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SOLUTION TO DETERMINE THE WORKING TIME AT THE MECHANISED LONGWALL IN THE NATURAL CONDITION OF QUANGNINH COAL SEAM, VIETNAM

Vietnam is currently unable to generate nuclear power, and coal still accounts for 32 percent of national energy production. Therefore, mining coal plays a crucial role in the national economy. On the other hand, all open pit coal mines in Quang Ninh will be closed to give the land back to the other industrial section, so the underground mines will be responsible for supporting the entire amount of coal, which is extremely difficult. Therefore, it must mechanise mining to increase output. The research of applicability has been implemented for a long time. Now, Vietnamese workers can operate domestic equipment. However, most mining plans are established from experience and imposed, so this hardly shows the construction reality in the underground mines. Indicators must be manually adjusted to match the previously established documents. This not only causes administrative risks but also wastes time and human resources in handling paperwork, leading to reduced labour productivity indirectly.

The key to a mining plan is time, therefore the article analyses the influence of uncertain mining conditions on the construction time. As a result, different working time parameters are determined suitably for different conditions, space, and construction time. The difference between actual construction time and ideal construction time is also made out. The mentioned results are a scientific basis for mine operators to adjust production plans appropriately to the characteristics of underground mines.

Keywords: Width of seam; steep angle; mining plan; longwall; quantity; working time; work efficiency; pause time

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1. Introduction

Vietnam is a country without nuclear power. Thermal power accounts for 32% of the country's total electricity [7]. Therefore, coal is a crucial cheap source of materials for the Vietnamese economy. At present, because the quantity of coal for thermal power plants is increasing, the depletion of coal may affect the sustainability of this industry [0,0] Quantity of annual coal is calculated based on consumption plans, including serving thermal power, cement, metallurgy, export. From this demand, companies exploiting underground coal build their plan, output target, and exploitation cost. With available experience and conditions. Depending on the seasonal weather, geological characteristics of the mines, characteristics of applied equipment, the infrastructure of transport tunnels, and ventilation. Companies allocate plans according to operating areas and specialised tasks. Monthly plans are divided into daily plans and shift plans, especially in each shift, the plans are divided into tasks and goals that need to be completed (usually 6-8 hours of working) for groups of workers.

A mining plan is a designed program to ensure that actual results adapt to proposed targets [4]. Production-optimised methods for underground mines are less developed than for open pit mines due to the diversity of unpredictable geological conditions, characteristics of human resources, equipment, technology, and implementation methods [8,27,14]. The intricate relationship between mining conditions, geological factors, and the capabilities of machines, equipment, personnel, and methods directly and indirectly influences coal production output. Optimization of production plans at underground mines is implemented in the short, medium and long term on aspects such as development layout, mining area planning, production plan establishment, and selecting and using equipment [27,23,31]. In Vietnam, mining technology has trended to partial or full mechanisation, helping underground coal companies to maintain and increase the quantity and reduce direct workers. This is safer than traditional manual mining methods [2,9]. To keep good profits the challenge for the coal industry is to optimise production plans to improve productivity and equipment efficiency [5].

Vietnam has experimented with applying mechanisation technology since 1978. After studying for a long time (including interrupted time), some mines have successfully applied now. However, there are not many studies on the quantification of production organisation criteria to have more effective production plans. This is one of the research directions that needs to be cared for and implemented [8].

A concept said that: Organising production is arranging people to work, monitor, command, and arrange materials, tools, and a place to produce an item [30,12]. Another concept said that: Production organisation is a directive method tending to a reasonable labour process with the physical elements of production in space and time for improving the efficiency of production [30,12]. Thus, a production organisation is a close combination of labour, labour materials and labour objects to suit production requirements, tasks, and scale and production technology is determined to produce quality products that meet the needs of the market.

First, a meticulous plan should be established to organise production. The operation efficiency of an underground mine depends on the production plan. Therefore, organising short, medium and long-term goals into tasks or manually establishing a short-term plan are drawbacks of the optimisation chain [15]. Underground mines often face uncertain conditions related to many different sources such as mining depth, geological conditions, shape of the coal seam, thickness, slope angle of the coal seam, reliability of equipment, the responsiveness of mine infrastructure and the efficiency of mining methods [14,17,33]. Therefore, each production plan that is established and approved at the beginning of the fiscal year must be balanced by several contingency indicators to increase the flexibility of the production plan [17]. In Mining areas of the underground mine, There is a chain of values such as transportation, loading, supply of compressed air, pressurised water, materials, etc., which are converted into specific products with the amount of coal per month, week, year and dug line metres per ton of coal [8,33]. These chains are interwoven and have a logical connection with each other. The efficiency of components depends on each other. This is the result of a combination of exploitation, plan, technical methods, and coordination of many related working departments [14,3]. However, the drawbacks of the method are its simplicity and no optimisation in the mining schedule [33,35] uncertain factors are even ignored in establishing a fixed plan, lack of adapting to future information such as attributes of supply infrastructure, materials, mine geological conditions, groundwater. There are theoretical tools that limit support from experts in establishing a mine plan to create mining sequences and decrease the risks from the mentioned random changes [9]. Short-time control originates from manufacturing and is a primitive period in mining [11]. The goal is to ensure the accuracy and timeliness of technical instructions that are challenged by many different factors, including potential factors (uncertainties), contact problems, inefficiencies in management and broken equipment.. unresolved problems negatively affect the production system [10]. An underground mining plan is effective when the basic production schedule meets the output target without significant accidents (called safety). Therefore, managing mining schedules is the daily work of people in the mine, especially managers, so this is an important factor for optimising mine productivity [12]. Information transparency, flexible plan establishment, delicate production and scientific decision-making need to be implemented [6]. Z. Song and his colleagues presented a method for controlling individual operating units and discussed the technical aspects of real-time optimisation systems in mining [19]. R. Howes and his colleagues presented the way to collect data in a work shift and analyse the management regime reflected in the exploitation diary of the longwall, thereby the causes of slowness are determined and quick reactions are proposed [14]. Richard Oechsner proposed a blueprint of management based on short-term control to improve performance, but it has not been applied yet [22]. P. Muchiri and his colleagues focused on a system called OEE (The Overall Equipment Effectiveness (OEE) rating is one of the Key Performance Indicators (KPIs) used in the TPM (Total Production Maintenance) system [16,18]. Overall Equipment Effectiveness (OEE) rating is one of the Key Performance Indicators (KPIs)) [10,18] machine performance is considered as a tool to evaluate the working efficiency of the longwall. Panagiotis Tsarouhas Consider the interaction between the main mining organisation and the supporting stages in underground mines. To compensate for limitations and being stuck in production organisation and abnormal conditions, a residual coefficient is set in the implementation plan, called (planisa) [33,25]. The core of the plan is designed based on safety standards and team spirit [24,4,19].

Time and workload are standardised measures of labour productivity [8,17,26] Furthermore, productivity is understood as the total product per standard unit of time, usually less than or equal to 1 [27,28].

Snopkowski and his colleagues believe that the continuity of output is an important indicator, called product intensity. [27,23] said that the production process is the important indicator, that is, the time employees spend on the working face, minus the lost time due to subjective and objective reasons [25,10,29]. Some opinions suggest that using the working time index is the real-time working at the working face, calculated by the output per shift or day [31,24,21]. This encourages workers to achieve better results in the next cycle, or helps the monitoring, adjustment, and evaluation department to have appropriate solutions for the issues happening at the working face [34,23,11]. Some opinions say that using effective equipment and machinery is very important for mines, [6,11,35] because cost is a big challenge and mining activities always face obstacles in production, so the best way is to improve the technique [16,18,26]. Determining efficiency based on the effectiveness of the cutting equipment in longwalls compared to standard time in the OEE model [33,35] The method of determining the applicability of cutters at the longwall face allows to obtain information to optimise the mining process.

Thus, the key to a successful mining plan is the time to form the final product, coal. Time depends on subjective factors such as the operating conditions of the machines, and the skill of the workers, and objective factors such as uncertain conditions related to many different sources such as mining depth, geological conditions, seam shape, thickness, slope angle, equipment reliability, responsiveness of mine infrastructure and efficiency of mining methods. In the article, authors research the dependence of time on basic uncertain conditions, and machine stopping state in Vietnam, including fluctuations in slope angle, thickness, rock.

2. Some natural factors affect the progress (productivity) of underground mining

Labour productivity is expressed through the progress of the cycle or the time for completing the production stages. The performance of each working area is affected by uncertain conditions such as thickness fluctuations, steep angles, clamping rock, groundwater conditions, CH_4, etc.

2.1. Thickness of seams

The thickness of the seam directly affects mining technology, efficiency and productivity [20]. In Vietnam, the height of a mechanised longwall's working face is about 2.2-3 m, when the height is over 3 m, the mechanised form of top caving is applied. Thickness fluctuations also affect mining efficiency. If the thickness fluctuates too much, the supports are continuously adjusted to the height. Sometimes the mechanised machine must cut the rock (when the seam is too thin) or use a drill and blasting to separate the rock at the top of the seam, then separate the coal. Also, the machine is required to stop when the coal needs to be loaded.

- **In case, the thickness of seam obeys the standard distribution model:**

  Average thickness of seam ($\underline{M}$) calculated:

$$\underline{M} = \frac{1}{N-1}\sum_{i=1}^{N} m_i \tag{1}$$

  Standard deviation) (D) calculated as a formula:

$$D = \frac{1}{N-1}\sum_{i=1}^{N}\left(X_i - \underline{X}\right)^2 \tag{2}$$

Variation coefficient of thickness as follows:

$$V_m = \frac{\sigma_m \cdot 100\%}{\underline{M}} \tag{3}$$

where $\sigma_m = D^2$ $\sigma_m = \sqrt{D}$ variance

- **In case, thickness is distributed in log function**

  Features of seams are determined as the formula: [13] expectation of calculation:

$$\underline{M} = e^{\overline{\ln \ln x} + \frac{1}{2}\sigma_{\ln}^2} \qquad \underline{M} = 10^{\overline{\lg x}} \cdot e^{2,65\sigma_{\lg}^2} \tag{4}$$

Standard deviation:

$$D = e^{2\mu + \sigma_{\ln}^2} \cdot \left(e^{\sigma_{\ln}^2} - 1\right) \Rightarrow D = 10^{2\overline{\lg x}} \cdot e^{5,3\sigma_{\lg}^2} \cdot \left(e^{5,3\sigma_{\lg}^2} - 1\right) \tag{5}$$

Variation coefficient:

$$V = \sqrt{e^{\sigma_{\ln}^2} - 1} \times 100\% \Rightarrow V = \sqrt{e^{5,3\sigma_{\lg}^2} - 1} \times 100\% \tag{6}$$

2.2. The influence of surrounding rocks, clamping rocks, the shape and structure of the coal seam

a. The influence of surrounding rocks and clamping rocks

A mining area is described as having an upper limit, a lower limit, and a lateral limit. In Vietnam, a longwall has an upper limit as an abandoned mining area, the lateral limits are adjacent mining areas or large faults, and the lower limit is the transportation longwall. Smaller faults can reduce working efficiency or interrupt the coal cutting time of the machine (the size of the fracture exceeds the ability of the cutting machine, the machine has to be stopped to handle the technique).

Rock layers in the coal seam are a challenge to coal exploiting time. If the clamping rock is soft enough to cut and separate from the solid block, the cutting time will be reduced (because clamping rocks are harder than coal). In case the rock is so hard that the machine cannot cut, stop the machine, drill and blast to break clamping rocks.

Weak foundations can cause subsidence of equipment, or move the support and conveyors difficulty, directly or indirectly prolonging the production time. In some cases, it is necessary to stop the machine until the equipment goes through the weak foundation area, then the longwall is taken to normal operating status.

Both faults and clamping rock limit the operating range of the equipment, leading to increasing auxiliary jobs, this directly increases the time to exploit a ton of coal, and simultaneously, reduces labour productivity. Most mechanised longwalls in Vietnam have lengths of about 120-150 m in slope direction, in some mines, it is evenly smaller. So the handled amount of ground or clamping rock accounts for a large proportion of the total length of the longwall.

b. Influence of fluctuations and structure of coal seam

To evaluate the variability of seam shape, not only consider the variability of seam thickness but also study quantitative analysis criteria such as the boundary module (μ), seam shape criteria (φ) and structure complexity coefficient (K_{cc}) [13,20].

Structure complexity coefficient (K_{cc}): Each coal seam consists of one or more layers of coal or is separated by one or more layers of clamping rock. The number of rock layers (N_k) is smaller than the number of coal layers (N_t): $N_k = N_t - 1$. The more the number of rock layers, the greater the complexity of the seam. The K_{cc} coefficient changes from 0-1; when K_{cc} reaches 0, the complexity of the seam increases, and the negative impact on coal mining also increases. The calculation formula is as follows:

$$K_{CC} = 1 - \frac{M_k}{M_t}\frac{N_k}{N_t} \tag{7}$$

The shape of seam is evaluated by boundary modules (μ) and shape criteria ($\varnothing$) as formula:

$$\mu = \frac{L\varnothing}{4,7a + 1,5\dfrac{S\varnothing}{a} - 1,77\sqrt{S\varnothing}} \tag{8}$$

$$\varnothing = \frac{v_m \cdot \mu}{k_{cc}} \tag{9}$$

$$K_{(h)} = \frac{1}{N-h}\sum_{i=1}^{N-h}\left[f\left(x_{i)}\right) - \underline{X}\right]\left[f\left(x_{i+h}\right) - \underline{X}\right] \tag{10}$$

The norm correlation coefficient is determined as the formula:

$$r_{(h)} = \frac{K_{(h)}}{\sigma^2} \tag{11}$$

Variability with using $r_{(h)}$ is calculated as follows:

$$V_N = \frac{\sigma_N}{X} = V\sqrt{1 - r_{(h)}^2} \tag{12}$$

The norm correlation coefficient:

$$R_{(h)}^{*} = e^{-a.h} \; ; \; a = \frac{\sum_{i=1}^{m} \ln \ln R_{(hi)}}{\sum_{i=1}^{m} h_i} \tag{13}$$

where: m – number of observation step; h – value of observation step.

2.3. Steep angle

Steep angle is a crucial index in determining the working limit of mining and supporting equipment. When the steep angle changes in the operating limit of the equipment, the performance of the machine is not affected much. However, steep angle changes widely or suddenly from tilt slope to vertical slope or higher, hydraulic supports are slipped. Too much change in the steep angle of the seam even causes breakage to the longwall and bend conveyor (Fig. 2). Moving through a zigzag section limits the operating range of the machine, and creates gaps in the supports for rocks to fall.

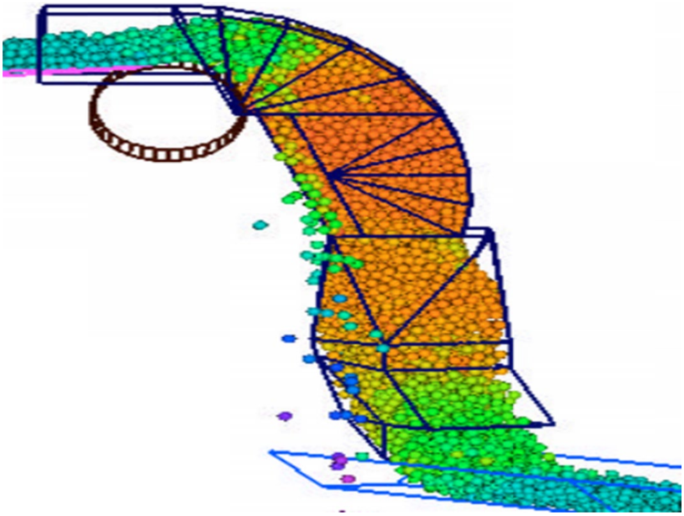


Fig. 2. Too much change of steep angle causes the seam to break and bend the conveyor, making it difficult to move the support equipment

Variability of steep angle is shown in formula:

$$\sigma_\alpha = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(\alpha_i - \underline{\alpha}\right)^2} \tag{14}$$

Where: σ_α – standard deviation of steep angle; N – the number of points for measuring the steep angle (sample set); α_i – the value of steep angle at measurement point i (degree); $\underline{\alpha}$ – the value of the average steep angle (degree).

The variable coefficient of steep angle (K_α): In mining design, the coefficient of variation of steep angle (Kα) is always paid attention, calculated by the formula:

$$K'_\alpha = 1{,}375 - 0{,}075x\sigma_\alpha \tag{15}$$

The mentioned technical parameters are the basis for choosing suitable extraction equipment to achieve important goals of economy, safety and productivity. The indexes of geometric characteristics, slope, thickness, uniformity of the coal seam, geomechanical characteristics of the seam, surrounding rock, and clamping rock affect the mining time, the productivity of the equipment, and the efficiency of the system, so it directly or indirectly affects the output of the mine or the mining plan.

TABLE 1

Classification of complexity according to the steep angle

Group	Level of complexity in mining	Index limit
Group 1	Simple and easy mining	$K'_\alpha \geq 1$; $\sigma_\alpha \leq 5$
Group 2	Relatively complicated (obstacles)	K'_α = 1÷0,625; σ_α =5 ÷ 10
Group 3	very difficult	K'_α < 0,625; σ_α > 10

The important criteria involved are the geometric properties of the coal seam (dip, thickness, and uniformity of coal seam), geological and hydraulic conditions (faults, fractures, joints, and underground water), and geomechanical properties of the coal seam and surrounding rocks. Extraction of inclined coal seams with gradients greater than 40 degrees is different from low-inclined seams and requires special equipment. Therefore, the influence of the above-mentioned parameters must be considered simultaneously in the selection of extraction equipment or steeply inclined seams.

3. Establishing the method of calculating the working time based on the mine geological elements

As analysed, the productivity of each longwall depends on many factors, divided into 3 groups including:

Group 1: mine geological factors: Geometric characteristics of the coal seam (dip, thickness and uniformity of the coal seam), geological and hydraulic conditions (faults, fracture, joints and groundwater) and geomechanical properties of the coal seam and surrounding rocks. These factors belong to uncertain conditions, formed during mining operations.

Group 2. Equipment factors. Equipment is selected on the basis of compatibility with the characteristics of group 1 in order to achieve important goals of economy, safety and productivity.

Group 3. Group on people and the supply infrastructure and transportation. Most coal mines in Vietnam have been operated for many years, with applied many types of mining technologies. Therefore, the technical infrastructure is relatively old but still meets the requirements of transportation and supply of materials and equipment for the annual production plan. Since 1978, workers and engineers have accessed modern production lines, so they understand operating methods. But the biggest challenge of the human factor is the movement of a large number of skilled workers to industries with low risks of labour accidents and More on-site working environment. However, it is easy to overcome the disadvantages through key training programs, improvement of the working environment and adequate remuneration.

The main factor affecting effective mining time is group 1. To solve the problem of labour productivity, there are many parameters and conflicting influences in mining. Therefore, it is necessary to have a general method to determine effective working time. This time is determined through the working parameters of machine and equipment, the number of tons of coal per unit of time or the proposed output targets.

In the article, the calculated time is the moving speed of the longwall per the total length of the longwall. The time components are calculated according to each production stage that corresponds to the working status of the equipment in longwall mining conditions.

3.1. Analysing working method in mechanised longwall

Fig. 3 shows that the exploitation cycle starts from the ventilating roadway down to the transporting roadway by the diagram A, B → G, and then a new similar cycle begins. To organise production, engineers establish an organisational chart for each cycle including the main stages such as coal cutting, transportation, moving the support forward, and auxiliary stages. The production cycle organisation chart is a drawing consisting of the elements of space, time and working stages in the longwall. The space (vertical axis) is to set zero – metres at the intersection of the longwall and the transport roadway. The highest position representing the length of the longwall is the intersection of the longwall and the ventilating roadway. The up direction is from the transport roadway (zero-metre) to the ventilating roadway (N-metre). Similar to the down direction. (Fig. 3 and Fig. 4). Each different symbol represents a completed job in a shift (horizontal axis). Details are in Fig. 4.

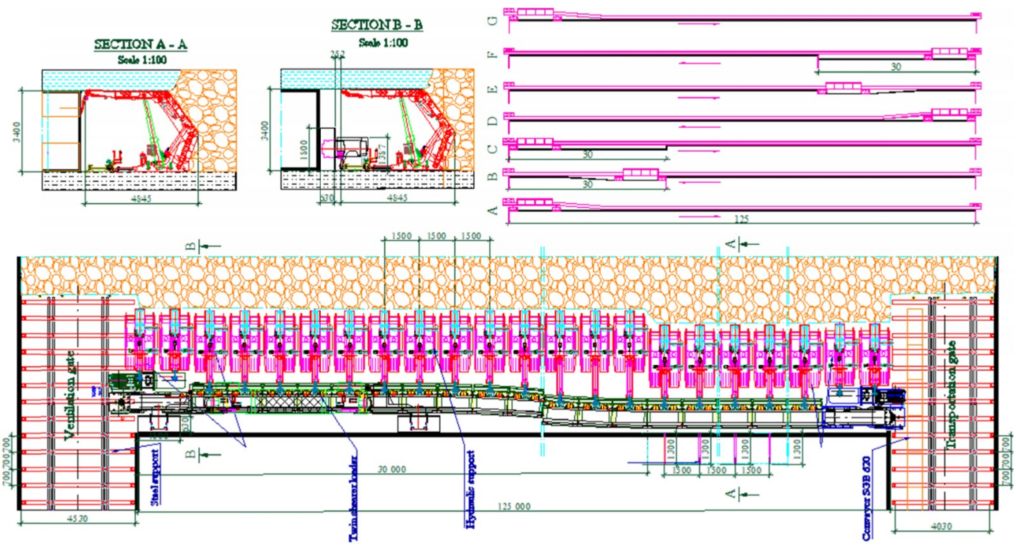


Fig. 3. Diagram of mining in a mechanised longwall

Fig. 4 shows that the work in the first shift from 7 am to 8 am is to create the initial coal cutting position at metre 153 to metre 123 and vice versa. The tasks include coal cutting, transportation and moving the support. From 8:00 a.m. to 11:00 a.m., cutting, transporting, and moving the support are implemented from metre 153 (near the ventilating roadway) to metre 0 (near the transport roadway). Repeat the same work in the direction from metre 0 to metre 153. The process of repair is implemented from 4:00 a.m. to 2:00 p.m., from metre 153 to metre 0. Work in the second shift 2 happens similarly. The third shift completes the final stages of the cycle, including equipment inspection, maintenance and repair of the longwall (Fig. 4).

Compared to 600,000 tons/year as designed, the exploitation result in 2021 is 2,000.22 tons, equivalent to 33%; In 2022, it gained 106,072 tons, equivalent to 48%; The first two periods of the year reached 247,367 tons, equivalent to 82% of the plan.

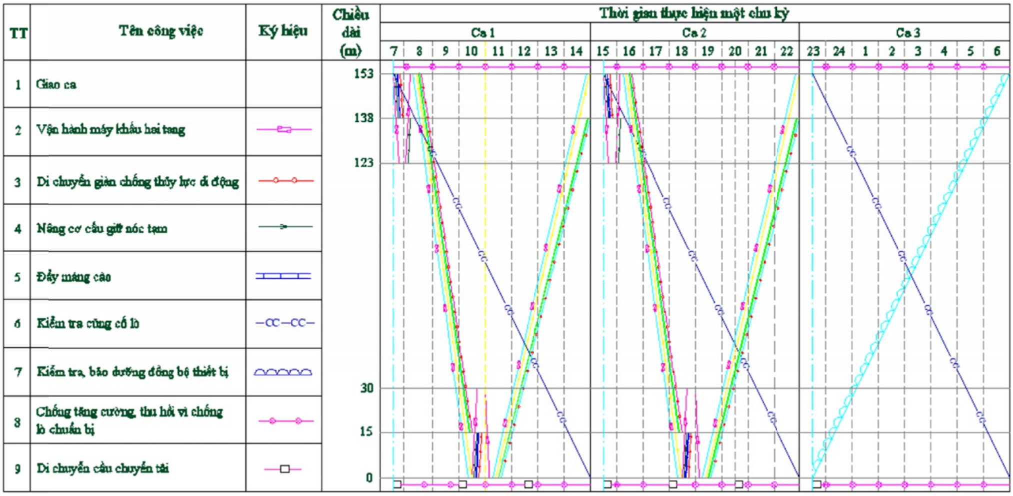
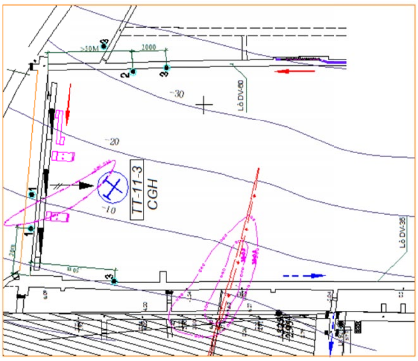
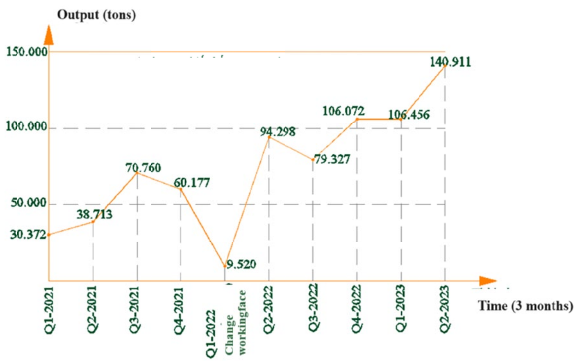


Fig. 4. Chart of organising the actual production cycle in Vietnam
TT – Ordinal number; 1,2..9 – shift work, Tên công việc – Jobs in a shift; Ký hiệu – Symbols;
Chiều dài (m) – Longwall length (m); Thời gian thực hiện một chu kỳ – Time of production cycle (h);
Ca1; Ca2; Ca3 – work shifts for each workday (h)



a. Chart of mining area 11-3



b. Statistics on output at the longwall 11-3 level 0-30

Fig. 5. Statistics on output from 2021 to the end of the second period of 2023 at a CGH longwall

There are many reasons why the actual capacity of the longwall does not meet the design, meaning that one or all stages must stop to handle problems of machine pause. Fig. 5b shows that from the fourth quarter of 2021, the longwall almost stopped production, the output only reached 9,520 tons per quarter, then gradually increased and reached 94,298 tons in the second quarter of 2022. Output decreased to 79,327 tons in the third quarter of 2022 because of difficult geological conditions such as weak foundations and many crushed rocks which reduced mechanised labour productivity and increased manual labour. The creation of cutting grooves at the end of the longwall is illustrated in Fig. 6.

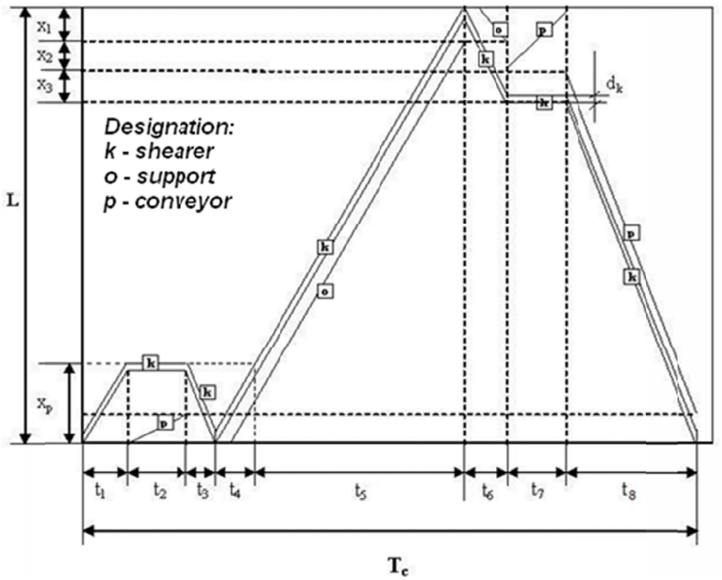


Fig. 6. Diagram of mechanised longwall stages in working time and space [29]

In Fig. 6. L – longwall length [m], Tc – time of production cycle (minutes), $t_1, t_2, ..., t_8$ – time for implementing individual stages of production cycle (minutes), d_k – machine length [m], x_1, x_2, x_3 – distance of activities and work performed within the scope of the cutter-rack system – rake chute (m), x_p – distance between the cutter stop and the intersection with the longitudinal wall (m). The time of one T_c cycle is calculated as the following formula:

$$T_c = \sum_{i=1}^{n} t_i \tag{3-1}$$

where: i – working stages in a cycle; n – a number of stages; t_i – Time to complete job i (minutes).

Most jobs are optimally arranged and taken in the same direction to use the whole space, time, and human resources reasonably. Jobs in the same production process are logically related to each other, so the progress of the cycle depends on the slowest jobs. Therefore, the flexibility and synchronisation of equipment and smooth operation of humans limit conflicts that cause delays or stop production. A work cycle is the base for determining the productivity of the working face. From this, it can determine time losses due to unforeseen events. The common denominator of organising the production cycle is time.

3.2. Determining parameters of working time

The conducting progress of underground coal mining stages in Quang Ninh depends greatly on geological fluctuations, technology, worker skills, management methods, and infrastructure for exploitation.These relationships are intertwined, containing many unclear factors. The mentioned analysis proved that the working time of the longwall is divided into two types: working time and interruption time for taking production to return to normal state. From formula (1), determine the component of working time as follows.

- **t_1 – time for mechanised machine excavating the mining space at transporting roadway in the upward direction:**

$$t_1 = (L_{KC} - L_M)/V_{KL}, \quad \text{minutes} \tag{3-2}$$

Where: L_{KC} – length of mining section at transporting roadway, m; L_M – length of machine, m; V_{KL} – Velocity of machine when excavating mining space, m/phút.

- **t_2 – Time taken to stop the machine, change direction, and complete moving the trough on the transporting roadway:**

$$t_2 = L_{MKC}/V_{VT}, \quad \text{minutes} \tag{3-3}$$

Where: L_{MKC} – length of a remaining trough that needs to be moved when the machine stops to change direction, m; $V_{VT} = L_{CM}/t_{CM}$ – speed of moving the trough, m/minute; L_{CM} – length of the trough, m; t_{CM} – time for moving 01 trough, minutes;

– when $L_{KC} \le (x_1 + L_M)$:

$$L_{MKC} = L_{KC} \tag{3-4}$$

x_1 – minimum distance from location of moving the trough to operation machine, m;

– when $(x_1 + L_M) < L_{KC}$ và $V_{VT} \ge V_{KL}$:

$$L_{MKC} = x_1 + L_M \tag{3-5}$$

– when $(x_1 + L_M) < L_{KC}$ và $V_{VT} < V_{KL}$:

$$L_{MKC} = x_1 + L_M + (L_{KC} - x_1 - L_M) \cdot (1 - V_{VT}/V_{KL}) \tag{3-6}$$

- **t_3 – is the time for the mechanised machine mining to be completed at the transporting roadway in a downward direction:**

$$t_3 = L_{KC}/V_{KX}, \quad \text{minutes} \tag{3-7}$$

V_{KX} – velocity of the machine when excavating downwards to create mining space, recorded in minutes.

- **t_4 – time calculated from stopping and changing the direction of the machine to moving the support at transporting roadway:**

$$t_4 = L_{VKC}/V_{VKC}, \quad \text{minutes} \tag{3-8}$$

where: L_{VKC} – length of the remain support section that is required to be moved at the transporting roadway when the machine pauses so that it can change direction, m; $V_{VKC} = L_1/t_{VKC}$ – speed of the moving the support, m/minute; L_1 – distance between the supports, m; t_{VKC} – time for moving just one support, minutes;

– when $L_{KC} \le (x_2 + L_M)$:

$$L_{VKC} = L_{KC} \tag{3-9}$$

where: x_2 – minimum distance from location of moving the support to the mechanised machine, m;

– when $(x_2 + L_M) < L_{KC}$ và $V_{VKC} \geq V_{KX}$:

$$L_{VKC} = x_2 + L_M \tag{3-10}$$

– when $(x_2 + L_M) < L_{KC}$ và $V_{VKC} < V_{KX}$:

$$L_{VKC} = x_2 + L_M + (L_{KC} - x_2 - L_M) \cdot (1 - V_{VKC}/V_{KX}) \tag{3-11}$$

- **t_5 – time when machine moves without load at the transporting roadway in an upward direction:**

$$t_5 = (L_{KC} - L_M)\,/V_{K0L}, \quad \text{minutes} \tag{3-12}$$

Where: V_{K0L} – velocity of the moving machine upwards in the state of no load, m/minutes.

- **t_6 – time when mechanised machine excavates to clear the roadway according to the upward direction:**

$$t_6 = (L_{LC} - L_{KC})\,/V_L, \quad \text{minutes} \tag{3-13}$$

where: L_{LC} – length of longwall, m; V_L – velocity of the machine in moving upwards, m/minutes.

- **t_7 – waiting time for changing direction of the machine at the head of longwall, minutes:**

$$t_7 = MAX\left\{t_6 \frac{(L_{LC} - L_{KC} - L_{KĐ})}{V_{VT}} + \frac{x_1}{V_L} \frac{(L_{LC} - L_{KC} - L_{KĐ})}{V_{VC}} + \frac{x_1}{V_L} + \frac{x_3}{V_{VT}} - t_6\right. \tag{3-14}$$

where: $V_{VC} = L_{VC}/t_{VC}$ – speed of moving the support in the body of the roadway, m/minutes; L_{VC} – distance between supports in the body of the roadway, m; t_{VC} – time of moving one support, minutes; x_3 – minimum distance from the location of the moving support to the location of moving trough, m;

- **t_8 – time for mechanised machine excavating the mining space at the ventilating roadway according to the downward direction:**

$$t_8 = (L_{KĐ} - L_M)/V_{KX}, \quad \text{minutes} \tag{3-15}$$

where: $L_{KĐ}$ – length of mining space at head of the longwall, m.

- **t_9 – time taken to stop the machine, change direction, and complete movement of the trough at the ventilating roadway:**

$$t_9 = L_{MKĐ}/V_{VT}, \quad \text{minutes} \tag{3-16}$$

where: $L_{MKĐ}$ – length of the remaining trough that needs to be moved at ventilating roadway when the machine stops to change direction, m:

– when $L_{KĐ} \leq (x_1 + L_M)$:

$$L_{MKĐ} = L_{KĐ} \tag{3-17}$$

– when $(x_1 + L_M) < L_{KĐ}$ và $V_{VT} \geq V_{KX}$:

$$L_{\mathrm{MKĐ}} = x_1 + L_{\mathrm{M}} \tag{3-18}$$

– when $(x_1 + L_M) < L_{KĐ}$ và $V_{VT} < V_{KX}$:

$$L_{MKĐ} = x_1 + L_M + (L_{KĐ} - x_1 - L_M) \cdot (1 - V_{VT}/V_{KX}) \tag{3-19}$$

- **t_{10} – time for mechanised machine finishing mining space at ventilating roadway according to the upward direction:**

$$t_{10} = L_{KĐ}/V_{KL}, \quad \text{minutes} \tag{3-20}$$

- **t_{11} – the time calculated from when the machine stops changing direction until the support finishes moving in the ventilating roadway:**

$$t_{11} = L_{VKĐ}/V_{VKĐ}, \quad \text{minutes} \tag{3-21}$$

where: $L_{\mathrm{VKĐ}}$ – length of the remaining support to be moved at the ventilating roadway when the machine stops to change direction, in metres:

$$V_{VKĐ} = L_2/t_{VKĐ} \tag{3-22}$$

where: $V_{VKĐ}$ – speed of moving the support at the ventilating roadway, m/minutes; L_2 – the distance between two supports that are adjacent to the ventilating roadway $t_{VKĐ}$ – time of moving 01 support at the ventilating roadway;

– when $L_{KĐ} \leq (x_2 + L_M)$:

$$L_{VKĐ} = L_{KĐ} \tag{3-23}$$

– when $(x_2 + L_M) < L_{KĐ}$ và $V_{VKĐ} \geq V_{KL}$:

$$L_{VKĐ} = x_2 + L_M \tag{3-24}$$

– when $(x_2 + L_M) < L_{KĐ}$ và $V_{VKĐ} < V_{KL}$:

$$L_{VKĐ} = x_2 + L_M + (L_{KĐ} - x_2 - L_M) \cdot (1 - V_{VKĐ}/V_{KL}) \tag{3-25}$$

- **t_{12} – time for a mechanised machine to move without load in a ventilated roadway moving downward:**

$$t_{12} = (L_{KĐ} - L_M)/V_{K0X}, \quad \text{minutes} \tag{3-26}$$

where: V_{K0X} – velocity of the machine when moving downward in the state of no load, m/minutes.

- **t_{13} – time for the machine clears the line in longwall according to the downward direction:**

$$t_{13} = (L_{LC} - L_{KĐ})/V_X, \quad \text{minutes} \tag{3-27}$$

where: V_X – velocity of machine when excavating downward, m/minutes.

- **t_{14} – waiting time for changing direction of the machine in the end of the longwall, minutes:**

$$t_{14} = MAX \begin{cases} t_{13} \dfrac{L_{LC} - L_{KC} - L_{KĐ}}{V_{VT}} + \dfrac{x_1}{V_X} \dfrac{L_{LC} - L_{KC} - L_{KĐ}}{V_{VC}} + \dfrac{x_1}{V_X} + \\ + \dfrac{x_3}{V_{VT}} \dfrac{L_{LC} - L_{KC} - L_{KĐ}}{V_{HT}} + t_{TH} - t_{13} + \dfrac{L_{KC}}{V_{HT}} \end{cases} \tag{3-28}$$

where: L_{HT} – length of the ceiling lowering section in the body of the longwall, m; V_{HT} – speed of lowering roof to recover coal, m/minutes;

– when $x_4 \le L_{KĐ}$:

$$t_{TH} = MAX \left\{ \frac{x_1}{V_X} + \frac{x_3}{V_{VT}} \frac{L_{KĐ} - x_4}{V_{HT}} + \frac{x_4}{V_{HT}} \right. \tag{3-29}$$

– when $x_4 > L_{KĐ}$:

$$t_{TH} = \frac{x_1}{V_X} + \frac{x_3}{V_{VT}} + \frac{x_4 - L_{KĐ}}{V_{VC}} + \frac{L_{KĐ}}{V_{HT}} \tag{3-30}$$

where: x_4 – minimum distance from location of recovering the coal to the location of moving the support, m.

In case that coal recovery height is equal to zero (no lowering ceiling of longwall):

$$t_{14} = MAX \begin{cases} t_{13} \dfrac{L_{LC} - L_{KC} - L_{KĐ}}{V_{VT}} + \dfrac{x_1}{V_X} \dfrac{L_{LC} - L_{KC} - L_{KĐ}}{V_{VC}} + \\ + \dfrac{x_1}{V_X} + \dfrac{x_3}{V_{VT}} - t_{13} \end{cases}, \quad \text{minutes} \tag{3-31}$$

- **Actual working time of 01 production cycle:**

$$T_{CK} = T_{LV} + t_{15} + t_{16}, \quad \text{minute} \tag{3-32}$$

where: t_{15} – time for maintaining, repairing machine, minutes; t_{16} – time for handling incidents, minutes.

- **Mining output in one cycle:**

$$A_{CK} = A_{KH} \cdot n_{KH} + A_{TH}, \quad \text{tons} \tag{3-33}$$

A_{KH} – output of one mining line:

$$A_{KH} = L_{LC} \cdot m_{KH} \cdot r \cdot k_{KH} \cdot \gamma, \quad \text{tons} \tag{3-34}$$

where: L_{LC} – length of longwall, m; m_{KH} – height of excavation area, m; r – depth of cutting, m; k_{KH} – mining coefficient; γ – density of coal, T/m^3; n_{KH} – number of mining lines in 01 cycle; A_{TH} – output of 01 recovery line:

$$A_{TH} = L_{LC} \cdot m_{TH} \cdot r_{TH} \cdot k_{TH} \cdot \gamma, \quad \text{tons} \tag{3-35}$$

m_{TH} – height of recovery coal, usually $m_{TH} = M - m_{KH}$
where: M – thickness of seam, m; r_{TH} – length of recovery section:

$$r_{\mathrm{TH}} = r \cdot n_{KH} \cdot k_{KH}, \quad \mathrm{m} \tag{3-36}$$

where: k_{TH} – coefficient of coal recovery.

Represented by:

$$A_{CK} = L_{LC} \cdot r \cdot k_{\mathrm{KH}} \cdot n_{\mathrm{KH}} \cdot \gamma \cdot (m_{\mathrm{KH}} + (M - m_{\mathrm{KH}}) \cdot k_{TH}), \quad \text{tons} \tag{3-37}$$

3.3. Determining the coefficient of standard working time

$$K_{tLC} = \frac{\sum_{i=1}^{15} t_i}{\sum_{i=1}^{16} t_i} = \frac{T_{LV} + t_{15}}{T_{LV} + t_{15} + t_{16}} \tag{3-38}$$

Where: K_{tLC} – Coefficient of standard deviation time; T_{LV} + t_{15} – total time that the longwall operates without interruption or adding manual treatment of interruptions, minutes; t_{16} – total interruption time (with or without the arised work), minutes.

3.4. Determining mining intensity

Mining intensity refers to the overall operating intensity of the production line. The analysis indicates that the intensity of longwall operations is determined by the speed of the slowest stage in the production process. Specifically, with longwall without ceiling lowering, the mining intensity depends on the speed of moving the support and the method of lowering coal. The longwall mining method involves lowering ceilings; mining intensity depends on the rate of ceiling descent. Technologies can help to accurately determine mining intensity during a production cycle, depending on the output in a cycle and the time and working mode of the machine. Mining intensity is an important factor used to evaluate and calculate the influence of the effective working time on exploited output.

Indicator of mining intensity fk is determined as formula:

$$f_K = A_{CK} / T_{CK}, \quad \text{T/minute}$$

Expressed as follows:

$$f_K = \frac{L_{LC} \cdot r \cdot k_{KH} \cdot n_{KH} \cdot \gamma \cdot (m_{KH+} \left(M - m_{KH}\right) \cdot k_{TH}}{\sum_{i=1}^{16} t_i}, \quad \text{T/minute}$$

4. Results and discussion

The analysis is based on the operating cycle of a longwall wall cutter, pausing time in a specific phase of the cycle. The method presented to determine the applicability of cutters allows receiving information for optimising the mining process.

The research results help to establish a method of calculating the working time for mechanised longwall in case of lowering or not lowering the ceiling. 14-time parameters (t_1 to t_{14}) have integrated the working ability of the equipment, the method of arranging the working space in the longwall, the method of operating the machine, and the view of the technician. The engineer arranges the working diagram (Fig. 3, Fig. 4), such as how to arrange the initial working space in the head (foot) of the longwall and how to cut coal in an uphill (downhill) direction. Along with how to move the support and trough, the time the machine moves with load (no load), how to recover roof coal (if any), and the operating method determine the working time of the machine. Those 14-time parameters show the technical features of the equipment, the natural conditions of the coal seam, the methods of operating management, layout, and exploiting the organisation of human factors. These factors can be adjusted suitably to real production.

The compulsory pause time of the machine for maintenance is t_{15}, the forced stopping time due to subjective and objective reasons is a random variable recorded at time variable t_{16}. The t_{15} is taken according to the manufacturer's recommendations. The t_{16} depends on random conditions. To minimise this time loss, it is necessary to control t_{15} well and enhance the application of management methods and other forecasting (deeper research about t_{16} in the next work). Understanding data about specific work during the operation of longwall cutters allows for precise repair operations in these areas. The built methodology and achieved results take great opportunities for practical application and improving the efficiency of mechanised longwall mining in underground mines.

5. Conclusions

The uncertain conditions in mining underground are only predicted when making a mining plan. These uncertain conditions reduce productivity or design capacity as well as mining plans due to stopping machines. Not only natural factors but also interior factors such as materials providing, transportation, the skill of workers, opinion of designing, ideas for the operation of managers, as well as direct or indirect factors affect working time or established plans. Information and behaviour are crucial bases for establishing the mining method that is suitable for actual conditions.

The closer the time for completing all mining cycles is to the estimated plan, the higher the efficiency of the production process. The indicator of time standard deviation is measured by the quotient of real constructing time per designed time and is equal to 1. In other words, mining intensity $f_K = 1$; $t_{16} = 0$. This is considered as an ideal condition.

Formulas from (3-1) to (3-60) are the scientific base for determining the efficiency of mechanised longwall. However, to determine the time for stopping the machine and reduced productivity, further research is required. There is not enough space to research clearly within the scope of this article.

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