An Assessment of Selected Work Organisation Variants in an Underground Hard Coal Mine with Consideration to Unit Mining Costs

Roman MAGDA [1)]

[1)] prof. dr hab. inż.; AGH University of Science and Technology, Krakow, Faculty of Mining and Geoengineering, Department of Economics and Management in Industry

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Abstract

The aim of the paper is to compare two forms of work organisation, the first of which assumes extending the mine's operation from five to six days a week, and the other – implementing a continuous work organisation system. To illustrate this in terms of unit mining costs, a model hard coal mine was used. In addition to the current organisational solution, which serves as the starting point for comparative analysis, solutions were proposed to increase the degree of utilisation of the existing production potential, mainly with regard to technical means of production and human resources. The proposed solutions assume increasing the intensity of use of technical means of production on an annual basis by extending the annual working time of selected mining crews. For the comparative analysis, three variants of the mine's operation in terms of the production organisation system were adopted. Under Variant I, treated as the baseline option, the current organisation of production is to be continued (5 days a week, Monday to Friday, excluding public holidays). Variant II provides for extending the working time of some mining crews to 6 days a week (from Monday to Saturday, excluding public holidays). Variant III assumes continuous operation for 7 days a week (excluding public holidays and several days for shaft inspections). Having adopted appropriate baseline assumptions for simulation calculations and a set of input data reflecting the characteristics of a specific mine, simulation calculations were performed and their results were used to carry out a comparative analysis of selected organisational solutions.

Keywords: hard coal mining, mine management, economics of mining production, unit production costs

Introduction

The favourable situation on the hard coal market, characterised by the prevalence of a relatively high price level, justifies undertaking study and research work on the possibilities of increasing production volumes in hard coal mines which currently operate on the market. Accordingly, two basic options can be identified in this respect: first – investing in new production potential, and second – increasing the utilisation of the production potential available at the moment. If the first option is followed, one must account for a relatively long waiting period before the production volume increases and for the need to allocate significant funds for that purpose. In the second option, the waiting period will be definitely shorter and the spending lower, allowing a more flexible adaptation of the production volume to fluctuations on the hard coal market.

The current production potential can be used to a broader extent through the application of suitable forms of work organisation, entailing, e.g. an increase to the production days over a specific period (week, month, year), which should result in a boost to the mining volume in that period.

The aim of this paper is to compare two forms of work organisation, the first of which assumes extending the mine's operation from five to six days a week, and the second one – implementing a continuous work organisation system. A model hard coal mine was used as an example. Unit mining costs were adopted as the criterion for comparative analysis.

In order to achieve the assumed research objective, the modelling of the account of costs by type was used for the three separate calculation variants, taking into account division into fixed and variable costs. Variant I (the baseline variant of the comparative analysis) assumes the current state of work organisation (five mining days per week, from Monday to Friday, excluding public holidays). The other two variants account for the above-mentioned work organisation forms, under which the mine's operation time is to be extended. Based on the data specific to Variant I, cost account models were developed for the other variants which take into account the forms of work organisation adopted for the analysis, i.e. extension of working time from five to six days per week (Variant II) or continuous work organisation (Variant III).

Comparative analysis of the adopted calculation variants

For the purposes of analytical research, three variants of systemic organisational solutions were adopted, as described below.

Variant I, considered a baseline for comparative analysis, concerns the standard four-shift work organisation on working days (Monday to Friday), excluding public holidays; the length of the working shift is 8 hours and the length of work at the coal face is 6 hours. The working conditions and terms for the payment of wages and other work-related benefits are governed by the provisions of the Labour Code, the collective labour agreement in force at the company, and the company's work regulations. The work is performed on working days from Monday to Friday, with an average of 40 hours of work performed by employees underground during a five-day working week. For work on Sundays, public holidays and

other days off work (resulting from the work schedule), in addition to the daily wage, an employee receives a day off which may but does not have to be taken. If an employee reports for work on a day which would otherwise be a day off, in addition to the daily wage, he or she is entitled to an allowance in the form of a grade pay for the work performed. The work regulations provide for the organisation of work on days off on a voluntary basis and allow overtime of no more than 416 hours annually.

Under Variant II, the mine's working time is to be extended from five to six days a week (Monday to Saturday), excluding public holidays; the length of the working shift is 8 hours and the length of work at the coal face is 6 hours. It differs from Variant I in terms of the mining volume (through the addition of Saturday output) and an increase in those items of the cost-by-type division, which result from the extension of the mine's operating time and an increase in the volume of annual coal production. The extension of the mine's operating time from five to six days a week, and including Saturdays in the working time balance, results primarily in a significant increase in personnel costs, as work on Saturdays should be treated as work on a day off, with all the consequences for personnel costs, as provided for in the above-mentioned provisions [6].

Variant III concerns an organisation system involving a continuous operation of the mine. In this system, mining continues on all days of the week (not only working days, but also Saturdays and Sundays), with the exception of public holidays and days for necessary service breaks to the production process in order to perform shaft inspections [7]. Under an organisational system in which a mining plant operates continuously, the majority of employees are directly involved in securing uninterrupted production, while the rest of the staff, who do not have to work under the continuous system, are employed on working days (Monday to Friday).

The continuous work system in a mine has been addressed by a number of papers [2,3,4,5] which followed in the wake of the concept for work organisation advocating the deployment of shift- and brigade-based systems. The crew working in the continuous work system is divided into equal teams (brigades), several of which work during the day on different shifts (each on a different one), while the rest of the crew rests. Work and rest day arrangements in a shift- and brigade-based system can be developed in a multi-variant way depending on mutual combinations of the frequency of breakdowns, the accumulation or splitting of days off, the length of the recurring cycle of days on and off work, and the rhythm of days off [2].

The shift-altering frequency specifies the interval between when a brigade moves from one shift to another and the length (expressed as the number of man-days) of work of a brigade on a specific (first, second, third or fourth) shift.

Assuming that each brigade works for several days on the same shift and then has one, two or several days off work, it is possible, by combining the number of shifts and the number of brigades, to distinguish a number of variants of work and rest day arrangements, while observing the rule that the number of working teams (brigades) is at least one more than the number of shifts.

For a 4-shift system (where the length of a shift is 8 hours and the length of work at the coal face is 6 hours), the following work-rest patterns can be developed, as presented in Fig. 1:

- the 4s-5b-1 variant (four shifts–five brigades–variety 1) – four days of work on shift 1, one day off, four days of work on shift 2, one day off, four days of work on shift 3, one day off, four days of work on shift 4, one day off, and so forth. On each day, four teams work, one team has a day off, and the cycle continues for 20 days;
- the 4s-5b-2 variant (four shifts–five brigades–variety 2) – five days of work on shift 1, one day off, five days of work on shift 2, one day off, five days of work on shift 3, one day off, five days of work on shift 4, two days off, and so forth. On each day, four teams work, one team has a day off, and the cycle continues for 25 days;
- the 4s-5b-3 variant (four shifts–five brigades–variety 3) – six days of work on shift 1, one day off, six days of work on shift 2, two days off, six days of work on shift 3, one day off, six days of work on shift 4, two days off, and so forth. On each day, four teams work, one team has a day off, and the cycle continues for 30 days.

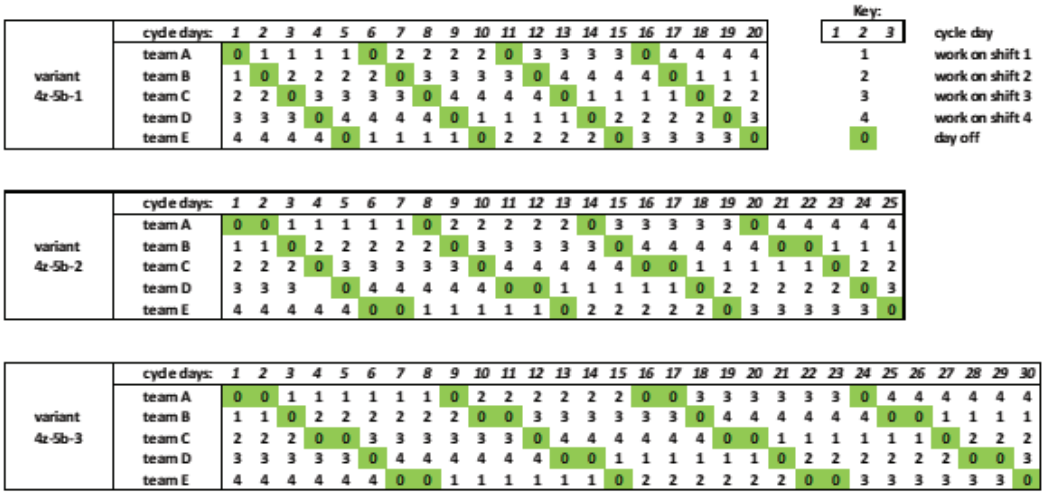
The analysis of the annual work time balance of working teams in the four-shift system with five working teams [1,3] showed that it comprises 281 ÷ 283 work shifts per year and, on average, includes 30 shifts more than the traditional four-shift system (with work performed only on working days). For work in such a system, an employee should receive an additional allowance taking into account the increased number of shifts during the year and work on Saturdays and Sundays.

Data on production costs by type for Variant I with a breakdown into fixed and variable costs in relation to the volume of production, in accordance with the accounting method, were treated as input data for the calculation of production costs for the other variants. The following assumptions were made:

1. Amortization costs (fixed and variable) are proportional to the number of production days.
2. The costs of equipment lease and rent, drilling and mining services, methane drainage services, training services, mining damage adjustment services, transport services and mining fee are proportionate to the volume of production.
3. The costs of materials, energy, other mining services, repair services, taxes and other charges are divided into a fixed part, independent of the volume of coal production, and a variable part proportional to that volume.
4. In Variant II, gross labour costs, social insurance (ZUS) surcharges and union benefits take into account the wage-related consequences of extending the working time of a mine from five to six days a week (a conversion rate of 1.14) and, in Variant III, of transition to continuous operation (a conversion rate of 1.52).
5. Real estate tax, environmental and PFRON (National Disabled Persons' Rehabilitation Fund) fees, insurance and other costs are fixed, regardless of the volume of coal production.
6. Unit variable costs are the same in all variants.

Results of sample calculations

Analytical tests were carried out on a sample coal mine characterised by average daily coal production of 19200 Mg/day, with the application of the work organisation variants



	cycle days:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
variant 4z-5b-1	team A	0	1	1	1	0	2	2	2	2	0	3	3	3	3	0	4	4	4	4	
	team B	1	0	2	2	2	2	0	3	3	3	3	0	4	4	4	4	0	1	1	1
	team C	2	2	0	3	3	3	3	0	4	4	4	4	0	1	1	1	1	0	2	2
	team D	3	3	3	0	4	4	4	4	0	1	1	1	1	0	2	2	2	2	0	3
	team E	4	4	4	4	0	1	1	1	1	0	2	2	2	2	0	3	3	3	3	0

Key:	
1 2 3	cycle day
1	work on shift 1
2	work on shift 2
3	work on shift 3
4	work on shift 4
0	day off

	cycle days:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
variant 4z-5b-2	team A	0	0	1	1	1	1	1	0	2	2	2	2	2	0	3	3	3	3	3	0	4	4	4	4	4
	team B	1	1	0	2	2	2	2	2	0	3	3	3	3	3	0	4	4	4	4	4	0	0	1	1	1
	team C	2	2	2	0	3	3	3	3	3	0	4	4	4	4	4	0	0	1	1	1	1	1	0	2	2
	team D	3	3	3		0	4	4	4	4	4	0	0	1	1	1	1	1	0	2	2	2	2	2	0	3
	team E	4	4	4	4	4	0	0	1	1	1	1	1	0	2	2	2	2	2	0	3	3	3	3	3	0

	cycle days:	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
variant 4z-5b-3	team A	0	0	1	1	1	1	1	0	2	2	2	2	2	2	0	0	3	3	3	3	3	3	0	4	4	4	4	4	4	
	team B	1	1	0	2	2	2	2	2	0	0	3	3	3	3	3	3	0	4	4	4	4	4	4	0	0	1	1	1	1	
	team C	2	2	2	0	0	3	3	3	3	3	3	0	4	4	4	4	4	4	0	0	1	1	1	1	1	1	0	2	2	2
	team D	3	3	3	3	3	0	4	4	4	4	4	4	0	0	1	1	1	1	1	1	0	2	2	2	2	2	2	0	0	3
	team E	4	4	4	4	4	4	0	0	1	1	1	1	1	1	0	2	2	2	2	2	2	0	0	3	3	3	3	3	3	0

Fig. 1. The work-rest pattern in a 4-shift system with five work teams [Source: 2, p. 49]

Rys. 1. Układ dni pracy i odpoczynku w systemie czterozmianowym z pięcioma zespołami roboczymi [Źródło: 2, s. 49]

described above. The daily mining capacity of the mine (the maximum level) is 24000 Mg/day and its use reaches 80% on average.

The most important assumptions and input data are as follows:

- Variant I: – the mine extracts coal 5 days a week in a four-shift work organisation system (three production shifts and one maintenance and repair shift) – the length of the work shift is 8 hours, the time spent at the coal face – 6 hours, the time spent specifically on mining – 18 hours/day, and the annual number of mining days assumed for calculations – 250.
- Variant II – the mine extracts coal 6 days a week (excluding public holidays), in a four-shift work organisation system (three production shifts and one maintenance and repair shift) – the length of the work shift is 8 hours, the time spent at the coal face – 6 hours, the time spent specifically on mining – 18 hours/day, and the annual number of mining days assumed for calculations – 300.
- Variant III – the mining plant extracts coal 7 days a week (excluding public holidays and several days for shaft inspections), in a four-shift work organisation system (three production shifts and one maintenance and repair shift) – the duration of the working shift is 8 hours, the time spent at the coal face – 6 hours, the time spent specifically on mining – 18 hours a day, and the annual number of mining days assumed for calculations – 350.

It has been assumed that the mine's annual mining capacity, which is the smallest amount resulting from the combination of production capacities – the extraction operations, the mine ventilation system, horizontal transport (haulage), vertical transport (hoisting), mineral processing plant – does not limit the annual coal production volume which can be as follows:

- Variant I: 4.8 million Mg/year
- Variant II: 5.76 million Mg/year
- Variant III: 6.72 million Mg/year

Number of employees:

- Variant I: 8000 people
- Variant II: 8000 people
- Variant III: 9500 people – this figure is based on the assumption that part of the current crew working at the main extraction operations (75% of the staff, i.e. 6000 people) must be expanded in a 5:4 ratio, i.e. by 1500 people, with the remaining 2000 people working under the regular Monday-to-Friday system.

The total annual costs and unit costs for each variant are presented in Table 1.

The data on total costs in Table 1 together fixed and variable for Variant I were adopted as data for the model coal mine. On the basis of this data and the assumptions listed above, appropriate calculations were carried out for Variants II and III. Their results are presented in the respective columns.

In Table 1 the results of the calculation of unit production costs for the individual variants of work organisation obtained by dividing the annual production costs by the volume of annual mining volume are presented as well.

Table 2 presents a relative percentage comparison of the selected values that apply to the respective calculation variants, assuming that the values for Variant I are at the level of 100%.

On comparing selected Variant I and II figures, it can be stated that the extension of the mine's operation time from five to six days a week will result in:

- a 20% increase in production volume,
- a 14% increase in total costs,
- a 14% increase in personnel costs,
- a 5% decrease in unit costs.

On comparing selected Variant I and III figures, it can be stated that the implementation of a continuous work system will result in:

- a 40% increase in production volume,
- a 40% increase in total costs,
- a 52% increase in personnel costs,
- the unit costs remaining at a comparable level.

Fig. 1. The work-rest pattern in a 4-shift system with five work teams [Source: 2, p. 49]
Rys. 1. Układ dni pracy i odpoczynku w systemie czterozmianowym z pięcioma zespołami roboczymi [Źródło: 2, s. 49]

No.	Specification	Costs [PLN thous./year]			Unit costs [PLN/Mg]		
		Variant I	Variant II	Variant III	Variant I	Variant II	Variant III
1	Amortization	278428	334113	389799	58.01	58.01	58.01
2	Materials	194589	219097	243606	40.54	38.04	36.25
3	Energy	127210	132470	137730	26.50	23.00	20.50
4	Equipment lease and rental	37173	44607	52042	7.74	7.74	7.74
5	Drilling and mining services	64630	77556	90482	13.46	13.46	13.46
6	Methane drainage services	14884	17861	20838	3.10	3.10	3.10
7	Other mining services	55432	61377	67323	11.55	10.66	10.02
8	Training services	22482	26978	31474	4.68	4.68	4.68
9	Mining damage services	11149	13378	15608	2.32	2.32	2.32
10	Repair services	81481	97772	114064	16.98	16.97	16.97
11	Transport services	59214	71057	82900	12.34	12.34	12.34
12	Other services	45767	45800	45833	9.53	7.95	6.82
13	Labour costs brutto	761976	868333	1158204	158.75	150.75	172.35
14	Welfare securities	162791	185513	247442	33.91	32.21	36.82
15	Union benefits	63043	71842	95825	13.13	12.47	14.26
16	Real property tax	8686	8686	8686	1.81	1.51	1.29
17	Royalties (exploitation fee)	10240	12288	14336	2.13	2.13	2.13
18	Environmental fee	283	283	283	0.06	0.05	0.04
19	PFRON charge	9218	9218	9218	1.92	1.60	1.37
20	Other taxes and charges	1455	1464	1472	0.30	0.25	0.22
21	Insurances	8467	8467	8467	1.76	1.47	1.26
22	Other costs	715	715	715	0.15	0.12	0.11
	Total sum	2019313	2308877	2836346	420.69	400.85	422.08

Tab. 2. Comparison of selected values characterising calculation variants [Source: own study]
Tab. 2. Porównanie wybranych wielkości charakteryzujących warianty obliczeniowe [Źródło: opracowanie własne]

Specification	Unit	Variant I	Variant II	Variant III
Production volume	million Mg/year	100%	120%	140%
Total costs	million PLN/year	100%	114%	140%
Personnel costs (gross labour costs, welfare securities, union benefits)	million PLN/year	100%	114%	152%
Unit costs	PLN/Mg	100%	95%	100%

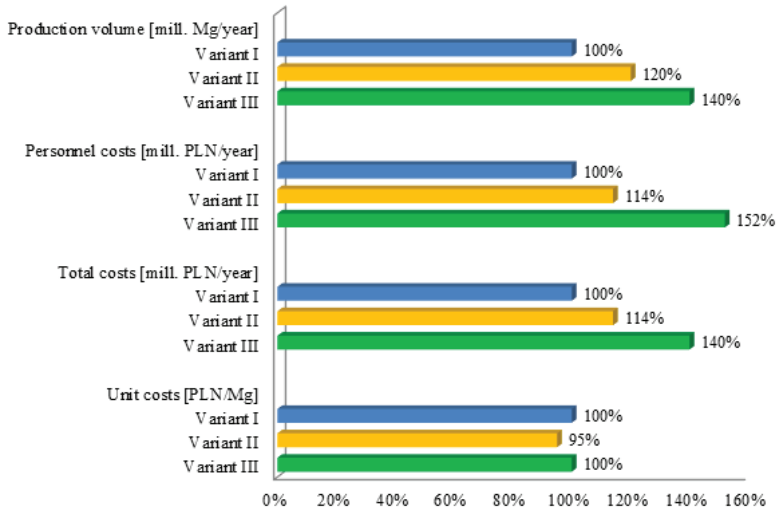


Fig. 2. Illustration of a relative comparison of the selected values characterising calculation variants [Source: own study]
Rys. 2. Ilustracja porównawcza wybranych wielkości charakteryzujących warianty obliczeniowe [Źródło: opracowanie własne]

Summary

Based on the obtained results of calculations, it can be concluded that extending the mine's operation time from five to six days a week is the preferred solution in terms of minimisation of unit production costs. With regard to the example at hand, this solution is characterised not only by a 20% increase in the production volume (which also entails revenue higher by approx. 20%, assuming no changes to the average fixed price of coal), but also a 5% decrease in the unit production costs.

The deployment of a continuous work system can result in the mining volume higher by 40% (which will also increase sales revenue), with the unit cost kept at a comparable level.

The obtained sample calculations regard the adopted, simplified model assumptions, as well as a good market situation guaranteeing the sale of any quantity of coal produced by the mine. In practice, the problem is more complex, the market situation is changing, and the largely unpredictable nature of mining production, in the context of an underground hard coal mine, further limits the possibility of assessing how various cost components will develop. Each case should be considered individually. The paper presents an example of assessing the benefits that can be derived from extending the working time of a coal mine during an economic upturn on the hard coal market. The results of simulation calculations presented in the article are deterministic and simplified. Further, more detailed research into the topic should be based on modelling and stochastic simulation.

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Ocena wybranych wariantów organizacji pracy w podziemnej kopalni węgla kamiennego w aspekcie jednostkowych kosztów wydobycia

Celem publikacji jest porównanie dwóch form organizacji pracy, z których pierwsza zakłada wydłużenie czasu pracy kopalni z pięciu do sześciu dni w tygodniu, a druga - wdrożenie systemu organizacji pracy ciągłej, na przykładzie pewnej, modelowej kopalni węgla kamiennego w aspekcie kształtowania się jednostkowych kosztów wydobycia. Obok aktualnego rozwiązania organizacyjnego, które stanowi punkt wyjścia dla analizy porównawczej, zaproponowano rozwiązania zmierzające do wzrostu stopnia wykorzystania posiadanego potencjału produkcyjnego w zakresie obejmującym przede wszystkim techniczne środki produkcji i zasoby ludzkie. Zaproponowane rozwiązania zakładają intensywniejsze wykorzystanie technicznych środków produkcji w skali roku poprzez wydłużenie rocznego czasu pracy niektórych załóg górniczych. Na potrzeby analizy porównawczej przyjęto trzy warianty funkcjonowania zakładu górniczego w aspekcie systemu organizacji produkcji. Wariant I, potraktowany jako wariant bazowy, zakłada dotychczasową organizację produkcji przez 5 dni w tygodniu (praca od poniedziałku do piątku, z wyłączeniem dni ustawowo wolnych od pracy). Wariant II zakłada wydłużenie czasu pracy niektórych załóg górniczych do 6 dni w tygodniu (praca od poniedziałku do soboty, z wyłączeniem dni ustawowo wolnych od pracy). Wariant III zakłada pracę ciągłą przez 7 dni w tygodniu (z wyłączeniem dni ustawowo wolnych od pracy i kilku dni przeznaczonych na przeglądy szybowe). Przyjmując odpowiednie założenia podstawowe do obliczeń symulacyjnych oraz zbiór danych wejściowych odpowiadających warunkom pewnego zakładu górniczego wykonano obliczenia symulacyjne, których wyniki użyto do analizy porównawczej wybranych rozwiązań organizacyjnych.

Słowa kluczowe: górnictwo węgla kamiennego, zarządzanie kopalnią, ekonomika produkcji górniczej, jednostkowe koszty produkcji