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Solutions to improving the efficiency of production organization at semi-mechanized longwall face I-6-2, Bac Quang Loi coal mine

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ABSTRACT

Dong Bac Corporation is the second largest coal producer in Vietnam with output accounting for more than 14% of the country's total production. According to the plan, coal production from underground mines is expected to increase to 60% of the total Corporation's production by 2025. To increase coal production in longwall mining, Dong Bac Corporation applies advanced technological solutions to modernize production stages, with the notable implementation of the semi-mechanized longwall mining technology. This technology uses a single-drum shearer and mobile hydraulic supports. The use of the technology has encountered challenges and difficulties, resulting in low production efficiency. The highest output achieved in the longwall face only reached 70% of the initial design capacity. The article presents the current status of technological innovation in underground coal mining of Dong Bac Corporation. The primary research subject is the semi-mechanized longwall face I-6-2 at Bac Quang Loi coal mine of Company 790, Dong Bac Corporation. Based on analysing the causes of difficulties, the authors provide solutions to improving production efficiency, safety, and the environment. Some solutions have been used in practice and have achieved positive and promising effects. Adjustment of production cycle organization chart to align with mining conditions has resulted in an increase in effective working time and a 17% rise in coal output. Accordingly, the authors propose technological orientations for the development of underground coal mining at Dong Bac Corporation.

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1. Introduction

In 2023, Vietnam produced 46 million tons of raw coal for different domestic and foreign demands. The two major parties, Vietnam National Coal - Mineral Industries Holding Corporation Limited (Vinacomin) contributed 39 million tons (accounting for 84.8%), and Dong Bac Corporation (DBC) - 6.66 million tons (accounting for 14.5%).

The underground coal production of DBC in 2023 took up 42% of the corporation's total output (2.82 million tons). According to the plan, this ratio is expected to increase to 60% by 2025 and will reach 72% (5.45 million tons) by 2030. Thus, in 7 years, the underground coal output of DBC should nearly double. To achieve this, the use of new technology to increase productivity and coal surface output is inevitable. This is the direction to contribute to the sustainable development of DBC's underground coal mining industry.

In general, the geological conditions of coal mines in Vietnam, especially underground mines are quite complicated. This is characterized by the large variations in thickness, slope angle of coal seams and the appearance of faults with large size and displacement amplitude.

Unlike Vinacomin, DBC is assigned to manage and exploit small coal mines. They are dispersedly distributed in the boundary areas of the Northeast coal basin. These coal mines of small size and modest reserves are located far away from each other and have more complex geological conditions than the coal mines of Vinacomin. Operating conditions of DBC's coal mines are more difficult because DBC is an agency of the Department of Defense.

Because of the complicated geological conditions as well as limited capital investment, DBC's underground coal mines are using rather obsolete technologies. Most coal mines use drilling and blasting technology with hydraulic props. Since 2019, DBC has put into practice a shearer at the longwall face 10.2T at Nam Khe Tam mine (Vu et al., 2021). The actual deployment process encountered many difficulties due to the novelty of technology for workers and the inadequacy of combining hydraulic props with shearers (Vu & Do, 2019).

From the acquired experience, from 2022, DBC has implemented a new step in the modernization of the coal mining process. Longwall face I-6-2 is designed for the use of mobile hydraulic supports and shearers (IMSAT, 2021). Significant improvements have been noted when compared to a longwall face with hydraulic props. However, in actual production, some problems caused the longwall face to not work as expected. Of note is the disparity in production organization between reality and design, which extends the production cycle. Furthermore, the variation in properties of the floor, coal face, and roof negatively affects the working space and slows down face advancing speed.

This paper proposes several solutions to addressing unfavourable issues and improving production efficiency for the semi-mechanized longwall face I-6-2. It primarily focuses on the development of a rational production organization chart.

2. Data and research methods

2.1. Research methods

In this paper, the data of the research were collected through a practical survey process. From these data, the authors analyzed the existing issues. Through theoretical research and analysis, the authors proposed appropriate and highly feasible solutions. The effectiveness of these solutions was verified through the results achieved in practical production.

2.2. Current status of semi-mechanized longwall face I-6-2

2.2.1. Design parameters

The longwall face I-6-2 uses a shearer to cut coal in combination with mobile hydraulic supports. This is the DBC's most technologically advanced longwall face. This coalface is currently operating in the area of seam 6, Bac Quang Loi coal mine of Company 790. In the mining area, the immediate roof and floor have low to medium stability. The main roof consists of siltstone and sandstone with a thickness of 5.4÷7.4 m and is from stable to very stable.

The semi-mechanized longwall face I-6-2 uses the longwall top coal caving (LTCC) method. The longwall face is supported by mobile hydraulic support GTL1600/16/24MK, extracted by a single-ended ranging drum shearer MG125/150-WD. The mined coal is transported by scraper conveyor SGZ630/2x90 (Figure 1).

Basic design specifications of the longwall face I-6-2 are shown in Table 1.

The main part of the longwall face is 50m long and is extracted by shearer MG125/150-WD with a cutting drum diameter of 1.3 m. The coalface height is 2.2 m. The process of cutting coalface is divided into two stages (Figure 2):

(a) Shearers MG125/150-WD

(b) Scraper conveyor SGZ630/2×90

(c) Mobile hydraulic support GTL1600/16/24MK

Figure 1. Main equipment of the longwall face I-6-2.

Table 1. Economic and technical indices of the longwall face I-6-2 by design (IMSAT, 2021).

No	Indices	Units	Values
1	The average thickness of coal seam	m	3.6
2	Average slope angle of coal seam	degree	16
3	Cutting height	m	2.2
4	Recovered coal layer	m	1.4
5	Longwall face length	m	60
6	Number of production cycles per day	cycle	3
7	Face advancing speed	m/day	2.4
8	Capacity of longwall face	T/year	150,000
9	Number of workers per day	worker	63
10	Direct labor productivity	T/ labor	9.2

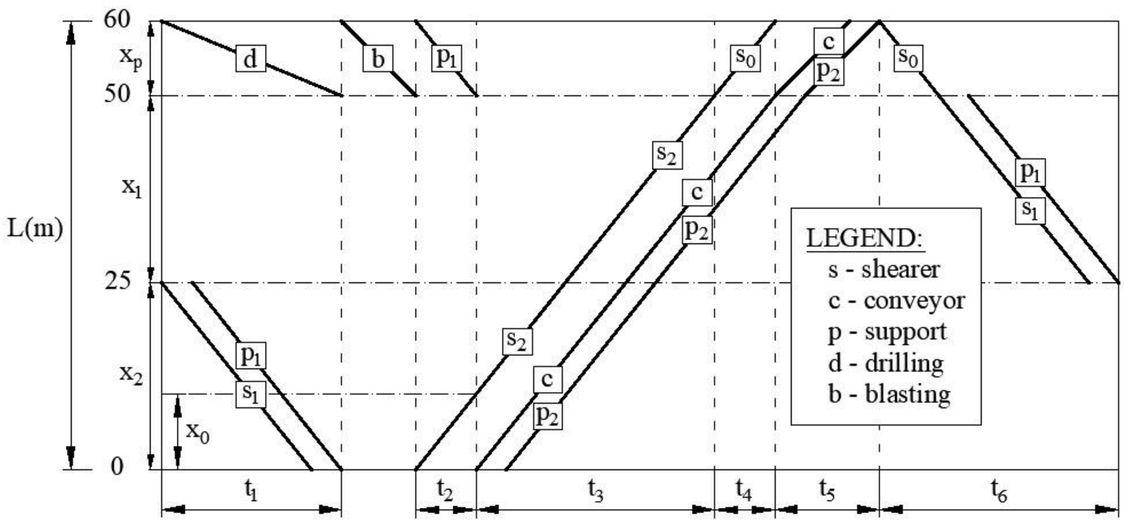

Figure 2. Organizational chart of the production cycle of longwall face I-6-2 by design.

(1) Shearer cuts the upper part of longwall face (s_1), support lifts the shield to temporarily hold the cut face (p_1);

(2) Shearer cuts the lower part of the longwall face (s_2), and moves conveyor (c) and mobile hydraulic supports (p_2) to a new position according to the cutting progress.

Due to the use of a downward-facing single-ended ranging drum shearer, the front end of the longwall face, which is adjacent to the ventilation roadway and has a length of x_p = 10 m, is created by drilling (d) and blasting (b). In this area, the shearer moves in an unloaded state (s_0).

The total movement time of the system "shearer - conveyor - support" is:

$$T = \sum_{i=1}^{6} t_i \text{, min} \tag{1}$$

According to the calculation of the original design, the time to complete a production cycle of the longwall face I-6-2 is one shift (8 hours). A cutting depth of 0.8 m allows the coalface to move 2.4 m per day.

2.2.2. Some problems encountered in practice

During its operation, semi-mechanized longwall face I-6-2 had a few problems that made it difficult for production activities. Some typical problems include:

(1) Organisation of production is widely different from the design. The arrangement and implementation of the process have not been as effective as expected. Therefore, the time to complete the production cycle of the longwall face is prolonged, reducing productivity and output. In one day, only 02 production cycles can be completed (compared to 03 cycles per day by design) which leads to a decrease in output. The actual output of the longwall face is 275÷363 tons/day, corresponding to the highest converted output of 108,900 tons/year.

(2) Face spall occurs at some locations at some time. This has a direct negative effect on the workspace and stability of the longwall face.

(3) In some locations, an unstable floor makes the supports prone to heave, which slows down the face advancing speed.

2.2.3. Reviews and analysis

Supports in the longwall face are mobile hydraulic supports. This type is not too new for the underground coal mining industry in Vietnam. However, for underground coal mines of Dong Bac Corporation, this can be considered as the most advanced type of support to be put into use.

At semi-mechanized longwall face I-6-2, the movement of mobile hydraulic supports was a big problem for workers. Currently, the time to fully move mobile hydraulic support according to face advancing speed is 15 minutes/support. In some adverse cases, movement time can be up to 25÷30 minutes/support.

In the initial production organizational chart, mobile hydraulic supports are moved along with the movement of the shearer and conveyor with a minimum distance of 10 m from the shearer's operating position (see Figure 2, s_2 and p_2). With a cutting speed along the longwall face of 1.0÷1.5 m/min, the moving speed of supports is designed with synchronous speed, corresponding to 1.5÷2.0 min/support. Thus, the difference between the actual moving speed and design is substantial. That is, the actual time t_2 is much larger than the original calculation. The main causes of this problem include:

(1) Technical competencies of workers:

Although mobile hydraulic supports are a familiar form of support in Vinacomin underground coal mines, this can be considered the most advanced form of support in DBC's coal mines, including the Bac Quang Loi coal mine. Currently, in DBC's underground coal mines, the most common type of used supports is hydraulic props.

Because of the short exposure and working time with mobile hydraulic supports, workers are still confused and do not have the necessary experience to master the operation. The immaturity when moving supports makes the operation time significantly longer.

(2) Influence of mining technical factors:

The size of mobile hydraulic support is significantly larger than that of conventional hydraulic props because it is composed of two beams. However, the movement is performed in turn on each side. That is, moving mobile hydraulic support can be considered as moving 02 combinations of the hydraulic prop with the box beam. Therefore, the state and connection between the two sides of support are very important in mine pressure control.

Under unfavorable geological conditions, stress concentrations often appear and cause negative effects on supports (Le & Mai, 2022). This makes it difficult to move the mobile hydraulic supports due to stress imbalance.

Besides, during the operation, when the coal face is not supported in time, a face spall occurs. This can happen on a local scale with a small area but still has a negative impact on other activities in the workspace. When the coal face is damaged, additional hydraulic props are required (Figure 3).

The main causes of these problems are:

(1) Variation in properties of coal and rock (Le et al., 2020);

(2) Mobile hydraulic supports do not guarantee the ability to completely cover the roof area of the coalface. There is always a certain space between supports, and between them and coalface. Typically, when the shields do not contact with the roof and longwall face (Figure 4), face spall can occur.

(3) Face advancing speed is slow due to many different factors, especially the prolonged movement of hydraulic supports. When coalface is in a spatial position for a long time, the "weariness" of the top coal and roof will increase due to mine pressure (Le et al., 2019). The mine pressure value, in this case, is inversely related to face advancing speed. As a result, longwall faces with slow advancing speed should be more prone to face spalling. In some locations, unstable floor is the cause of heave problems. Local heave of the floor affects the operation of mobile hydraulic supports. Supports can be shortened, tilted or deflected. Generally, the connection of each individual mobile hydraulic support at the face is reduced. Large deviations in support position make it difficult to move.

In general, when facing unfavorable factors of mining technical conditions, hydraulic supports operate passively along with different stress distributions. Operation time of support therefore also increases significantly. The extended time of moving supports directly affects the performance of other stages in the production cycle (Nguyen et al., 2020). Therefore, the organizational chart of the initial production cycle of longwall face I-6-2 does not match reality.

3. Solutions to the improvement of production efficiency at the semi-mechanized longwall face I-6-2

Based on the above analyses, semi-mechanized longwall face I-6-2 has operated inefficiently mainly due to the prolonged movement of supports and the unreasonable organization of production. This problem has existed since the commencement of the face. In theory, this problem can be solved by adopting more advanced, modern, and suitable equipment. However, due to limitations in human resources and investment capital, it is not feasible to modernize equipment for DBC at present. It is necessary to have specific and practical technical solutions to overcome the above problems.

Figure 3. Additional support by hydraulic props at the longwall face I-6-2.

Figure 4. Hydraulic supports are not close to coalface at longwall face I-6-2.

Problems such as face spall and floor heave do not occur frequently and are of the small area. Therefore, within the scope of this paper, their handling is not considered in detail. Some general recommendations that can be assessed to prevent these problems include:

(1) Increase the stability of the coalface by chemical injection or water injection;

(2) Controlling the supporting process to ensure technical quality: the mobile hydraulic supports must have a suitable flow load, be erected perpendicular to the coal surface, the top of the beam close to the top coal and coalface;

(3) Use additional solutions to increase the contact area between hydraulic supports and the floor to distribute the load evenly and reduce settlement;

(4) Increase face advancing speed.

Increasing the movement speed of the longwall face is also the goal of arranging and adjusting the production organizational chart (Snopkowski et al., 2017). The new production cycle organizational chart must be built based on the inputs, which are collected from actual production, to ensure adaptability, suitability as well as feasibility (Nguyen et al., 2019). A new production cycle organizational chart should be the basis for stable and sustainable operation of coalface I-6-2.

Training and improving skills for workers should always be prioritised and fostered. Over time, along with the increase in skills and practical experience, the time to perform the tasks must be shortened. However, this is a non-quantitative factor that cannot be quantified precisely. Therefore, the proposed solution is built based on the inputs at the time of data collection, (see Section 2.2.2).

According to Figure 2 and formula (1), the main time of production stages related to the system "shearer - conveyor - support" includes:

+ t_1: Shearer cuts the upper part (s_1) of the bottom half of coalface (x_2). Support lifts the shield to temporarily hold the face (p_1);

+ t_2: Shearer cuts the lower part of coalface (s_2) and creates a safe distance to prepare to move the conveyor;

+ t_3: Shearer cuts the lower part of coalface (s_2), moves conveyor (c) and hydraulic supports (p) to follow;

+ t_4: Shearer moves in an unloaded state (s_0) in top section of coalface (x_p). Movement of the conveyor (c) and supports (p_2) continues in the main part of the longwall face;

+ t_5: Completing the movement of conveyor (c) and supports (p_2), including section x_p;

+ t_6: Shearer cuts the upper part (s_1) of the top half of coalface (x_1). Support lifts the shield to temporarily hold the face (p_1);

During the period $t_1 = t_6$, the mobile hydraulic support only lifts the shield to temporarily hold the upper space of the coalface. The lifting speed of the shield should keep up with the moving speed of the shearer.

During period t_2, there is only the cutting operation of shearer to create a safe distance for subsequent operations. This distance is taken as 10 m. Then, there is no time relation between the shearer and other equipment.

During periods t_3 and t_4, the shearer moves at the same time as the movement of the conveyor and hydraulic support at a certain safe distance. This is the period that accounts for a large proportion of total time T. The time of this process is the moving time of the equipment with the slowest speed in the complex system of "shearer - conveyor - support".

During the interval time t_5, the shearer stopped moving at the top of longwall face. The movement of conveyor (c) and supports (p_2) was completed over the whole length of coalface, including the top section xp. Value t_5 depends on the moving speed of the conveyor and supports.

The average moving speed at longwall face I-6-2 of the shearer is v_1 = 1.5 m/min, v_2 = 1.0 m/min for the conveyor and v_3 = 15 min/support = 0.05 m/min with mobile hydraulic support. Thus, the moving speed of shearer is 30 times of the supports. However, during actual production, when moving speed of supports is slow, the cutting operation of the shearer is usually not continuous but interrupted into segments.

To increase face advancing speed, the movement of supports, instead of moving by a worker crew in series behind the shearer and conveyor, needs to be done by many different crews (Snopkowski et al., 2021). Each team of workers should be in charge of moving the support over a certain length of x (m) (Figure 5).

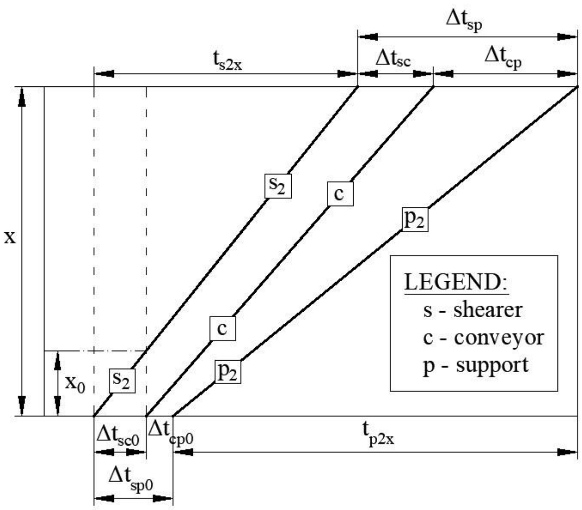

Figure 5. Diagram showing the time relationship between the equipment "shearer - conveyor - support".

The objective is to minimize the time Δt that used to perform main tasks on section x, that is:

$$R\Delta t = \Delta t_{sp} + t_{s2x} = \Delta t_{sp0} + t_{p2x} \rightarrow MIN \quad (2)$$

Equivalent to:

$$\begin{cases} \Delta t_{sp} = \Delta t_{sc} + \Delta t_{cp} = \Delta t_{sp0} + t_{s2x} - t_{p2x} \\ t_{s2x} = \dfrac{x}{v_{s2}} \\ \Delta t_{sp0} = \Delta t_{sc0} + \Delta t_{cp0} \\ t_{p2x} = \dfrac{x}{v_{p2}} \end{cases} \rightarrow MIN \quad (3)$$

Where: Δt_{sp} - time elapsed between when the shearer finished cutting and when all of the supports were moved; t_{s2x} - time to cut coalface; Δt_{sp0} - time interval from the start of moving shearer to the start of moving support; t_{p2x} - movement time of supports; Δt_{sc} - time interval from when shearer has finished cutting to the time when the conveyor is moved; Δt_{cp} - time interval from when the conveyor is finished moving to the time supports are moved; v_{s2} - moving speed of shearer; Δt_{sc0} - time interval from the start of moving shearer to the start of moving conveyor; Δt_{cp0} - time interval from the start of moving conveyor to the start of moving support; v_{p2} - movement speed of supports.

Under normal conditions, the conveyor (c) begins to be moved behind shearer (s_2) at a safe distance x_0 = 10 m. With the moving speed of shearer $v_{s2} = v_1 = 1.5$ m, then:

$$\Delta t_{sc0} = \frac{x_0}{v_{s2}} \approx 7\ min \quad (4)$$

The time interval Δt_{cp0} is determined based on the fact that the conveyor has moved a segment before to ensure space for moving the hydraulic supports. Based on the moving speed of conveyor $v_c = v_2 = 1.0$ m/min and the length of each conveyor section, $\Delta t_{cp0} = 5$ min can be taken.

So:

$$\Delta t_{sp0} = \Delta t_{sc0} + \Delta t_{cp0} \approx 12\ min \quad (5)$$

In fact, Δt_{sp0} is the time interval that is initially set. It has an effect on the value of Δt_{sp}, but changing this value is not entirely reasonable and does not bring noticeable differences.

Therefore, when the moving speed of equipment, the most important of which is the moving speed of supports $v_{p2} = v_3 = 0.05$ m/min, has not been improved, the value of Δt depends on the length x of each section. It means that:

$$\Delta t \rightarrow MIN \leftrightarrow x \rightarrow MIN \quad (6)$$

To ensure the safety during work, $x \geq x_0$. Thus, the smallest value of Δt corresponds to $x = x_0$. This means that the longwall face should be divided into segments with a length of x_0 = 10 m to perform the movement of supports at the same time.

4. Results and Discussions

Based on the necessary calculations, newly built production organizational chart is shown in Figure 6.

As shown in Figure 6, there are times when 06 worker crews are working simultaneously. They move the supports corresponding to 06 segments on the entire face length.

Before applying the proposed solution, the field organization was also different from the design. However, the calculation and construction process is not specific which makes the production process sometimes untidy and not professionally organized. Work assignment is often not proactive, but depends heavily on the end state of the previous production shift. This was due to not

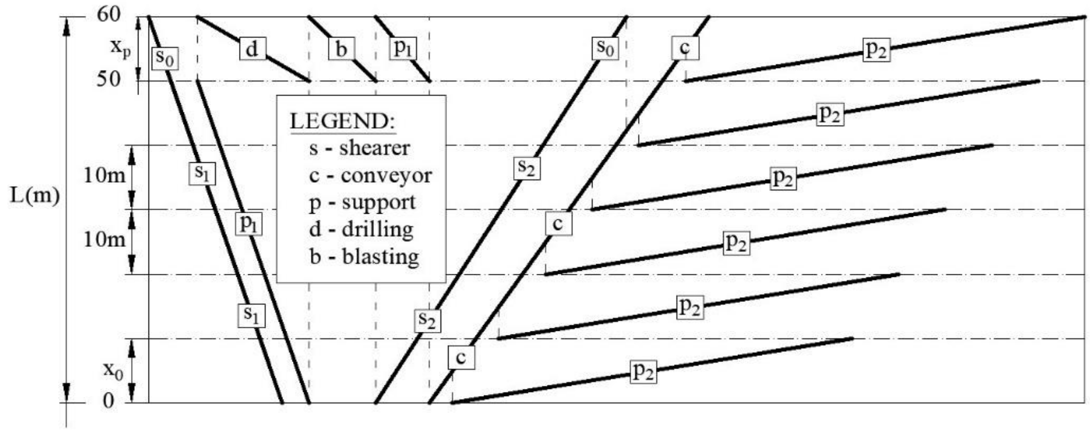

Figure 6. Organizational chart of the production cycle of the longwall face I-6-2 after adjustment.

being able to fully control the time to complete the production cycle.

With the new production organizational chart, the time to move the supports has been calculated and built specifically in relation to the space and time with other stages. Labor and work arrangement are clearly quantified. Using multiple worker crews at the same time has shortened the complete time of production cycle. As a result, the effective working time factor is significantly increased.

During the application period from April 2023, the average coal output of longwall face I-6-2 has reached 425 tons per day, an increase of 17% compared to before the application. Although labor productivity is not too different due to the need to arrange more workers, the management, organization and implementation have been significantly more favorable. This demonstrates the effectiveness of the solutions.

In the future, mechanization of coal mining is an inevitable trend to ensure safety and improve the economic-technical criteria of coalface (Duong et al., 2019). Being assigned to small-scale mines in complex geological conditions, the selection of appropriate mechanization equipment for DBC is a big challenge. However, in order to achieve the goal of sustainable and long-term development, DBC needs to design and invest in synchronous mechanized coalfaces (Phuong, 2022).

Practice shows that semi-mechanized coalfaces such as longwall face I-6-2 have also yielded higher economic and technical indicators than those using drilling and blasting. However, supports do not provide the ability to synchronize equipment. Proposed solution in this paper is directional when solving similar problems to maximize efficiency with the limitation of existing conditions. In the near future, semi-mechanized longwall faces will still be used in DBC's underground coal mines.

For a higher level of development, DBC needs to research and put into practice the coalfaces that use a complex of light mechanized equipment. These coalfaces use mechanized supports that are light in weight and small in size with a working load of less than 3,900 kN. The advantages of mechanized supports are: compact size; low investment costs; easy to transport and install; more flexibly adapting to fluctuating and complex geological conditions.

Light-weight mechanized supports have been tested by Vinacomin in several coal mines such as Ha Long, Mong Duong. Initially, it has brought positive effects and will be widely used in the near future. Therefore, this is the basis for DBC to consider and apply for their coal mines.

5. Conclusions

At DBC, semi-mechanized longwall face I-6-2 uses the most modern technology with shearer and mobile hydraulic supports. However, during the operation, there were many difficulties that led to unexpected results.

From the analysis of existing problems, this paper has proposed solutions to the adjustment of the production organizational chart to improve output and labor productivity. The proposed solutions use the field parameters, in which the moving speed of mobile hydraulic supports plays a decisive role. The application of the solutions in practical conditions facilitates the organization, management, administration, and assignment of work and increases the coal output of the longwall face by 17%.

The proposed calculation and construction method can be used to adjust the production organization chart in similar geological-mining cases. In the future, DBC is recommended to invest in trending technological innovations to ensure sustainable development for their underground coal mines.

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Contributions of authors

Dung Tien Thai Vu - idea proposal, manuscript writing; Khai Cao Nguyen - methodology, review & editing; Phuc Quang Le - review & editing; Luong Xuan Nguyen - document collection.

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