Розділ 3. Фізика гірничих процесів на великих глибинах

UDK 658.012.23: 622.014.2 https://doi.org/10.37101/ftpgp24.01.006

STOCHASTIC SIMULATION OF UNDERGROUND COAL EXTRACTION SCHEDULE

A. Merzlikin[1*], L. Zakharova[2], Y. Merzlikina[1]

[1]Donetsk National Technical University, Lutsk, Ukraine
[2]Branch for Physics of Mining Processes of the M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine, Dnipro, Ukraine
[*]Corresponding author: e-mail: artem.merzlikin@donntu.edu.ua

ABSTRACT

Purpose. Improvement of the technique of stochastic modeling of the schedule of mining by introducing and taking into account mutual dependencies between elementary operations of the main processes of coal mining.
Methods. The energy complex of Ukraine depends on the supply of gas, oil, nuclear fuel, as well as on the development of its coal industry. Underground coal mining is carried out in exclusively dangerous and specific conditions. Risks posed by uncertainty worsens the coal mining program, which usually leads to chronic failure to maintain the schedule of mining operations. This reduces profitability of coal mining and, as a consequence, affects the economic condition of the industry as a whole. In this paper, for the first time, the mining Gantt chart is considered as a complex of continuous and discrete operations.
Findings. Application of the stochastic modeling method allows you to create many options for the implementation of the mining work schedule and thus cover all potentially possible implementations. As a result of the research, the method of stochastic modeling was improved by introducing and taking into account the interdependencies between the elementary operations of the main mining processes.
Practical implications. For the conditions of uncertain coal mining, it was established that the most promising ways to reduce mining risks are modern information technologies, which are based on monitoring early signals of the stochastic environment in which coal mining takes place.
Keywords: schedule of mining operations, uncertainty, stochastic simulation, elementary operations, risks

1. INTRODUCTION

The importance of the coal industry as a guarantor of the country's energy independence has always been relevant, and in the context of the armed conflict in the east of the country it has grown even more. Almost all domestic coal is mined underground, which is associated with a number of specific features, namely: intense rock pressure, risk of explosion of methane-air mixture or coal dust, rock bumps, limited space of underground workings, unprecedented level of danger, high capital intensity of fixed assets, unfriendly ecological atmosphere of the underground space. Added to this is a high level of geological uncertainty of coal deposits created by geological micro-faults (GMF), reliable exploration of which is currently unattainable. Such conditions give rise to the uncertainty of the internal and external (primarily geological) environment, in which mining of excavation pillars is carried out in modern coal mines. These uncertainties are the cause of various risks of underground coal mining, the neutralization, reduction or avoidance of which is a separate topical problem [1]. These risks negatively affect the coal mining program, which usually leads to chronic non-fulfillment of the mining schedule. This reduces the profitability of coal mining, which affects the economic condition of the industry as a whole.

According to [2-6], risks are associated with the uncertainty, which is heterogeneous in form and content. Risk is one way to remove the uncertainty, which is lack of reliable knowledge, lack of unambiguity. There are the following main types of uncertainty [6]. Subjective uncertainty is related to the inability to accurately predict people's behavior during operation. People differ from each other in their education, experience, creative abilities, interests. Individual reactions vary from day to day, depending on the state of health, mood, contacts with other people, etc. A number of documents [7] regulates all mining operations, unlike the vast majority of industries. However, individual reactions of longwall miners and other underground workers might significantly affect the uncertainty of the parameters of the extraction schedule.

Technical uncertainty is considered to be much lower [8] compared to human uncertainty and is related to the reliability of equipment, predictability of production processes, complexity of technology, level of automation, production volume, rate of renovation. However, the specificity of underground coal mining is that the share of technical uncertainty is no less than other types of uncertainty. This is due to geological uncertainty, which is especially often caused by the presence of GMF of coal seams [9].

Social uncertainty is determined by people's desire to form social ties and help each other, to behave in accordance with mutually accepted obligations, service relations, roles, incentives, conflicts, traditions. The structure of such relationships is not defined. In particularly severe and dangerous conditions of the underground coal mining, team cohesion plays a special role in ensuring stability of the excavation site.

Thus, all the uncertainty components play a comparable role in generating the risks of the underground coal mining. All these risks are automatically integrated and taken into account by the longwall extraction schedule, which is a Gantt chart [10]. Thus, the risks of coal mining can be investigated by studying such schedules. The most detailed study of schedules is achieved by their stochastic simulation [11]. This approach was first used by the author of this article to analyze the longwall extraction schedules at the excavation site of a modern coal mine. The aim of the research was to study the influence of certain factors on the lag behind the coal production plan.

2. MATERIALS AND METHODS

Longwall 12 of the Southern mining face, block 10, PJSC "Pokrovsk Coal Mine" was chosen as the research object. The coal seam with a thickness of 1.45 m was extracted at a depth of 800 m. The immediate roof is represented by sandstones with a strength of 4 to 16, with a thickness of 7 to 20 m. The direct roof is represented by unstable siltstones, with a strength of 2.4 to 3.8 and with a thickness of 0.5 to 12 m. The bottom of the seam is represented by unstable siltstones with a thickness of 0.5 to 6 m.

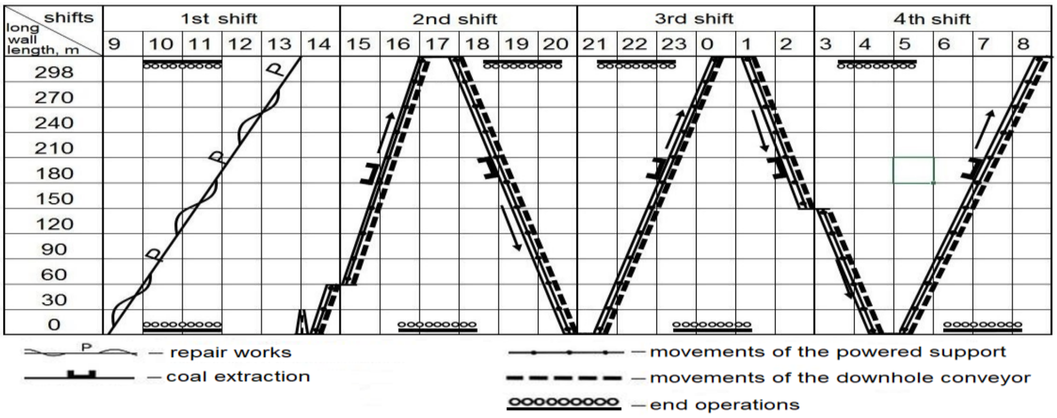

Figure 1. The coal extraction diagram of 12 Southern longwall, block 10. Gantt chart

Longwall 12 of the southern mining face of block 10 was equipped with a modern mining mechanized complex 3KD90T, shearer JOY, armored face conveyor SPTs-230. The pillar was extracted according to the combined mining system with a longwall retreat. The roof was controlled by its complete. During the day, the longwall was moved by 5 m by excavating five runs (Fig. 1).

The powered support sections moved sequentially behind the shearer-loader. Coal extraction took place during three working shifts, and in the first shift planned preventive and repair works were performed.

3. RESULTS AND DISCUSSION

Fig. 2 shows a typical longwall extraction schedule, which corresponds to the schedule in Fig. 1. This schedule was studied by stochastic simulation, a detailed description of which is given in [1]. The peculiarity of stochastic simulation is that the duration of the schedule is introduced not as deterministic quantities, but as certain distributions of random values of these quantities. The laws of these distributions are studied on the basis of analysis of factual data. For example, the PERT method takes into account the optimistic, pessimistic and most likely estimates of the performance of each operation [12]. However, this method has limited possibilities, as it calculates only three options for the schedule: optimistic, pessimistic and most probable. This leads to a certain distortion of the simulation results because it does not take into account the marginal variants of possible implementations of the schedule, as a result of which the distortion of the simulation results can reach 24% and even more.

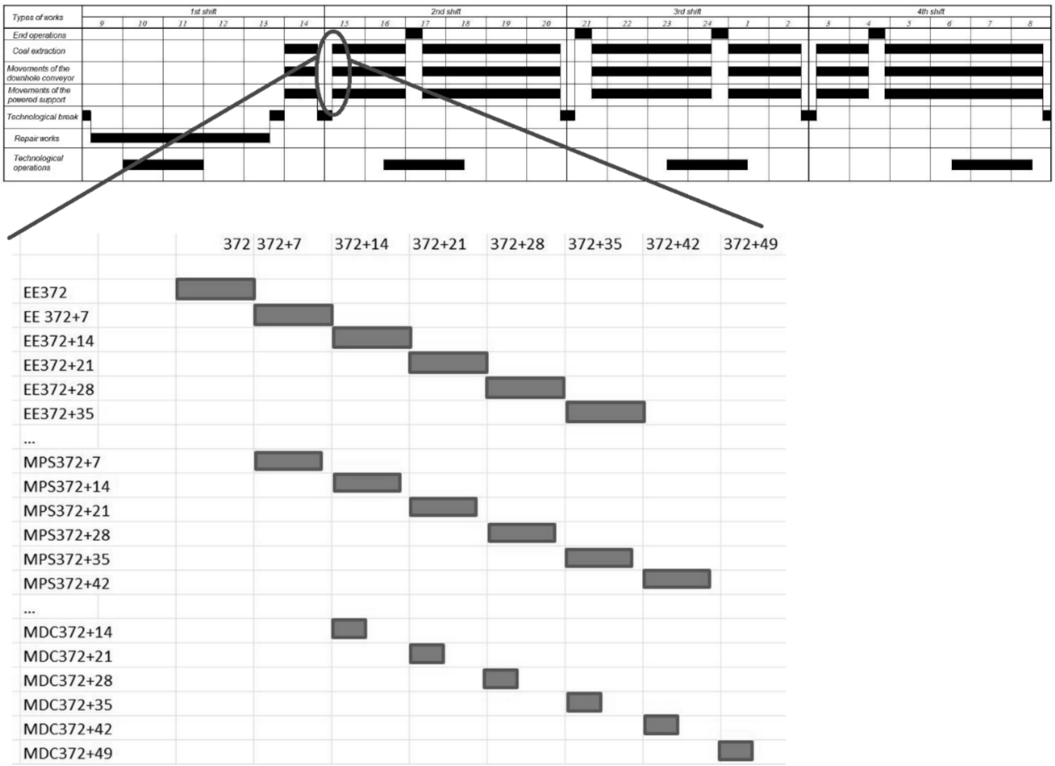

Figure 2. Gantt's chart: (a) – generalized; (b) – detailed: EE – elementary extraction, MPS – movements of the powered support, MDC – movement of the armored face conveyor. (EE372+7, – 372–minets+7seconds)

That is why this paper uses a stochastic simulation method (Monte Carlo method), which makes it possible to create hundreds or even thousands of variants of the schedule, and thus covers all potential possible implementations. This ensures the maximum possible reliability of the results of stochastic simulation.

In addition, the peculiarity of the extraction processes during underground coal mining is that the schedule shown in Fig. 2, a is unsuitable for performing stochastic simulation.

The reason is that such a schedule is too generalized, rough, and does not take into account the important relationships and interdependencies between coal mining processes. The peculiarity of these processes is that they are a set of continuous and discrete operations. Fig. 3 shows an enlarged fragment of the longwall within the area of the combined machine operation. Therefore, the combined machine destroys a layer and loads coal continuously, and movement of the powered support sections and the armored face conveyor is carried out by discrete portions.

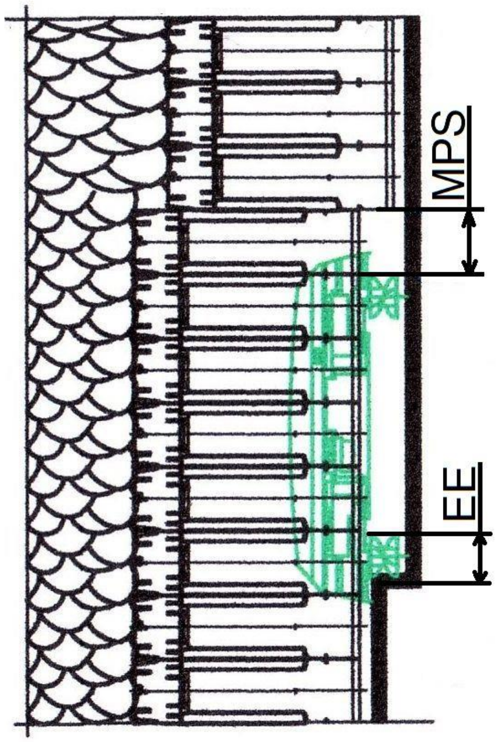

Figure 3. Illustration of elementary (single) coal extraction

Physically, the minimum elementary portion of the discrete extraction operation coincides with the width of the powered support section. As a rule, modern powered support sections have a width of 1 m. The notch depth (or the length of the shearer auger) is also 1 m. Thus, after moving the shearer along the face conveyor, a 1×1m area of the coal seam (in plan view) is extracted, and immediately after that, the powered support section is moved to support the exposed area of the immediate roof.

The sections move sequentially as the shearer-loader moves along the face, which ensures the maximum possible stability of the seam roof that is being extracted.

It is important that it is impossible to move the section of the powered support and a site of the armored face conveyor without elementary coal seam excavation in the size of 1×1m in the plan. The concept of elementary coal seam extraction was first introduced in [13]. This methodological approach allowed establishing new significant patterns of displacement of the rocks of the immediate roof, which is important in terms of ensuring its stability. However, the decomposition of longwall extraction to the level of elementary is of great importance in terms of stochastic simulation of the schedule.

Fig. 4 shows a fragment of the longwall extraction schedule, taking into account the uncertainty. As can be seen, the time of the beginning of the elementary extraction or movement of the powered support section and the time of completion, as well as the duration of the work itself is in reality uncertain. In the general case, the distribution of these parameters is arbitrary. For example, the start of the elementary seam extraction by the shearer-loader may fluctuate less than the finish time, and the most elementary work on the schedule may look as if they overlap.

However, a specific random implementation of the schedule will look deterministic, for example, as shown in the fragment (b) of Fig. 2. The elementary extraction operations are marked as EEx+c, where the first digit means minutes of the schedule (from the 1st to the 1440th during the day), and the second one means seconds. Movements of the powered support sections are designated as MPSx+c, and movements of the armored face conveyor as MDCx+c. The longwall extraction is planned so that the extraction operation is critical in terms of schedule. The rest of the basic operations (movements of the powered support sections and the conveyor) depend on the first one and are carried out right after its completion.

In theory, the critical schedule pathway should be through coal seam operations. In Fig. 2, it can be seen that the elementary seam extraction operations follow one another continuously, while the elementary movements of the powered support sections and the armored face conveyor have a time reserve and can float in terms of production.

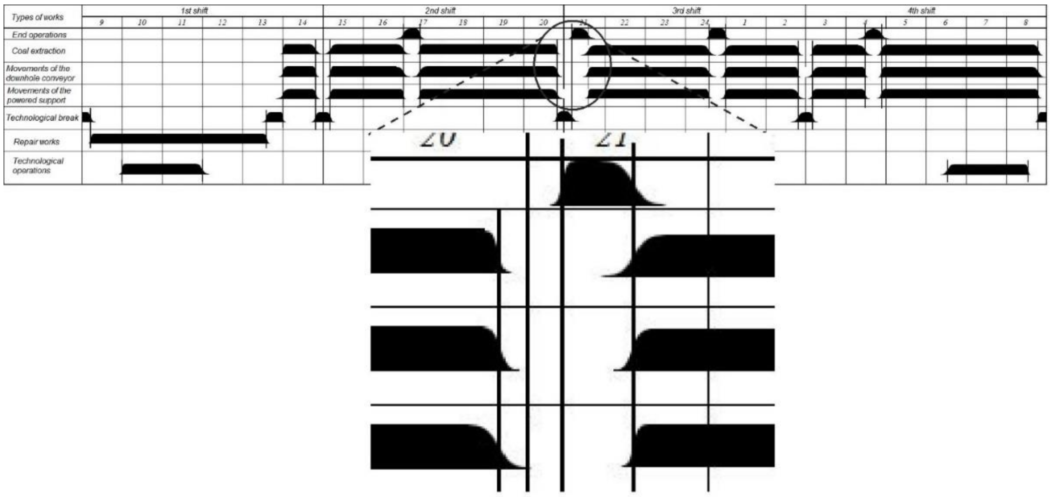

Figure 4. Gantt chart of the main extraction processes taking into account uncertainty

However, the peculiarity of rock pressure requires that the discrete work on the movement of the powered support sections followed immediately after the completion of the elementary seam extraction, which provides the fastest possible reinforcement of the immediate roof of the coal seam after its extraction. In reality, even in a longwall that operates in a stable design mode, unexpected delays usually occur that violate the theoretical schedule shown in Fig. 2, and the actual operating schedule takes a form similar to that shown in Fig. 5. The fragment of the schedule shows how the delay of the elementary extraction operation occurred at the moment, the beginning of which coincides with 372 minutes and 7 seconds of the schedule of longwall extraction.

There are many reasons for the delay in extraction operations. The most probable causes are related to the breakdown of the combined machine, power outage that feeds the drive of the combined machine, malfunction of the armored face conveyor, stoppage of the transport chain on the conveyor lane, negative manifestations of rock pressure, such as deterioration of the immediate roof and its collapse, risk of explosion of the methane-air mixture and many other reasons, which are usually uncertain. It is important that such a delay is undesirable because it increases the risk of not fulfilling the plan.

So immediately after eliminating the cause of the delay, the shearer operator tries to make up for lost time by increasing the intensity of the extraction. The first elementary excavations after stopping are thus carried out in a shorter time and such acceleration may not affect the safety of workers. However, if such acceleration of the extraction process lasts for a long time, it may increase the concentration of explosive methane to an unacceptable level, which creates a real risk of explosion of the methane-air mixture.

The schedule in Fig. 5 also shows that the movement of the powered support sections can be carried out in parallel or with an overlay in time to compensate for the temporary increase in the rate of the coal seam extraction and to ensure the stability of the immediate roof. However, it should be borne in mind that the power of the oil station that feeds the hydraulic chocks of the powered support is limited and this physically limits the number of sections that can move simultaneously. Therefore, accelerating the extraction may create additional risks associated with the collapse of the immediate roof of the coal seam.

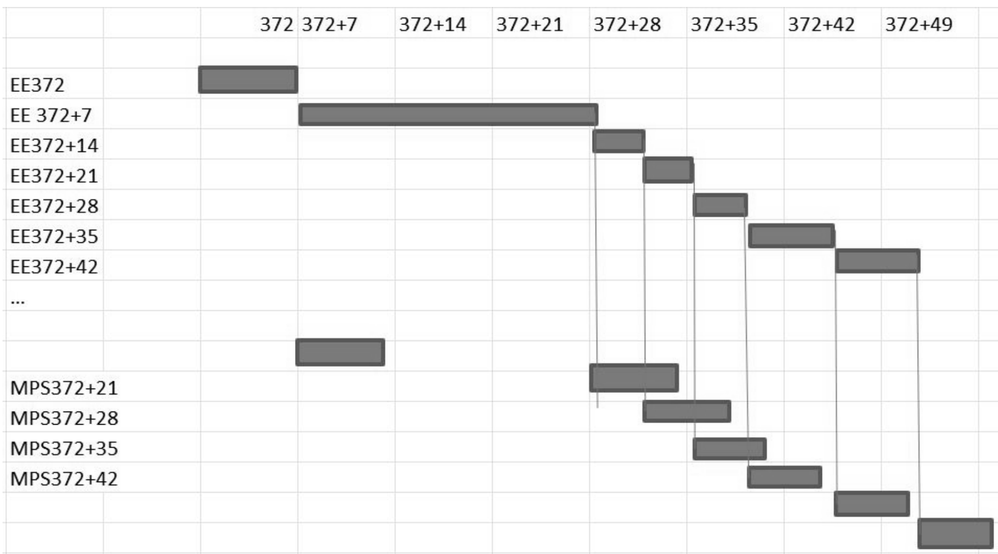

Figure 5. One of the possible implementations of the Gantt schedule under conditions of delay of the shearer

Fig. 6 shows the results of stochastic simulation of the longwall extraction schedule taking into account the uncertainty of the time of execution of elementary coal seam extraction operations. Fragment (a) of Fig. 6 shows the exponential distribution of the execution time of elementary extraction operations, designed on the statistical analysis of a representative number of observations of the actual execution time of the specified operation.

The scheduled time of the elementary coal seam extraction in this particular case is 7 seconds, but with a certain probability, the duration of this operation can increase to 12 seconds. This distribution is determined only by taking into account the delays due to internal causes that occur directly in the longwall, and such delays were studied only in the stable operational mode of the longwall. In other words, this distribution does not take into account significant unforeseen reasons for stopping the longwall extraction, such as those that occur during the longwall face cross of GMF of the coal seam.

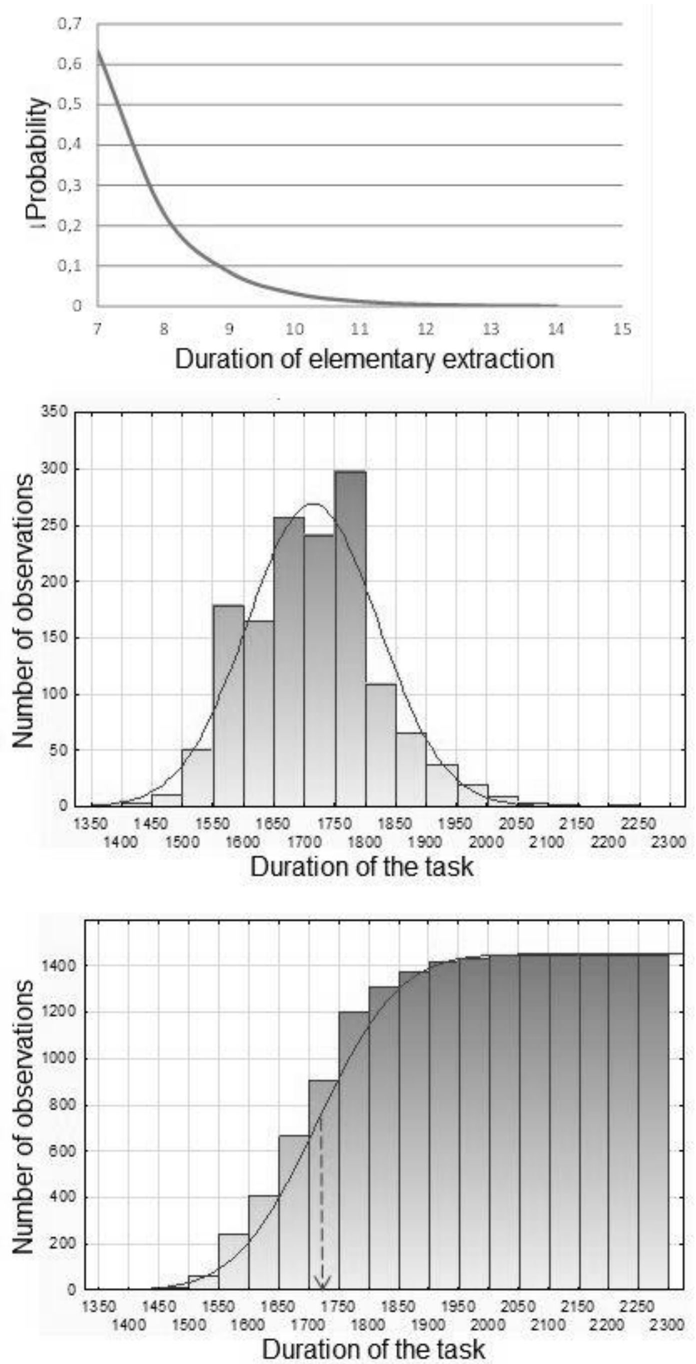

Figure.6. Distribution of probability duration of coal mining: (a) density of duration of elementary extraction; (b) - density duration of the daily task; (c) - cumulative distribution of the duration of the task

Fragment (b) of Fig. 6 shows the density of the distribution of the time of the daily extraction plan, taking into account the distribution of the elementary excavation operations, shown in Fig. 6, a. Although all indeterminate time parameters had an asymmetric form of exponential dependence, the execution time of the daily plan is distributed symmetrically and approaches the normal law, which naturally reflects the fundamental law of large numbers and testifies to the validity of stochastic simulation.

The most probable time of fulfilling the daily plan of coal production is 1714 minutes (fragment b), which is 1.19 times more than the length of the day (1440 minutes). Moreover, the probability of the plan fulfilling even during such time does not exceed 51.7% – fragment (c). To fully guarantee that the daily plan of coal production will be fully implemented, it is necessary to spend 2059 minutes, which is 42.4% more than the length of the day. We emphasize that these risks are acceptable because they do not affect the risk of coal mining.

Unfortunately, miners usually try to compensate for this lag by accelerating coal production, which in most cases is limited by the gas factor. This is what leads to catastrophes related to methane-air explosions in the CIS countries, China, and many other countries where underground coal is mined. The risk of a catastrophic explosion occurs almost immediately after exceeding the concentration of methane permissible level in the presence of an open ignition source of an explosive gas mixture. Such risks are easy to predict and control, and the problem of explosion-related disasters is purely subjective to human safety.

However, delays in excavation operations are compensated in other ways as well. The most popular of these are related to the reduction of repair shifts when preventive inspection of equipment and minor repairs is replaced by coal extraction. Such substitutions lead to deferred risks, which are masked in terms of causes, as they occur with a long delay. It is especially dangerous to postpone repair of the powered support. If a section or group of powered support sections moves for some time without proper resistance to the immediate seam roof, it can collapse, which will not only delay the extraction but also create a dangerous situation in which miners can be injured and often die.

The same risk arises when fines and pieces of rock accumulate above the powered support sections, which are rather pliable and do not provide an opportunity to create proper resistance to the immediate roof. The hidden nature of this risk is even greater, because the exposure of the immediate roof is usually not completely flat and smooth, which makes it difficult to visually control the possible accumulation of piles and pieces of rock over the support sections. Such control is currently subjective and therefore its reliability is too low.

Thus, a whole problem is created with the operability of the powered support sections. In the conditions of underground coal mining, the reliability of the powered support is one of the most vulnerable factors, as their reliability, durability, and maintainability [14] are difficult to ensure.

The current monitoring of the geological environment of the excavation site and the forecast of risks based on early signals play an important role in the occurrence of risks of coal mining [15, 16]. Accumulation of damages in the immediate roof that does not receive proper resistance of the powered support occurs on an exponent, and the probability of loss of its stability is defined by the exponential dependence:

$$P(t) = e^{\lambda t},$$

where $\lambda = pn$, (p is the probability of collapse of the roof, n is the number of cycles of longwall movement).

Thus, the probability of roof falls is consistent with the Poisson distribution. According to statistics, the probability of collapse of the immediate roof in the area of the extraction pillar, outside the GMF is 0.023. The average intensity of roof falls, the probability of which exceeded 10%, was 0.1. Under such conditions, the collapse of the immediate roof is modeled as Markov processes [17]. It is important to use this tool to predict the risks associated with the collapse of the immediate roof.

Monitoring and forecasting of parameters of GMF plays an important role in the GMF transition areas. The most promising at present is the use of prediction methods based on neural networks and genetic algorithms, which makes full use of previously accumulated information about discontinuities, which in turn allows determining the coordinates and amplitude of the MF in the predicted area of the minefield [9].

The results of the forecast allow determining the feasibility of the cross of the GMF, to develop a plan-schedule of the transition, and to justify preventive measures to reduce the negative impact during the meeting of the geological gap. In turn, the timeliness of preventive measures in longwalls allows working out the disturbed areas of the minefield with minimal losses of speed, quality of coal, and reduced wear of equipment.

Today, the standard method of designing longwall extraction takes into account only the internal factors that operate within the longwall. However, to ensure the necessary reliability of risk assessment, it is necessary to take into account factors created by the external environment [18]. In the case of the mining face, one of the main external factors is the transport chain, through which the extracted coal is transported on the conveyor lane, the main preparatory workings, and so on until delivery to the earth's surface.

Fig. 7 shows a fragment of the schedule, which took into account the uncertainty of the transport chain. The coal transportation operation was included as part of the extraction schedule, although it is not usually accepted. Unlike the interrelationships of the internal factors of the longwall, the extraction operation now becomes dependent on transporting the extracted coal. This is shown in Fig. 7 in such a way that during the transport delay (for example, due to the rupture of the lane conveyor belt) the seam extraction is suspended because the extracted coal has nowhere to go.

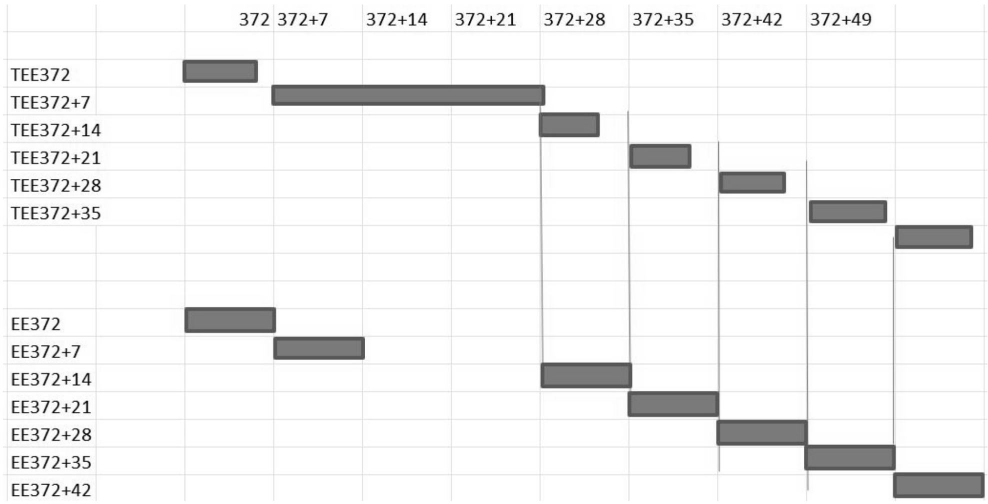

Figure 7. A fragment of the possible implementation of the Gantt chart, taking into account the work of the transport chain

Fig. 8 shows the distribution of the time for the daily rate of coal production taking into account the risks associated with the transport chain operation. Under such conditions, the most probable time to fulfill the daily plan has now increased to 1,845 minutes, or 28%, which is 9% longer than without transport risks, and it takes 2,200 minutes to complete the planned task. Such risks further push miners to violate safety rules and force them to make up for the plan at the expense of their lives.

4. CONCLUSIONS

To reduce the risks of coal mining, measures should be based on the recommendations of ISO 31000: 2009, as amended for the peculiarities of underground coal mining. According to the standard, the most effective way to avoid risk is to avoid or cancel the operation that is the source of the risk. However, capital investments in underground coal mining are too high to stop working on the extraction pillar, as the investments have already amounted to several million dollars.

Therefore, they usually try to cross the GMF, which often occur in the mining face. If it is impossible to make such a cross, the disturbed area will be left as decommissioned inventories, the new startup room will be cut, the mechanized complex will be moved to it and the extraction pillar will be worked out. The losses from such a GMF transition can reach hundreds of thousands of dollars.

Acceptance of risk in the vast majority of cases in underground coal mining is impossible for safety reasons. Thus, this method is simply unacceptable in the coal industry.

It is often almost impossible to eliminate the source of the risk of coal mining. This is especially true of the GMF cross, which is inherent in the geological nature of the field. Rather, a method based on reducing the likelihood of risk will be more acceptable. Thus, in the case of the GMF cross, innovative technologies for predicting the GMF parameters or methods of its cross play an important role in reducing the risk of stopping the mining face [9].

Possibilities of reducing the risks of coal mining by changing the sequence of operations are very limited, due to the limited space of underground workings and the specific interdependence of the main and auxiliary processes of coal mining.

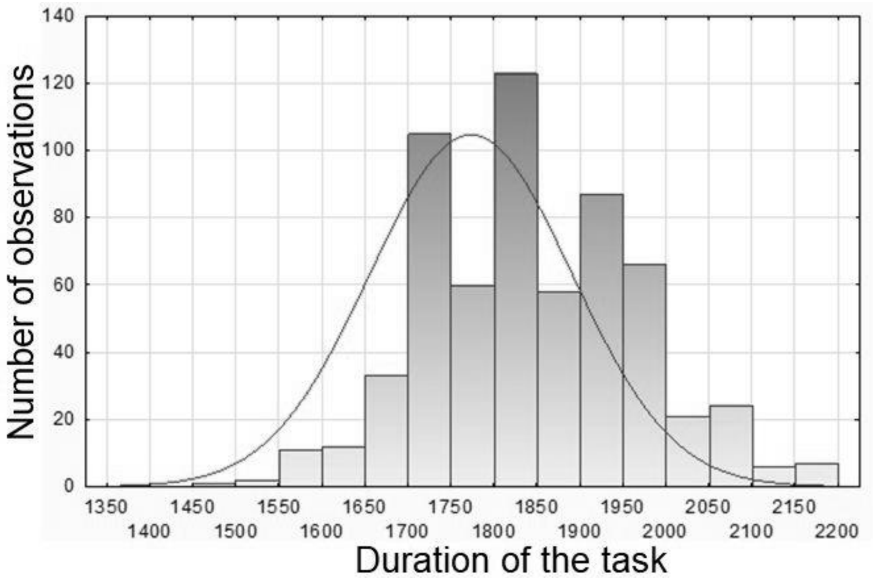

Figure 8. Distribution of time execution of daily norm of coal mining taking into account work of a transport chain

Sharing the risks of coal mining is possible, but currently, risk insurance in the coal industry is not widespread. More acceptable, effective and most promising is the adoption of more informed decisions. Here a lot of room for improvement is created by modern information technology of complex system management.

Coal mining is characterized by significant features such as limited space, high uncertainty of geological development conditions, intense rock pressure, the danger of explosion of the methane-air mixture or coal dust, rock bumps, high capital intensity of fixed assets, and unfriendly ecological atmosphere of underground space. These features impose significant restrictions on the choice of technologies to reduce and avoid the risks of underground coal mining.

The technique of stochastic simulation of the longwall extraction schedule was improved by introducing and taking into account interdependencies between elementary operations of the basic processes of longwall extraction.

It is proved that the traditional method of design of longwall extraction has a significant drawback, which reduces the reliability of the design because the extraction schedule does not take into account uncertainties and ignores ancillary processes that are essential for fulfilling the coal production plan.

In the process of creating a schedule of longwall extraction, it is necessary to introduce a reliability margin to take into account the uncertainty. The reliability margin during longwall extraction can range from 19 to 25%, and the additional margin for related operations (transportation and others) reaches 50% depending on the state of the technological chains. This means that the schedule of longwall extraction must be created taking into account the specific state of technology, equipment, and organization of production processes of the coal mining.

All critical parameters of the extraction site environment must be indicated in the documents prepared for the launch of the mining face and approved by the inspection. First of all, it is a condition of preparatory workings, condition of the mine atmosphere, a condition of a transport chain, a condition of the powered support, its deterioration rate, hoisting capacity. Abstract planning away from the specific environment of the longwall creates potential risks of non-fulfillment of planned coal production or increases the probability of catastrophes.

The most promising ways to reduce the risks of coal mining are modern information technologies based on monitoring early signals of the stochastic environment in which coal mining is carried out, forecasting GMF, modern logistics systems, including ground vehicles, and automated expert systems. During the creation of the schedule of longwall extraction, it is expedient to carry out work on drawing up the excavation environment compliance statement which is signed by representatives of the inspection. Compliance with this requirement provides an important legal basis for narrowing the conditions and possibly eliminating the chance of catastrophes associated with explosions of air-methane mixtures.

Conflicts of interest

The authors declare no conflict of interest.

Ethical statement

The authors state that the research was conducted according to ethical standards.

Acknowledgments

Many thanks to Victor Nazimko for her invaluable assistance with the data analysis for this research.

REFERENCES

1. Mayevskiy V., Zakharova L., Merzlikin A. (2011). Stochastic Simulation of Risk of a Program for Mining Development at a Coal Mine. Problems of Simulation and Computer Aided Design of Dynamic Systems. *Scientific Papers of Donetsk National Technical University*. Vol. 10 (197), 101-110.
2. *Risk Management – Risk Assessment Techniques*. (2009) ISO/IEC 31010:2009. 2-nd Edition. 264 pp.
3. Kahneman, D., Slovic, P., & Tversky, A. (1982). Judgment under Uncertainty. Cambridge *University Press*. https://doi.org/10.1017/CBO9780511809477
4. David, H., & Peter, S. (2020). *Practical Project Risk Management. Berrett-Koehler Publishers*. 176 pp.
5. Hansson, S.O., Zalta, E.N. (2014). "Risk". The Stanford Encyclopedia of Philosophy. *Special Issue: Risk and Moral Theory*. (Vol. 21, No. 2), 207-216.
6. Risk: An introduction Bernardus Ale 200. (2016) "Risk Management – An Analytical Study". IOSR *Journal of Business and Management*. (Vol. 34, No. 1), 83-89.
7. Safety rules in coal mines: RLALP 10.0-1.01-10. (2014). *Department of Labor Protection and Emergencies of the Ministry of Coal Industry of Ukraine,* Kyiv. 198 pp.
8. Vallero, D. A., & Vesilind, P. A. (2006). *Socially Responsible Engineering*. John Wiley & Sons, Inc. 365 pp. https://doi.org/10.1002/9780470121436.
9. A.V. Merzlikin. (2005). *Elaboration prognosis method of micro-faults on thin declivitous coal layers,* PhD. dissertation, National Mining University, Dnipropetrovsk.

10. *The standard for project management and a guide to the project management body of knowledge (PMBOK guide)*. (2021). 7th ed. Pennsylvania. Project Management Institute. 661 pp.

11. Zakharova L.N., Nazimko V.V. (2012). Investigation of development program and mining risk at a coal mine. *Radio-electronic and computer systems. National Aerospace University «Kharkiv Aviation Institute».* Vol 1 (53), 157-164.

12. Trietsch, D., & Baker, K. R. (2012). *PERT 21: Fitting PERT/CPM for use in the 21st century. International Journal of Project Management*, 30(4), 490–502. https://doi.org/10.1016/j.ijproman.2011.09.004

13. Nazimko I.V. (2012). Assessment of the stability of the immediate roof during mining of the excavation area. *Journal of Donetsk Mining Institute*. Donetsk. DonNTU. Vol. 1, 399-409.

14. Gnedenko B.V., Belyaev Yu.K., Solovev A.D. (1969). *Mathematical methods of reliability theory. New York*. Academic Press. 506 pp.

15. Nazimko V.V., Kratt O.A., Merzlikin A.V. (2013). Dynamic model for research project risk coal mining. Problems of Simulation and Computer Aided Design of Dynamic Systems. Scientific. *Papers of Donetsk National Technical University*. Volume.1(12)-2(13), 75-86.

16. Nazimko V.V., Merzlikin A.V. (2016). Development and rationale of the new method to forecast of risks coal mining. *Research and practice journal*: Kremenchuk Mykhailo Ostrohradskyi National University: Kremenchuk: KrNU, vol. 1 (17), 62-71.

17. Nazimko V.V., Merzlikin A.V., Selezneva Yu. (2012). Improving a mathematical model of the reliability of a working face taking into account rock pressure influence. Ground control in minning. (Vol. 20), 20-28.

18. Ke, H., Liu, H., & Tian, G. (2015). An Uncertain Random Programming Model for Project Scheduling Problem. *International Journal of Intelligent Systems*, 30(1), 66-79. https://doi.org/10.1002/int.21682

ABSTRACT (IN UKRAINIAN)

Мета. Удосконалення методики стохастичного моделювання графіка видобутку вугілля шляхом введення та врахування взаємозалежностей між елементарними операціями основних процесів видобутку вугілля.

Методи. Енергетичний комплекс України залежить від постачання газу, нафти, ядерного палива, а також від розвитку вугільної промисловості. Видобуток вугілля підземним способом ведеться у виключно небезпечних і специфічних умовах. Ризики, пов'язані з невизначеністю, погіршують програму видобутку вугілля, що зазвичай призводить до хронічного недотримання графіку вуглевидобутку. Це знижує рентабельність видобутку вугілля і, як наслідок, впливає на економічний стан галузі в цілому. В роботі, вперше розглядається, діаграма Ганта для інтелектуального аналізу, як комплекс неперервних і дискретних операцій.

Результати. Застосування методу стохастичного моделювання дозволяє створювати багато варіантів реалізації графіка гірничих робіт і таким чином охоплювати всі потенційно можливі реалізації. В результаті проведених досліджень удосконалено метод стохастичного моделювання шляхом введення та врахування взаємозалежностей між елементарними операціями основних гірничих процесів.

Практичні результати. Для умов невизначеності гірничих робіт встановлено, що найбільш перспективними шляхами зниження ризиків видобутку вугілля є сучасні інформаційні технології, які базуються на моніторингу ранніх сигналів стохастичного середовища, в якому відбувається основні процеси вуглевидобутку.

Ключові слова: планограма гірничих робіт; невизначеність; стохастичне моделювання; елементарні операції; ризики

ABOUT AUTHORS

Artem Merzlikin, Candidate of Technical Sciences (Ph. D.), Public Higher Education Institution Donetsk National Technical University, 56 Potebni Street., Lutsk, Ukraine, 43018. E-mail: artem.merzlikin@donntu.edu.ua

Ludmila Zakharova, Doctor Technical Sciences, Branch for Physics of Mining Processes of the M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine, 15 Simferopolskaya Street, Dnipro, Ukraine, 49005. E-mail: mila2017ma@gmail.com

Yelyzaveta Merzlikina, Public Higher Education Institution Donetsk National Technical University, 56 Potebni Street., Lutsk, Ukraine, 43018. E-mail: yelyzaveta.merzlikina.fem@donntu.edu.ua