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FRAMEWORK FOR THE DEVELOPMENT OF SOFTWARE PROGRAMS FOR THE DESIGN OF MONITORING, DIAGNOSTICS AND MANAGEMENT IN UNDERGROUND COAL MINES

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Abstract The amount of information received by the operator in modern control rooms is constantly increasing. Therefore, to effectively manage coal mines, it is necessary to form efficient software packages, because computer integrated information systems provide several new management capabilities to operators. The methodological approaches presented in this paper provide a basis for the formation of software packages that support the formation of information systems, analysis of the impact of operator training on the speed of response to alarms, and the impact of underground coal exploitation on the environment. The results presented in the paper are software programs for underground exploitation that supports a multi-hierarchically distributed computational integrated system, a review of experimental research supported by a software package formed to assess the impact of operator training on the speed of response to alarm information on visual and audio devices; formation of a software package for calculating horizontal and vertical deformations of undermined soil; calculation of soil deformation stabilization time, calculation of gas emissions from the ventilation plant; and calculating the emission of gases from the boiler room chimney to coal.

Keywords: Coal mines; control room; information systems; alarm signals; software.

1. INTRODUCTION

Changes in technology and working conditions in underground coal mining and constant demands to increase production and to bring under technical control complex conditions of underground mining require changes in hardware, software, and scope of measured and detected parameters in existing systems of local measurement and management and centralized monitoring of mine parameters. This paper aims to research the parameters of new working and technological conditions, to consider the necessary software changes and extensions, to develop data processing and management programs, to research the harmonization of information displays, and to analyze the impact of underground coal exploitation on the mine environment.

The results of this research paper should create a technical basis for the design, production, and application of modern information systems, which should link safety, reduce costs and increase the volume of production and raise the level of efficiency of underground coal mining. Efficient control of a fragmented and complex mining production process, accompanied by a large amount of data, is solved by the implementation of control rooms in which the process of central monitoring, decision-making, and management in real-time, where the human operator is actively involved in the process of informing, alarming and management decisions-making. An important requirement for

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proper and efficient functioning in control rooms is solving the problem of functional compliance between the operator (O) and the information-management elements in it.

Analysis of the existing research, related to the application of information technologies in coal mines with underground exploitation, showed several technological units of research, dictated by the complexity of the underground exploitation process. Each technological unit is an object of individual monitoring, control, and automation and is characterized by parameters that, from the aspect of information technology, ie applied informatics and ergonomics, should be measured or detected and based on processing this data from information displays in CR and control algorithms for local and/or remote control.

1.1. Literature review

Previous studies of this topic promoted the following program areas: injuries in the underground coal mine [1, 2]; emergencies and disasters in mines [3-6]; research of underground mine work environment parameters and ventilation [7-9]; environmental monitoring, [10-13]; safety systems in underground coal mines [14-17]; communication in mines, wired and wireless [18-20]; human factors – related design tips for safer mining equipment [21-24]; research and development of remote control systems [25-28]; different methods of automatization in underground coal mining systems [29].

2. METHODOLOGY

2.1. Formation of an information system

The information system (IS) of the Rembas mine, with its final configuration, includes the pits; Senjski mine, Strmosten, Jelovac, and Pasuljske livade with a common (main) CR located in Resavica (Figure 1.) and that the separation of the pits is such that it is possible to monitor all parameters from one common CR. The adopted concept allows the permanent crew of operators to be kept only in the main CR, which significantly reduces the number of workers engaged in the system.

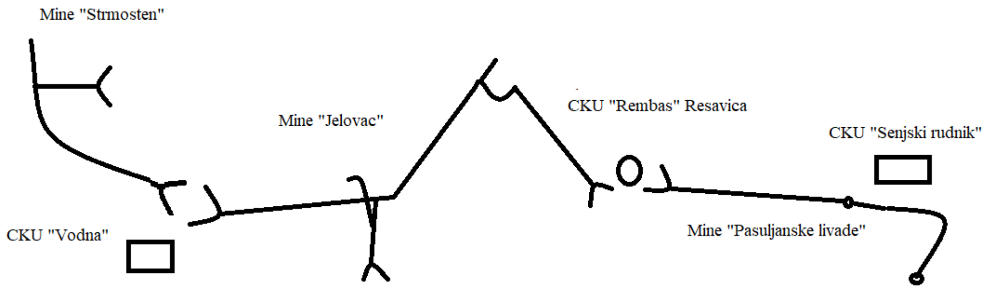

Figure 1. Layout of mines and pit CR in Rembas mine system.

Based on the technical conditions and requirements and technical characteristics of control devices, appropriate devices for measuring data in the mine were selected, and based on mining projects were installed in the mines for information collection for the new information system. More detailed

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technical characteristics and descriptions of these devices are presented in the paper by Marjanovic et al. [30]. Here we will only list them concerning the parameters they measure: methane concentration is measured by BM-3 device, carbon monoxide concentration is measured by BCO-1R device, the oxygen concentration is measured by BO-1 device, short circuit control on ventilation doors, and depression of the main fan is done with the BP-2 device. The methodologies described in more detail in the papers by Grozdanovic et al. [26, 27] enabled modeling of solutions related to improving the working capacity of operators, more rational and humane design, and modeling of information systems.

2.2. Impact of underground coal exploitation on the environment

Within these researches, a methodology for the analysis of the impact of underground coal exploitation on the environment has been established. Coal exploitation, as an important energy source, has a negative impact on environmental processes. Globally, the impact of underground coal exploitation on the environment can be expressed through the consequence of human activity and the impact of pollutants emitted into the water, air, and soil. The impact of individual technological units is shown in Figure 2.

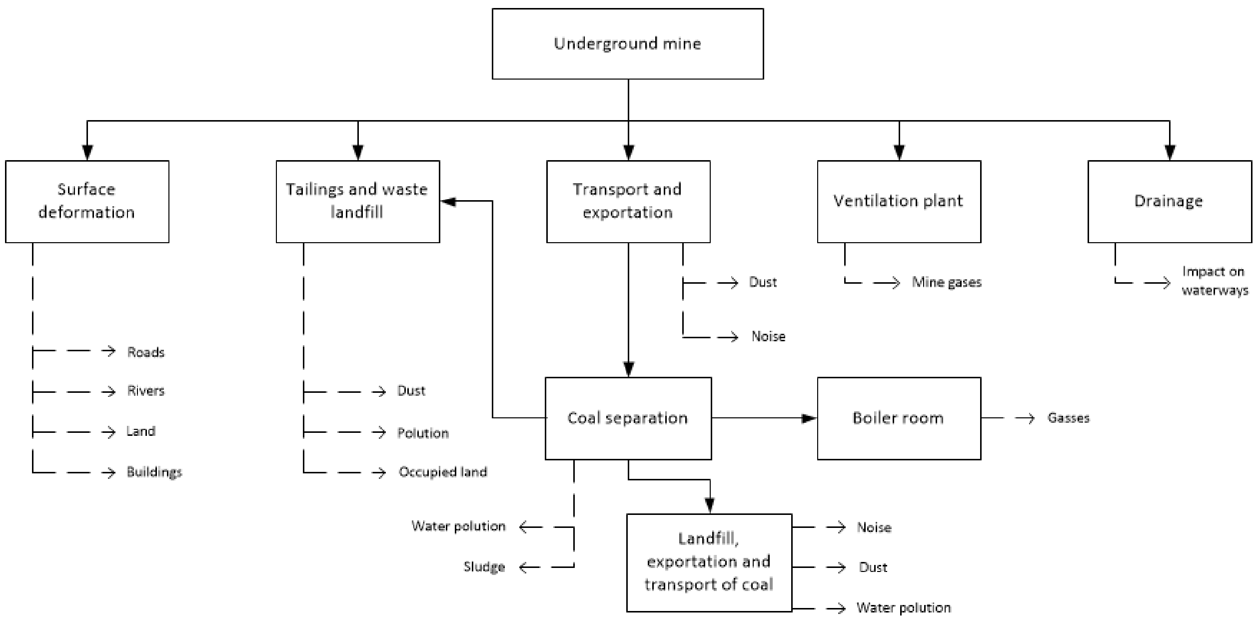

Figure 2. Impact of technological units of underground coal exploitation on the environment.

2.3. Influence of operator training on the speed of reaction when an alarm occurs

In the CR of coal mines with underground exploitation of roads, there is the appearance of alarm information on the means of displaying information and control panels. The speed of reaction, ie the speed of acceptance and understanding of the alarm message, among other conditions, certainly depends on the training and ability of the operator to perform his activities. An experiment was performed in which 28 subjects aged 18 to 50 participated, divided into two groups, control (K) with 10 subjects and experimental (E) with 18 subjects. The control group consists of subjects with no

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previous experience working in CR, while the subjects in the experimental group had previous experience.

The stimulus material consisted of linear seeds of the Soko mine with the arrangement of symbols of seven measuring devices of the methanometry system and one speaker from the alarm-speech system (Figure 3) and a picture of a control panel with 50 signal units (Figure 4) arranged in three fields (25 green, 15 red and 10 yellow).

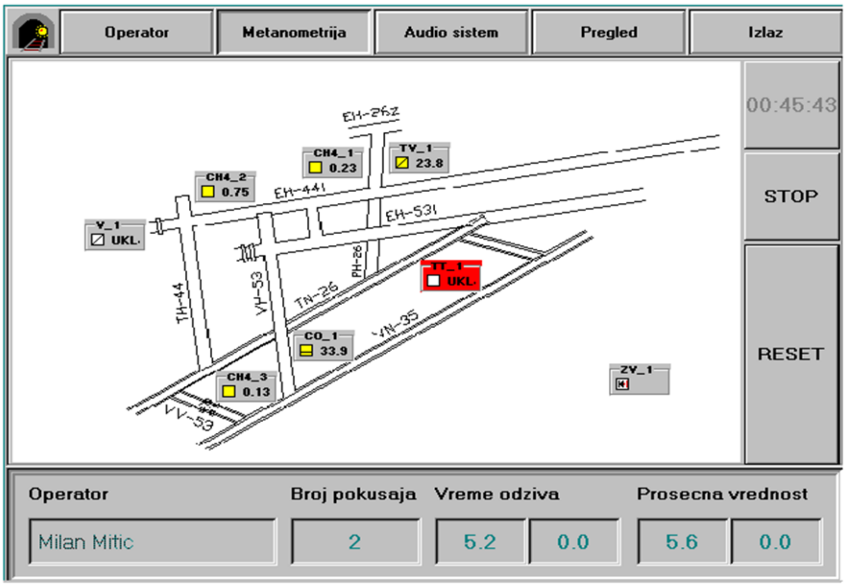

Figure 3. Example of stimulus material "METHANEMETRY".

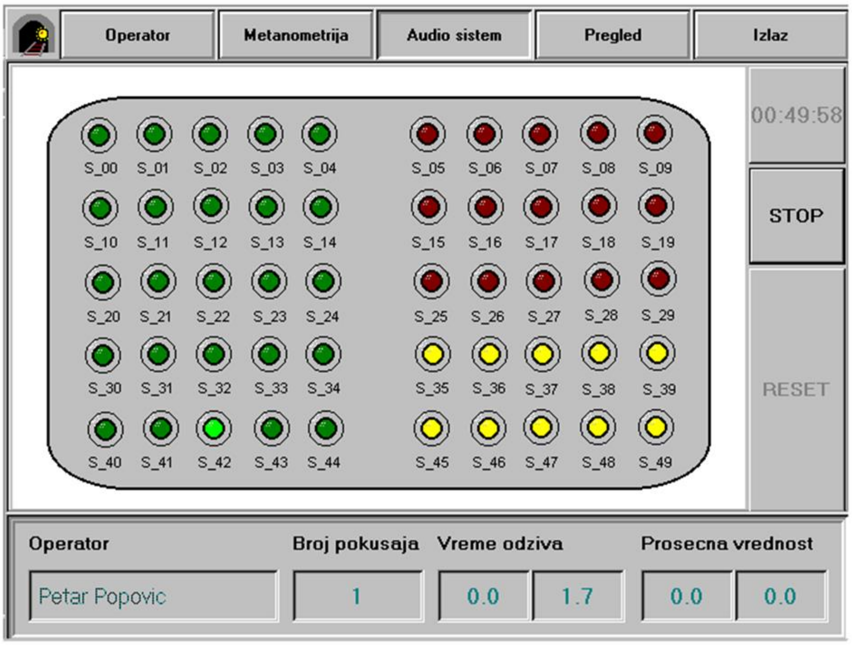

Figure 4. A keyboard used as stimulus material.

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In about 10 seconds from the activation of the test program, a sound and light alarm will activate. One of the marked fields in the picture is red. In the field "Number of attempts" enter the number 1. In this situation, the respondent should activate the RESET button and thus reset the resulting alarm. The time elapsed from the alarm to RESET is measured and entered in the left-field "Response time". After this reset, an image of the keyboard appears on the screen instead of a linear scheme. One of the 50 buttons will light up and an audible alarm signal will be heard. The respondent should locate the illuminated button and reset this alarm. The time for methanometric alarms is recorded in the left-field "Response time", and in the right field for alarms of the audio system. In the fields "Average value" the average values of alarms executed so far are constantly present.

The methodologies described in more detail in the paper by Grozdanovic et al. [31] present the impact of operator training on the success of letter and number detection, and recognition of information representations depending on the color combination In these experiments, which preceded the experiment presented in this paper, the same experimental groups participated. These methodologies were the basis for the formation of software packages "PROSIB", "PROBIR" and "PROVRE". The first two software packages are presented in detail in the paper by Grozdanovic et al. [31], and the third in this paper.

3. RESULTS

3.1. Software package that supports a multi-hierarchically distributed computer integrated system

The described hardware structure of the spatial layout of mines and pit CR systems "Rembas" is supported by a purpose-built software package: “An underground exploitation program supported by a multi-hierarchically distributed computer integrated system (DCIS), consisting of four transit dispatch centers (TDCs) and the main dispatch center”. The name of this program is SCADA PROPEK4W. The essential units of this program package are:

a) system configuration, which enables the creation of a new image of a part of the mine, modification of an existing image, selection of parameter types, and definition of all necessary attributes of the selected parameter. Within these sectors, panels of configured parameters are displayed. From the analog input parameters, the operator can select methane, carbon monoxide, flue gases, oxygen, temperature, and humidity, flow ventilation rate, separate ventilation rate, a short circuit on the ventilation door, and depression of the main fan;
b) the real-time operation, when according to the correct configuration of the system and physical connection of all measuring devices DRIS is ready for operation. The main function of PROPEK4W is to monitor all input parameters. Therefore, in the central part of the screen alarm, there is an automatic display of the image of the sector where the panel with the parameter that is in the alarm. The alarm is entered in the list of alarm events, with the activation of the appropriate sound signal and automatically printed. communication at all levels of DCIS.
c) data analysis, in addition to monitoring the measurement parameters in real-time mode, the program allows detailed analysis of data collected for a certain time. The operator is allowed to tabularly and graphically monitor all changes in parameters for the selected period.

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d) shift report, allows the operator to view and print the values of parameters for a period of one second to thirty days. The display form is the start and end of the selected time interval; fields with selected parameters, which contain address, location, symbolic name, and unit of measure, date of alarm occurrence, a moment of alarm occurrence, a moment of alarm end, extreme value during alarm and name of the operator who confirmed the alarm occurrence.

3.2. Formation of a software package for calculating environmental impact parameters

Within the elaboration of the methodology for considering the impact of underground coal exploitation on the environment, mathematical models for calculating the impact were made, based on which software packages were performed that perform the mentioned calculations. These are the following calculations:

a) Calculation of horizontal and vertical deformations of the undermined soil (software package HEVDZ). Mathematical statistics methods are used, where the assumption is that the array is layered and divided by a series of cracks into a large number of parts, whose displacements have a stochastic character. movements of a large number of classical elements obey the laws of mathematical statistics. Equations derived in this way contain coefficients that can be related to the geometric characteristics of the displacement process.
b) Calculation of soil deformation stabilization time (VSDZ software package). The method for these investigations is based on the assumption of terrain settlement saturation, accepting the premise that the settlement rate is proportional to the difference of the final settlements of the analyzed point on the surface. The value of the subsidence rate coefficient is practically determined by geodetic methods, by surveying the surface of the terrain before the start of exploitation and after the end of underground exploitation.
c) Calculation of gas emissions from the ventilation plant (EGDK software package). The amount of gas coming out of the mine and emitted into the atmosphere is calculated. It depends on the amount of air coming out of the ventilation shaft and the percentage of harmful gas in that amount of air. The air coming out of the mine contains methane, carbon monoxide, carbon dioxide, and more. as a rule, it has increased humidity and temperature.
d) Calculation of emissions from the boiler room chimney to coal (EGDK software package). To calculate the concentration of sulfur dioxide on the ground, which is the result of emissions from the boiler room chimney using coal as fuel, the smoke height measured from the top of the chimney is measured. in the mathematical model are wind speed, emission point height, chimney heat emitted, and sulfur dioxide concentration.

Using these software packages, the impact of underground coal exploitation on the environment on the road Soko Banja-Knjazevac, the river Izgava and the air near the ventilation plant were considered.

3.3. Formation of a software package for presenting the results of the experiment on the influence of operator training on the speed of response to alarms

To perform this experiment, the software package PROVRE was made. The comparison of the obtained data was performed using the T-test.

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By activating the Overview field in Figure 4, a statistical overview is obtained. An example of the content of the statistical survey is given in Table 1, in which the designation PM indicates the reaction time within methanometry, and the designation PA the reaction time in the audio system.

Table 1. Test results for one subject.

Operator	System	Nmb or resets	Time pm	Time pa
Petar Petrovic	Methanometry	1	2.2	
		2	2.1	
		-		
		-		
		-		
		7	0.5	5.5
		-	-	
		-	-	
		-	-	
		10	1.2	2.9
		-		
		-		
		-		
		17	0.6	2.3
	Audible system	25	2.1	1.6
		26	2.0	1.3
		-		
		-		
		-		
		74	2.2	1.2
average reaction time for methanometry			1.7	3.6
average reaction time for an audible system			2.6	1.7

Table 2 shows data from experiments and T-test processing.

Table 2. Overview of results from MET, AS, ASM, and METAS experiments.

Figure	Group	N	Mvrt	Standard deviation	T	Ss
MET	K	10	1.29	0.4306	0.038	0.970
	E	18	1.28	0.4475		
AS	K	10	1.75	0.3567	0.152	0.881
	E	18	1.73	0.3786		
ASM	K	10	3.54	1.4983	-0.892	0.381
	E	18	3.98	1.0866		
METAS	K	10	2.68	0.5534	0.052	0.959
	E	18	2.67	0.6911		

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The following tags are used in the presentation of the experiment results: E - an experimental group of subjects; K - control group of subjects; N - number of subjects; t, t-ratio from T-test; SS - statistical significance; MET - methanometry, data based on linear scheme, Figure 1; AS-alarm system, data based on the control panel, Figure 2, ASM, AS in MET-alarm occurrence in the audio system while the linear scheme is dominant on the screen, MET AS, MET in AS-alarm occurrence on the linear scheme after the alarm of each signaling device in Figure 3, MVRT- mean value of reaction time in seconds.

4. DISCUSSION

Grozdanovic et al. [26] used an analytic-synthetic model for IS research in underground coal mines and identified 23 indicators ranked with the use of the analytic hierarchy process (AHP) method. As the research on the formation of the information system, the impact of underground coal mining on the environment, and the impact of operator training on the speed of response to alarms, presented in our paper, are among the top-rated indicators, their importance will be further discussed here.

In most cases, information systems are implemented using generic software, ie special-purpose software packages. Different database management software systems today can meet the needs of different users, as there is the possibility of data sharing by different applications. The application of visual computer technology is also important, which uses the conversion of a large number of data from databases and computer simulations, into image information displays, ie in the form in which the operator most effectively receives, analyzes, and exchanges information. Technological development enables the upgrading of new functions and the constant expansion of the possibilities of information systems, ie the development of distributed, intelligent information systems in which their role is gradually transformed from a data processing system to a system for assistance in acquiring skills.

The success of the recognition of information displays by the operator is important for its efficiency. Therefore, experimental research related to the recognition of display information on the color monitor screen was conducted. The results of the experiment confirmed the results of other research, that trained operators perform the necessary activities more successfully, accurately, and quickly. Alarm displays and information are often present in IS underground coal mines, so the operator must read and understand the alarm message accurately and quickly carry out the necessary activities. That is why he must be well trained and trained. The described experiment in the work can be used for testing and education of operators. The developed methodology can also be used for new experimental research that can be organized in the coming period, and which is needed given the complexity of the O-IS relationship, which has an important role in increasing the safety of underground coal mining.

The most visible and one of the biggest damages that mining causes to the environment are the degradation of land, which is characterized by tailings dumps and mining openings (shafts, trenches, ditches). A particularly drastic case of terrain damage occurs due to subsidence of the surface when the excavated area collapses.

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Mining also acts as a major polluter of water and air. Water pollution is a constant problem in the narrow and wider areas around the mine. Tailings, exposed to atmospheric influences, gradually release into the surrounding watercourses particles with a higher or lower percentage of harmful substances. Cleaning and washing coal in wet separations that do not have a closed system also poses a latent hazard to surrounding watercourses. To protect the mines from groundwater and surface water, streams and rivers are relocated, and protective structures (canals, wells) are built, which sometimes leads to a change in the microclimate. Mining activity pollutes the air, especially due to the release of dust into the atmosphere around the mine. These hazards represent only a part of the manifested and possible negative consequences of mining activities on the environment. By defining them, it is possible to determine measures for environmental protection.

5. CONCLUSION

The process of underground coal exploitation consists of several technological units, which on the one hand are clearly individually defined, and on the other hand, are interconnected by the totality of the technological process. Each of the technological units is characterized by a large number of parameters that need to be detected, measured, and displayed in the CR. The increased number of parameters also requires the exploration of new ways of presenting the information. However, it should be investigated whether the existing means of displaying information can accept new information obtained through the implementation of new software packages. These researches go beyond the problems of this paper, so they are only mentioned as a possible subject of further research. Based on previous research, it is indisputable that underground coal mining has multiple negative effects on the environment. However, very little has been done to evaluate the impact of the application of IS in addressing this important issue. The paper presents a methodology for the application of information technology resources to assess this impact. Based on this methodology, concepts of specific applications can be developed, which are currently not available in Serbian coal mines. The operator must immediately register the alarm signals, interpret them correctly and take the actions planned for that alarm situation quickly. Speed and accuracy of response in alarm situations are the best prevention to eliminate potential causes of accidents. In the event of an accident, the data from the IS are used to reconstruct the events that have occurred and to determine the responsibility for their occurrence. Therefore, more frequent training of operators is needed to increase the speed of response.

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