SILESIAN UNIVERSITY OF TECHNOLOGY PUBLISHING HOUSE

SCIENTIFIC PAPERS OF SILESIAN UNIVERSITY OF TECHNOLOGY 2022
ORGANIZATION AND MANAGEMENT SERIES NO. 160

THE CONCEPT OF THE MAIN DEWATERING MODEL IN A COAL MINE CONSIDERING TECHNICAL, MANAGERIAL, AND ECONOMIC CRITERIA

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Purpose: The primary purpose of the article is to cross-sectionally present the concept of a model for optimizing the main drainage system in a coal mine.
Design/methodology/approach: The stated goal was achieved by using several research methods, including a literature study of existing technical system models and technical system modeling. Finally, the methodology used was based on a layered approach, which was verified by testing in a mine environment.
Findings: In the course of the work, it was found that the main drainage system at the Sobieski Coal Mine is very complex. The energy intensity of the main dewatering process was identified as the main problem. The proposed concept of a layered model of the main dewatering system makes it possible to identify the influence of technical, management and economic parameters of the system.
Research limitations/implications: The research limitations are due to the complexity of the system, the difficulties arising from the specificity of the mine environment, the lack of the possibility of ongoing diagnostics of the entire infrastructure (e.g. pipeline specification, the ability to measure sediment in water galleries, smooth change of the speed of drive mechanisms, etc.).
Practical implications: The results of the research work will be recommendations for engineering and technical staff aimed at reducing the energy intensity of the system.
Social implications: the conducted research is part of the current trend of searching for methods to reduce the energy intensity of systems and equipment.
Originality/value: The originality of the issue stems from the proposed concept of a layered model of the main drainage system, taking into account technical, organizational and economic parameters. Determining the relationship between the elements of each layer will enable the development of an optimization method to reduce the energy intensity of the system.

Keywords: main dewatering system, technological processes, energy intensity, technical system model.

Category of the paper: Conceptual paper.

1. Introduction

The production of hard coal in underground mines requires large capital expenditure and high operating costs. Large-scale activities are undertaken in coal mining companies to optimise operating costs. In mines with a large inflow of water from the rock mass, costs related to the operation of the main dewatering system are of significant importance. Research and development work is being carried out with a view to improving the efficiency of the use of technical and technological infrastructure and the organisation of the main dewatering processes, enabling the reduction of failures and disruptions to the system's operation, and thus reducing the costs of operation of the main dewatering system. Improving the effectiveness of the main dewatering system requires the implementation of solutions comprising tasks at the investment and operational levels based on continuously developing technical and technological solutions. This article presents a concept of the main dewatering model in a hard coal mine. The concept was developed on the basis of research undertaken at the Sobieski Coal Mine of TAURON Wydobycie S.A. The research, conducted between January 2021 and November 2021, included an in-depth analysis of the technical infrastructure and technological processes carried out within the main dewatering system. Research was also conducted based on the available literature. The proposed layered model of the main dewatering in a coal mine includes the following layers: process, infrastructure, interference and economic. The developed concept will enable a complete and coherent identification and quantification of the elements of the main dewatering system in order to analyse and recommend the possibility of applying selected technical, technological as well as organisational solutions to improve the effectiveness of the system.

2. Research methodology

Research to determine the basic elements and their mutual relationships was carried out in the period January 2021 - November 2021 at the Sobieski Coal Mine, in a mine with a high level of water inflow from the rock mass. The research process included an in-depth analysis of the main dewatering system, taking into account the analysis of the technical infrastructure (mainly the operation of machinery and equipment, their configuration and operation) and the identification and inventory of technological processes. The establishment of technological process metrics made it possible to determine the mutual relationships between technological processes and the technical and organisational parameters characterising these processes.

Figure 1 shows a schematic of the research model used to develop the concept of the main dewatering model. The research was divided into 3 stages. For each stage, research tasks were defined and selected research methods were applied, which resulted in the achievement of the intended effects within a given stage.

	Stage 1	Stage 2	Stage 3
Research tasks	1. Recognition of the legal, technical, and organisational conditions for the operation of the main dewatering. 2. Analysis of the technical infrastructure of the main dewatering system.	1. Identification of technological processes. 2. Identification of system problems and disturbances. 3. Identification of technical, managerial, and economic criteria determining the operation of the system.	1. Establishing layers in the main dewatering system. 2. Establish relationships between the different layers of the system. 3. Development of a layered model of the main mine dewatering.
Research methods used	1. A study of literature. 2. Face-to-face interviews with engineering and technical staff and system operators. 3. Analysis of source materials.	1. Analysis of technical documentation of machinery and equipment. 2. Analysis of data on the operation of machinery and equipment. 3. On-site visit including observation of the operation of the system under analysis. 4. Face-to-face interviews with engineering and technical staff and system operators.	1. A literature study in systems analysis. 2. Analysis of existing technical systems models. 3. Analysis of possible modelling concepts for the main dewatering system.
Results obtained	1. Determine the determinant of the functioning of the main dewatering system. 2. Identification of technical, legal and organisational conditions. 3. Identification and inventory of the technical infrastructure elements of the system under analysis.	1. Establish the primary and secondary technological processes of the main dewatering system. 2. Categorising processes and assigning weights. 3. Establish metrics for identified processes. 4. Identify key problems, interferences and failures in the system under analysis. 5. Definition of criteria determining the operation of the system.	Conceptualisation of the main dewatering model in a coal mine.

Figure 1. Scheme of the research model used to develop the concept of the main dewatering model (own elaboration).

The 1st stage was focused on identifying legal conditions and analysis of the technical infrastructure of the main dewatering system at the Sobieski Coal Mine. Direct interviews with the engineering and technical staff were of great importance at this stage. As a result, technical, legal and organisational conditions for the functioning of the main dewatering system in the hard coal mine were identified elements of technical infrastructure of the system were identified and inventoried.

The 2nd stage involved an in-depth analysis of the technical documentation of the machinery and equipment of the main dewatering infrastructure, as well as the analysis of the operating data of this equipment. This enabled the full identification and categorisation of technological processes, the establishment of metrics for these processes and the identification of key disturbances and failures that occur in the analysed system.

The 3rd stage was aimed at developing a concept of the main dewatering model in a coal mine. The concept was built on the basis of establishing the layers in the main dewatering system and the relationships between these layers.

Finally, the research carried out enabled the development of a conception for a layered model of the main dewatering in a coal mine, which is described further in this article.

3. Literature study on the main dewatering system in hard coal mining

The system of main dewatering of hard coal mines is a very broad topic and has a connection with many fields of knowledge. It is related to, among others, legal issues (Act of 9 June 2022…; Journal of Laws of the Republic of Poland, Regulation of the Minister of Energy of 23.11.2016…), cost aspects which have been noted by many authors (Dorosiński, 2016; Stępniewski, 1985, pp. 173-479) and technical issues (Kałuża; Wilk S., Golec, Wilk A., 2008, pp. 17- 81; Tajduś, Sroka, Misa, Dudek, 2019).

Legal aspects

The overriding legal act is the Act of 9 June 2011. Geological and Mining Law (Act of 9 June 2022…), which obliges hard coal mines to, among other things, develop hydrogeological documentation and carry out dewatering in order to extract minerals. Moreover, it obliges mines to continue dewatering of seams even after termination of mining activities. Another document is the Regulation of the Minister of Energy of 23.11.2016 on detailed requirements for the conduct of underground mining plants (Journal of Laws of the Republic of Poland, Regulation of the Minister of Energy of 23.11.2016…). This act regulates, among other things, the topic of requirements for the main dewatering pump chambers, the minimum number of pumps in the system and water hazard alarm signaling. The legal act concerning mine dewatering is also the Regulation of the Minister of Environment of 29 January 2013 on natural hazards in mining plants (Journal of Laws of the Republic of Poland, Regulation of the Minister of the Environment of 29 January 2013…). Among other things, it regulates the criteria for assessing natural hazards by introducing a three-stage water hazard scale. This act is referred to in the article (Szymański, 2013, pp. 1-8). The authors of the article point out that in order to avoid the deterioration of water hazards in hard coal mines, it is necessary to: improve the existing procedures and legal regulations for the assessment, monitoring and control of water hazards and emphasize these issues in hydrogeological documentation, as well as improve the quality of hydrogeological documentation and revise the procedure for the opinion and approval of documentation. Another document used in the mine is the internal regulation of the Manager of the Energy Department (Kierownik Działu Energo-Mechanicznego…, 2017, pp. 1-3), which contains a detailed instruction for the inspection of the technical condition of the equipment of the main dewatering system. This document introduces, among others, the concept of current, periodic and annual inspection and documentation containing records related to dewatering.

Cost aspects

The topic of mine dewatering costs was taken up by Korbiel and Wojciechowski (Korbiel, Wojciechowski, 2019, pp. 413-419). The authors indicate that depending on the depth of the mine and the average water inflow, the dewatering costs consist of: the costs of electricity supplying the electric motors driving the pumps, the costs of depreciation of the equipment, the costs of service and the costs of eventual water disposal together with environmental charges. In turn, the authors of the article (Jonek-Kowalska, Turek, 2013, pp. 727-740) estimated that the maintenance of dewatering areas of closed mines costs more than 50 million USD annually. However, the results of the conducted research and forecasts allow us to conclude that there are possibilities to reduce the overall costs by 17% in the perspective to 2030. In 2016, an article (Dorosiński, 2016) was published, in which the author points out that in Silesia there are many liquidated hard coal mines. However, the fact that a coal mine has ceased production does not mean that it no longer requires further technical supervision. Gumińska and co-authors in a 2021 article (Gumińska, Plewa, Grodzicka, Gumiński, Rozmus, Michalak, 2021, pp. 1-15) presented the results of a technological and economic analysis of mine water treatment systems prior to its discharge into the environment. The analysis made it possible to determine the profitability of investments taking into account the concentration of TSS (total suspended solids) in mine water. The simulation results showed that it is economically viable to use a water treatment system if natural sedimentation carried out in underground mine water passages or in sedimentation basins located on the ground surface is ineffective for TSS removal. In contrast, Masood Noshin and co-authors in 2020 (Masood, Edwards, Farooqi, 2020, pp. 2-16) raise the topic of the true cost of coal mining. The paper reviews the impact of coal mining on water resources, land subsidence, interruption of hydrological channels, floods and decreasing water level. This represents the main measurable impact of the mining sphere on the hydrological environment.

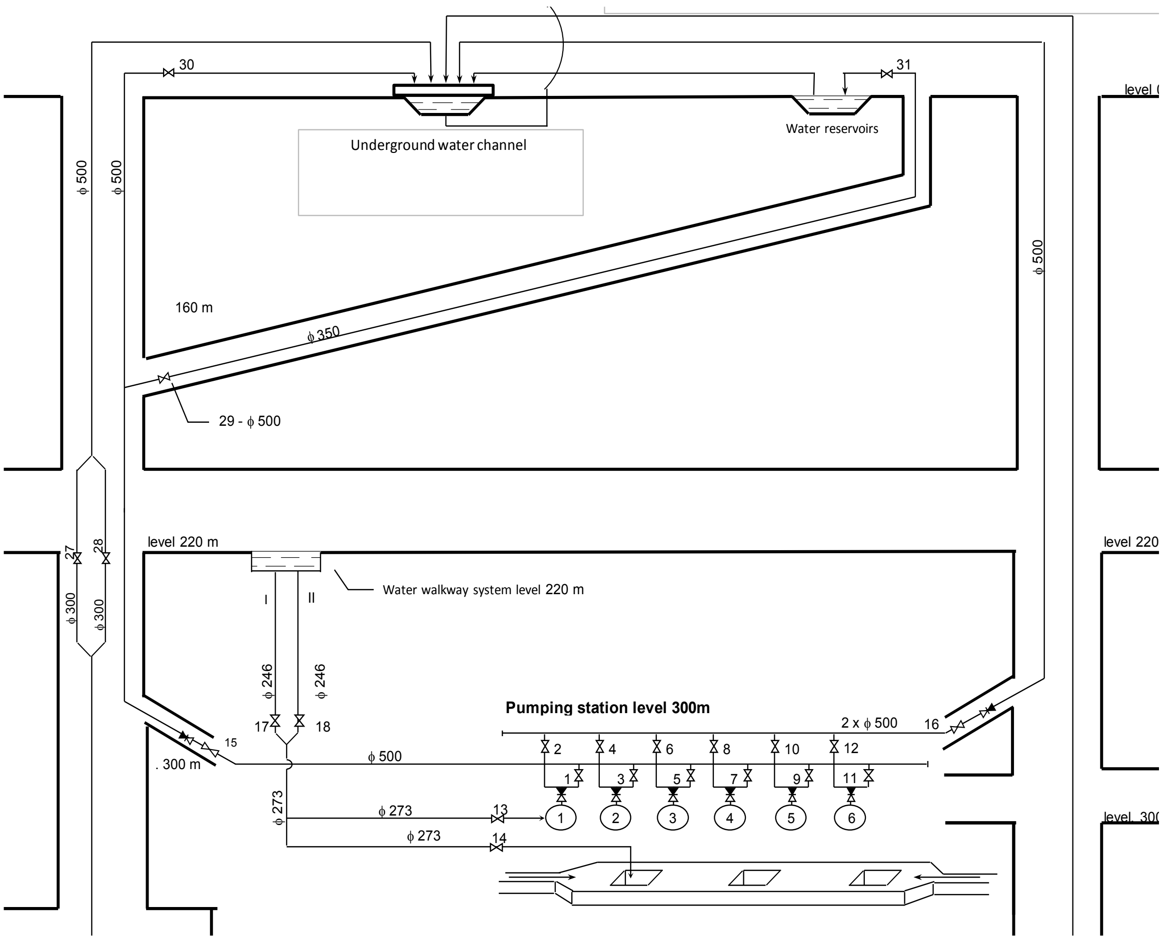
Technical aspects

Among the items analysed in the literature study, Mieczysław Stępniewski's book entitled Pompy [English translation Pumps] (Stępniewski, 1985, pp. 173-479) deserves attention. It is a comprehensive collection of thorough theoretical knowledge of hydromechanics and principles of operation of positive displacement and centrifugal pumps, methods of their calculation and design, together with examples. It discusses the phenomena occurring during the operation of pumps, their operating characteristics, principles of parameter regulation and cooperation in pumping systems. Submersible pumps are used in mines to remove local underflows. The article (Kałuża, pp. 1-6) is devoted to this type of pumps. Each submersible pump design is characterised by one basic common requirement; the driving electric motor must be tight against the pumped medium. Additionally, mine conditions are an area of application where explosive hazards are present. An interesting item is an article from 2007 (Mikoś, Kalukiewicz, Wojciechowski, 2007, pp. 1-53). The authors experimentally determined the relationship between the shape of the suction jet velocity fields and the pumping capacity. The information obtained may be a starting point for the development of a new, energy-efficient way of regulating the efficiency of centrifugal pumps. The article from 2016 (Szymański, 2016) refers to modern control systems that should include smart (artificial intelligence) procedures to ensure optimal and energy-efficient dewatering of mine workings. In turn, the article (Rózkowski, Zdechlik, Chudzik, 2021, pp. 1-18) touches on the topic of open-pit mines. It is interesting to note the numerical modelling method used to find a solution for minimising the environmental impact of dewatering. This case study analyses possible dewatering solutions related to the change of the mining dewatering system: liquidation by flooding of a depleted deposit and dewatering of a new one located in its vicinity. Authors of the article: "In an underground mine by using a 3D finite" (Hu, Zhang, Yang, Fan, Li, Wang, Lubale, 2020) describe a 3D groundwater model using the FEFLO simulation program. This model consists of combined regional and local geological models, integrating 16 hydrogeological cross-sections and borehole logging data to predict underground dewatering in the studied area. In turn, the handbook of Pakuła and Strączyński (Pakuła, Strączyński, 2013, pp. 129-201) and the article by Wilk and co-authors (Wilk S., Golec, Wilk, A., 2008, pp. 17-81) are items dedicated to practitioners who deal professionally with pumps in mining. Correct selection, installation and operation are the condition for long-term and failure-free operation. Szymański in 2013 published an article (Szymański, 2013, pp. 1-8), which presents selected methods of diagnostic testing of the drive system of main dewatering pumps, with particular emphasis on the diagnostics of the systems: power supply, control and the drive part of the pump. In 2019, the article (Tajduś, Sroka, Misa, Dudek, 2019, pp. 1-12) was published, which addressed the topic of water hazards resulting from the end of mining, occurring on the surface. The authors presented examples of regions, where serious damage caused by surface rising has been observed and compiled a dozen examples of these events for coal mines. Konsek and Czapnik in their article (Konsek, Czapnik, 2020, pp. 99-110) draw attention to the fact that liquidation of mines and restructuring of hard coal mining in the Upper Silesian Coal Basin (Polish: Górnośląskie Zagłębie Węglowe – GZW) – due to the presence and necessity of protection of active mines, does not solve the problem of dewatering of the mines that have been liquidated. According to the authors, the cheapest, safest and technically simplest solution is the Central Mines Dewatering Plant [Polish: Centralny Zakład Odwadniania Kopalń (CZOK)] implemented by the Mining Restructuring Company S.A., which comprehensively deals with the deep-sea dewatering system. It turns out that the amount of water flowing into the underground of mines is not constant. For information on this topic, see the 2017 article (Karpiński, Batko, Kmiecik, Tomaszewska, Zdechlik, 2017, pp. 1-60). The paper characterizes the variability of underground water inflows to the workings of the Sobieski Coal Mine, in the years 1970-2013. The topic of water hazards was also taken up by Zając (Zając, 2017). The issue of water inflow to the mine and its dewatering is dealt with by various services, which should closely cooperate in this respect. The intake of water in the place of its occurrence and its discharge into the mine dewatering system belongs to the mining and power engineering services. These services are also responsible for the maintenance and operation of the mine dewatering system. The literature study prepared by the authors of the article, structured in legal, economic and technical aspects, confirms the multidisciplinary character of the subject. Thus, it illustrates the great scientific potential of the area of interest and a wide spectrum of possibilities for analysing the issue of main mine dewatering systems. This topic is and will remain valid also after the end of operational activity of Polish mines.

In the literature study, the authors did not find any research concerning the drainage system as a system divided into separate layers. The proposed concept is unique and could be applied in other production enterprises to create structures, component layers, and interconnection between these layers.

4. Process structure and technical and technological infrastructure of the main dewatering system

The Sobieski Coal Mine is one of the three plants operating within TAURON Wydobycie S.A. (TAURON Group). Among the key processes affecting the Company's functioning in terms of both organisation and costs is the mine's main dewatering system. This system is a complex organism which is responsible for the safety of miners, has an impact on the proper organisation of production activities and is a significant cost factor in the mine's operations.



No. Agreg.	Pump type	Q m^3 /min	Engine type	P kW	n rpm
1	OW 200AM/5	5	Sf 355Y-4	400	1485
2	OW 300/5	12	SCUdm 134t-E	1000	1485
3	OW 300/5	12	SCUdm 134t-E	1000	1485
4	OW 300/5	12	SDUd 134T	1000	1480
5	OW 300/5	12	SDUd 134T	1000	1480
6	OW 300/5	12	SDUd 134T	1000	1480

Figure 2. A section of the main mine dewatering system – schematic diagram.

Of particular importance is the energy intensity of the system and the cost of the infrastructure (OPEX, CAPEX). This is due to the very high degree of waterlogging in the mine, with an average inflow of approximately 60 m^3/min of water from the rock mass. This translates directly into coal extraction costs. In order to illustrate the scale of the problem, it should be assumed that on average, 1 tonne of excavated material yields approximately 10 m^3 of water, which must be pumped several hundred metres, through a pipeline initially leading through galleries, and later through a vertical shaft to the surface of the mine.

In the course of the analysis of the issue, in order to structurize knowledge, the authors of the article decided to recognise the main dewatering system from a process point of view, so that after the analysis of mutual influences and interrelations, management recommendations could be developed for the engineering and technical staff that would make it possible to achieve effects in the form of organisational, technical and cost optimisation.

First, the basic processes of the main dewatering system were identified. By definition, these are all those processes which, if they are disturbed, will cause great difficulties or complete immobilisation of the mine's main dewatering system. The basic processes include all those processes that belong to the main link of the main dewatering system of a coal mine. 6 basic processes were identified and they are shown in Figure 3.

The process of pumping mine water from deep underground to the surface of the mine.	**The process of cleaning waterways.**	**Overhaul process for pumps and electric motors.**	**The investment process for pumps and electric motors.**	**The process of supervising the pumping of mine water within the main dewatering system.**	**The process of rectifying a system failure due to the failure of a pumping unit.**

Figure 3. Basic processes.

All other processes, which are of a supporting nature to the main processes, should be considered as auxiliary processes. 15 auxiliary processes have been identified, examples of which are shown in Figure 4.

Process of vibration analysis of the pump unit.	**Process for measuring the electricity consumption of pumping units.**	**Validation process for flow meters and pressure gauges.**	**Process for monitoring solid pollutants flowing into waterways.**	**Process for determining the actual efficiency of pumping units.**	**Process for determining pipeline characteristics.**

Figure 4. Examples of auxiliary processes.

The complexity and sophistication of the main dewatering system imposes the need to carry out an inventory and preliminary analysis of all identified processes occurring within the system, and then to select them from the point of view of their importance for the functioning of the main dewatering system.

The concept of process importance on a scale of 1-5 was introduced:

1. an auxiliary process associated with the main dewatering system, the inadequate implementation or lack thereof of which does not affect the main dewatering process,
2. an auxiliary process related to the main dewatering system,
3. auxiliary process of the main dewatering system related to the main dewatering system to monitor and diagnose the main dewatering system,
4. an essential process, the absence of which will result in significant disruption to the mine water pumping process,
5. the primary process, the absence of which will result in stopping the main dewatering process.

Furthermore, in order to carry out a multifaceted analysis, the concept of process categories was also introduced and defined as follows:

A. discrete process – is limited to where it occurs,
B. continuous process – occurs throughout the system's operating cycle,
C. technical process – related to technical infrastructure,
D. management process – related to the process of supervision and management of the system.

The next stage of the work was to identify the elements at the input to each primary and secondary process and to identify the elements at the end of each process (which is the result of carrying out the process). This analysis took into account the change in state of the object on which the process is performed, the parameters, the type of energy, the control pulses, etc. An example of element identification is shown in Table 1.

Table 1.
Examples of process input and output elements

Process name	Elements at the entrance for the process	Elements at the output from the process
The process of pumping mine water from deep underground to the mine surface	Underground mine water, electricity, process start signal, exceeded water column level in the water gallery	Mine surface water in collecting vessels, process shutdown signal, permissible water column level in the water gallery

The next stage of the work was to identify the technical infrastructure that is assigned to each basic and auxiliary process. Each process requires e.g. equipment, accessories, machines, devices, instruments, tools, without which the process would not be possible to carry out. Examples of infrastructure assigned to basic processes are presented in Figure 5.

The process of pumping mine water from deep underground to the surface of the mine.	**The process of cleaning waterways.**	**Overhaul process for pumps and electric motors.**	**The investment process for pumps and electric motors.**	**The process of supervising the pumping of mine water within the main dewatering system.**	**The process of rectifying a system failure due to the failure of a pumping unit**
Screens, piping, pump units, valves, expansion vessels, control and monitoring equipment.	Loaders, underground locomotives, sludge pumps, turnstiles, haulage trucks, track, measuring tools, hand tool, shaft equipment.	Specialised machinery of repair and production companies.	Specialist machinery for repair and production companies.	Control and measuring equipment, supporting devices: computer hardware, computer software report books, control devices.	Control and measuring tools, locksmith tools and instruments, spare parts, consumables.

Figure 5. Basic processes with the associated technical infrastructure.

Next, each process was assigned an estimate of costs in the form of labour intensity of technological processes necessary to operate it (in the case of operating the process internally) or cooperation costs in the case when the process cannot be performed on one's own e.g. due to lack of appropriate technical competence.

Process for determining the operating points of pumping units and pipelines	**Process for monitoring the degree of pollution of waterways**	**Pollution monitoring process for water settling tanks**	**Cleaning process for water settling tanks**
4 day stays/ 2 persons	**4 days/ 1 person**	**6 day stays/ 2 persons**	**approx. 6 000 000 PLN - external company**

Figure 6. Labour intensity of exemplary auxiliary processes.

Of great importance for the proper functioning of the main dewatering system is the correct identification of potential process disturbances. The disturbing events may be of various character and dimension. Their proper inventory affects their effective counteraction through the application of prediction principles. Examples of disturbances and threats they may cause to the system equipment and operation of the mine are presented in Table 2.

Table 2.
Examples of disturbances and the risks they may cause to system equipment and mine operations

Disturbance	Threat
bearing temperature of the pump and the electric motor exceeded	overheating of bearings, seizure, damage to housing and rotating parts
failure of the pump gland seal	aeration, cavitation and loss of power and efficiency
malfunction of signals and indications of measuring instruments	misdiagnosis of the current state of machinery, sudden stoppage of pumping units, flooding of the seams, danger to mine operations, danger to crew's lives, loss of control over the system

5. Layer model concept for the main dewatering system

The completion of the research tasks made it possible to develop the concept of a layered model of the main dewatering system. A conceptual diagram of this layered model is shown in Figure 7.

The model of the main dewatering system includes four layers which include elements of other types i.e.:

1. a layer of primary and secondary processes,
2. a layer of infrastructure elements,
3. a layer of process disruption (problems, failures, downtime, upgrades),
4. a layer of technical and economic effects.

The primary and auxiliary processes layer includes all identified primary and auxiliary processes of the main dewatering system. This layer is the starting layer for further analysis. The identification of these processes required contacts with the staff of the Sobieski Coal Mine, local inspections underground in the pumping chambers, familiarisation with the diagrams of the main dewatering system, familiarisation with the system reporting, diagnostic software and work organisation. All these factors must ensure compliance with the current Mining Law regulations and thus ensure the safety of the workforce and continuity of the Mine's operational activities.

The infrastructure elements layer includes the technical equipment necessary to implement the processes of the main dewatering system. These include machinery, equipment, pipelines, control and measuring instruments, tools, control devices, computer equipment. The main part of this infrastructure is located on the equipment of the mine. The remainder of the necessary infrastructure is held by manufacturers of machinery and equipment for the mining industry, who carry out production or repairs, and by service providers who carry out orders at the mine site with their own equipment, e.g. cleaning of water galleries or cleaning of water settling tanks.

The process disturbance layer comprises a set of factors that negatively affect the functioning of the main dewatering process leading to its failure or complete shutdown. They are phenomena that must be anticipated and prevented. Various types of diagnostic equipment are used for this purpose. Appropriate equipment with control and monitoring elements makes it possible, based on current observation, to prevent emergency states or to prepare in advance for their occurrence. Currently, each pumping unit in the Sobieski Coal Mine is equipped with vibration sensors, temperature sensors, pressure sensors, flowmeters and ammeters. The measurement results are recorded by specialised computer software in the on-line mode and are subject to ongoing analysis by supervisory staff.

The layer of technical and economic effects is the resultant layer in the main dewatering system. Technical and economic effects can be divided into positive and negative ones. The task of the authors of this article is, among other things, to determine the cause-effect relationships between the elements of the process of the main dewatering system and to identify measures enabling the reduction of negative effects and the strengthening of positive effects.

The layers defined in the model are interconnected by numerous relationships that illustrate the complexity of the main dewatering system under analysis. In the layer diagram, each relationship is marked with a symbol that reflects the way in which specific elements of different layers are related. In general, the symbol $\mathrm{R}^{\mathrm{ij}}_{\mathrm{k,l-m}}$ denotes the relation between the element of the *i*-th layer and the *j*-th layer of the model, which is the *k*-th relation between these layers, namely between the *l*-th element in the *i*-th layer and the *m*-th element in the *j*-th layer.

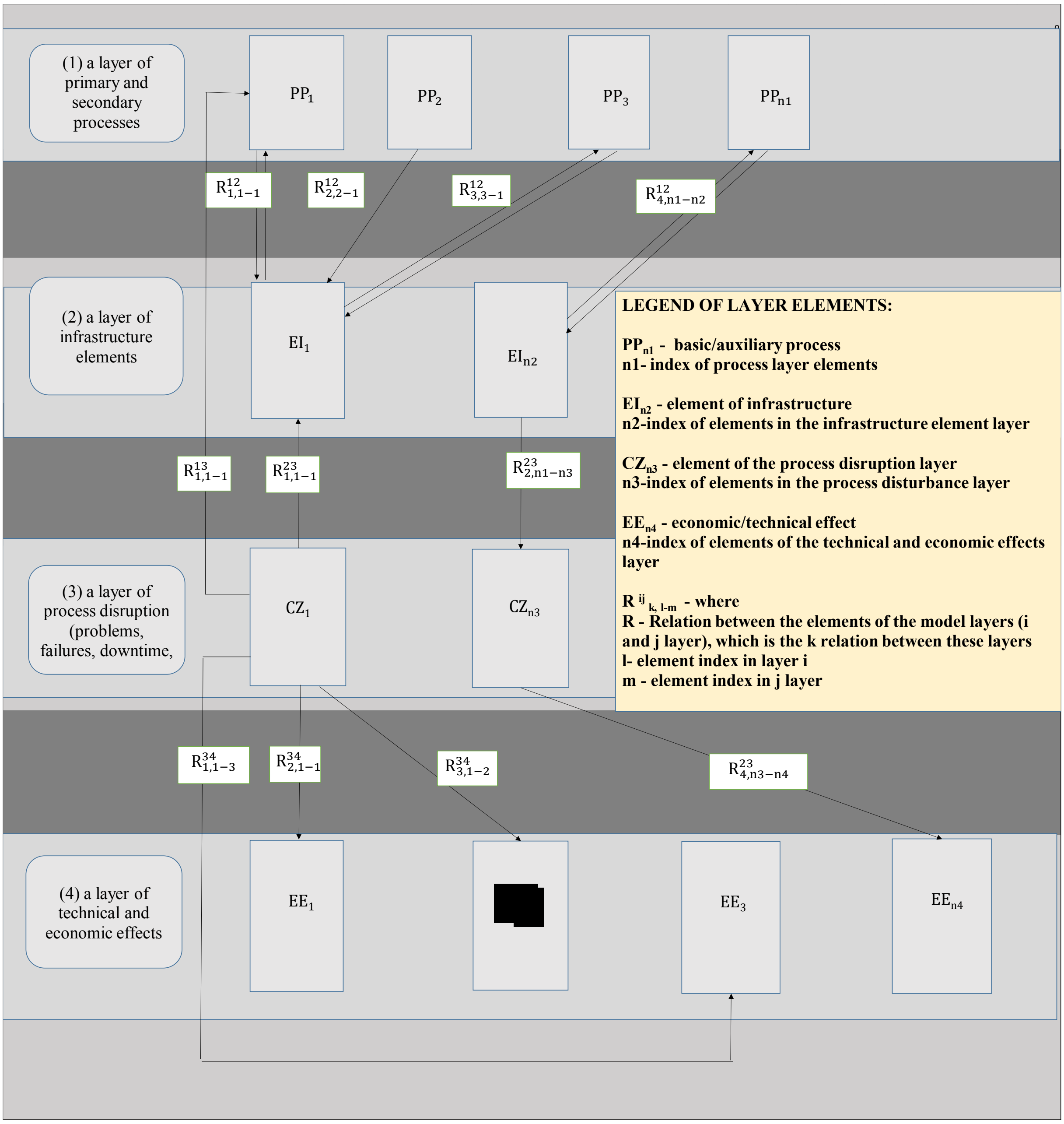


Figure 7. Schematic diagram of a layered model of the main dewatering system in a coal mine

In order to complete the proposed model and develop a method to optimise the operation of this system, it will be necessary to determine the target decision variables, which are the parameters that determine the operation of the main dewatering system. Generally, these parameters can be divided into 3 groups: technical parameters, organisational parameters and economic parameters. Each of the established parameters requires identification and initial quantification.

The following parameters can be included in the group of technical parameters:

- water pressure in the pipeline,
- capacity of the pump unit,
- the vibration level of the pump unit,
- oil temperature of the engine bearing and pump,

- efficiency of the pump unit,
- length of main dewatering pipelines,
- operating point: pump unit – pipeline,
- the current drawn by the motor of the pump unit,
- electricity consumption of the pump unit motor.

The following parameters can be included in the group of organisational parameters:

- number of manual workers,
- number of supervision staff,
- shift work,
- frequency of inspections,
- frequency of checks on measuring instruments,
- frequency of verification of measuring instruments.

The following parameters can be included in the group of economic parameters:

- the cost of electricity consumption,
- labour costs for manual workers,
- the cost of janitorial staff,
- capital expenditure,
- refurbishment costs,
- depreciation of machinery and equipment,
- cost of materials,
- cost of external services,
- environmental costs,
- costs of other utilities (except electricity),
- costs of surveillance of surface infrastructure.

The proposed model of the main dewatering system requires consideration of both economic, technical and technological conditions and the specifics of the system's operation in a hard coal mine. The established criteria and decision variables enable the development of a method for optimising the operation of this system, in which the total cost of operation of the system taking into account investment outlays and operating costs will be the objective function.

6. Conclusions

Recognition of the operating conditions of the main dewatering system in a selected coal mine enabled the preparation of a concept for a main dewatering model. The concept is based on a layered approach, which takes into account technical, economic and management criteria.

Ultimately, the developed concept of the main dewatering model in a hard coal mine will be enriched with an optimisation method that will make it possible to achieve stable operation of the system while minimising maintenance costs.

The research conducted allows the following conclusions to be drawn:

1. The main dewatering system is a complex system whose main task is to drain mine water that flows from the rock mass as a result of coal mining. The efficiency of operation of this system is an important element in the economic efficiency of a hard coal mine due to the high capital expenditure and operating costs of the main dewatering system.
2. The concept of the main dewatering system was based on a layer model including 4 layers, i.e. process layer, infrastructure elements layer, process disturbance layer, technical and economic effects layer. The model takes into account the identified elements of individual layers and the existing relationships between the elements of the aforementioned layers.
3. The development of a method for optimising the use of machinery and equipment of the main dewatering system with the use of the proposed model requires detailed quantitative research to establish the functional relationships characterising the identified relations between the individual layers and, ultimately, to build the objective function, which will be the total cost of operation of the system taking into account the investment and operating costs.
4. The parameters determining the operation of the main dewatering system in a hard coal mine, which are the decision variables, can be divided into technical, organisational and economic parameters. Establishing cause-and-effect relationships makes it possible to determine the objective function, which is key to the optimisation analysis of the operation of the main dewatering system.
5. The method for optimising the use of main dewatering machines and equipment and its implementation will make it possible to achieve measurable financial savings related to efficient use of the existing technical infrastructure. The proposed concept and optimisation method will be implemented and verified in a selected hard coal mine. Ultimately, the developed solution will be able to be used in other mining plants, especially in those with a high-water hazard.

References

1. Act of 9 June 2022 Geological and Mining Law, Art. 4, Art. 50, Art. 90.
2. Dorosiński, M. (2016). Kosztowna konieczność. *Górnicza Izba Przemysłowo Handlowa, Biuletyn Górniczy, Nr 1-2(246),* http://www.giph.com.pl/biuletyn-gorniczy/biuletyn-gorniczy-nr-1-2-246-styczen-luty-2016-r/kosztowna-koniecznosc.
3. Gumińska, J., Plewa, F., Grodzicka, A., Gumiński, A., Rozmus, M., Michalak, D. (2021). *Analiza ekonomiczna zastosowania systemu technologicznego do usuwania zawiesin stałych z wód odwadniających kopalń*, 1-15.
4. Hu, L., Zhang, M., Yang, Z., Fan, Y., Li, J., Wang, H., Lubale, C. (2020). *Estimating dewatering in an underground mine by using a 3D finite element model.* https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0239682.
5. Jonek-Kowalska, I., Turek, M. (2013). Cost Rationalization of Maintaining Post-Industrial Regions. *Pol. J. Environ. Stud., Vol. 22, No. 3*, 727-740.
6. Journal of Laws of the Republic of Poland, Regulation of the Minister of Energy of 23.11.2016 on detailed requirements for the conduct of underground mining operations (Journal of Laws item 1118), §28, §37, §38, §66, §69, §121, §138, §450, §454, §528-532.
7. Journal of Laws of the Republic of Poland, Regulation of the Minister of the Environment of 29 January 2013 on natural hazards in mining plants (Journal of Laws, item 230), Chapter 7, §24-27.
8. Kałuża, G. *Konstrukcja i badania zatapialnych pomp wirowych przeznaczonych do pracy w przestrzeni zagrożonej wybuchem.* Główny Instytut Górnictwa Kopalnia Doświadczalna „BARBARA" Zakład Bezpieczeństwa Przeciwwybuchowego, https://docplayer.pl/27623932-Dr-inz-gerard-kaluza-konstrukcja-i-badania-zatapialnych-pomp-wirowych-przeznaczonych-do-pracy-w-przestrzeni-zagrozonej-wybuchem.html, 1-6.
9. Karpiński, M., Batko, R., Kmiecik, E., Tomaszewska, B., Zdechlik, R. (2017). *Czasowa zmienność wielkości dopływów wód dołowych do wyrobisk ZG Sobieski*, 1-60.
10. Kierownik Działu Energo-Mechanicznego (2017). *Instrukcja szczegółowa przeprowadzania okresowych i bieżących kontroli stanu technicznego urządzeń i układu systemu głównego odwadniania*, 1-3.
11. Konsek, S., Czapnik, A. (2020). Docelowy model odwadniania zlikwidowanych kopalń w Górnośląskim Zagłębiu Węglowym. *Systemy Wspomagania w Inżynierii Produkcji, Energia i Górnictwo – perspektywy zrównoważonego rozwoju, Vol. 9, iss. 2,* 99-110.
12. Korbiel, T., Wojciechowski, J. (2019). Systemy wspomagania w inżynierii produkcji, Analiza kosztów eksploatacji systemu głównego odwadniania kopalni węgla kamiennego. *Górnictwo – perspektywy i zagrożenia, Vol. 8, iss. 1*, 413-419.
13. Mikoś, M., Kalukiewicz, A., Wojciechowski, J. (2007). Wpływ wydajności pompy wirowej na kształt pola prędkości strugi w przewodzie ssawnym. *Maszyny Górnicze, 1*, 1-53.

14. Masood, N., Edwards, K.H., Farooqi, A. (2020). Environmental Geochemistry Laboratory, Department of Environmental Sciences, Faculty of Biological Sciences, Quaid-i-Azam University, Islamabad, PO 45320, Pakistan b Camborne School of Mines and Environment and Sustainability Institute, 2020 r., University of Exeter, Tremough Campus, Penryn, TR10 9EZ, UK, 2-16.
15. Pakuła, G., Strączyński, M. (2013). *Podręcznik eksploatacji pomp w górnictwie*. WarsyawaŁ Wydawnictwo Seidel-Przywecki Sp. z o.o., 129- 201.
16. Rózkowski, K., Zdechlik, R., Chudzik, K. (2021). Open-Pit Mine Dewatering Based on Water Recirculation—Case Study with Numerical Modelling. *Energies, Vol. 14, Iss. 15,* 10.3390/en14154576, 1-18.
17. Stępniewski, M. (1985). *Pompy*. Warszawa: WNT, 173-479.
18. Szymański, Z. (2013). *Nowoczesne metody sterowania i badań diagnostycznych kopalnianych pomp głównego odwadniania*, http://beta.nis.com.pl/userfiles/editor/nauka/22013_n/Szymaski_02-2013.pdf, 1-8.
19. Szymański, Z. (2016). Smartsterowanie, czyli o nowoczesnych metodach sterowania i badań diagnostycznych kopalnianych pomp głównego odwadniania. *Pompy, pompownie, 1*, https://www.kierunekpompy.pl/magazyn,smartsterowanie-czyli-o-nowoczesnych-metody-sterowa-nia-i-badan-diagnostycznych-kopalnianych-pomp-glownego-odwadniania.html.
20. Tajduś, K., Sroka, A., Misa, R., Dudek, M. (2019). *Zagrożenia powierzchni terenu deformacjami ciągłymi i nieciągłymi aktywującymi się podczas zatapiania podziemnych kopalń.* Instytut Mechaniki Górotworu PAN, https://imgpan.pl/wp-content/uploads/2019/07/Kwartalnik-19-4-02-Tajdus.pdf, 1-12.
21. Wilk, S., Golec, K., Wilk, A. (2008). *Górnicze pompy stacjonarne.* Gliwice: Zakład Mechaniki Przemysłowej „ZAMEP", 17-81.
22. Zając, C. (2017). *Materiały dydaktyczne dla górników. Zagrożenia wodne*.