in places remote from the national electric network system. In this case installation of electricity may take a considerable amount of time. This may be a disadvantage of electric-driven equipments (Anon., 1980).

Prebench is, as its name implies, the capability to make prebenching if needed. This condition may arise if the thickness of the overburden is slightly more than the digging-depth capability of excavation equipment, here, as Chironis (1986) states, scrapers, front end loaders or shovels are capable to perform this job.

Climbing is another parameter related to excavation equipments. If the place of the mine is mountaneous or very steep, then equipments may have to climb steep grades to move between pits or benches as Merritt (1978) explains. If the grades will be considerably high, draglines or bucket wheel excavators are seriously affected.

Maneuvering space is another parameter to classify equipments according to the width of the pit. If it is limited perhaps due to topographical reasons, then smaller equipments become more favorable (Anon., 1977).

To determine whether pit width will be suitable for excavation machinery to work properly or hauling units to move in the pit, pit-width is important. The narrow the pit, the more disadvantageous the equipments working with hauling units.

3.11. Parameters Relating to Overburden Characteristics

For larger excavation equipments, like dragline, bucket wheel excavator and stripping shovels, one of the most striking parameters is the bearing capacity of ground. Stefanko et. al. (1973) give an example of a dragline pit with ground preparation due to the incompatibility of ground. Should this situation occurs, larger excavation equipments are adversely affected.

It is known that electric-driven machines can achieve more than 90% availability, compared with 70-80% for diesel-driven equipments. A diesel-driven engine loses 1% of the gross HP for every 10°F (5.56°C) above 60°F (15.56°C). In places with high average weather temperatures, diesel-driven excavation equipments will become disadvantageous compared to electric-driven ones (Anon., 1979).

The type of material to be hauled also affects the type of hauling unit which in turn affects the excavation machinery. If the material is large rock, then bucket wheel excavator-conveyor combination will not be suitable to this condition due to the incompatibility of conveyors in handling large-sized waste (Pfleider, 1972).

Size of the material to be hauled is another parameter to be considered. Because some kinds of equipments are very sensitive to material size, like

scrapers which cannot handle materials greater than about 200 mm. size as Pearse (1984) states.

Pearse (1984) states that condition of the haul roads, if poor, soft, muddy or rough significantly affects the cycle times of hauling units. If the haul roads will need frequent preparation, then excavation equipments working with haul units will be disadvantageous.

The support ability of overburden is important in places with water-saturated sediments. In this case, undisturbed material may not support spoil piles formed by a large dragline. Hird (1980) states that spoil piles may be very large due to high water content of the waste material. Here, equipments forming spoil piles will become disadvantageous.

If there are bands of reject material above coal seams, at nights or in poor visibility conditions these may dilute the coal extraction as Pundari (1981) states. In such a case, higher equipments which have poor visibility compared to smaller ones will be affected adversely.

Breaking of rock particles into satisfactory size is important due to loading and hauling purposes. When after ripping and blasting rock particles are not in a size that can be handled by a front end loader or a scraper, then these equipments will be affected

adversely (Anon., 1965).

Selectivity in operations is one of the major advantages of hydraulic mining shovels, if selectivity is a must in excavation then these equipments will be awarded (Anon., 1977).

Wear on bucket of excavating equipment may be high due to high clay and quartz content or longer duration of contact with the soil. Kumaraswamy and Mozumdar (1987) state that such a condition may cause problems for bucket wheel excavator operations.

3.12. Use of Parameters in the Developed System

3.12.1. Selected Expert System Tool

In developing the expert system, PCPLUS is used. PCPLUS, an acronym of PERSONAL CONSULTANT PLUS, is an expert system shell in which knowledge-based systems can be implemented.

The system runs on IBM Personal Computer compatible machines with at least 512 k Bytes of memory, the favorable amount being 768 k Bytes and at least 10 M Bytes of harddisc drive (User's Guide, 1985).

The core rule-based functionality of PCPLUS is modeled after the EMYCIN system developed at Stanford University in the 70s. The core knowledge components of PCPLUS are; FRAMES, to organize knowledge into manageable

units, PARAMETERS, to represent facts associated with a given situation and RULES, to enforce consistency and specify how additional factors can be determined.

Frames organize a knowledge base into smaller, related subtopics. The frames in the knowledge base are listed in a hierarchical tree. They can be used to represent physical structure, subproblems, individual events and any other conceptual relationships that exist in the application. In each frame exist parameters and rules to solve the subproblem associated with that frame.

Parameters are items representing facts about a problem domain. They take on values during consultation like the variables in conventional programming languages.

PCPLUS contains rules to make deductions between parameters. Every rule has a premise (IF clause) to be evaluated to determine if its action (THEN clause) is to be applied.

PCPLUS supports both backward-chaining and forward-chaining methods, the former being the default search method. The forward-chaining method is supported by ANTECEDENT rules.

The use of uncertain information is a standard part of PCPLUS and can arise when the user is unsure of a response or when a rule with an unsure conclusion is

encountered. The certainty of a rule's action is based upon both the certainty factors which are numeric measures of confidence, associated with the parameters and the certainty of its conclusion. The certainty factor range to be assigned to a parameter ranges from -100 to +100.

3.12.2. Frames

The developed system consists of 9 frames. The equipment selection problem is divided into sub-problem domains that handle the problem considering the parameters relevant to them. By this way in each frame, equipments can be listed separately according to the conditions of each frame.

The frames in the knowledge base are as follows; Diggability frame, Mining frame, Water frame, Highwall-Spoil frame, Topography frame, Coal-seam frame, Economy frame, Topsoil frame, Equipment frame and lastly the Root frame (Figure 3.1.).

Diggability frame determines whether the formations in the mine are diggable with the excavating equipments in the list or not. Because of this reason this frame is the most important one among others in that it is capable to make a preliminary election of equipments.

OPEN PIT EXCAVATING EQUIPMENT SELECTION SYSTEM

Frames :
DIGGABILITY
TOPSOIL
ECONOMY
COAL-SEAM
HIGHWALL-SPOIL
WATER
EQUIPMENT
TOPO
MINING
ROOT

Figure 3.1. Frames in the Knowledge Base

Mining frame contains major parameters like the annual rate of production, life of the mine, overburden thickness etc. which can be said to have majority over others. Also in this frame parameters relating to general pit conditions are included.

The domain of water frame is to determine whether existence of water in the mine can affect the equipments or not.

In highwall-spoil frame, the stability of highwalls, benches and spoil piles are investigated.

In topography frame, general topographic parameters are directed to the user.

Coal-seam frame consists of parameters that are used to determine the characteristics of coal seams.

Economy frame has parameters with the available fund and delivery times of equipments.

Topsoil frame contains parameters about vegetation, water condition and bearing capacity of topground.

Equipment frame has a number of parameters each representing a different capability of excavating equipments. So this frame is used to get information about the expectations of the mine owner from equipments.

Finally, the root frame contains parameters related with the characteristics of the overburden.

3.12.3. Parameters

Parameters in each frame are utilized to get information about the specifications of the mine from the user. The developed system has only one goal parameter of which the value is traced, namely EQUIP, all of the rules in the system were written to find the possible value of this parameter.

In diggability frame, parameters prompted for to determine the total rating which in turn is used to classify the equipments are; the uniaxial compressive strength of the formation, seismic wave velocity, average joint spacing, hardness of the formations and degree of weathering.

Other parameters which can largely affect the choice of excavating equipments are asked in mining frame. These parameters are; annual rate of production, projected life of the mine, overburden thickness, distance to move the overburden and the topography of the mine area. These five parameters are assumed to have more impact on equipment selection and they assign large certainty factors to equipments in the list than others. Among other parameters in the mining; starting of mining activities with a box-cut, climbing needed for excavation equipments, width of the pit, construction of long

overburden panels, prebenching requirements, disturbance of adjacent land, bridges between pit and waste area can be mentioned.

The water parameters also play a deterministic role in equipment selection. Presence of water in the pit and parameters asked depending on this condition may change the previously favored equipment.

Highwall and spoil-pile stability parameters, if answered in a way to unfavor the equipments working at the toe of benches, affect them largely. Also existence of huge boulders affect bucket wheel excavator worsely while instability of spoil piles makes a dragline to be assigned a negative certainty factor.

Topography parameters take into the consideration the elevation which, in high lands affect the diesel-driven equipment. The after-mining use of the area, the dimensions of the mining place are contained in the topography frame.

Coal-seam parameters are among important parameters in this program. Here, the number of coal seams, thickness of parting between coal seams, support characteristics of the coal seam, presence of stray seams are asked to user.

In economy parameters, available fund and the delivery of equipments determine the choice.

Among topsoil parameters, bearing capacity of topground affects large equipments while heavy plant rooting is important for bucket wheel excavator, also condition of soils affects crawler-type equipments.

Equipment parameters are composed of various capabilities of equipments. All of them are asked to user to determine the most likely equipment capable of performing the user's desires. Among the parameters; availability, service life, operator fatigue, spoil-pile maintaining, road surface maintaining, haulroad construction, mobility can be mentioned.

Final parameters are root parameters which mostly relate to the characteristics of the overburden. Some of those parameters are ; type of material to be hauled, support ability of overburden, wear occurring in bucket teeth, visibility of reject materials.

3.12.4. Rules

Rules used in the program are of two types. The first type of rules is directly assigning certainty factors to the equipments according to the results of the parameters. Here, the system does not trace the parameter's value, instead after prompting the value for a parameter it directly applies the THEN part of the rule to conclude the parameter (Figure 3.2.).

OPEN PIT EXCAVATING EQUIPMENT SELECTION SYSTEM

Rule 70 :
IF : PILEWATER
THEN: EQUIP =*
DRAGLINE -10
SHOVEL 10
BWE 10
BACKHOE 10
HYDSHOVEL 10
SCRAPER 10
DOZER -10
FEL 10
DOZ-SCR -5
UTILITY: 10

Figure 3.2. Example of Directly Certainty Factor Assigning Rules

Second type of rules is tracing rules. If a parameter's value is depending on the value of another parameter then the second parameter's value is traced and the result of this parameter becomes the input of the first parameter. To do this, dummy rules are utilized to conclude the goal parameter. Here, more than one rule can be tried. For example in the rule 272, the value of NOSTRAY is traced to apply the THEN part of the rule (Figure 3.3). To prove that the value of NOSTRAY is YES, a rule is searched of which the THEN part contains the parameter NOSTRAY, this rule is the rule 271 (Figure 3.4.). But, again to prove that NOSTRAY is YES the IF part of rule 271 should be satisfied. For this reason another rule is searched which contains parameters STRAY2 or STRAY3 in its THEN part. This rule is the rule 269 (Figure 3.5.). By asking to the user the value of STRAY and STRAYEXT the goal parameter can be concluded.

Parameters that directly apply certainty factors and candidate equipments and certainty factors that are assigned to equipments are given in Appendix A.

OPEN PIT EXCAVATING EQUIPMENT SELECTION SYSTEM

Rule 272 :

IF : NUMSEAM = 1 AND NOSTRAY AND SUPPORT = GOOD AND SEAMPOS = FLAT

THEN: EQUIP =* DRAGLINE 10
SHOVEL 10
BWE 10
BACKHOE 10
HYDSHOVEL 10
SCRAPER 10
DOZER 10
FEL 10
DOZ-SCR 10

UTILITY: 12

Figure 3.3. Example of Tracing Rules, Step 1

Rule 269 : _____

IF : STRAY AND ! STRAYEXT

THEN: STRAY2

UTILITY: 12

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4. EVALUATION OF THE DEVELOPED EXPERT SYSTEM

4.1. General

In this study, a knowledge-based expert system was developed to help selecting excavation machinery to be employed in overburden removal in open-pit mines.

The system contains a list of equipments all of which are currently used in surface mines individually or in combinations. The equipments are;

- i. Dragline
- ii. Bucket wheel excavator
- iii. Electric excavator
- iv. Hydraulic excavator
- v. Hydraulic backhoe
- vi. Front end loader - ripper combination
- vii. Scraper
- viii. Dozer
- ix. Pusher - scraper combination

Among these equipments, some of them are assumed to be working without hauling equipments, these are dragline bucket wheel excavator, dozer, scraper and ripper - scraper combinations which perform excavation and hauling operations by themselves. However, electric and hydraulic excavators and front end loader-ripper combinations were assumed to be only digging the soil while trucks are

performing hauling of waste material.

Stripping shovels were not included into the equipment list because of their very limited reach which is a disadvantage as overburden thickness increases and the reason that no big stripping shovels were constructed for about two decades (Fung, 1981).

4.2. Search Strategy of the System

The developed expert system has a search mechanism which starts from the most important frame and continues through other frames. The reason is; it was decided that the most important feature for an excavating equipment is its capability to excavate the formations in the mine. Should an equipment is not capable to perform this very important duty, it will be worthless even it is found to be proper to be utilized by most of other parameters. For example, in a mine with extremely hard digging conditions, utilization of a bucket wheel excavator would be meaningless due to its comparatively low digging power even remaining conditions favor the use of it. Another reason is that, diggability is the only frame which can elect some equipments from the equipment list absolutely by assigning them the available largest negative certainty factor which is -100.

The search is continued by analyzing the parameters of mining frame. The searching rank of the system is

presented in Figure 4.1. Mining frame is assumed to contain the important parameters to determine the most likely excavating equipment. So its place is beneath the diggability frame in the searching rank. This frame contains parameters like the annual rate of production, the projected life of the mine, thickness of the overburden, etc. all of which could be said to be conclusive parameters.

After leaving the mining frame, the number of candidate equipments drops to a smaller number, or in other words, some of the equipments can be said to be lucky against others, because, parameters in diggability and mining frames have more influence on the selection of excavating equipments than others.

The search continues with water frame in which parameters are devoted to determination of the position of equipment in the existence of water in the pit. If there is no water problem in the pit, then this frame will be passed.

Following water frame comes the stability frame. Also in this frame, parameters are used to determine the stability of highwalls and spoil piles. If there will be a possibility of instability of spoil piles, then equipments forming spoil piles will be assigned negative certainty factors, while in case of unstable benches and highwalls, equipments working under benches will be

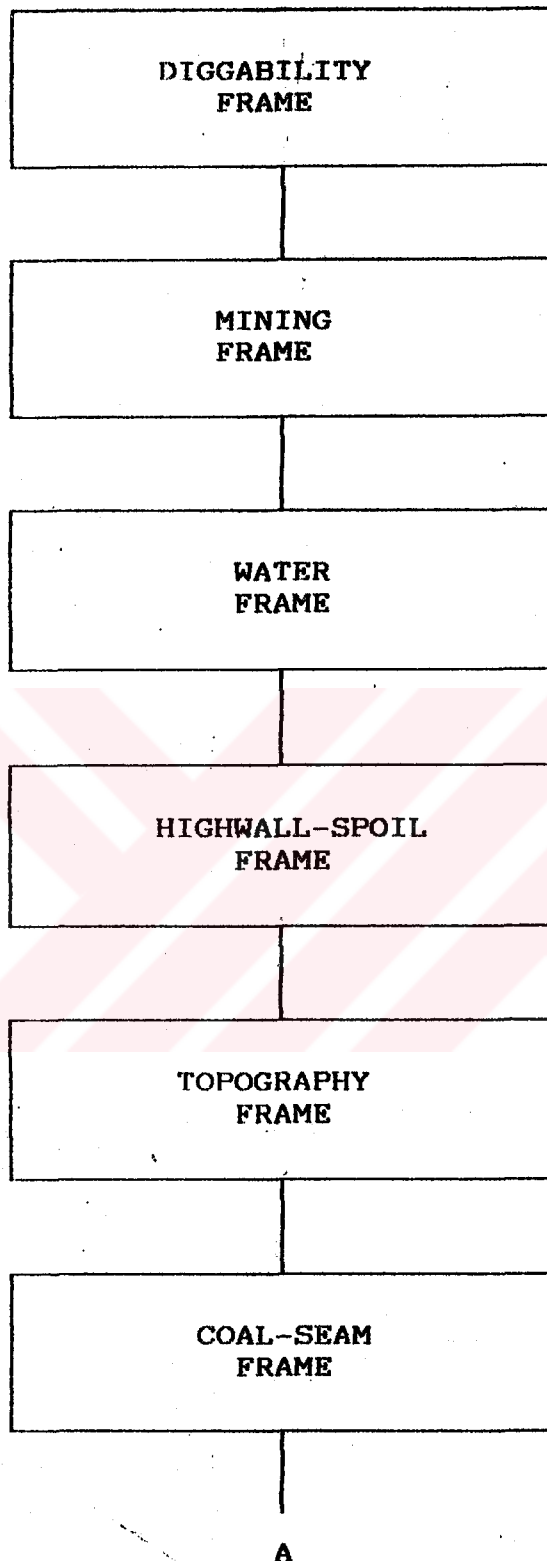


Figure 4.1. The Searching Rank of the System.

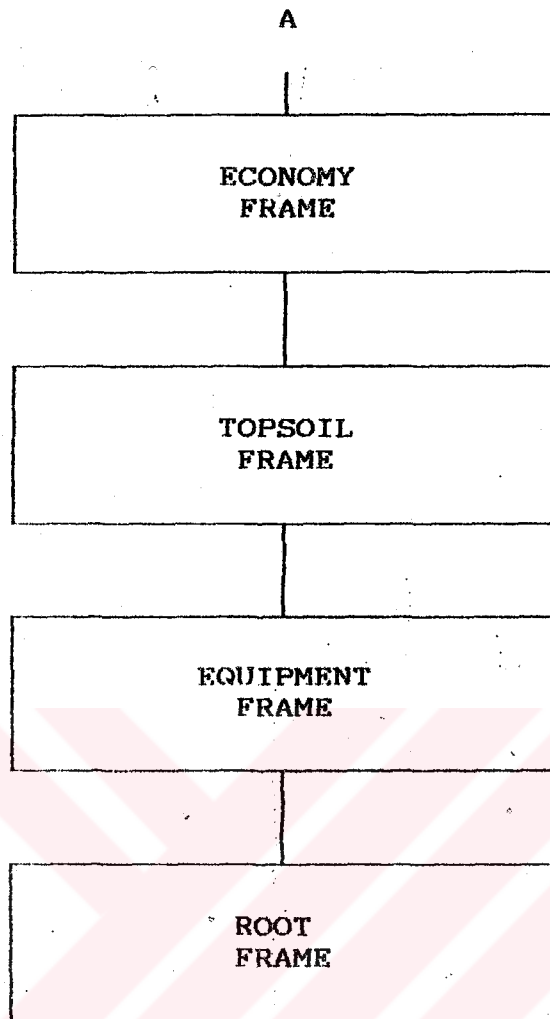


Figure 4.1. Continued

assigned negative certainty factors.

The search continues with the topography frame. Here, mostly, use of mining place after operations are completed is discussed. In case of reclamation and regrading to original contours of the soil requirements appear, some equipments are affected adversely while others with hauling units are assigned positive certainty factors. Also, in this frame equipments are ranked according to the elevation which, if high, affects diesel-driven equipments.

After finishing parameters of topography frame, coal-seam frame is entered. The aim of this frame is to determine whether some equipments could be affected adversely when there exists more than one coal seam or when the support characteristics of coal seam is poor or when coal seams are dipping.

When searching through economy frame, system tries to find equipments against existing monetary restrictions, and delivery specifications of equipments.

Topsoil frame is beneath the economy frame in searching rank, it deals with the possible problems that might arise if reclamation will not be performed.

In equipment frame, system tries to learn the expectations of users from excavation equipments. For this purpose a number of questions are directed to the

user.

The final frame is the root frame to be searched. Even this frame is the last one in searching rank, it is not of the least importance one among others. This frame is entered at the end of searching to prevent mistaken instantiations of frames and to ensure a good search throughout the knowledge base. This frame is searched to take information about the physical characteristics of the overburden.

4.2.1. Certainty Factor Association into the Rules

The developed system consists of more than 220 rules. These rules, as explained before, work with certainty factors. The system has only one goal parameter to trace its value and find a solution. For this reason a large part of the rules in each frame contain parameters which directly assign a certainty factor to the goal parameter. The remaining rules are used as dummy rules to change the direction of searching.

Parameters which directly apply a certainty factor to the goal parameter have a prompt property. By this way, they appear as questions to the user during consultation. Other parameters which do not have this property are called as intermediate parameters and are not asked to the user, instead they only take the replies assigned to initially asked parameters and change direction of the search mechanism.

To include the uncertainty about a subject into the problem, most of the parameters have certainty factor ranges to determine how much the user is certain in his reply to the question.

During consultation, according to the replies assigned to the parameters, each equipment in the list is given a certainty factor which can be positive or negative. Every parameter is treated in the same manner during consultation and certainty factors assigned to equipments are added. At the end of consultation, equipments are listed in descending order according to their cumulative certainty factors. If an equipment is affected very adversely from questions, and its cumulative certainty factor is negative, then it appears in the list with a "Not" in front of it, meaning that it is not a proper equipment for the conditions.

4.3. Sample Consultations and Evaluation of Consulting Process

If the developed system is desired to be consulted, then at the first screen which is the activities screen (Figure 4.2.), the "CONSULT" option should be chosen. By this way, the program can be consulted. Figure 4.3. shows an example of a parameter's prompt with a certainty factor range.

There are four sample consultations of the system to give examples of the results.

OPEN PIT EXCAVATING EQUIPMENT SELECTION SYSTEM

Activities :

CONSULT
DEVELOP
BUILD

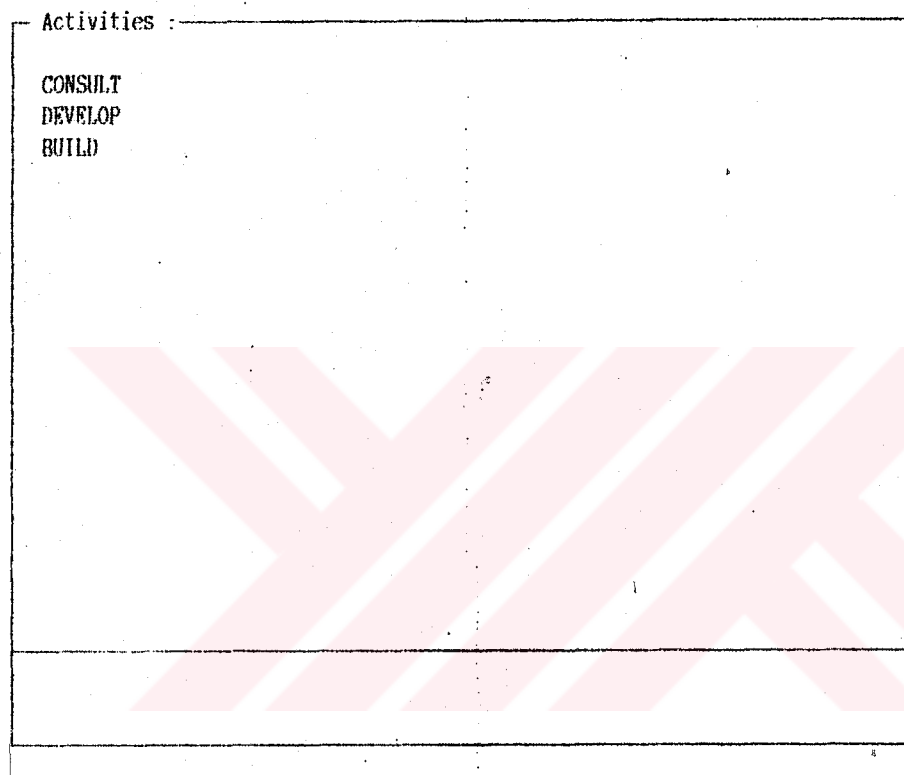


Figure 4.2. Activities Screen of the System

OPEN PIT EXCAVATING EQUIPMENT SELECTION SYSTEM

DO YOU BELIEVE THAT THE ROAD SURFACES ARE CAPABLE TO CARRY THE HAULING VEHICLES WITHOUT PREPARATION ?	
No	Yes
.....	YES/NO
1. Use the arrow keys or first letter of item to position the cursor	
2. Press RETURN/ENTER to continue	

Figure 4.3. Parameters asked with Certainty Factor Ranges

4.3.1. Sample Consultation 1

In the first consultation of the system, the aim was to select an excavating equipment that work properly in a mine, the general specifications of which are considerably high amount of annual stripping rate, no water problem in the pit, unstable highwalls but stable spoil piles, medium to medium-to-hard digging conditions.

Since the firstly entered frame is the diggability frame, parameters relating to diggability are started to ask to the user. As explained before, the most important parameter is the uniaxial compressive strength of formations in that if it exceeds 40 MPa., use of dragline and bucket wheel excavator are prohibited and they are taken out of the equipment list by assigning them the lowest negative certainty factor which is -100.

If an equipment is assigned -100 certainty factor at the beginning, it can never collect enough cumulative certainty factor in the coming questions and it is simply neglected. A punishment like this can be given to an excavating equipment only at the starting of a consultation where the cumulative certainty factors of all the equipments are zero. That's why the diggability frame is located at the top in consultation based on the previously made assumption that if an excavating equipment is not capable to perform digging, then it is worthless and only the diggability frame can assign

absolutely lowest certainty factors to equipments.

Here, the uniaxial compressive strength value is entered as 15 MPa which affects none of the equipments. After other parameters are entered, the diggability class is found as "Hard" which prohibits the use of front end loader, dozer, dozer-scraper combination and scraper as seen in Figure 4.4.

After diggability frame, the remaining bucket wheel equipments are dragline, bucket wheel excavator, electric shovel, hydraulic backhoe and hydraulic shovel.

In mining frame, annual rate of production is entered as "High" with a certainty factor of 60%. The value of this parameter favors large equipments. Then comes the projected life of the mine as "Long", again preferring large equipments. Thickness of overburden is "45 meters" which also works for larger equipments. The distance to waste area is "50 meters", this is especially striking for dragline because this value is within the reach range of draglines. If it would be entered a higher number then dragline would be punished very heavily. Topography is "Flat-to-rolling" which affects none of the equipments.

After these parameters, dragline and bucket wheel excavator collect the highest certainty factors, electric shovel follows them.

Among other parameters of mining frame, care is given to assign proper responses to questions to be consistent with the conditions of a large mine.

In water frame, parameters are entered in a way to indicate that pit water is not a problem in the mine, but because of heavy rainfall, bucket wheel excavator is affected adversely.

When consultation continues with Stability frame, presence of outsized boulders makes bucket wheel excavator lose a certain number from its cumulative certainty factor. Here since the spoil-pile stability is entered as "Good", dragline is not punished, but due to existence of unstable highwalls, bucket wheel excavator is assigned a negative certainty factor.

Bucket wheel excavator gains more certainty factor in the topography frame, because user wants to employ the mine area as farming fields after mining operations are finished, this means reclamation where bucket wheel excavator shines due to its excellent waste-removing system.

Economy frame does not affect these equipments, because the available fund is entered as "High" and delivery time of equipments can take a "long" duration of time which favor the use of large equipments.

In topsoil frame, the "Presence" of heavy plant rooting and "Slushy" condition of soil affect bucket

wheel excavator while dragline is not affected.

Most of the parameters in equipment frame are assigned "No" values. The reason for this is that in large mines excavating equipments perform only stripping work, they are not employed in secondary jobs. Since the mine is a large one, the equipment should only perform digging. So, this decision was reached not to be inconsistent with the goal of the mine owner. Finally, at the root frame, one of the important parameters is the wear of bucket of excavating equipment, which is meaningful for bucket wheel excavators. This parameter is given "No" value which does not affect equipments. Other is the capability of the ground to carry the weight of large excavating equipments. Also this was entered as "Yes" meaning that ground is capable to do this.

After about 70 questions, the final conclusion is reached. The most proper equipment is the dragline with a certainty factor of 92%, second equipment is the bucket wheel excavator with 79% certainty and third one is the electric shovel with 62% certainty as seen in Figure 4.4. Here, the difference between bucket wheel excavator and shovel is mostly caused from the distance of waste removal. Shovel is very disadvantageous compared to bucket wheel excavator since the distance is very short for costly truck hauling.

SAMPLE CONSULTATION 1

(" Consultation record for: (OPEN-PIT EXCAVATING EQUIPMENT SELECTION SYSTEM)"

"DIGGABILITY RULES... :: YES"

"UNIAXIAL COMPRESSIVE STRENGTH :: \"15\""

"AVERAGE DISCONTINUITY SPACING :: \"350\""

"SEISMIC VELOCITY :: \"2500\""

"WEATHERING OF THE FORMATIONS :: \"MODERATELY-WEATHERED\""

"HARDNESS OF THE FORMATIONS :: \"25\""

"JOINT SET NUMBER EXISTING IN THE FOR... :: \"ONE\""

"MINING PARAMETERS... :: YES"

"RATE OF ANNUAL PRODUCTION :: \"HIGH:60%\""

"THE PROJECTED LIFE OF THE MINE :: \"LONG\""

"THICKNESS OF THE OVERBURDEN :: \"45\""

"LENGTH OF THE HAUL ROADS FROM PIT TO... :: \"50\""

"THE TOPOGRAPHY AROUND THE MINE :: \"FLAT-TO-ROLLING:80%\""

"BOX-CUT TO START MINING ACTIVITIES :: \"YES\""

"HAULING ROAD BRIDGE ACROSS SPOIL PILES :: \"YES:70%\""

"DISTURBANCE OF THE ADJACENT LAND :: \"YES\""

"ELECTRICITY INSTALLATION :: \"YES:70%\""

"PREBENCHING OPERATIONS :: \"YES\""

"CLIMBING ABILITY OF EXCAVATING EQUIP... :: \"NO\""

"STEEP RAMPS IN HAUL WAY :: \"YES:70%\""

"SHARP TURNS IN THE HAULAGE WAYS :: \"YES:90%\""

"WIDTH OF THE PIT :: \"YES:50%\""

"SPACE FOR EQUIPMENT TO MANEUVER :: \"YES:60%\""

"LONG OVERBURDEN PANELS TO BE REMOVED :: \"YES\""

"WATER, GROUND WAT... :: YES"

"WATER CONTACTING WITH SPOIL PILES :: \"NO\""

"THE GROUND-WATER CONDITION :: \"NO\""

"AMOUNT-OF-RAINFALL :: \"YES:50%\""

"THE WATER SPILLING INTO THE PIT :: \"NO\""

"HIGHWALLS AND SP... :: YES"

"OUTSIZED BOULDERS WITHIN THE FORMATIONS :: \"YES:60%\""

"THE STABILITY OF HIGHWALLS :: \"NO:80%\""

"LANDSLIDING OF SPOIL PILES :: \"NO\""

"MATERIAL FALLING FROM HIGHWALLS :: \"YES\""

"SPOIL PILE STABILITY :: \"NO:70%\""

"FRAME CONTAINING... :: YES"

"THE ELEVATION OF THE MINE FROM SEA L... :: \"1234\""

"THE LAND PERMIT OF THE MINE :: \"LEASED\""

"THE CONDITION OF THE MINED OUT AREAS :: \"YES\""

"THE FARM-LAND POSSIBILITY OF THE MIN... :: \"YES\""

"THE AREA OF THE MINE :: \"YES:70%\""

Figure 4.4. Sample Consultation 1

"FACTS AND RULES WIT... :: YES"

"NUMBER OF COAL SEAMS PRESENT :: \"2\""

"STRAY SEAMS PRESENT :: \"YES\""

"EXTRACTION OF STRAY SEAMS :: \"YES\""

"COAL SEAM SUPPORT CHARACTERISTICS :: \"MODERATE:60%\""

"POSITION OF THE COAL SEAMS :: \"FLAT-LYING\""

"THICKNESS OF THE PARTING BETWEEN COA... :: \"6\""

"PARAMETERS AND RUL... :: YES"

"AVAILABLE FUND FOR EXCAVATION MACHINERY :: \"HIGH\""

"THE DELIVERY TIME OF THE EXCAVATION ... :: \"NO\""

"EXPANSION OF THE OPERATIONS :: \"NO\""

"TOPSOIL RULES AND ... :: YES"

"BEARING CAPACITY OF TOPGROUND :: \"YES:70%\""

"CONDITION OF SOILS :: \"YES\""

"HEAVY PLANT ROOTING :: \"YES:70%\""

"RULES AND PARAM... :: YES"

"ACCESS ROAD CONSTRUCTION ABILITY :: \"NO\""

"AVAILABILITY OF THE EXCAVATING EQUIP... :: \"YES\""

"SERVICE LIFE OF THE EQUIPMENT :: \"YES\""

"OPERATOR FATIGUE WHEN WORKING :: \"YES\""

"HAUL ROAD CONSTRUCTION ABILITY :: \"NO\""

"LOADING FROM OVERBURDEN POCKETS :: \"NO\""

"DUMMY PARAMETER :: \"YES\""

"MAINTAINING SPOIL PILES :: \"YES\""

"HAULING UNIT SUBJECT TO IMPACTS :: \"NO\""

"MAINTAINING ROAD SURFACES :: \"NO\""

"MOBILITY REQUIRED :: \"YES\""

"COLD WEATHER CONDITIONS :: \"NO\""

"DUMMY PARAMETER :: \"YES\""

"THE NECESSITY OF EXCAVATING SELECTIVELY :: \"YES\""

"WEAR OCCURRING ON THE BUCKETS OF BWEs :: \"NO\""

"SURFACE OVER WHICH MATERIAL IS MOVED... :: \"NO:70%\""

"BEARING CAPACITY OF WORKING LEVELS :: \"YES\""

"THE AVERAGE TEMPERATURE IN THE REGION :: \"22\""

"SUPPORT ABILITY OF OVERBURDEN TO SPO... :: \"YES\""

"VISIBILITY OF REJECT MATERIAL :: \"YES\""

"BREAKAGE OF ROCK PARTICLES :: \"YES\""

"MATERIAL TO BE HAULED :: \"LARGE-ROCK\")

SUITABLE EQUIPMENT is as follows:

DRAGLINE (92%) with blasting

BWE (79%) with blasting

SHOVEL (62%)

BACKHOE (35%)

HYDSHOVEL (35%)

Not DOZER (99%)

Not SCRAPER (99%)

Not FEL (99%)

Not DOZ-SCR (99%)

Figure 4.4. Continued

4.3.2. Sample Consultation 2

The purpose of the second consultation was to select an excavating equipment for a mine of which general specifications are hard digging conditions, medium amount of annual stripping rate, water problem in the pit, stable highwalls and spoil piles.

As explained before, the first frame instantiated is the diggability frame. Here, the uniaxial compressive strength of the formations is entered as 50 MPa. This value exceeds the 40 MPa limit of undiggability for dragline and bucket wheel excavator. So, these two equipments are eliminated from the equipment list. With entering other parameters of diggability frame, the diggability class is found as "Hard" and also the use of dozer, scraper, front-end loader and dozer-scraper combination are prohibited due to their insufficient digging power. The consultation progress is given in Figure 4.5.

After leaving the diggability frame, the equipments available to be used in the mine are hydraulic shovel, hydraulic backhoe and electric shovel.

In the mining frame, annual production rate is entered as medium with 80% certainty. This parameter's value does not affect any particular equipments currently standing in the list. The thickness of the overburden is entered as "35 meters", the value of this parameter may

not be the upper limit of overburden thickness for remaining equipments. The distance to move the overburden is "2500 meters" which favors the use of equipments working with hauling units. The topography is entered as "Steeply-sloping" which unfavors the use of large equipments and favors smaller, mobile equipments.

After mining frame, remaining three equipments, namely electric shovel, hydraulic backhoe and hydraulic shovel collect similar cumulative certainty factors.

In water frame, parameters are entered to indicate the water problem in the pit. Here, only the hydraulic backhoe is favored and others are assigned negative certainty factors.

Parameters of highwall-spoil frame are utilized to indicate the stability of benches and spoil piles. In this case, equipments in the list pass this frame satisfactorily.

In topography frame, user desires to employ the mine area as farming fields after mining operations are completed and enters the position of the mine as a narrow area. Both responses require the use of equipments working with hauling units. Because in the first, reclamation and land restoration is best achieved with the employment of hauling units while in the second, due to topographical reasons, smaller equipments are preferable.

In coal-seam frame, either the number of coal seams or extraction of stray seams require more flexible operations which can be achieved with the employment of mobile, smaller equipments.

Slushy conditions of topsoil and incompatibility of topground to carry the weight of equipments make these three equipments to lose from their cumulative certainty factors.

Finally, among important parameters, selective mining makes hydraulic shovels preferable, but since service life of electric shovels are more than hydraulic shovels, and user wants an equipment with high service life, electric shovel gains.

At the end of the consultation, the equipment to be selected is hydraulic backhoe with a certainty factor of 91%, hydraulic shovel follows it with a certainty of 89% and the third equipment is electric shovel of which the certainty factor is 84%. The ranking of the equipments and consultation progress can be seen in Figure 4.5. The difference between hydraulic backhoe and the hydraulic shovel is very small and mostly caused from the heavy water problem in the pit. Also, the difference between electric shovel and hydraulic shovels are coming from their diggability powers. Since hydraulic shovels are powerful than electric shovels (Paşamehmetoğlu et al., 1988), and the diggability condition of the formations is

hard, then hydraulic shovels are assigned more certainty factors than electric shovels in the diggability frame.



SAMPLE CONSULTATION 2

(" Consultation record for: (OPEN-PIT EXCAVATING EQUIPMENT SELECTION SYSTEM)"

"DIGGABILITY RULES... :: YES"

"UNIAXIAL COMPRESSIVE STRENGTH :: \"50\""
 "AVERAGE DISCONTINUITY SPACING :: \"200\""
 "SEISMIC VELOCITY :: \"1270\""
 "WEATHERING OF THE FORMATIONS :: \"FRESH-TO-NOT-WEATHERED\""
 "HARDNESS OF THE FORMATIONS :: \"50\""
 "JOINT SET NUMBER EXISTING IN THE FOR... :: \"TWO-OR-MORE\""

"MINING PARAMETERS... :: YES"

"RATE OF ANNUAL PRODUCTION :: \"MEDIUM:80%\""
 "THE PROJECTED LIFE OF THE MINE :: \"LONG:70%\""
 "THICKNESS OF THE OVERBURDEN :: \"35\""
 "LENGTH OF THE HAUL ROADS FROM PIT TO... :: \"2500\""
 "THE TOPOGRAPHY AROUND THE MINE :: \"STEEPLY-SLOPING\""
 "BOX-CUT TO START MINING ACTIVITIES :: \"YES\""
 "HAULING ROAD BRIDGE ACROSS SPOIL PILES :: \"YES:60%\""
 "DISTURBANCE OF THE ADJACENT LAND :: \"NO\""
 "ELECTRICITY INSTALLATION :: \"YES\""
 "PREBENCHING OPERATIONS :: \"NO\""
 "CLIMBING ABILITY OF EXCAVATING EQUIP... :: \"YES\""
 "STEEP RAMPS IN HAUL WAY :: \"YES\""
 "SHARP TURNS IN THE HAULAGE WAYS :: \"YES\""
 "WIDTH OF THE PIT :: \"YES:50%\""
 "SPACE FOR EQUIPMENT TO MANEUVER :: \"YES:70%\""
 "LONG OVERBURDEN PANELS TO BE REMOVED :: \"YES:70%\""

"WATER, GROUND WAT... :: YES"

"WATER CONTACTING WITH SPOIL PILES :: \"YES\""
 "THE GROUND-WATER CONDITION :: \"YES\""
 "AMOUNT-OF-RAINFALL :: \"YES:50%\""
 "THE WATER SPILLING INTO THE PIT :: \"YES\""
 "FLOODING OF THE BENCH FLOOR :: \"YES\""

"HIGHWALLS AND SP... :: YES"

"OUTSIZED BOULDERS WITHIN THE FORMATIONS :: \"NO:70%\""
 "THE STABILITY OF HIGHWALLS :: \"YES:60%\""
 "LANDSLIDING OF SPOIL PILES :: \"NO:70%\""
 "MATERIAL FALLING FROM HIGHWALLS :: \"NO:60%\""
 "SPOIL PILE STABILITY :: \"NO:60%\""

"FRAME CONTAINING... :: YES"

"THE ELEVATION OF THE MINE FROM SEA L... :: \"2700\""
 "THE LAND PERMIT OF THE MINE :: \"PURCHASED\""
 "THE CONDITION OF THE MINED OUT AREAS :: \"YES\""
 "THE FARM-LAND POSSIBILITY OF THE MIN... :: \"YES\""
 "THE AREA OF THE MINE :: \"NO:60%\""

Figure 4.5. Sample consultation 2

"FACTS AND RULES WIT... :: YES"
 "NUMBER OF COAL SEAMS PRESENT :: \"4\""
 "STRAY SEAMS PRESENT :: \"YES\""
 "EXTRACTION OF STRAY SEAMS :: \"YES\""
 "COAL SEAM SUPPORT CHARACTERISTICS :: \"POOR:70%\""
 "POSITION OF THE COAL SEAMS :: \"DIPPING\""
 "THICKNESS OF THE PARTING BETWEEN COA... :: \"5\""
"PARAMETERS AND RUL... :: YES"
 "AVAILABLE FUND FOR EXCAVATION MACHINERY :: \"MEDIUM:70%\""
 "THE DELIVERY TIME OF THE EXCAVATION ... :: \"YES\""
 "EXPANSION OF THE OPERATIONS :: \"YES\""
"TOPSOIL RULES AND ... :: YES"
 "BEARING CAPACITY OF TOPGROUND :: \"NO:60%\""
 "CONDITION OF SOILS :: \"YES\""
 "HEAVY PLANT ROOTING :: \"NO\""
"RULES AND PARAM... :: YES"
 "ACCESS ROAD CONSTRUCTION ABILITY :: \"NO\""
 "AVAILABILITY OF THE EXCAVATING EQUIP... :: \"YES\""
 "SERVICE LIFE OF THE EQUIPMENT :: \"YES\""
 "OPERATOR FATIGUE WHEN WORKING :: \"YES\""
 "HAUL ROAD CONSTRUCTION ABILITY :: \"YES\""
 "LOADING FROM OVERBURDEN POCKETS :: \"YES\""
 "DUMMY PARAMETER :: \"NO\""
 "MAINTAINING SPOIL PILES :: \"YES\""
 "HAULING UNIT SUBJECT TO IMPACTS :: \"NO\""
 "MAINTAINING ROAD SURFACES :: \"NO\""
 "MOBILITY REQUIRED :: \"YES\""
 "COLD WEATHER CONDITIONS :: \"NO\""
 "DUMMY PARAMETER :: \"YES\""
 "THE NECESSITY OF EXCAVATING SELECTIVELY :: \"YES\""
 "WEAR OCCURRING ON THE BUCKETS OF BWEs :: \"YES\""
 "SURFACE OVER WHICH MATERIAL IS MOVED... :: \"YES:80%\""
 "BEARING CAPACITY OF WORKING LEVELS :: \"YES\""
 "THE AVERAGE TEMPERATURE IN THE REGION :: \"25\""
 "SUPPORT ABILITY OF OVERBURDEN TO SPO... :: \"YES\""
 "VISIBILITY OF REJECT MATERIAL :: \"YES\""
 "BREAKAGE OF ROCK PARTICLES :: \"NO:80%\""
 "MATERIAL TO BE HAULED :: \"BULKY-MATERIAL\"

SUITABLE EQUIPMENT is as follows: BACKHOE (91%)
HYDSHOVEL (89%)
SHOVEL (84%)
Not DRAGLINE (99%)
Not BWE (99%)
Not DOZER (99%)
Not SCRAPER (99%)
Not FEL (99%)
Not DOZ-SCR (99%)

Figure 4.5. Continued

4.3.3. Sample Consultation 3

Since the consultation process of the system is briefly explained in previous sample consultations, here only general mine specifications and results will be given. Consulting process can be seen in Figure 4.6.

In this case, the diggability of formations is "Easy" affecting none of the equipments adversely. The annual production rate is entered as "Low", the projected life of the mine as "Short", thickness of the overburden as "35 meters", the moving distance of waste as "500 meters" and topography as "Steeply-sloping". Here, parameters are entered to indicate that this is a small, low-production mine. Also there exists no water problem in the pit, highwalls and spoil piles are stable, reclamation will be performed and mine area will be used as farming fields, there are more than one coal seam with stray seam extraction, available fund is low, operational flexibility is required.

At the end of consultation, the first equipment is the front-end loader with 94% certainty. Dozer-scraper combination follows it with 93% certainty and third equipment is the following equipments with the same certainty factor; scraper, backhoe and hydraulic shovel with 90% certainty.

SAMPLE CONSULTATION 3

```

(" Consultation record for: (OPEN-PIT EXCAVATING EQUIPMENT SELECTION SYSTEM)"
":attr (GREEN HIGH) DIGGABILITY RULES... :: YES"
"UNIAxIAL COMPRESSIVE STRENGTH :: \"12\"""
"AVERAGE DISCONTINUITY SPACING :: \"50\"""
"SEISMIC VELOCITY :: \"1550\"""
"WEATHERING OF THE FORMATIONS :: \"COMPLETELY-WEATHERED\"""
"HARDNESS OF THE FORMATIONS :: \"17\"""
"JOINT SET NUMBER EXISTING IN THE FOR... :: \"TWO-OR-MORE\"""
":attr (GREEN HIGH) MINING PARAMETERS... :: YES"
"RATE OF ANNUAL PRODUCTION :: \"LOW:90%\"""
"THE PROJECTED LIFE OF THE MINE :: \"SHORT:80%\"""
"THICKNESS OF THE OVERBURDEN :: \"35\"""
"LENGTH OF THE HAUL ROADS FROM PIT TO... :: \"500\"""
"THE TOPOGRAPHY AROUND THE MINE :: \"STEEPLY-SLOPING:70%\"""
"BOX-CUT TO START MINING ACTIVITIES :: \"YES\"""
"HAULING ROAD BRIDGE ACROSS SPOIL PILES :: \"YES\"""
"DISTURBANCE OF THE ADJACENT LAND :: \"NO\"""
"ELECTRICITY INSTALLATION :: \"NO:70%\"""
"PREBENCHING OPERATIONS :: \"YES\"""
"CLIMBING ABILITY OF EXCAVATING EQUIP... :: \"YES\"""
"STEEP RAMPS IN HAUL WAY :: \"YES\"""
"SHARP TURNS IN THE HAULAGE WAYS :: \"YES\"""
"WIDTH OF THE PIT :: \"YES:50%\"""
"SPACE FOR EQUIPMENT TO MANEUVER :: \"YES:50%\"""
"LONG OVERBURDEN PANELS TO BE REMOVED :: \"NO\"""
":attr (WHITE HIGH) WATER, GROUND WAT... :: YES"
"WATER CONTACTING WITH SPOIL PILES :: \"NO\"""
"THE GROUND-WATER CONDITION :: \"NO\"""
"AMOUNT-OF-RAINFALL :: \"YES:60%\"""
"THE WATER SPILLING INTO THE PIT :: \"NO\"""
":attr (YELLOW HIGH) HIGHWALLS AND SP... :: YES"
"OUTSIZED BOULDERS WITHIN THE FORMATIONS :: \"NO:80%\"""
"THE STABILITY OF HIGHWALLS :: \"YES:70%\"""
"LANDSLIDING OF SPOIL PILES :: \"YES:50%\"""
"MATERIAL FALLING FROM HIGHWALLS :: \"NO:90%\"""
"SPOIL PILE STABILITY :: \"NO:50%\"""
":attr (YELLOW HIGH) FRAME CONTAINING... :: YES"
"THE ELEVATION OF THE MINE FROM SEA L... :: \"2100\"""
"THE LAND PERMIT OF THE MINE :: \"PURCHASED\"""
"THE CONDITION OF THE MINED OUT AREAS :: \"YES\"""
"THE FARM-LAND POSSIBILITY OF THE MIN... :: \"YES\"""
"THE AREA OF THE MINE :: \"NO:80%\"""

```

Figure 4.6. Sample consultation 3

".attr (RED HIGH) FACTS AND RULES WIT... :: YES"
 "NUMBER OF COAL SEAMS PRESENT :: \"2\""
 "STRAY SEAMS PRESENT :: \"YES\""
 "EXTRACTION OF STRAY SEAMS :: \"YES\""
 "COAL SEAM SUPPORT CHARACTERISTICS :: \"POOR\""
 "POSITION OF THE COAL SEAMS :: \"FLAT-LYING\""
 "THICKNESS OF THE PARTING BETWEEN COA... :: \"2\""
 ".attr (CYAN HIGH) PARAMETERS AND RUL... :: YES"
 "AVAILABLE FUND FOR EXCAVATION MACHINERY :: \"LOW\""
 "THE DELIVERY TIME OF THE EXCAVATION ... :: \"YES\""
 "EXPANSION OF THE OPERATIONS :: \"YES\""
 ".attr (BLUE HIGH) TOPSOIL RULES AND ... :: YES"
 "BEARING CAPACITY OF TOPGROUND :: \"NO:70%\""
 "CONDITION OF SOILS :: \"NO\""
 "HEAVY PLANT ROOTING :: \"YES\""
 ".attr (MAGENTA HIGH) RULES AND PARAM... :: YES"
 "ACCESS ROAD CONSTRUCTION ABILITY :: \"YES\""
 "AVAILABILITY OF THE EXCAVATING EQUIP... :: \"YES\""
 "SERVICE LIFE OF THE EQUIPMENT :: \"NO\""
 "OPERATOR FATIGUE WHEN WORKING :: \"YES\""
 "HAUL ROAD CONSTRUCTION ABILITY :: \"YES\""
 "LOADING FROM OVERBURDEN POCKETS :: \"YES\""
 "DUMMY PARAMETER :: \"YES\""
 "MAINTAINING SPOIL PILES :: \"YES\""
 "MAINTAINING ROAD SURFACES :: \"YES\""
 "MOBILITY REQUIRED :: \"YES\""
 "COLD WEATHER CONDITIONS :: \"NO:70%\""
 "HAULING UNIT SUBJECT TO IMPACTS :: \"NO\""
 "DUMMY PARAMETER :: \"YES\""
 "THE NECESSITY OF EXCAVATING SELECTIVELY :: \"YES\""
 "WEAR OCCURRING ON THE BUCKETS OF BWEs :: \"NO\""
 "SURFACE OVER WHICH MATERIAL IS MOVED... :: \"YES\""
 "BEARING CAPACITY OF WORKING LEVELS :: \"YES\""
 "THE AVERAGE TEMPERATURE IN THE REGION :: \"19\""
 "SUPPORT ABILITY OF OVERBURDEN TO SPO... :: \"YES\""
 "VISIBILITY OF REJECT MATERIAL :: \"NO\""
 "BREAKAGE OF ROCK PARTICLES :: \"YES\""
 "MATERIAL TO BE HAULED :: \"BULKY-MATERIAL:70%\"")

SUITABLE EQUIPMENT is as follows: FEL (94%)
 DOZ-SCR (93%)
 SCRAPER (90%)
 BACKHOE (90%)
 HYDSHOVEL (90%)
 SHOVEL (32%)
 Not BWE (16%)
 Not DRAGLINE (69%)
 Not DOZER (98%)

Figure 4.6. Continued

4.3.4. Sample Consultation 4

General specifications given in this case are; medium digging conditions, medium annual stripping rate, life of the mine is medium, overburden is thicker, dumping distance is shorter, topography is flat-to-rolling. No water problem exists in the pit, highwalls are stable, however spoil piles not. No reclamation is needed because land will not be used after mining operations are finished. There is only one coal seam in the mine with no stray seam extraction. Available fund is medium and the equipment is not desired to be employed as a utility tool. General specifications can be seen in Figure 4.7.

Selected equipments are, in descending order, bucket wheel excavator with 89% certainty, electric shovel with 88% certainty and hydraulic shovel and backhoe, each sharing the same certainty factor, 87%.

SAMPLE CONSULTATION 4

```

(" Consultation record for: (OPEN-PIT EXCAVATING EQUIPMENT SELECTION SYSTEM)"
":attr (GREEN HIGH) DIGGABILITY RULES... :: YES"
"UNIAxIAL COMPRESSIVE STRENGTH      :: \"28\"""
"AVERAGE DISCONTINUITY SPACING     :: \"120\"""
"SEISMIC VELOCITY                   :: \"1300\"""
"WEATHERING OF THE FORMATIONS       :: \"HIGHLY-WEATHERED\"""
"HARDNESS OF THE FORMATIONS        :: \"11\"""
"JOINT SET NUMBER EXISTING IN THE FOR... :: \"TWO-OR-MORE\"""
":attr (GREEN HIGH) MINING PARAMETERS... :: YES"
"RATE OF ANNUAL PRODUCTION         :: \"MEDIUM:90%\"""
"THE PROJECTED LIFE OF THE MINE     :: \"MEDIUM:80%\"""
"THICKNESS OF THE OVERBURDEN        :: \"65\"""
"LENGTH OF THE HAUL ROADS FROM PIT TO... :: \"200\"""
"THE TOPOGRAPHY AROUND THE MINE     :: \"FLAT-TO-ROLLING\"""
"BOX-CUT TO START MINING ACTIVITIES :: \"YES\"""
"HAULING ROAD BRIDGE ACROSS SPOIL PILES :: \"YES\"""
"DISTURBANCE OF THE ADJACENT LAND   :: \"NO\"""
"ELECTRICITY INSTALLATION           :: \"YES\"""
"PREBENCHING OPERATIONS             :: \"NO\"""
"CLIMBING ABILITY OF EXCAVATING EQUIP... :: \"NO\"""
"STEEP RAMPS IN HAUL WAY            :: \"YES\"""
"SHARP TURNS IN THE HAULAGE WAYS    :: \"YES\"""
"WIDTH OF THE PIT                  :: \"YES\"""
"SPACE FOR EQUIPMENT TO MANEUVER    :: \"YES\"""
"LONG OVERBURDEN PANELS TO BE REMOVED :: \"YES\"""
":attr (WHITE HIGH) WATER, GROUND WAT... :: YES"
"WATER CONTACTING WITH SPOIL PILES  :: \"NO\"""
"THE GROUND-WATER CONDITION         :: \"NO\"""
"AMOUNT-OF-RAINFALL                :: \"NO\"""
"THE WATER CONGEST IN THE PIT       :: \"NO\"""
":attr (YELLOW HIGH) HIGHWALLS AND SP... :: YES"
"OUTSIZED BOULDERS WITHIN THE FORMATIONS :: \"NO\"""
"THE STABILITY OF HIGHWALLS         :: \"YES\"""
"LANDSLIDING OF SPOIL PILES         :: \"YES\"""
"MATERIAL FALLING FROM HIGHWALLS    :: \"NO\"""
"SPOIL PILE STABILITY               :: \"YES:80%\"""
":attr (YELLOW HIGH) FRAME CONTAINING... :: YES"
"THE ELEVATION OF THE MINE FROM SEA L... :: \"1500\"""
"THE LAND PERMIT OF THE MINE        :: \"PURCHASED\"""
"THE CONDITION OF THE MINED OUT AREAS :: \"NO\"""
"THE AREA OF THE MINE              :: \"YES\"""

```

Figure 4.7. Sample Consultation 4


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":attr(RED HIGH) FACTS AND RULES WIT... :: YES"
"NUMBER OF COAL SEAMS PRESENT :: \"1\"
"STRAY SEAMS PRESENT :: \"YES\"
"EXTRACTION OF STRAY SEAMS :: \"NO\"
"COAL SEAM SUPPORT CHARACTERISTICS :: \"MODERATE\"
"POSITION OF THE COAL SEAMS :: \"DIPPING\"
":attr (CYAN HIGH) PARAMETERS AND RUL... :: YES"
"AVAILABLE FUND FOR EXCAVATION MACHINERY :: \"MEDIUM\"
"THE DELIVERY TIME OF THE EXCAVATION ... :: \"NO\"
"EXPANSION OF THE OPERATIONS :: \"NO\"
":attr (BLUE HIGH) TOPSOIL RULES AND ... :: YES"
"BEARING CAPACITY OF TOPGROUND :: \"YES\"
"CONDITION OF SOILS :: \"NO:80%\"
"HEAVY PLANT ROOTING :: \"YES\"
":attr (MAGENTA HIGH) RULES AND PARAM... :: YES"
"ACCESS ROAD CONSTRUCTION ABILITY :: \"NO\"
"AVAILABILITY OF THE EXCAVATING EQUIP... :: \"YES\"
"SERVICE LIFE OF THE EQUIPMENT :: \"YES\"
"OPERATOR FATIGUE WHEN WORKING :: \"YES\"
"HAUL ROAD CONSTRUCTION ABILITY :: \"NO\"
"LOADING FROM OVERBURDEN POCKETS :: \"NO\"
"UTILITY PURPOSE :: \"NO\"
"MAINTAINING SPOIL PILES :: \"NO\"
"MAINTAINING ROAD SURFACES :: \"NO\"
"MOBILITY REQUIRED :: \"NO\"
"COLD WEATHER CONDITIONS :: \"NO:70%\"
"HAULING UNIT SUBJECT TO IMPACTS :: \"NO\"
"DUMMY PARAMETER :: \"YES\"
"THE NECESSITY OF EXCAVATING SELECTIVELY :: \"YES\"
"WEAR OCCURING ON THE BUCKETS OF BWEs :: \"NO\"
"SURFACE OVER WHICH MATERIAL IS MOVED... :: \"YES\"
"BEARING CAPACITY OF WORKING LEVELS :: \"YES\"
"THE AVERAGE TEMPERATURE IN THE REGION :: \"16\"
"SUPPORT ABILITY OF OVERBURDEN TO SPO... :: \"YES\"
"VISIBILITY OF REJECT MATERIAL :: \"YES\"
"BREAKAGE OF ROCK PARTICLES :: \"YES\"
"MATERIAL TO BE HAULED :: \"BULKY-MATERIAL:80%\"

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SUITABLE EQUIPMENT is as follows: BWE (89%)
                                   SHOVEL (88%)
                                   BACKHOE (87%)
                                   HYDSHOVEL (87%)
                                   FEL (78%)
                                   DRAGLINE (58%)
                                   Not DOZ-SCR (98%)
                                   Not DOZER (99%)
                                   Not SCRAPER (100%)

```

Figure 4.7. Continued

5. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The major conclusions and recommendations for further research are as follows:

(i). A review of the literature has revealed that as expert system is a relatively new technology, its application in the mineral industry is limited. Furthermore, the applications for the surface mine equipment selection are very few and still at their development stage.

(ii). In this study an expert system for overburden removal equipment selection is developed using PCPLUS expert system shell. The system uses 85 parameters and 224 rules in decision process. It can be used for the following equipment types; dragline, bucket wheel excavator, scraper, electric excavator, hydraulic excavators (hydraulic excavator and backhoe), dozer, pusher-scraper combination, front-end loader from which electric and hydraulic excavators and front-end loader are assumed to be used in combination with trucks.

(iii). The rules were derived from the available literature, from case studies and from the consultation with experts. The developed expert system has a user-friendly interface and has the ability to provide the help during consultation. The knowledge base is suitable

to be updated by additional information.

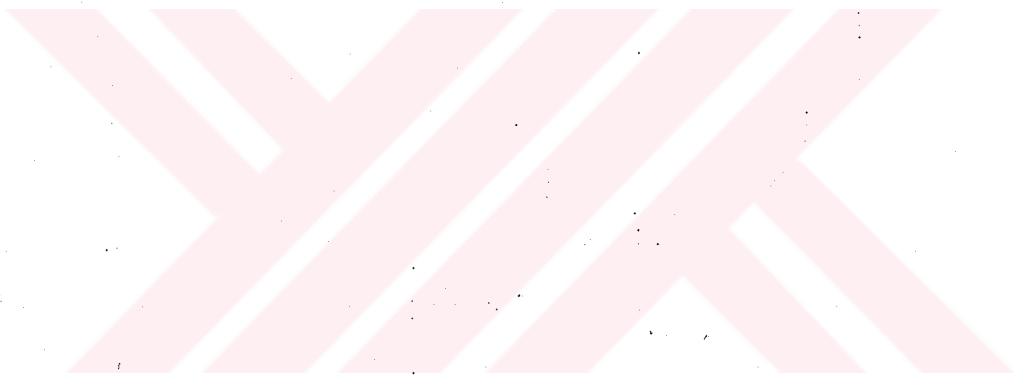
(iv). The major parameters used by the system are the diggability of formations, annual overburden removal rate, thickness of the overburden, distance to move the waste and general topography. Parameters related to water conditions, stability of highwalls and spoil piles, economics, coal seams, topsoil, equipments, overburden characteristics are also utilized in selection of proper equipment.

(v). A number of sample consultations were conducted and the equipments selected with highest certainty factors in each sample consultation seem to be proper choices when the conditions which led to this conclusion are investigated.

(vi). In the system, some of the parameters are directly asked to the user, instead of finding the values of them and fuzzy values are used for some parameters which necessitate the knowledge and the judgement of the user. However, the system is still being improved.

(vii). The system selects only one primary excavating equipment for the conditions given for a mine and its alternatives in descending order according to cumulative certainty factors associated with them. However, a mine may use any combinations of the equipments present in the equipment list. This is another shortcoming of the system which is under investigation.

(viii). The developed system is dealing with descriptive fuzzy data more than numeric ones. But, it can be designed to incorporate numeric programs into the system to make comments about the outputs of them.



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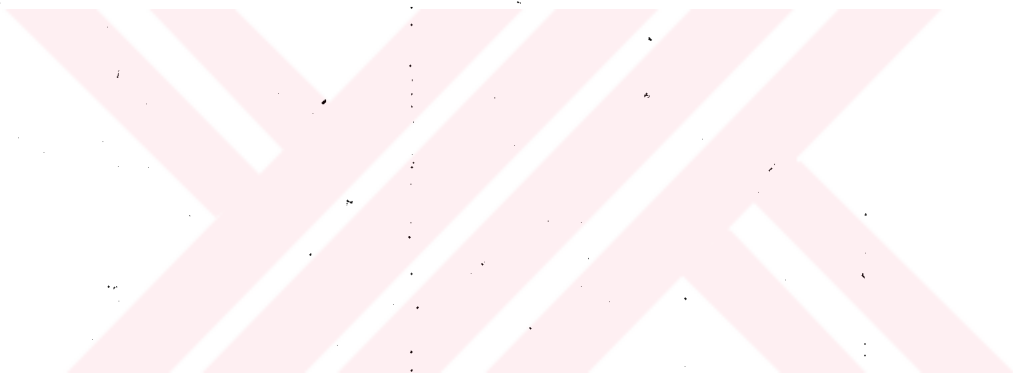
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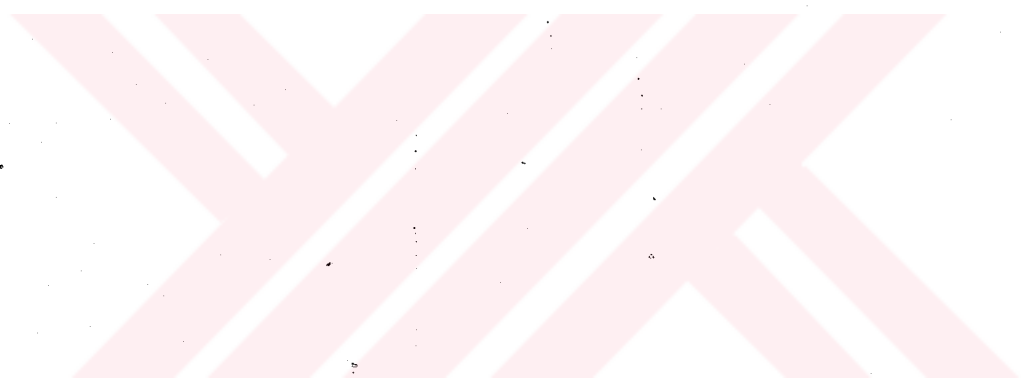
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APPENDICES



APPENDIX A

CERTAINTY FACTORS ASSIGNED TO EQUIPMENTS BY PARAMETERS

Parameter		Dr.	F. Sho	BWE	Scra.	Dozer	Backh	H. Sh.	FEL	Dz-Sc
The Value of	(>5)	50		50						
UNTAXIAL	(5-20)	40		50						
COMPRESSIVE	(20-41)	30		30						
STRENGTH	(41-111)	-100		-100						
UCS (MPa)	(>111)	-100		-100						
TOTAL RATING	(<25)		50		50	50	50	50	50	50
After Entering	(25-45)		40		-100	40	50	50	40	40
The	(45-65)		30		-100	30	40	40	30	30
Diggability	(65-85)		30		-100	-100	40	40	-100	-100
Parameters	(>85)		30		-100	-100	40	40	-100	-100
Annual	(LOW)	-30	-30	-30	30	30	30	30	30	30
RATE of	(MEDIUM)	0	0	0	0	-10	10	10	-10	5
PRODUCTION	(HIGH)	30	30	30	-30	-30	-20	-20	-30	-20
Projected	(SHORT)	-25	-25	-25	20	20	0	0	20	20
LIFE of	(MEDIUM)	0	0	0	-5	-5	0	0	0	0
the MINE	(LONG)	20	20	20	-20	-20	-10	-10	-20	-20
Average	(<11)	-10	-10	-10	10	10	10	10	10	10
THICKNESS	(11-30)	10	10	10	10	10	10	10	10	10
of the	(30-50)	20	20	20	-50	-100	20	20	20	-100
OVERBURDEN (m)	(>=50)	20	20	40	-100	-100	20	20	20	-100

Parameter	Dr.	F. Sho	BWE	Scra.	Dozer	Backh	H. Sh.	FEL	Dz-Sc
(0-50)	20	-20	20	20	20	-20	-20	20	20
LENGTH (50-100)	20	-20	20	20	20	-20	-20	20	20
of (100-150)	-20	-20	20	20	-20	-20	-20	20	20
Haul ROADS (150-301)	-40	20	20	20	-50	20	20	20	20
(m) (>300)	-50	20	20	20	-50	20	20	20	20
(MOUNTANEOUS)	-20	20	-20	20	20	20	20	20	20
TOPOGRAPHY (STEEP)	-15	20	-15	20	20	20	20	20	20
Around (ROLLING)	0	20	0	20	20	20	20	20	20
The (FLAT-ROLLING)	10	20	10	20	20	20	20	20	20
MINE (FLAT)	20	20	20	20	20	20	20	20	20
Starting to Mining (YES)	10	-10	-10	10	10	-10	-10	-10	10
With a BOX-CUT (NO)	0	0	0	0	0	0	0	0	0
A Hauling BRIDGE (YES)	0	-10	-10	10	10	-10	-10	-10	10
Can Be Constructed Between Spoil Piles (NO)	0	0	0	0	0	0	0	0	0
DISTURBANCE of (YES)	0	0	0	0	0	0	0	0	0
Adjacent Land Is Permitted (NO)	-10	10	10	10	10	10	10	10	10
ELECTRICITY Can (YES)	0	0	0	0	0	0	0	0	0
Be Installed Easily in the Mine (NO)	-5	-5	-5	5	5	5	5	5	5
PREBENCHING Should (YES)	-5	0	-5	0	0	0	0	0	0
Be Carried Out Before Stripping (NO)	0	0	0	0	0	0	0	0	0
Equipment Should (YES)	-5	0	-5	0	0	0	0	0	0
CLIMB Steep Grades When Moving (NO)	0	0	0	0	0	0	0	0	0

Parameter		Dr.	E. Sho	BWE	Scra.	Dozer	Backh	H. Sh.	FEI	Dz-Sc
There are STEEP RAMPS in Haulage Ways	(YES)	10	-10	10	-10	10	-10	-10	-10	-10
	(NO)	0	0	0	0	0	0	0	0	0
There are SHARP TURNS in Haulage Ways	(YES)	5	-5	5	-5	5	-5	-5	-5	-5
	(NO)	0	0	0	0	0	0	0	0	0
Pit is WIDE Enough for Equipments to Move	(YES)	0	0	0	0	0	0	0	0	0
	(NO)	10	-10	-10	10	10	10	10	10	10
Pit is Wide Enough for Hauling Units to MANEUVER	(YES)	0	0	0	0	0	0	0	0	0
	(NO)	10	-10	-10	10	10	10	10	10	10
There are LONG OVERBURDEN PANELS to be Removed	(YES)	10	10	10	10	10	10	10	10	10
	(NO)	-10	-10	-10	0	0	0	0	0	0
Water is in CONTACT with SPOIL PILES	(YES)	-10	10	10	10	-10	10	10	10	-5
	(NO)	0	0	0	0	0	0	0	0	0
There are Outsized BOULDERS in the Formations	(YES)	-5	10	-20	-20	-10	10	10	-10	-15
	(NO)	0	0	0	0	0	0	0	0	0
HIGHWALLS and BENCHES are STABLE in the Mine	(YES)	20	20	20	20	20	20	20	20	20
	(NO)	-20	-20	-20	-20	-20	-20	-20	-20	-20
LANDSLIDES May Occur in the Spoil Piles	(YES)	-10	10	10	10	5	10	10	10	10
	(NO)	10	10	10	10	10	10	10	10	10
MATERIAL May Fall from Highwalls Preventing Working	(YES)	10	-10	-10	-10	-10	-10	-10	-10	-10
	(NO)	0	0	0	0	0	0	0	0	0
SPOIL PILES Will Be Stable If Formed	(YES)	10	10	10	10	10	10	10	10	10
	(NO)	-10	10	10	10	-5	10	10	10	10

Parameter		Dr.	E. Sho	BWE	Scra.	Dozer	Backh	H. Sh.	FEL	Dz-Sc
ALTITUDE of the Mine (m)	(0-305)	0	0	0	0	0	0	0	0	0
	(306-610)	3	3	3	-3	-3	-3	-3	-3	-3
	(611-914)	6	6	6	-6	-6	-6	-6	-6	-6
	(915-1219)	9	9	9	-9	-9	-9	-9	-9	-9
	(1220-1524)	12	12	12	-12	-12	-12	-12	-12	-12
	(1525-1829)	15	15	15	-15	-15	-15	-15	-15	-15
	(1830-2134)	18	18	18	-18	-18	-18	-18	-18	-18
	(2135-2438)	21	21	21	-21	-21	-21	-21	-21	-21
	(2439-2743)	24	24	24	-24	-24	-24	-24	-24	-24
	(2744-3048)	27	27	27	-27	-27	-27	-27	-27	-27
	(>3048)	30	30	30	-30	-30	-30	-30	-30	-30
The AREA in Which Mining is Performed is a Large Area	(YES)	0	0	0	0	0	0	0	0	0
	(NO)	-10	0	-10	0	0	0	0	0	0
AVAILABLE	(HIGH)	20	20	20	20	20	20	20	20	20
FUND to Purchase Equipment	(MEDIUM)	-10	-10	-15	10	10	0	0	10	10
	(LOW)	-30	-30	-40	0	10	0	0	0	0
The DELIVERY Time of the Equipment is Short	(YES)	-10	-10	-10	10	10	10	10	10	10
	(NO)	0	0	0	0	0	0	0	0	0
Operations in the Mine May EXPAND or CONTRACT Suddenly	(YES)	-10	-10	-10	10	10	10	10	10	10
	(NO)	0	0	0	0	0	0	0	0	0
BEARING CAPACITY of Topground is Suitable	(YES)	0	0	0	0	0	0	0	0	0
	(NO)	-10	-10	-10	10	10	10	10	10	10

Parameter		Dr.	E. Sho	BWE	Scra.	Dozer	Backh	H. Sh.	FEL	Dz-Sc
The SOIL is Slushy to Cause Problems	(YES)	-5	-5	-5	0	-5	-5	-5	0	0
	(NO)	0	0	0	0	0	0	0	0	0
There are HEAVY PLANT ROOTING	(YES)	0	0	-10	-10	0	0	0	0	-5
	(NO)	0	0	0	0	0	0	0	0	0
ACCESS ROAD Construction Ability Required	(YES)	-10	-10	-10	0	10	-10	-10	-10	10
	(NO)	0	0	0	0	0	0	0	0	0
AVAILABILITY of Equipment Should Be High	(YES)	5	10	-10	-10	10	5	5	-5	-5
	(NO)	0	0	0	0	0	0	0	0	0
Long SERVICE LIFE is Required	(YES)	10	10	10	-5	-5	5	5	-5	-5
	(NO)	0	0	0	0	0	0	0	0	0
Operators Should Be Subjected to Less FATIGUE	(O.K)	5	5	5	5	5	5	5	-5	5
	(NO)	0	0	0	0	0	0	0	0	0
HAUL ROAD Construction Ability Required	(O.K)	-10	-10	-10	0	10	-10	-10	-5	10
	(NO)	0	0	0	0	0	0	0	0	0
Equipment Should Be Capable to Load from POCKETS	(YES)	-5	-5	-5	5	-5	5	5	5	5
	(NO)	0	0	0	0	0	0	0	0	0
Equipment Should Be Capable to MAINTAIN Spoil Piles	(YES)	-10	-10	-10	5	10	-10	-10	10	10
	(NO)	0	0	0	0	0	0	0	0	0
Hauling Units Should not Be Subjected to IMPACT	(YES)	5	-5	5	5	5	5	5	5	5
	(NO)	0	0	0	0	0	0	0	0	0
Equipment Should Be Capable to MAINTAIN Roads	(YES)	-5	-5	-5	5	5	-5	-5	5	5
	(NO)	0	0	0	0	0	0	0	0	0

Parameter		Dr.	E. Sho	BWE	Scra.	Dozer	Backh	H. Sh.	FEL	Dz-Sc
Equipment Should Be MOBILE	(YES)	-10	-10	-10	10	0	0	0	0	10
	(NO)	0	0	0	0	0	0	0	0	0
The Place Where Mining is Performed is a COLD Place	(YES)	-5	5	-5	5	5	5	5	5	5
	(NO)	0	0	0	0	0	0	0	0	0
In the Operations SELECTIVITY is Required	(YES)	-10	-10	10	10	10	10	10	10	10
	(NO)	0	0	0	0	0	0	0	0	0
The Waste Material is ABRASIVE	(YES)	-5	0	-10	-10	0	10	10	5	-10
	(NO)	0	0	0	0	0	0	0	0	0
Haul Roads are Capable to CARRY the Hauling Units	(YES)	0	0	0	0	0	0	0	0	0
	(NO)	10	-10	10	-10	10	-10	-10	-10	-10
WORKING LEVELS are Capable to Carry the Equipments	(YES)	0	0	0	0	0	0	0	0	0
	(NO)	-10	-10	-10	10	10	10	10	10	10
Average TEMPERATURE in the Mine (°)	(0-15.55)	0	0	0	0	0	0	0	0	0
	(15.55-21.11)	2	2	2	-2	-2	-2	-2	-2	-2
	(21.12-26.67)	4	4	4	-4	-4	-4	-4	-4	-4
	(26.68-32.22)	6	6	6	-6	-6	-6	-6	-6	-6
	(32.23-36.68)	8	8	8	-8	-8	-8	-8	-8	-8
	(>36.69)	10	10	10	-10	-10	-10	-10	-10	-10
Overburden Can SUPPORT the Spoil Piles	(YES)	0	0	0	0	0	0	0	0	0
	(NO)	-10	10	10	10	10	10	10	10	10
REJECT Material Can Be Seen Easily	(YES)	0	0	0	0	0	0	0	0	0
	(NO)	-5	5	-5	5	5	5	5	5	5

Parameter	Dr.	E.Sho	BWE	Scra.	Dozer	Backh	H.Sh.	FEL	Dz-Sc
Rock Particles (YES)	0	0	0	0	0	0	0	0	0
are Easily BROKEN (NO)	0	0	-10	-10	0	10	10	-10	-10
MATERIAL (LARGE-ROCK)	10	10	-10	-10	10	-10	-10	-10	-10
to Be (FREE-FLOWING)	0	0	0	0	0	0	0	0	0
HAULED (BULKY)	0	0	0	0	0	0	0	0	0

Abbreviation Name

Dr. DRAGLINE

E.Sho. ELECTRIC SHOVEL

BWE BUCKET WHEEL EXCAVATOR

Scra. SCRAPER

Dozer DOZER

Backh. HYDRAULIC BACKHOE

H.Sh. HYDRAULIC SHOVEL

FEL FRONT END LOADER

Dz.Sc. DOZER-SCRAPER COMBINATION

T. C.
TÜRKİYE KÖRFEZİ KURUMU
Dokümantasyon Merkezi