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Applying a Technical-Economic Approach to Calculate a Suitable Panel Width for Longwall Mining Method

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Abstract

Providing an approach to calculate a suitable panel width for the longwall mining method is considered considering both the technical and economic factors. Based on the investigations carried out, a technical-economic model is proposed to calculate a suitable panel width. The proposed model is a combination of the rock engineering system-based model and the technical relationships to estimate the expected actual face advance rate of the longwall panel and also the economic relationships to determine the operational costs. Applying the technical conditions to the presented model is conducted by the vulnerability index of the advancing operation, which considers the face advance rate as the main important factor that controls the operational costs of the longwall face. The performance evaluation of the presented model is possible by the recordable field data, which is one of its advantages. This process is carried out by a case study, and the results obtained indicate that the developed approach can provide an applicable tool to calculate a suitable panel width.

1. Introduction

Calculating the suitable panel dimensions is one of the most important issues in a panel design in the longwall mining method; the panel width is the most critical dimension. Increasing the distance from a suitable panel width increases the operation costs. Increasing the uncontrollable gas propagation, increasing the roof instability (especially, uncontrollable roof falls), increasing the delays and appearance of the floor instability, reducing the efficiency of the equipment and the workers, and other problems all result in reducing the productivity and increasing the operation costs. All of these problems can be caused by an unsuitable panel width.

The panel width, its effect on the production operation, and its suitable value have been investigated by many researchers in the previous years. Onyemaobi [1] has presented an approach based on the economic calculations (an economic model consisting of cost and income) for an optimal determination of longwall panel dimensions based on four criteria. Tsuruoka and Shikasho [2] have developed a cost-economic model, determining the costs based on a function of the face length. Majumdar and Ray [3] believed that the cost was the most effective criterion involved in determining the optimum geometry for a panel design; they provided calculations in this regard. Grayson and Peng [4] have emphasized on optimizing the longwall dimensions by minimizing the total mining cost. Majumdar and Ray [5] have provided a logical approach to optimize the panel dimensions based on an economic model. They stated that the production cost was the main

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criterion. Lama [6] has analyzed the effect of the panel width on the coal production. Mishra [7] has performed a comprehensive analysis on the optimization of the development layout, longwall production, and face cost evaluation using the data gathered from the Australian longwalls. Peng and Tsang [8] have investigated the effects of the panel width on the powered supports and gate entries using the 3D computer modeling techniques. They explained that the shield support load distribution in a longwall face was mainly affected by the roof condition, degree of gob compaction, and interaction between the shield and roof strata. ŞİMŞİR and KÖSE [9] have considered a cost analysis to estimate an optimum panel width for the longwall panels in a case study. Peng [10] has studied the trends of panel width for the U.S. longwalls from 1975 to 2005 with an average positive growth rate of approximately 2.3%. Peng pointed out the development in equipment as a reason for this progress. Trackemas and Peng [11] have addressed the factors involved in increasing the panel width and the solutions to the technical concerns for increasing the longwall face width from the currently accepted industrial standard of 1,050 ft. to 1,600 ft. They explained that the additional design considerations for equipment, roof control, ventilation design, infrastructure, and longwall moves were required for this purpose. McMillan [12] has emphasized on the geotechnical conditions (roof competence and structure) and the management of goaf gas as the primary technical factors, capital availability, resource dimensions, existing equipment dimensions and capability, seam dip, and the protection of surface features as the other factors involved in determining a suitable panel width. Malli and Yetkin [13] have provided an approach to optimize the panel dimensions by considering the mining losses and stress distribution. Their approach suggests an optimum zone that provides a more efficient and a safer panel dimension planning. Behera et al. [14] have reviewed the design of an optimum panel longwall face, stating that selection of the longwall face length is highly sensitive to the ground control components (referring to the intensive periodic weighting and the front abutment loading), gas release rate (in the case of gassy mines), and face operation cost. Fan et al. [15] have presented a novel panel design method, taking into consideration the reducing water loss during the mining operation, which is based on evaluating and ranking the impact of the panel size on the hydraulic permeability of weakly cemented strata. Based on their findings, they determined that the optimal size for a panel could be determined and validated by the water level field observations.

Regarding the calculation of the operation efficiency in longwall mining, three conducted research works have been carried out by Brodny et al. [16], Brodny and Tutak [17], and Aghababaei et al. [18]. The references [16] and [17] have focused on the efficiency of mining machines in the longwall face but in the reference [18], the operation efficiency covers the mining machinery plus the ability of the mining personnel, ventilation, and other effective components in a longwall face operation.

According to the studies carried out so far, in order to calculate a suitable longwall panel width, all the approaches have used one or two effective technical factors alone or are just based upon the economic calculations. Considering one or two effective technical factors alone or developing a mere economic method cannot result in a comprehensive solution because it ignores many other important factors that have undeniable influences. These factors are the coal seam inclination, roof conditions, floor and face, methane propagation, and some other factors and constraints. Each one of these factors can cause an intensifying effect on the other factors. For example, a steep inclination of the longwall face in the condition of the existence of a weak roof increases instability, which results in increasing the delays and the operation costs. This work presents a comprehensive model to calculate a suitable panel width that considers the effects of all the important factors on a longwall face operation. In this research work, we provided a model that simultaneously considered the economic and technical factors and also the operation efficiency. Also the rock engineering system (RES) was used to apply the technical conditions to the model. There are many parameters affecting the operation in the longwall face, each of which has different effects on the system. These parameters are also affected by each other, and bad conditions for each one of them can worsen the conditions for the others, which make faster the occurrence of problems. RES uses a method that enables a comprehensive assessment of the factors and interactions; its advantage is that all the potential influencing factors can be included initially.

In order to investigate the model outputs and its performance, a case study was considered in the Parvadeh-I coal mine (E_0, E_2, E_3, W_0, W_1, and W_2 panels, extraction being made by retreating the longwall method) (Figure 1). This mine is located in SE of Tabas (Iran). In Parvadeh-I, the main geological units are mudstone, siltstone, and sandstone; also the orientation of the larger horizontal stress is NE to SW [19-21]. The information about the considered panels is presented in Table 1. The control system of the powered supports in this mine is manual.

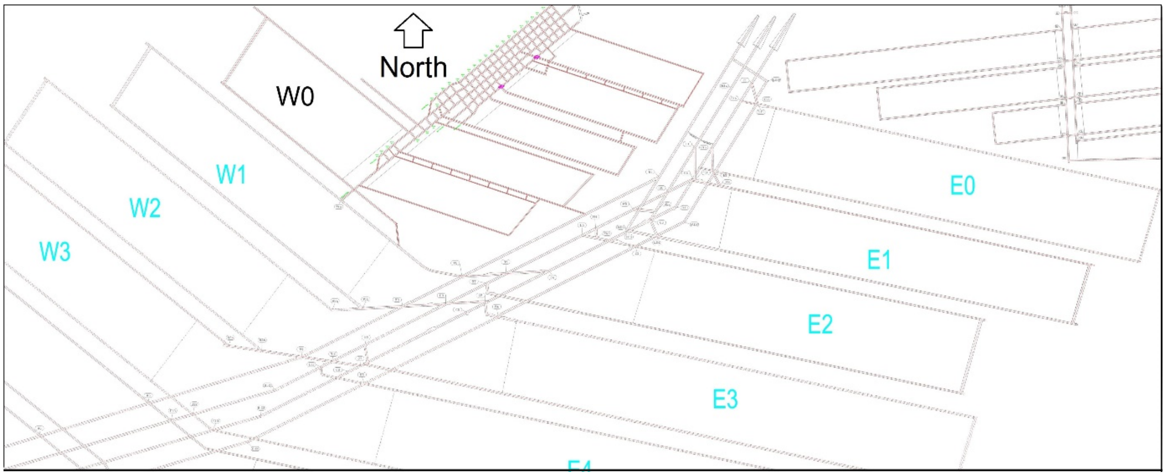

Figure 1. Location of the longwall panels in the case study.

Table 1. An information summary about the considered case study.

Code of panel	Length of panel (m)	Panel width (m)	Depth (m)	Average dip of coal seam (degree)	Ave. gas propagation (m^3/ton.coal)	Ave. face advance rate (m/day)	Description
E_0	1060	198	95	12.4	13.15	1.41	Extracted
E_2	900	213	250	24.9	12.86	4.62	Extracted
E_3	1233	207	368	19	1.6	4.87	Extracted
W_0	420	207	180	<15	8.8	5.47	Extracted
W_1	812	190.5	260	15.7	13.69	2.94	Extracted
W_2	827	205.5	365	12.8	17.19	2.91	Extracted

2. Adopted approach for research work

2.1. A summary of rock engineering system method

The rock engineering system (RES) was introduced by Hudson [22]. RES was developed to analyze the relationships and interactions between the effective parameters in the rock mass. This analysis quantifies the levels of interaction between the parameters, the results of which can be used for the next engineering analysis. The foundation of this method is based on the interaction matrix. All the parameters affecting the system are located along the leading diagonal of the matrix, and the other positions are filled by the values that describe the degree of interaction between the parameters (Figure 2). The interaction matrix is the processor of the RES method used to determine the weighting of each parameter in the system. In this work, the ‘‘expert semi-quantitative’’ (ESQ) method [22] was used to numerically code the interaction matrix. In the ESQ method, the level of interaction between the parameters was valued by the numbers 0 to 4. The numbers 0, 1, 2, 3, and 4 refer to "no interaction", "weak", "medium", "strong", and "critical interaction", respectively. The weighting of each parameter can be determined by Equation (1).

$$a_i = \frac{(C_i + E_i)}{(\sum_{i=1}^{n} C + \sum_{i=1}^{n} E)} \times 100 \quad (1)$$

where a_i is the weighting factor, C_i is the cause of the ith parameter, and E_i is the effect of the ith parameter.

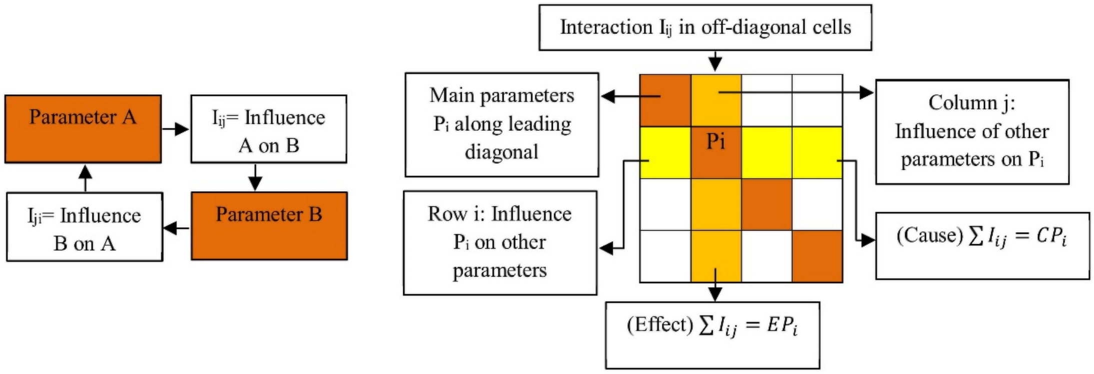

Figure 2. A general view of the interaction matrix including the principle of interaction between two parameters and matrix coding (taken after [22]).

2.2. Presentation of model

In the RES-based model, the face advance rate (FAR) is considered as the main and direct factor involved in determining a suitable panel width. All the economic calculations and operational costs of the longwall face are dependent on this factor. Reduction of FAR decreases the coal production and increases the operating costs. The reduction rate of FAR relative to its value in the normal operating conditions was estimated by the vulnerability index of FAR (VI_{FAR}). Aghababaei *et al*. [18] have presented an RES-based model to predict the face advance rate and determine the operation efficiency at the longwall mining panel. In the proposed model in the present work, their research work with some modifications in the number of effective parameters was applied to calculate the maximum possible practical face advance rate that was used as the input data of the economic calculations.

In the developed model, Equation (2) was applied to determine the sum of the operational costs in each panel.

$$TOC_{lw} = AFC_{oc} + PS_{oc} + S_{oc} + PRD_{oc} + SRD_{oc} + RRD_{oc} + R\&D_{oc} \quad (2)$$

where TOC_{lw} is the total operation direct costs of the longwall mining ($/ton.coal), AFC_{oc} is the AFC (Armored face conveyor system) operational costs ($/ton.coal), PS_{op} is the powered supports operation costs ($/ton.coal), S_{oc} is the cutting machine (shearer loader) operational costs ($/ton.coal), PRD_{oc} is the panel roadways development operational costs ($/ton.coal), SRD_{oc} is the setup room development operational costs ($/ton.coal), RRD_{oc} is the recovery room development operational costs ($/ton.coal), and $R\&D_{oc}$ is the recovery and installation operation costs of the longwall system including the withdraw, transfer, overhaul, and reinstallation of the equipment ($/ton.coal).

Each parameter in Equation (2) should include all the related costs including the maintenance, labor, machine parts, materials (such as rock bolts and drilling materials), and fuel and oil costs as well as the overhead costs. In order to determine each component in Equation (2), Equations (3) to (11) were applied. In these equations, AFC_c is the total operation cost of AFC per each meter of the AFC length ($/m.day), PR_{ea} is the expected actual production rate of coal per day (ton.coal/day), H_f is the height of the face wall (m), SG_c is the specific gravity of coal (ton/m^3), TWT is the total working time (h/day), PS_c is the total operational cost of each powered support ($/day), WPS is the width of each powered support (m), S_o is the total operation cost of the cutting machine (shearer loader) per day ($/day), PRD_c is the total operational costs of the panel roadways development per meter ($/m), P is the total production of the panel (ton.coal), LTG is the length of Tailgate (m), LMG is the length of Maingate (m), PL is the panel length, SRD_c is the total operational cost of the setup room development per meter ($/m), RRD_o is the total operational cost of the recovery room development per meter ($/m), and $R\&D_c$ is the total operational cost of recovery and installation of the longwall system including the withdraw, transfer, overhaul, and reinstallation of the equipment ($).

$$AFC_{oc} = \frac{(AFC_c)(PW)}{PR_{ea}} \quad (3)$$

$$PR_{ea} = \frac{(FAR_{ea})(PW)(H_f)(SG_c)}{TWT} \quad (4)$$

$$PS_{oc} = \frac{PS_c\left(\frac{PW}{WPS}\right)}{PR_{ea}} \quad (5)$$

$$S_{oc} = \frac{S_o}{PR_{ea}} \quad (6)$$

$$PRD_{oc} = \frac{PRD_o(LTG + LMG)}{P} \quad (7)$$

$$P = (PL)(PW)(H_f)(SG_c) \quad (8)$$

$$SRD_{oc} = \frac{(SRD_c)(PW)}{P} \quad (9)$$

$$RRD_{oc} = \frac{(RRD_c)(PW)}{P} \quad (10)$$

$$R\&D_{oc} = \frac{R\&D_c}{P} \quad (11)$$

In order to estimate FAR_{ea}, Equations (12) to (15) were applied, respectively. In these equations, FAR_{mpt} is the maximum possible theoretical face advance rate (m/day), PW is the panel width, EShS is the equivalent shearer machine speed (considered to be equal to 16 ft/min in the condition of the manual control system for powered supports in Parvadeh-I and equal to 40 ft/min for the electrohydraulic control system [23]), UST is the unavoidable stop times due to work of the equipment at longwall face, TUWT is the total useful working time in a day (being equal to 900 min in the Parvadeh-I conditions), WW is the web width of shearer machine (being equal to 0.8 m for the cutter machine in Parvadeh-I), FAR_{mpp} is the maximum possible practical face advance rate, VI_{FAR} is the vulnerability index of the advancing operation in the considered panel, a_i is the weighting of the ith parameter, Q_i is the value (rating) of the ith parameter, and Q_{max} is the maximum value assigned for the ith parameter (normalization factor). When the VI value approaches 0, the risk level of the hazard is lower, while when its value approaches 100, it shows that the risk level of the hazard is higher at the considered site. FAR_{ea} is the expected actual face advance rate in the technical conditions of the considered panel, and E_e is the expected operation efficiency of the considered panel (%).

$$FAR_{mpt} = \left[\frac{TUWT}{\frac{PW}{EShS} + UST}\right] WW \quad (12)$$

$$FAR_{mpp} = \left[\frac{(100 - VI_{FAR})}{100}\right] FAR_{mpt} \quad (13)$$

$$VI_{FAR} = 100 - \sum_{i=1} a_i \frac{Q_i}{Q_{max}} \quad (14)$$

$$FAR_{ea} = FAR_{mpp}\left(\frac{E_e}{100}\right) \quad (15)$$

In order to calculate a suitable panel width, TOC_{lw} was determined based on the estimated FAR_{ea}, panel dimensions, and other factors involved for different widths of each considered longwall panel in its corresponding technical conditions. Therefore, the total operation direct costs of a suitable panel width for each considered longwall panel was determined using Equation (16). In this equation, TOC_{PWn} is the total operation direct costs of the nth panel width and TOC_{PWs} is the total operation direct costs of a suitable panel width. All of these calculations were done using the formulation in the Excel software.

$$TOC_{PW_s} = Min[TOC_{PW1}, TOC_{PW2}, \ldots, TOC_{PWn}] \quad (16)$$

For the RES-based model, six major effective parameters were designated to form the interaction matrix based on [18]. These parameters affect FAR, which is the most important factor controlling the operating costs. Thus P_1 is the coal mine roof rating (CMRR), P_2 is the gas propagation (m^3/ton.coal), P_3 is the safety factor of the coal face (SF calculated by Equation (17)), P_4 is the ratio of joint spacing to cut depth at face, P_5 is the longitudinal inclination of the longwall face (degree), and P_6 is the rock mass ratting (RMR) of the floor. Based on these parameters, the interaction matrix was generated for VI_{FAR}, and matrix coding was fulfilled by the ESQ method (Table 2). The coding was obtained based on the experiences and views of the experts in the field of longwall mining. The outputs of the interaction matrix are presented in Table 3.

$$SF = \frac{\frac{\sigma_{c.w}}{\sigma_{yy}}}{f} \quad (17)\ [24]$$

In Equation (8), SF is the safety factor of the coal face, $\sigma_{c.w}$ is the wall coal strength of the first 0.75 m of the coal face, σ_{yy} is the vertical induced stress at the first 0.75 m of the coal face, and f is the correction factor of joint orientation at coal seam; f is equal to (1-B), where B is the orientation factor for the critical joint set. In order to determine the front abutment stress at the first 0.75 m of the coal face, the results of numerical modeling in Parvadeh-I [20 and 21] and the Wilson's equations [25] about "calculation of vertical stress distribution and yield zone" were applied. In order to determine f, the joint orientation factor developed by Hutchinson and Diederichs [26] for the stability graph analysis method was used. Therefore, according to the amount of field stresses, strength of coal face, and joint orientation parameters in each panel, SF of each panel was calculated. The effect of field stresses appears in abutment stresses for a longwall panel, where the front abutment stress and the side abutment stress are the most important for the two main parts of each panel including the face and roadways, respectively. The effect of the front abutment stress on the stability of the face was considered by the SF factor.

Table 2. Coding of the interaction matrix for the parameters affecting FAR at a longwall mining face.

P_1	0	1	0	0	0
0	P_2	0	0	0	0
0	1	P_3	0	0	0
2	1	1	P_4	0	1
0	0	1	0	P_5	0
0	0	1	0	1	P_6

Table 3. Weighting of the effective parameters.

Parameter code	C_i	E_i	Interactive intensity (C+E)	Dominance (C-E)	a_i (%)
P_1	1	2	3	-1	15.00
P_2	0	2	2	-2	10.00
P_3	1	4	5	-3	25.00
P_4	5	0	5	5	25.00
P_5	1	1	2	0	10.00
P_6	2	1	3	1	15.00

Calculation of Q_i/Q_{max} in Equation (14) requires rating the parameters' values based on their influence on FAR. Totally, a range of 0 to 5 in six classes was considered for this purpose; 0 denotes the worst case (maximum VI of FAR), and the highest value is the best case (minimum VI of FAR). Rating the parameters were carried out and the results obtained were tabulated in Table 4. Divisions for rating of P_1 and P_6 were done based on five classes of rock mass quality including "very poor rock", "poor rock", "fair rock", "good rock", and "very good rock". Division of P_2 was chosen based on the amount of gas propagation in coal mines in the four categories including low, intermediate, high, and extremely high. An additional class was set for the times when the methane drainage operation was performed; its rate was determined based on the quality of the operation. P_3 was rated in four classes based of the safety factor of the face with an additional class for the times when powered supports were equipped with face guard (F.G). The rate of the last class was determined based on the level of increase in the face stability by F.G against abutment stresses. Rating of P_4 was considered in six classes based the number of joints in the exposed span created by the cutting machine with an additional class for the times when F.G rapidly supported the unprotected span in front of the roof at the face. Rating for P_5 was carried out in four classes. The faces with inclination of less than 15 degrees and more than 45 degrees had the best and worst operation conditions, respectively. Increasing the inclination increased the required support load (based on Wilson [27]), decreased the face advance rate, and created other problems in the longwall panels. The coal seams with an inclination of more than 45 degrees were rarely mechanized due to the worst operational conditions.

Table 4. Rating the principal parameters.

Parameter code		Value/description and rating						
P_1	Value	<21	21-40	41-60	61-80	81-100		
	Rating	0	1	2	3	4		
P_2	Value	<5	5-10	10-15	15<	Doing methane drainage		
	Rating	3	2	1	0	3		
P_3	Value	<0.75	0.75-1	1-1.25	1.25<	If F.G applied & SF<1		
	Rating	0	1	2	3	1 to 3*		
P_4	Value	<0.25	0.25-0.5	0.5-0.75	0.75-1	1-1.25	1.25<	If F.G applied and P_4<1
	Rating	0	1	2	3	4	5	3 to 5*
P_5	Value	<15	15-30	30-45	45<			
	Rating	3	2	1	0			
P_6	Value	<21	21-40	41-60	61-80	81-100		
	Rating	0	1	2	3	4		

*Depending on value of P

2.3. Organizing database

In order to perform the accurate calculations on VI in each panel, a comprehensive database was created along each panel gate so that the length of each gate was divided into intervals with an equal distance, and the required data by all of the recorded and surveyed geological and geo-mechanical information was determined for them. The statistics results of the amount of parameters in the created database are presented in Table 5.

Table 5. Statistics results of the amount of parameters in the database.

Parameter Code	Average	Min	Max	SD
P1	44.48	13.70	55.60	8.93
P2	10.55	1.60	17.70	5.30
P3	1.44	0.74	3.08	0.90
P4	1.30	0.07	1.88	0.65
P5	15.01	10.00	31.00	5.21
P6	36.28	19.00	42.00	5.47

In the Parvadeh-I coal mine, the conventional recovery room concept (not pre-driven recovery room concept) is adopted to the withdrawal equipment, whose related operational costs are divided into the development costs and the withdraw costs. The development costs include the extraction and support operation costs. For the two stages of recovery and setup operation, the longwall system equipment is completely overhauled.

It should be noted that the subsidence constraints was not involved in this work. If subsidence was important for the considered coal mine, it would be a constraint, not an effective parameter.

3. Results and discussion

The provided approach was examined on the case study and the results obtained were discussed. In Figure 3, the results of the economic model for a panel length equal to 1000 m without applying the technical conditions are illustrated; a suitable panel width is equal to 210 m at the lowest value of TOC_{lw}. The results of the determined VI_{FAR}s on the considered panels are presented in Table 6.

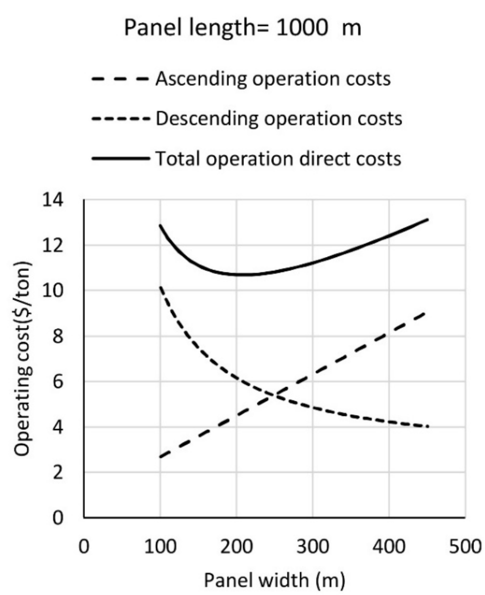

Figure 3. Calculation of a suitable panel width by the economic model with panel length = 1000 m.

Table 6. Results of the determined VI_{FAR}s and their description for the considered case study.

Panel code	Ave. VI_{FAR}	Min VI_{FAR}	Max VI_{FAR}	St. Dev.
E_0	28.06	23.33	45.83	7.23
E_2	67.53	46.67	90	11.91
E_3	50.25	40.42	56.25	3.9
W_0	35.2	27.08	55.83	10.74
W_1	47.47	38.33	74.17	10.74
W_2	41.86	41.67	45	0.8

The performance of the RES-based model to predict FAR has been proven by Aghababaei *et al.* [18]. However, due to the modifications applied in this research work, the performance of the presented RES-based model was proven by investigating the correlation between the estimated VIs and FAR at the considered panels (Figure 4).

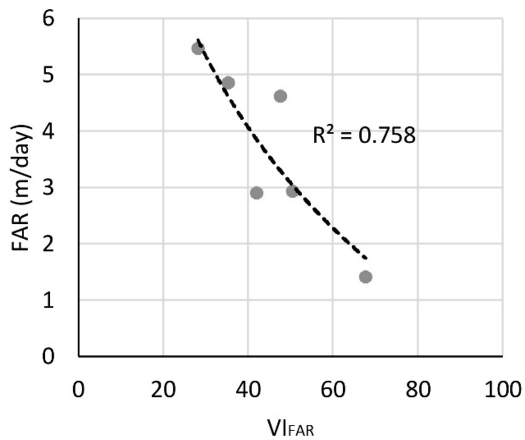

Figure 4. Correlation between the mean of VI_{FAR}s and FAR in each panel for the considered longwall panels; a logarithmic regression analysis.

In the following, using the developed approach, a suitable panel width was calculated for each panel (Table 7). PW_{T-E} is the suitable panel width, which is determined by the technical-economic model. In order to investigate the performance of the technical-economic model and the influence of selection of a suitable panel width on the operation efficiency, the relationship between $[(PW_e)-(PW_{T-E})]$ and the operation efficiency was charted in each considered panel and the results obtained were illustrated in Figure 5. The operation efficiency has been determined by Aghababaei *et al*. [18] for the considered panels. $[(PW_e)-(PW_{T-E})]$ is the difference between the width of the extracted panel (PW_e) for each considered panel and its (PW_{T-E}) value. Also this process was carried out for $[(PW_e)-(PW_{T-E})]$ and FAR, whose relevant results could be seen in Figure 6.

Table 7. Calculating a suitable panel width by the technical-economic model for the considered panels.

Panel code	PW_e (m)	PW_{T-E}, calculated by the model (m)
E_0	198	180
E_2	213	130
E_3	207	150
W_0	207	180
W_1	190.5	160
W_2	205.5	160

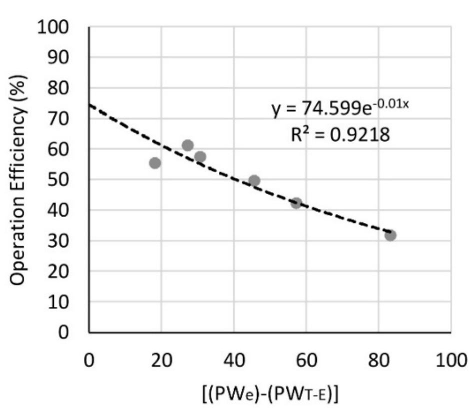

Figure 5. Correlation between $[(PW_e)-(PW_{T-E})]$ and the operation efficiency for the considered longwall panels.

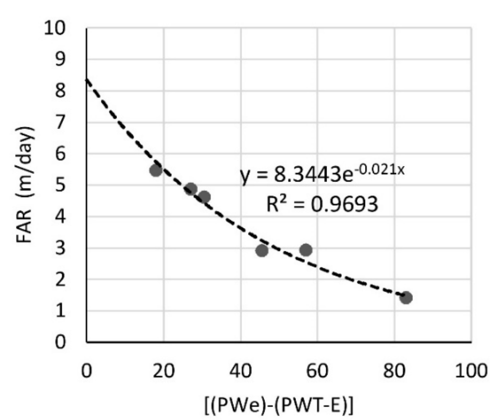

Figure 6. Correlation between $[(PW_e)-(PW_{T-E})]$ and FAR for the considered longwall panels.

The results shown in Figures 5 and 6 show that with increase in the difference between the designed panel width and the calculated suitable panel width, the operation efficiency decreases. This means that the selection of a non-optimal panel width in addition to an increase in the operational costs causes a reduction in the operation efficiency and also causes a double increase in the costs by the technical factors.

Three conducted investigations confirmed the performance of the developed model. First, using the presented methodology for calculation or prediction of FAR, investigated by Aghababaei *et al*. [18], the performance of the model was validated by the field data. Also the performance of the presented RES-based model in this work was investigated and the results obtained were illustrated in Figure 4. Secondly, the results shown in Figures 5 and 6 show that the presented technical-economic approach produce realistic outcomes; a higher distance from a suitable point results in a lower efficiency and a higher operational cost. The coefficient of determination (R^2) in all the Figures 4, 5, and 6 is in an acceptable range.

Application of a fully mechanized longwall equipment and upgrading the present system has been a major concern for mechanized coal mines that also include the Parvadeh-I coal mine. Based on the presented model, it is possible to apply the effect of using a fully mechanized longwall system (see Table 4, rating of P_3 and P_4). In this regard, calculations in three system including the equipped powered supports with manual control system, the equipped powered supports with manual control system and F.G, and the equipped powered supports with electrohydraulic control system and F.G were carried out, and the related results were shown in Figures 7, 8, and 9. The results obtained show that equipping the powered supports with F.G and then using the electrohydraulic control system with F.G cause an increase in the suitable panel width with average 9.4 and 63.5% and a decrease in the operation costs with average 14.8 and 41%, respectively.

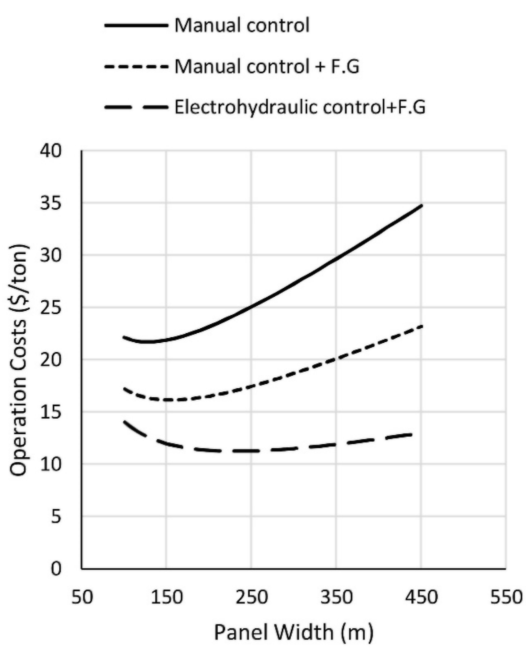

Figure 7. Comparing the effect of applying different control systems of powered supports on suitable panel width and operation costs in the E_2 panel.

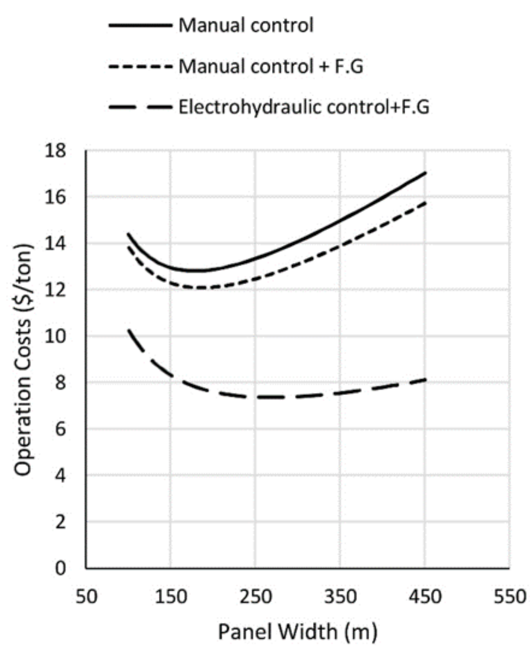

Figure 8. Comparing the effect of applying different control systems of powered supports on suitable panel width and operation costs in the E_0 panel.

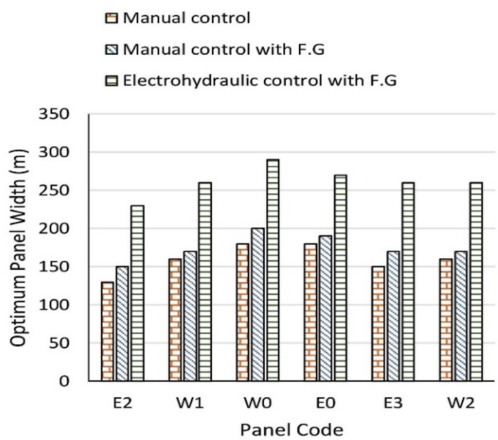

Figure 9. Comparing the effect of applying different control systems of powered supports on suitable panel width and operation costs in the considered panels.

The influence of increase in the panel length on a suitable panel width and operational costs was investigated for the panels and the results of the E_0 panel in two system types of powered supports were illustrated in Figures 10 and 11, respectively. The results obtained show that there is no most suitable panel length based on the presented technical-economic (cost model) model for the considered case study. This means that the longer the panel, the better. It could be concluded from the results that with increase in the panel length, the operational costs were reduced but the decline rate was downtrend, tending to zero.

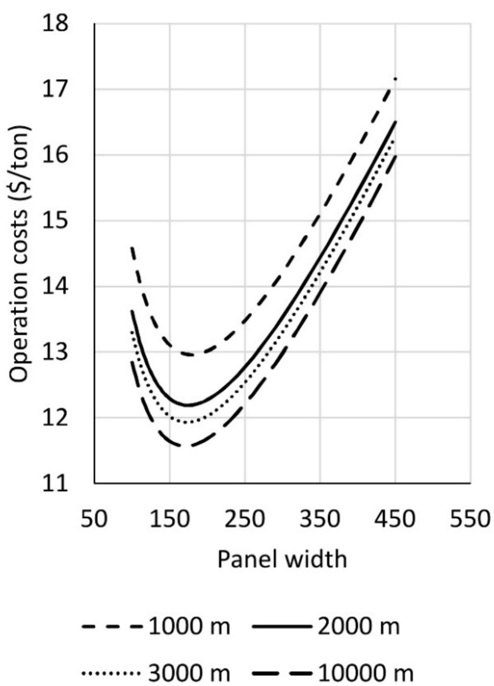

Figure 10. Relationship between the panel width (range of 100-450 m) and operation costs in different panel lengths in E_0 panel; manual control system.

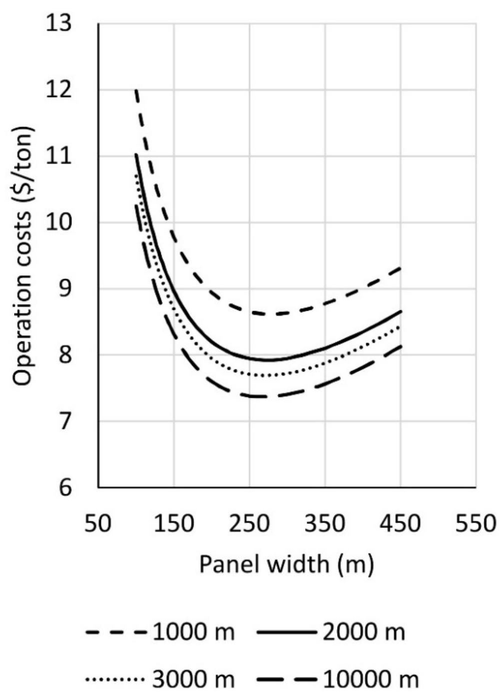

Figure 11. Relationship between the panel width (range of 100-450 m) and operation costs in different panel lengths in E_0 panel; electrohydraulic with F.G system.

The results obtained show that defining a general model on variations in the operation efficiency on different levels of mining operation is possible. Based on the achievements and taking a template from the general conceptions, a general model on this issue was presented, illustrated in Figure 12. This is required to be more investigated with a lot of field data from other mines. A professional operation mining creates a maximum width from the reference line in both the minimum operation efficiency at maximum $[(PW_e)-(PW_{T-E})]$ and the maximum operation efficiency in minimum $[(PW_e)-(PW_{T-E})]$. A professional mining constructs the maximum available operation efficiency in a planned panel width near a suitable panel width. To the contrary, reaching the maximum available operation efficiency could not occur at a suitable panel width for a weak mining operation.

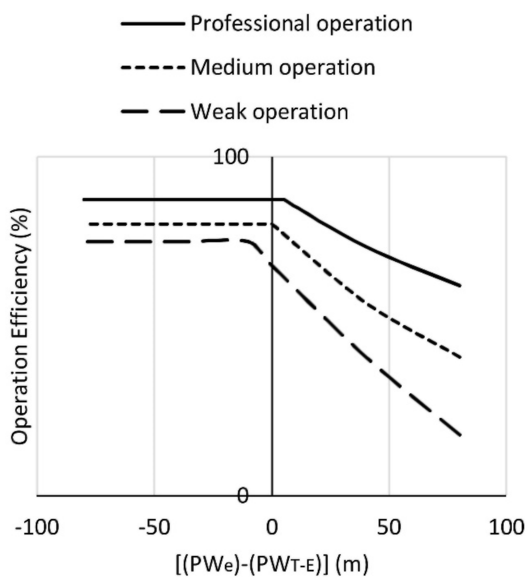

Figure 12. Presented general model on variations in the operation efficiency on different levels of a mining operation.

Providing a pattern to estimate a suitable panel width based on the mining realities can be very interesting. This is a sensitive issue in a longwall mining operation, like cut-off grade of minerals in open-pit mining. According to the investigations and results, the following pattern is recommended for a systematic estimation of a suitable panel width in a longwall mining operation (Figure 13).

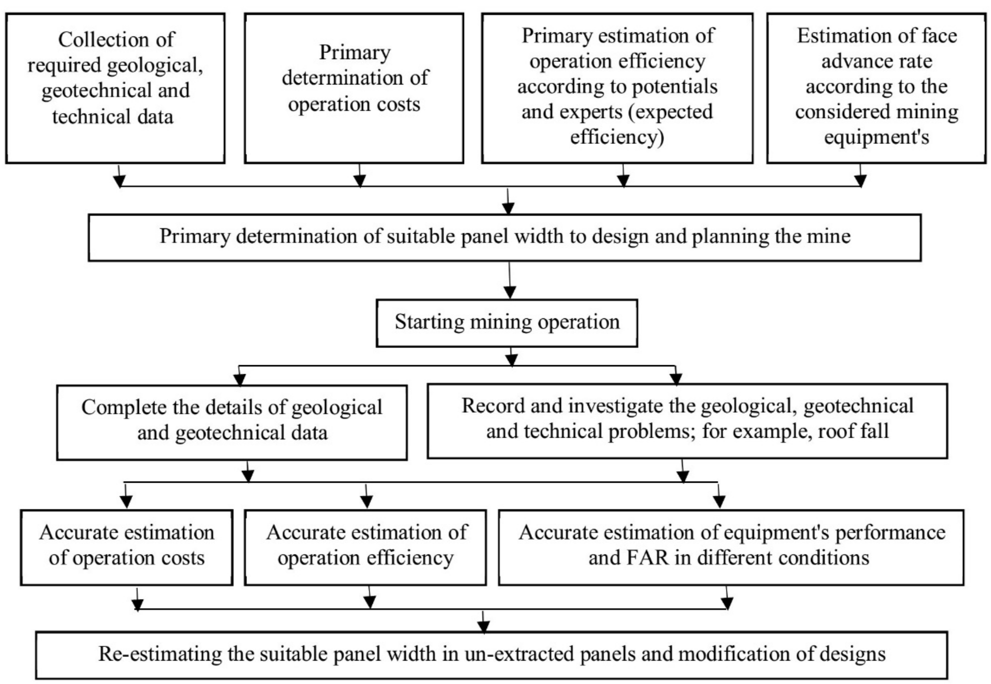

Figure 13. Recommended pattern to estimate a suitable panel width in longwall mining by the presented model.

4. Conclusions

This work provided a technical-economic approach to calculate a suitable panel width in the longwall mining method. Investigations showed that FAR was the most important factor to control the operational costs of longwall panel and determine a suitable panel width. Therefore, an

RES-based model was presented to apply the technical conditions to the technical-economic model. The provided approach was applied to the Parvadeh-I coal mine to evaluate the performance of the model. The results obtained from the technical-economic model indicated that there was a relationship between the difference of the selected panel width and a suitable panel width with the operation efficiency; increase of the difference causes reduction in the operation efficiency. Investigations showed that the model could be the best and the easiest way to estimate a suitable panel width because the operational costs of longwall panel were directly affected by the face advance rate and this model as the validated method produced reliable results. This claim, of course, requires further investigations worldwide. The results obtained show that applying a fully mechanized longwall system causes a significant increase in a suitable panel width and also reduction of variation rate in the operation costs with panel width against a semi-mechanized system. The presented method can be used for the traditional, semi-mechanized, and fully mechanized mining methods. The presented methodology provides a realistic and proper tool because it can be validated and also can use recordable field data.

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بکارگیری یک مدل فنی-اقتصادی جهت تخمین یک عرض پهنه مناسب برای روش معدنکاری جبهه کار طولانی

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چکیده:

این مقاله دستورالعملی را جهت تخمین یک عرض مناسب پهنه برای روش معدنکاری جبهه کار طولانی ارایه می‌دهد که هر دوی پارامترهای فنی و اقتصادی را بطور همزمان لحاظ کرده است. مدل کلی معرفی شده، ترکیبی از یک مدل مبتنی بر سیستم مهندسی سنگ و روابط فنی جهت تخمین نرخ پیشروی واقعی مورد انتظار یک پهنه جبهه کار طولانی و همچنین روابط اقتصادی جهت تعیین هزینه های عملیاتی است. اعمال شرایط فنی در مدل بوسیله اندیس آسیب پذیری عملیات پیشروی انجام گرفت که نرخ پیشروی سینه کار را به عنوان مهمترین فاکتور کنترل کننده هزینه های عملیاتی در نظر می‌گیرد. در دستورالعمل مورد استفاده، امکان تعیین کارایی مدل بوسیله داده‌های برجای قابل ثبت وجود دارد که این را می‌توان به عنوان یکی از مزایای آن در نظر گرفت. برآورد کارایی مدل با در نظر گرفتن یک مورد مطالعاتی انجام گرفت و نتایج نشان داد که روش ارایه شده می‌تواند به عنوان یک ابزار کاربردی برای تخمین عرض مناسب پهنه مورد استفاده قرار گیرد.

کلمات کلیدی: عرض مناسب پهنه، نرخ پیشروی، مدل فنی-اقتصادی، سیستم های مهندسی سنگ، معدنکاری جبهه کار طولانی.