Shortwall stoping versus sub-level longwall caving-retreat in Eli coal fieds

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Transaction Paper

Synopsis

This study deals with the presentation of the mechanized longwall mining project introduced some years ago to increase productivity and output of Aegean Lignite Establishment (ELI) owned by Turkish Coal Enterprises (TKI) and the comparison of this method with a planned alternative new mining method called 'shortwall mining' where continuous miners will be introduced as primary coal excavation machines.

Following the planning phase, production costs have been calculated for both mining methods on the basis of a panel having a height of 7.5 m. In addition to cost analysis, both methods have been evaluated using 'the multi-dimensional objective system'. In this evaluation the value synthesis has been carried out according to scoring models.

Lastly, the advantages and disadvantages of both production methods have been stated by analysing them according to related criteria. In the light of outputs gathered from the analyses, it has been determined that the shortwall mining method will out perform the longwall method.

Keywords: continuous miner, shortwall mining, longwall mining, multi-dimensional objective system.

Introduction

In coalfields (ELİ, GLİ) in the western part of Turkey, operated by a state-owned company called TKI, the seams have a thickness of 5–30 m and an inclination of 10–25°[1]. Due to such features, a sublevel longwall caving-retreat method has been applied in these mines. Although conventional methods were used until recently, mechanized systems have been launched in these areas. There are also some mines which are not mechanized. Further studies are being carried out both for the mechanized current fields and the establishment of mechanized systems in the areas for future planning.

Since the coal-seams in the field in question are quite thick, a horizontal slicing method has been used to obtain the current production. In one slice, with 2.8 m headroom and 4.7 m sub-level caving height, approximately 7.5 m thick coal is produced[2]. By using the sub-level caving method, some savings are obtained in development drift costs. However, during the caving operation coal losses and dilutions inevitably occur. The sum of coal losses amounts to approximately 20%.

The aim of this study is to find ways to reduce the coal losses (resulting from caving operations) and to increase productivity. In this regard, shortwall mining in which a continuous miner is as used as a direct cutting tool is proposed to be an alternative to longwall mining. To be able to make a comparison between these two methods, a 400 m-long panel with 50 m face length has been chosen for further evaluations. Conclusions have been reached by comparing the costs of both methods. Further evaluations have been made using a scoring model on the basis of a multidimensional objective system and value synthesis.

The coal-seam properties

The coal-seam in question, where the costs have been calculated for production methods and where the necessary comparisons have been done, is of relatively good quality and slightly hard. The average heat content is around 4 500 kcal/kg. Uniaxial compressive strength amounts to 250–300 kgf/cm^2. The seam thickness is 15 m on average, depending on the tectonics. The dip of the seam ranges between 10–25°. The hangingwall of the seam consists of marl and the footwall of clay. The cohesion of the floor clay lies in the range of 0–0.9 kg/cm^2 and the angle of internal friction lies in the range of is 14–37°[3]. This clay is easily affected by water and humidity and shows some swelling behaviours. Due to this

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drawback of the clay, vehicles face the danger of sinking into the floor. The uniaxial compressive strength of the hangingwall is around 1 100 kg/cm^2. This high strength causes the occurrence of big blocks[4].

Current longwall mining method applied in the mine

The current method used in the above-mentioned mines is a sub-level longwall caving-retreat method. In this method, the face is formed perpendicular to the seam strike and implemented in the form of slices 7.5 m thick from the top downwards (Figure 1). Because the geotechnical properties of the floor clay are too weak, development drifts were driven in the marl which forms the hangingwall[2].

The face is perpendicular to the strike of the seam and therefore the face advance is in the strike direction. When forming the panel, the entries of the panel are opened up along the strike in the level where the face will be built up. Tailgate entry is driven within 1–2 metre coal side so as not to face up the clay and headgate entry is driven in coal-marl contact. When the panel border is reached, starter entry is formed by combining headgate and tailgate entries. The face formed in this way advances along the strike of the seam as the retreating longwall (Figure 1). In this method, face length depends on seam thickness and pitch. The length of the panel, however, is either arbitrariry chosen or dependent on the natural limitations. Since the field is rather faulty, panel borders are generally determined by faults. It is both possible to manage one single panel or more than one over the other.

The excavation is carried out by means of a single drum shearer; its specifications are given in Table I. The section height of coal thickness in the range of 2.8 m is cut by this machine and the remaining 4.7 m part is caved through the caving window over the self-advancing hydraulic support units (Figure 2). In order to get the corner coal on the floor as seen in Figure 3[2], a dead-end face is formed by leaving some coal over the floor, and thus coal loss is reduced. Inside the face, a calliper-type shield support system is used as support equipment[2].

Currently, the shearer performs two cuts per shift. The total coal production from a face is about 1125 tons/day.

Suggested method (shortwall mining)

Shortwall mining is a production method in which excavation and loading are carried out by continuous miner under the protection of roof supports. The shortwall mining technique is similar to longwall mining but with shorter face lengths, ranging between 40 and 90 m [5]. Panel dimensions for shortwall mining are given below:

Panel length : 600–1200 m
Panel width (face length) : 40–90 m
Slices thickness (face height) : 2.5 m

Apart from the support system, the ventilation system, cutting machine and haulage equipments are the same as the ones used in room and pillar mining in which a continuous miner is used[6].

Preparations in the panel

The preparations are the same as the current longwall method. The process differs from the current one in the preparation of headgate and tailgate entries. The headgate will have a 14 m^2 and the tailgate a 10 m^2 cross-section. These entries will be opened by the continuous miner. As a support system, the GI profile will be used. The starter entry has a width of 6 metres and height of 2.5 m, and the digging will be carried out by continuous miner. The initial face support will consist of timber support to be replaced by self-advancing hydraulic support units in the production phase.

Excavation and support system

The excavation in the face will be carried out by continuous miner and shortwall support systems will be used as face

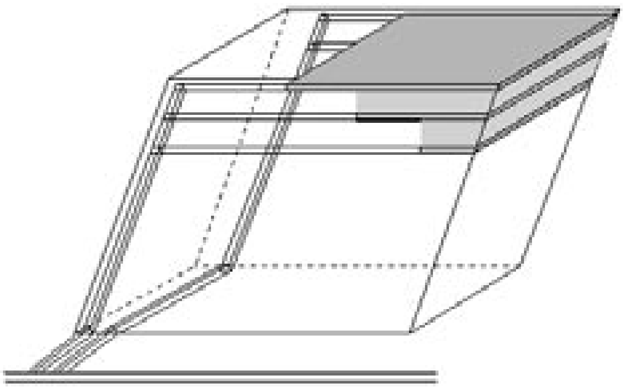

Figure 1— The panels in the present longwall method

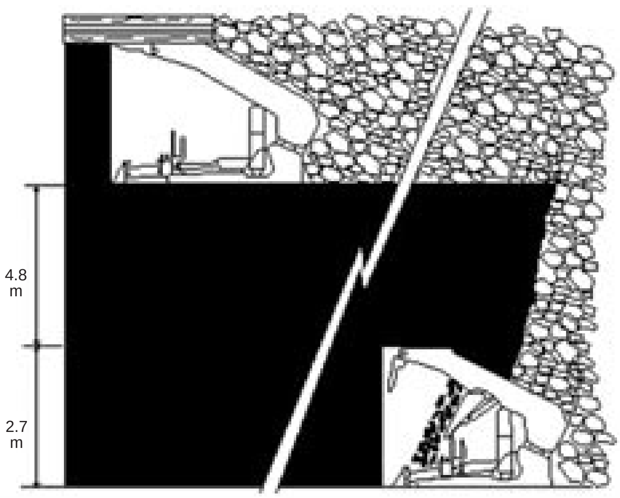

Figure 2— Sub-level caving system in present longwall method

Table I

Specifications of a single drum shearer

Motor power	150 kW
Cutting height	1.8–3.6 m
Rotation speed of drum	32–39 rpm
Diameter of drum	1500 mm
Cutting depth	625 mm
Max. traction speed	6.2 m/min
Weight	16 tons
Length of shearer	3200 mm

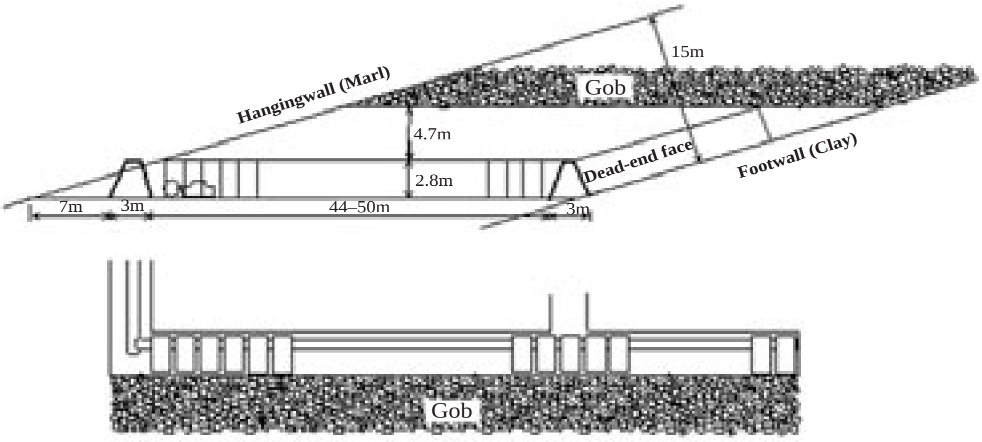

Figure 3—Layout and section views of longwall panel

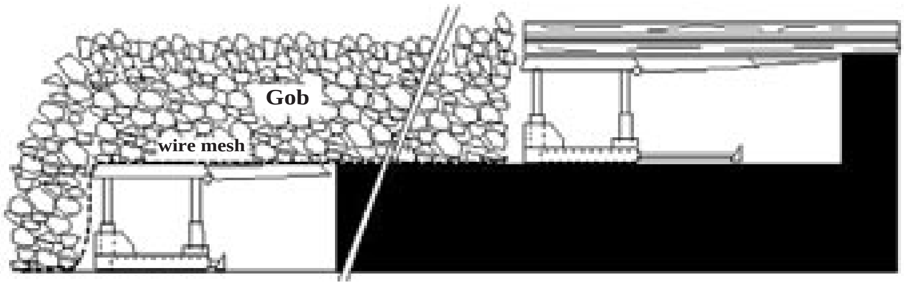

Figure 4—Advance of the faces in the shortwall method

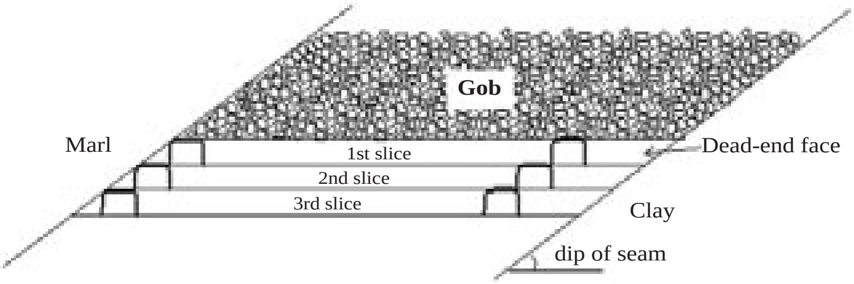

Figure 5—The slices in the shortwall method

support. Due to the drawbacks of working on an inclined face, it has been planned to form the face horizontally, similar to the one carried out in the present system. However, the coal caving process with back draw will not be necessary for production. All of the coal will be produced by digging at the face (Figure 4 and Figure 5). Slice thickness or face height has been planned to be 2.5 metres. A wire mesh will be spread on the floor of the upper slice in order to prevent dilution and form the artificial roof for the next slice (Figure 4).

Since the faces are formed one under the other without any floor pillar, the triangular pillar problem at the foot and tail will diminish. Since the footwall of the mine is clay, the tailgate entry will be advanced 2–3 metres on the coal inside, away from the footwall in order to avoid the swelling problem of clay. In order to get the portion left on the floor, a dead-end face will be set up, as given in Figure 5.

The continuous miner will start excavation from the headgate, continuing to the tailgate, and carry out the excavation up to the end of the dead-end face and finally return to the headgate again (Figure 6). The conveyor and the support units will be placed as a unified single face. Two of the support units that are congruent with the tailgate will be advanced in a different manner (Figure 6).

Production capacity

Optimum cutting drum design for continuous miners is recognized as a vital factor in determining the excavation efficiency[7]. Since the roof of the face consists of caved goaf, the stope width should be as narrow as possible. Therefore, a unique* continuous miner, which has a short drum length, has been chosen. Some of the specifications of this continuous miner and some geometrical parameters of the excavation room are given in Tables II and III, respectively[8].

*It may be possible to order a continuous miner with shorter drum length

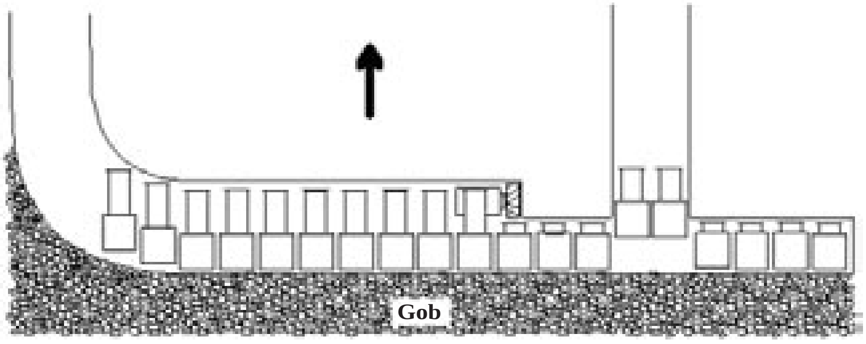

Figure 6. Excavation process in the shortwall panel

Depending on the values given in Tables II and III, the production capacity of the continuous miner is calculated as follows[9]:

$$V_{ph} = \frac{HP \times \eta}{SE} \text{ and} \quad [1]$$

$$W_{ph} = V_{ph} \times \rho \quad [2]$$

where

- V_{ph} : production (m^3/hour)
- HP : power of cutting engines (kW)
- η : a factor related to production method (for the continuous miner: 0.80)
- SE : specific cutting energy for coal (kW-h/m^3)
- W_{ph} : hourly production (tons/hour)
- ρ : density of coal (tons/m^3)

$$V_{ph} = \frac{90 \text{ kW} \times 0.80}{0.4 \text{ kW-h/m}^3} = 180 \text{ m}^3\text{/hour}$$

$$W_{ph} = 180 \text{ m}^3 \times 1.5 \text{ t/m}^3 = 270 \text{ tons/hour}$$

$$= 4.5 \text{ tons/minute}$$

This approach provides a fairly high production capacity. On the other hand, both from the literature and similar mining applications, it is known that approximately 30% of the time in one shift is spent on cutting and loading. Considering this point, the production period amounts to

480 minute/shift x 30/100 = 144 minute/shift

Depending on this assumption, the production per shift will be around:

44 min/shift x 4.5 tons/min ≅ 650 tons/shift

The face length (X) from which this production will be realized can be calculated as follows:

Capacity = Cutting width x Face height x Density x Face length†

The remaining shift time is spent on the maintenance of the machines, and entrance and exit activities to and from the mine. In the light of the values obtained above, if the production is carried out in two shifts, the daily production is calculated to be 1300 tons.

†Cal loss in the panel is not considered in the production calculations

Costs and cost comparison

The development costs

This section deals with the calculation of development costs for both methods. However, these calculations cover only the developments drifted in the panel because the other development costs are the same for both methods, and thus have no effect on the comparison of the two methods. In this regard, the development costs of headgate, tailgate and starter entries have been taken into consideration. These costs consist of drilling, blasting, loading, haulage, maintenance, support and labour costs.

The development entries are primarily drifted by electro-hydraulic drilling and loading machine. The cross-section of the headgate entry is 14 m^2 and tailgate entry is 8 m^2. In the shortwall method, a continuous miner will be used in the driving of entries. The cross-section of the headgate will be 14 cm^2 and tailgate 10 m^2.

The development drifts costs are calculated as given in Table IV. The essential thickness of the panel slice in the assessment is 7.5 m. This value is the height of a portion of the production headroom realized from one panel in the

Table II

Technical specifications of the continuous miner

Length	6309 mm
Height	1520 mm
Width	1710 mm
Weight	16.6 tons
Max. cutting height	2613 mm
Min. cutting width	1830 mm
Walking speed	0.03–0.14 mm
Engine power	90 kW

Table III

Geometrical parameters of excavation room in the shortwall method

Average face length	50 m
Cutting width	1.83 m
Face height	2.5 m
Coal loss	5%

longwall method. In the shortwall method, however, the face headroom is 2.5 metres. This, accordingly, requires three panels above each other in order to produce the portion that is 7.5 meters thick. Therefore, the development cost of a panel in a shortwall can be compared with the development costs of a longwall if the former cost items are multiplied by 3.

As a result of the calculation depending on the values given in Table IV, the development costs calculated for longwall panel and three shortwall panels were found to be $49214 and $849441, respectively.

Production costs

In this mine, excavation in the present longwall method is done with a single drum shearer. The shortwall mining method is proposed as an alternative. The excavation has been planned to be carried out with the continuous miner. Another remarkable difference between the two methods is that sub-level caving will not be applied for shortwall mining. It is estimated that coal loss will be considerably reduced in this way. Some parameter values pertaining to both methods are given in Table V. The unit costs related to these values are given in Table VI. Fixed cost in Table VI includes the development costs as investment costs of panel drifts and the investments in the face. Operating cost contains costs of labour, energy, maintenance, material, etc. As seen in Table VI, the unit cost for longwall mining has been determined to be $8.04 /ton and for shortwall mining $ 8.12 /ton.

Comparison of profitability of the production methods

Unit production costs for both methods are similar to each other. However, the excessive coal losses in the longwall method (in the shortwall method more is produced from the same slice thickness) cause a decrease in total income. the sale price of coal is about $55 /ton. For comparison of profits based on the values gained from the calculations above, the following figures are obtained (supposing that other costs ($DC) are the same):

Total profit of longwall method per panel = [($55 /ton–$8.04 /ton) x 180000 ton]–$ΔC
= $8452800–$ΔC

Total profit of shortwall method per 3 panel = [($55 /ton–$8.12 /ton) x 213750 ton]–$ΔC
= $10020600–$ΔC

Comparison of alternative methods using the multi-dimensional objective system

To base the investment decisions of the alternatives always and only on monetary objectives such as cost, profit etc. may not always lead to optimal solutions. Particularly selecting a mining method in this way will disregard the very important restrictions and/or criteria such as security, technical suitability, organization, mechanization etc. Therefore it is advisable in some cases to look for rational solutions instead optimal ones. These kind of solutions will be possible if the evaluation is carried out on the basis of a multi-dimensional objective system.

After the formulation of a hierarchical objective system and derivation of related criteria, a scaling method is selected in order to reach a value-synthesis for stopping methods. In this study the priorities of criteria have been determined using an ordinal scaling method. Several methods and techniques have been proposed to obtain weight estimates[10–12]. In this study, the weights of criteria have been calculated on the basis of the following formula:

$$g_i = \frac{2(N+1-R_i)}{N(N+1)} \cdot 100 \qquad [3]$$

where

**g_i : weight of the criteria
Ri : ordinal scaling degree
N : number of criteria

After determining the weights of the criteria, an objective efficiency judgement scheme was formed (Table VII). Later, the objective efficiency of the alternative production methods was determined for each criterion (Table VIII). Having determined the alternative objective efficiencies, the scores (out of 10) of alternative production methods according to each criterion were determined with the help of the objective efficiencies judgement scheme (Table IX). After this procedure, value synthesis was carried out by calculating the total scores (out of 10) of thealternative methods.

Table IV
Unit development costs of the methods

	Longwall mining		Shortwall mining	
	Unit cost ($/m)	Total cost ($)	Unit cost ($/m)	Total cost ($)
Headgate entry (400 m)	565.55	226 200	331.19	132 476
Tailgate entry (400 m)	546.38	218 552	318.95	127 580
Starter entry (50 m)	908.84	45 442	461.82	23 091
Total		490 214		283 147

Table V
Some values related to the two mining methods

	Longwall mining	Shortwall mining
Panel length (m)	400	400
Face length (m)	50	50
Panel height (m)	7.5	2.5 x 3
Coal loss (%)	20	5
Development cost of the panel ($)	490 214	849 441
Investment in the face ($)	2 120 000	1 850 000
Coal amount which will produced from a panel (ton)(slice thickness: 7.5 m)	180 000	213 750
Daily output (ton)	1125	1300

Table VI
Unit costs

	Longwall method	Shortwall method
Fixed cost ($/ton)	4.06	5.18
Operation cost ($/ton)	3.98	2.94
Total unit cost ($/ton)	8.04	8.12

**The number in Figure 7 determines the weights of objectives

Table VII

Objective efficiencies judgement scheme

No. (j)	Weight(g_i)	Score criteria	$9 \leq n_i \leq 10$	$7 \leq n_i \leq 8$	$4 \leq n_i \leq 6$	$2 \leq n_i \leq 3$	$0 \leq n_i \leq 1$
1	10	Safety	Very good	Good	Intermediate	Bad	Very bad
2	3.3	Concentration	Very good	Good	Intermediate	Bad	Very bad
3	4.4	Operating cost	Very low	Low	Intermediate	High	Very high
4	5.6	Mechanization	Mechanization degree: good, Remote control: yes, labour requirement: no	Mechanization degree: good, remote control: yes, labour requirement: coercible	Mechanization on degree: intermediate, remote control: no.	Mechanization degree: semi-mech., labour requirement: excess	Unmechanized
5	6.7	Capacity (ton/day)	> 1500	1500–1250	1250–750	750–500	500 >
6	7.8	Profit (million $) (based on a panel)	> 8.5	6.5–8.5	4.5–6.5	2.5–4.5	2.5 >
7	5.9	Development cost	Very low	Low	Intermediate	High	Very high
8	3.0	Equipment cost	Very low	Low	Intermediate	High	Very high
9	1.1	Labour (man/face)	< 10	10–15	15–20	20–25	25 <
10	2.2	Flexibility (increase of production)	100%	70%	50%	30%	0
11	20.0	Rate of coal loss (%)	0–5	5–10	10–15	15–20	> 20
12	6.7	Easy digging (ton/min)	> 8	8–6	6–4	4–2	2>
13	4.2	Multipurpose usage	Gallery opening, excavation, loading, usage of several production methods	Gallery opening, excavation, loading	Excavation, loading, haulage	Excavation, loading	Only face excavation
14	3.3	Grain size (Average grain size)	Very good	Good	Intermediate	Bad	Dust
15	5.8	Face advance speed (m/day)	> 7	7–5	5-3	3-1	1 >
16	2.5	Digging area (m^2)	> 7	7–5	5-3	3–1	1 >
17	1.7	Manoeuvre time (min)	< 5	5–10	10-15	15–20	20 <
18	5.0	Removal capability	Removal itself	Unnecessary to disassemble for removal. This process requires a short time	Unnecessary to disassemble for removal. This process requires a long time	It must be completely disassemble for removal. This process requires a short time	It must be completely disassembled. This process requires a long time
19	0.8	Demand to labour instructions	1 week	1 month	3 months	6 months	1 year

Table VIII

Alternative objective efficiencies

	No. (j)	Criteria	Weight (g_i)	Alternatives	
				Longwall mining method	Shortwall mining method
Safety	1	Safety	10	Good	Good
Economy	2	Concentration	3.3	Intermediate	Good
	3	Operating cost	4.4	Intermediate	Intermediate
	4	Mechanization	5.6	Mechanization: intermediate Remote control: no	Mechanization: intermediate Remote control: no
	5	Capacity	6.7	1203.75	1303.87
	6	Profit ($million) (based on a panel)	7.8	8,003,812 - Δ*T	8,909,313 - Δ*T
	7	Development cost	5.9	Intermediate	High
	8	Equipment cost	3.0	High	High
	9	Labour	1.1	20	14
	10	Flexibility	2.2	Production cannot be increased	Production can be increased about 30%
Production loss	11	Rate of coal loss	20.0	25	5
Technical sufficiency	12	Easy digging	6.7	2.6	4.5
	13	Multipurpose usage	4.2	It can carry out digging and loading processes	It can be used for gallery opening, digging and loading processes. And It can be used in several mining methods
	14	Grain size	3.3	Intermediate	Intermediate
	15	Face advance speed	5.8	2.5	7.32
	16	Digging area	2.5	1.75	4.57
	17	Manoeuvre time	1.7	10	10
	18	Removal capability	5.0	It must be completely disassembled for removal. This process requires a long time	It can move itself
	19	Demand to labour instructions	0.8	3 ay	6 ay

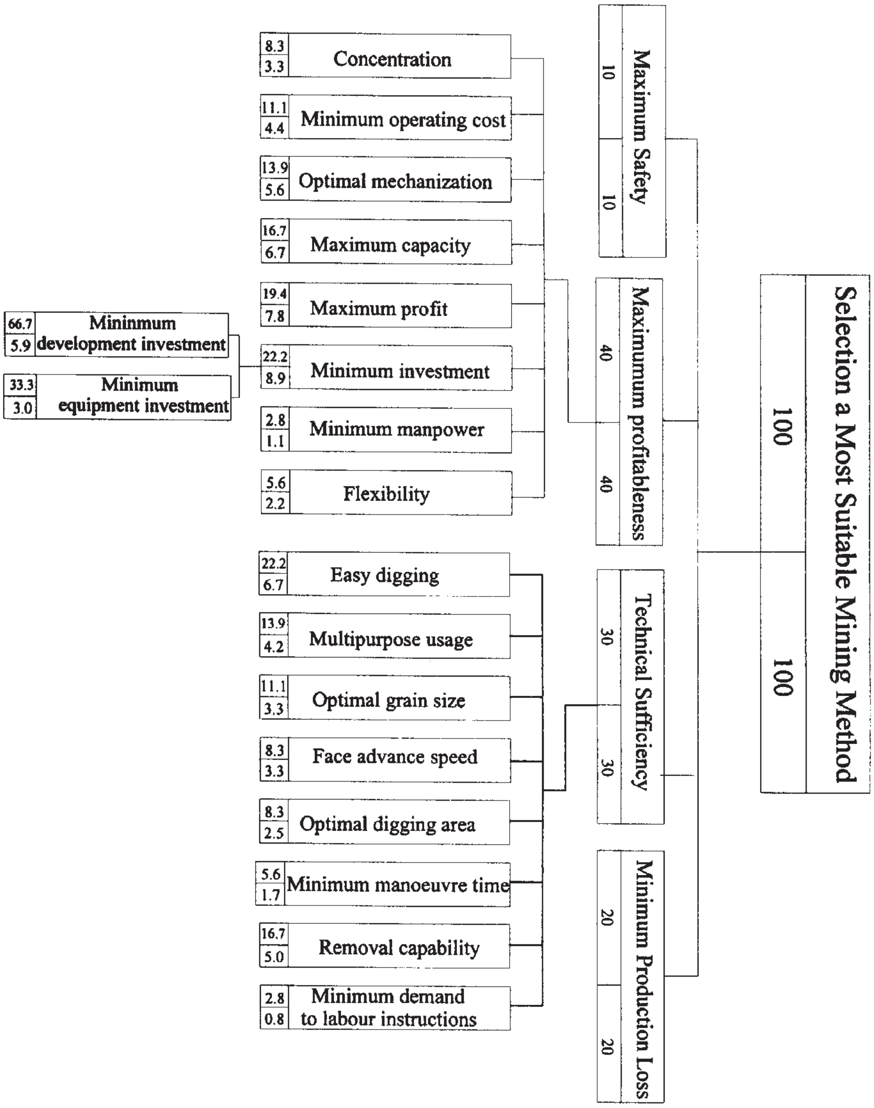

Figure 7—Objectives hierarchy

$$\sum \text{Score} = \sum (g_i \times V)/100 \quad [4]$$

where

g_i: weight of the criteria

V: alternative efficiency value

As can be seen in Table IX, after the examination of alternative production methods in the multi-dimensional objective system, the shortwall mining system received 7.4 out of 10 and the longwall mining method received 4.08. This means the shortwall mining method is preferable to longwall mining.

Conclusions and suggestions

Aegean Lignite Establishments has been using the sub-level longwall caving-retreat method for exploitation of large coal reserves in the Soma Region. This study deals with the selection of new mining methods for forthcoming mining operations in untouched parts of this coalfield, because the coal losses of the present method are considerably higher than is unacceptable for most cases. This study has taken the applicability of shortwall mining with continuous miners into consideration and compared both methods on the basis of monetary and non-monetary criteria.

In this regard, the following results have been obtained as a result of technical and economical comparisons carried out for the two production methods.

- ➤ Total slice thickness in longwall mining is 7.5 m. 2.8 m of this slice is to be excavated from the face and 4.7 m from back caving. In shortwall mining, on the other hand, the whole slice thickness is 2.5 m. All coal is to be excavated from the face.
- ➤ Longwall production capacity: 1 125 tons/day
- ➤ Shortwall production capacity: 1300 tons/day.
- ➤ When comparing the two methods, a 7.5 m slice thickness has been taken as a basis and costs and profits have been calculated on the basis of this reserve.

Economic comparison results in (main development costs have been excluded since they are equal):

- ➤ Longwall production cost : \$8.04 /ton
- ➤ Shortwall production cost : \$8.12 /ton
- ➤ Profit of longwall method : \$8452800–\$ΔC
- ➤ Profit of shortwall method : \$10020600–\$ΔC

Table IX

Objective efficiency values synthesis of alternatives

	No (j)	Criteria	Weight (gi$_j$)	Alternatives	
				Longwall mining method	Shortwall mining method
Safety	1	Safety	10	8	8
			∑	0.8	0.8
Economy	2	Concentration	3.3	6	7
	3	Operating cost	4.4	5	5
	4	Mechanization	5.6	6	6
	5	Capacity	6.7	6	8
	6	Profit ($million) (based on a panel)	7.8	7	9
	7	Development cost	5.9	5	2
	8	Equipment cost	3.0	7	7
	9	Labour	1.1	4	7
	10	Flexibility	2.2	1	3
			∑	2.27	2.9
Production loss	11	Rate of coal loss (%)	20.0	1	10
			∑	0.20	2.00
Technical sufficiency	12	Easy digging	6.7	2	5
	13	Multipurpose usage	4.2	3	9
	14	Grain size	3.3	5	5
	15	Face advance speed	5.8	3	9
	16	Digging area	2.5	3	5
	17	Manoeuvre time	1.7	7	7
	18	Removal capability	5.0	3	9
	19	Demand to labour instructions	0.8	6	2
			∑	0.99	2.11
		Total (value synthesis)		4.26	7.4

These discrepancies are caused from the coal loss of 20-25% in longwall mining. This loss is around 5% or less in shortwall mining. If a simple calculation is made by considering the coal loss rate as 20%, in a panel whose height is 7.5 m, it is clearly understood that coal worth $ 2500000 based on sales revenues is given up to underground. This value is significant magnitude to be considered only for a panel. When considered for all reserve, a lot of raw material will be lost applying longwall method.

In addition to the production loss of the longwall method, it is also a matter of concern that dilution to the coal that is taken from the back will be very high. When the calculations above were done, these extra costs arising from dilution were not taken into account. This case not only increases operating costs, but it also decreases the quality of the coal and brings about extra costs for the same quality coal.

Therefore, it is more likely that shortwall mining will be preferred for this coalfield. Additionally, both methods have been compared according to a multi-dimensional objective system. The longwall method received a score of 4.26, and shortwall mining 7.4 out of 10.

Considering the comparisons above, it can be easily seen that shortwall mining has more advantages. However, the following questions need to be answered in subsequent studies.

- Investigation of the implications that will emerge when the shortwall mining system is applied at a 7.5 m thick slice.
- Examining the unexpected results in the tailgate part, which originated from roof control problems in the shortwall.
- Generally speaking, shortwall mining exhibits much more usefulness in terms of both organization and speed of production. Some *in situ* researches have to be carried out in this report.
- The possibility of ordering a continuous miner with shorter drum length in order to increase safety demands.

According to the explanations mentioned above, it is concluded that the shortwall method must be examined in detail because it is a new method for the area and it may give better results than the present mining method.

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