

# Human Factors in the Development of the Hydraulic System of the Powered Roof Support

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## Abstract

The growing demand for mineral resources, including hard coal, requires the continuous improvement and development of technologies to improve safety, productivity and performance. The implementation of automation and digitization in mines has been ongoing for several years. Machinery and equipment development and improvement is also ongoing. The authors discuss the development and improvement of powered roof support, which is a critical part of the longwall system. The powered roof support is responsible for the safety of equipment and people working in the longwall. It supports the face and immediate roof and moves the longwall system forward as the shearer removes the coal and the roof collapsing (goafing) behind the shields. The aim of this study was to examine the human factors involved in the development and improvement of the hydraulic support system of powered roof support. The research was carried out among employees in hard coal mines using mainly surveys. The research allowed the authors to examine and analyze the information provided by the miners concerning powered roof support in the era of Industry 4.0 (the Fourth Industrial Revolution). According to the research findings, miners expect improvement in the reliability of the powered roof support, and they want the key operating parameters, especially the required load capacity, to be monitored in real-time so adjustments and improvements can be made. The results of the research point out the needs and expectations of miners. Their opinions should determine the direction and any research gaps into powered roof support.

## Keywords

survey research; work safety; human factor; underground coal mining; powered roof support, performance improvements



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## Introduction

The global demand for mineral resources has been growing steadily over recent years. This is related to population growth, industry and technology developments, global poverty reduction, progressive urbanization and increasingly diverse technical applications. The increase in demand for raw materials generates new technological, economic and environmental requirements and challenges (Wajs et al., 2021), especially considering the new thrust for sustainability and green mining. These help drive the search for innovative solutions aimed at increasing the efficiency of production processes (Woźniak and Hardygóra, 2020; Bajda and Hardygóra, 2021; Gładysiewicz et al., 2017; Baiul et al., 2020), reducing energy consumption (Kawalec et al., 2020; Bortnowski et al., 2021; Borkowski, 2020; Góralczyk et al., 2020; Kawalec et al., 2018) and improving safety (Zimroz et al., 2011; Ziętek et al., 2020; Dlouhá et al., 2019; Pokorný et al., 2016; Pokorný et al., 2018; Adach-Pawelus and Pawelus, 2021), as well as the reconstruction of ecologically disturbed systems (Dlouhá and Dubovsky, 2019; Dlouhá et al., 2021; Dubovský et al., 2021). It is necessary to search for new opportunities for process optimization and automation (Patyk et al., 2021; Król and Kisielewski, 2014; Dlouhá and Hamříková, 2018). Digital technologies, more powerful computers and modern computer software are used for this purpose (Janus and Krawczyk, 2021; Doroszuk and Król, 2019; Bardziński et al., 2020; Dlouhá and Kozlová, 2019; Hamříková and Dlouhá, 2017)). An important aspect in the optimization of these is the collection and analysis of data (Grzesiek et al., 2021; Wodecki et al., 2020).

One of the strategic raw materials in the Polish economy is hard coal. Despite the ongoing energy transformation, coal remains the country's primary source of energy production (Figure 1). Therefore, coal is still a key raw material for ensuring Poland's energy security, especially with increasing electricity consumption. However, the extraction of this raw material is becoming increasingly difficult and costly due to the increasing mining depth and the more complex coal seams remaining (Kotwica et al., 2021).

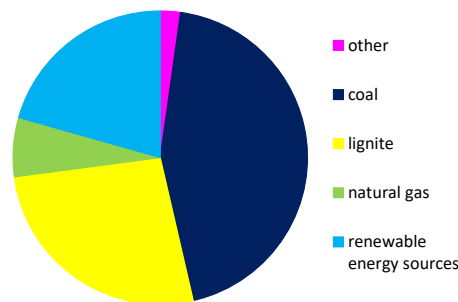


Fig. 1. Electricity production in Poland in 2022 (Dusilo, 2023)

In the mining industry, radical changes have been observed for several years already, which are part of the fourth industrial revolution. Industry 4.0 integrates people and digitally controlled machines using wireless networks and information technologies. The doctrine of Industry 4.0 in mining is mainly aimed at increasing efficiency (Świątek et al., 2021; Rajwa et al., 2019; Ji et al., 2020), reducing waste, improving the safety of workers in mines (Prostański, 2017; Uth et al., 2019; Szurgacz et al., 2022 a) and reducing costs (Krauze et al., 2021).

Industry 4.0 is not only about technology but also about new ways of working and integrating these technologies with the roles of the workforce. Technology cannot exist without human intervention, analysis and control. It serves people and is created and used by them (Dlouhá and Hamříková, 2019). Therefore, an important element in the development of technology is also the human factor.

The aim of this study was to examine the human factor in the further development of the hydraulic system of the powered roof support. The powered roof support, the armoured conveyor belt, and the cutting machine (roadheader, shearer or plow) form a mechanized longwall system. The mechanized systems are the basic equipment for longwalls in the Polish hard coal mining industry. The purpose of the support is maintenance and control of the roof, ensuring the safety and progression of the entire system along the longwall face (Szurgacz et al., 2022 b). Therefore, the improved development and operation of powered roof support are necessary to ensure efficient and safe coal exploitation.

In order to examine the human factor in the development of powered roof support, research surveys were carried out. Surveys are a commonly used method for examining opinions concerning a specific topic. They are used in various branches of the economy (Stephens et al., 2021; Smirniakova et al., 2021; Lu et al., 2022), education, development (Hamdan et al., 2021; Kjellgren et al., 2021), health (Damery et al., 2021; Valeri et al., 2021; Benedetti et al., 2021; Vargas et al., 2021; Al Awaji et al., 2021) and social life (Díaz-Jiménez et al., 2021; Urbanaviciute et al., 2021; Arapovic-Johansson et al., 2020; Tsui, 2021).

The research conducted for this paper was carried out in hard coal mines in Poland. The research covered several aspects. The authors verified the miners' awareness of the implementation of new technologies in mines

and their knowledge of Industry 4.0. They assessed existing technological solutions, with particular emphasis on powered roof support. They also identified the expectations and needs of miners in the improved development and operation of powered roof support.

According to the research, the future development of powered roof supports is necessary not only because of the new requirements imposed on the mining industry but also because of the miners' needs. The miners expect, among others, improvement in the reliability of powered roof supports, control of the parameters of their work and improvement of safety conditions at their workplaces.

## Materials and methods

### *The human factor in the operation of a powered longwall support*

Providing employees with as high a level of safety as possible is of particular importance in mining, which because of the nature of mining, can be hazardous. The safety of operating a mechanized longwall lining is the result of important basic elements: the technical condition of the mechanized housing, the crew and the impact of natural hazards. Thus, the influence of the human factor on the operation of mechanized longwall shoring can be described by the following (Grenda and Turzyńska, 2016):

$$H_F = \frac{R}{100 \cdot T_C \cdot N_H} - \sum S \quad (1)$$

where:

$H_F$  – the factor that determines the human factor in the operation of a mechanized longwall lining,  
 $R$  – the magnitude of the risk of a hazardous event related to the maintenance of the longwall workings roof,  
 $T_C$  – coefficient determining the technical condition of mechanized longwall support,  
 $N_H$  – coefficient determining the impact of natural hazards on the operation of mechanized longwall support,  
 $\sum S$  – coefficient determining the systems used to control the operation of the powered roof support.

### *Survey research*

In order to examine the human factor in the development of powered roof support, research surveys were carried out. The research was of a diagnostic nature to learn the opinions of employees in hard coal mines related to the development of powered roof support in the era of Industry 4.0. The tool used in the research was a carefully crafted questionnaire.

The guidelines adopted during the preparation of the questionnaire were a clear and transparent form and the short time needed to complete it. The questionnaire consisted of multiple choice questions, to which the respondents replied: YES, NO, and I DON'T KNOW. Questions and answers were written in tabular form to make it easier for the respondent to complete the survey quickly. The questionnaire contained a total of 40 questions and personal data questions.

The research was carried out on a group of 200 workers employed in the 15 hard coal mines belonging to the Polish Mining Group. People working on a daily basis on the longwall were invited to take part in the survey, as they could offer relevant opinions. The respondents included miners, mechanics and electricians. The study involved both manual workers as well as medium and higher supervision workers. The age of the respondents ranged from 21 to 50 years, and their work experience ranged from 1 to 31 years. The division of the examined group according to the department in which they work is shown in Figure 2a, and Figure 2b presents the division of respondents by position.

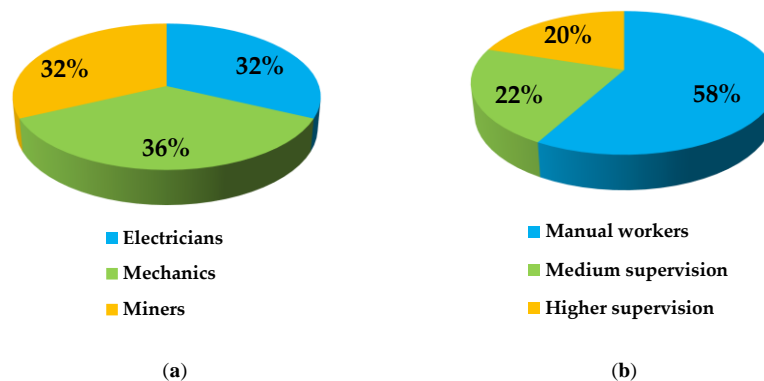


Fig. 2. The breakdown of the respondent group by (a) department they work in; (b) position

The main objective of the research project was to assess the current and future development of powered roof support with particular emphasis on the hydraulic system. The research was conducted in four stages. The first stage concerned the knowledge of Industry 4.0 and the approach of miners to innovative solutions. The second stage was aimed at learning the opinions of mine workers concerning the field of automation and digitization of mining, as well as their work safety. The respondents' opinions on the current state of powered roof supports were examined in the third stage. In the fourth and final stage, the tests focused on the expectations of miners in terms of future development of the technology of powered roof supports.

Tables 1-4 present the survey questions. The questions were divided into 4 groups. Each group contains 10 questions from a given research area. The following tables (Table 1-4) provide examples of responses.

*Table 1. Questions on the development of technology for underground mining in the era of Industry 4.0*

Question Number	Question	Answer
1	Do you know what Industry 4.0 is?	No
2	Are you interested in new solutions in the field of Industry 4.0?	No
3	In your opinion, does the development of technology translate into a faster rate of economic growth?	Yes
4	In your opinion, does the implementation of innovative solutions affect the success of the company?	Yes
5	In your opinion, can Industry 4.0 solutions reduce production costs?	Yes
6	Do you think that companies need to introduce innovative solutions in order to be competitive in the international market?	Yes
7	Would you like your work to be partially replaced by intelligent machines?	No
8	Are you concerned that automation, together with Industry 4.0, could lead to job reductions?	Yes
9	Do you notice innovative solutions in your daily work?	Yes
10	Do you trust new technologies?	Yes

*Table 2. Questions concerning innovative solutions in mining*

Question Number	Question	Answer
1	Do you think mines need innovative solutions?	Yes
2	Do you support the introduction of automation and digitization in mines?	Yes
3	In your opinion, is the extraction at the appropriate level?	Yes
4	In your opinion, does automation affect an increase in production?	Yes
5	Do you think that the progress of the longwall should be increased?	I don't know
6	Do you think it is possible to increase the number of daily work cycles for the roadheader?	I don't know
7	Do you think that the Mines should strive to intensify production and the concentration of extraction?	Yes
8	Do you feel safe in your workplace?	Yes
9	Do you think that new technologies improve work safety?	Yes
10	Do you think that new solutions should be sought to improve work safety?	Yes

*Table 3. Questions concerning current solutions regarding powered roof supports*

Question Number	Question	Answer
1	Do you think that the current development of powered roof supports is at an appropriate level?	Yes
2	Do you think that the powered roof support sections meet their requirements?	Yes
3	Do you know what the load capacity of powered roof support is?	Yes
4	In your opinion, does the powered roof support work with the required load capacity?	No
5	Do you think that the roof of the longwall is properly supported?	No
6	In your opinion, are the current section control systems reliable?	No
7	Do you notice any problems when moving a section of the powered roof support?	Yes
8	In your opinion, are there frequent failures of the hydraulic system of the roof support, e.g. leakage of the props?	Yes
9	Do you believe that powered roof supports require improvements and innovative solutions?	Yes
10	In your opinion, can reliable operation of the powered roof support affect the increase in extraction?	Yes

*Table 4. Questions concerning technology development in the field of powered roof support*

Question Number	Question	Answer
1	Do you think that efforts should be made to reduce the failure rate of	Yes

	the powered roof supports' sections?	
2	Do you think that the reliability of the section should be improved?	Yes
3	In your opinion, should the operating parameters of the powered roof support be monitored?	Yes
4	Do you think it is necessary to check that the sections obtain the initial load capacity?	Yes
5	In your opinion, is it possible to fully automate the relocation of sections?	No
6	Do you think that the current section control systems should be improved?	No
7	Do you expect support in the process of expanding the sections and obtaining the required load capacity?	Yes
8	In your opinion, does the time of relocating the sections of the powered roof supports affect the amount of extraction?	Yes
9	Do you think it is possible to speed up the operation of relocating the sections?	I don't know
10	In your opinion, should we look for new solutions aimed at reducing the time of relocating the sections?	I don't know

## Results

Human factor research in developing the hydraulic system of powered roof support was carried out in four areas, as mentioned earlier.

### *Stage 1 – technology development for underground mining in the era of Industry 4.0*

The results of research in the scope of the first area concerning the development of technology for underground mining in the era of Industry 4.0 are presented in Figure 3.

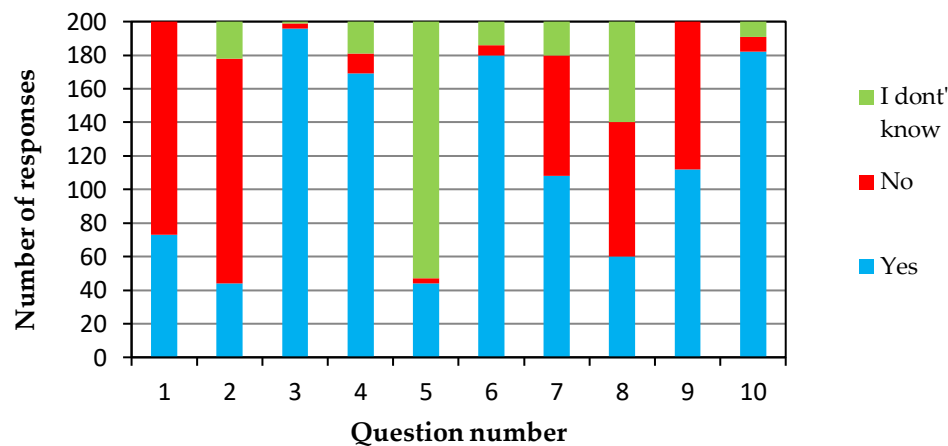


Fig. 3. Results of Area Number 1 Surveys for Table 1

The conducted research shows that 36.5% of respondents knew what Industry 4.0 is, and 22% of respondents were interested in the new solutions possible using Industry 4.0 technologies. The concept of Industry 4.0 was known to both manual workers as well as supervisors, the vast majority of whom have secondary or university education. Regardless of the knowledge of the concept of Industry 4.0, almost all respondents agreed that the further development of technology should translate into a faster rate of economic growth.

The vast majority of the surveyed employees believed that the implementation of innovative solutions also affected the success of the company. 84.5% of the respondents answered question 4 in the affirmative. More than half of the respondents found it difficult to assess whether Industry 4.0 solutions could reduce production costs. Only 22% of respondents believed that Industry 4.0 could have an impact on reducing production costs, and 1.5% disagreed with this statement. On the other hand, the question of whether innovative solutions were necessary for the company to be competitive in the international market was positively answered by as many as 90% of the respondents.

More than half of the employees (52%) would like their work to be replaced by intelligent machines. 38% of the respondents did not express such willingness, and 10% had no opinion. At the same time, as many as 40% of respondents were afraid of job reductions caused by automation and Industry 4.0. Only 30% of respondents did not have concerns about job reductions, and the same amount of respondents did not have an opinion on this subject. More than half of the respondents (56%) noticed innovative solutions in their daily work. Despite concerns about job cuts, the vast majority, 91% of respondents, declared having trust in new technologies.

**Stage 2 – innovative solutions in mining**

Figure 4 summarizes the answers for the second area - the field of innovative solutions in mining.

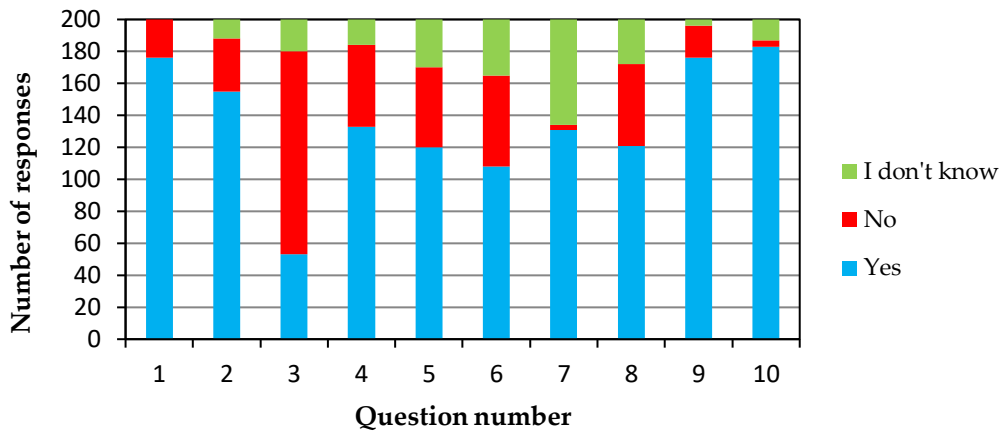


Fig. 4. Survey results for Area Number 2 for Table 2

Almost all respondents (88%) agreed that the Mines need innovative solutions. Respondents also agreed on the introduction of automation and digitization in mines. As many as 77.5% of respondents support such operations.

The miners working in the longwall are not satisfied with the current level of extraction. 63.5% of the respondents believe that the extraction is not at an appropriate level. Only 26.5% of respondents claim to be satisfied in this situation. Most respondents (66.5%) claim that automation affects the increase in extraction. In addition, most miners believe that the progress of the longwall should be increased. This opinion is shared by as many as 88% of the respondents. At the same time, 54% of respondents believe that it is possible to increase the number of roadheader operating cycles per day. The miners also see a need to intensify the production and concentration of extraction. 66.5% of the surveyed employees support such activities, only 1.5% say the contrary, and 33% have no opinion on this issue.

More than half of the miners (60.5%) deemed their workplace safe. 25.5% of the surveyed employees have no sense of security in their daily work. The respondents agree that new technologies improved work safety. As many as 88% of miners shared this opinion. Although more than half of miners feel safe in their workplace, as many as 94.5% of respondents see the need to look for new solutions in the field of improving safety.

**Stage 3 – current solutions for the powered roof support**

In the third stage, the focus was on the assessment of current solutions in the field of powered roof supports. The results of the research are presented in Figure 5.

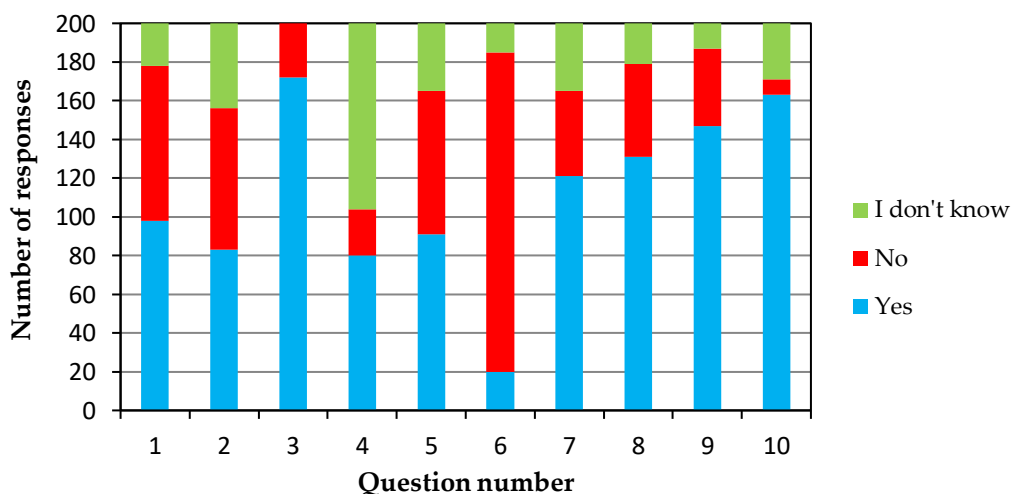


Fig. 5. Survey results for Area Number 3 for Table 3

Almost half (49%) of miners believe that the current development of powered roof supports is at the right level. 40% of respondents did not express satisfaction with the currently used powered roof supports, and 11% of respondents do not have an opinion on this subject. Similar answers were obtained to the question of whether the powered roof supports met their requirements correctly. 41.5% of respondents answered affirmatively, 36.5% said no, and 22% did not express a clear opinion.

The vast majority of employees (86%) knew what powered roof support's load capacity is. At the same time, when it came to obtaining the required load capacity and the right support for the excavation roof, the opinions were divided. 40% of the respondents believed that the powered roof supports work with the required load capacity, and 12% said they do not. In turn, 45.5% of the respondents answered that the excavation roof is properly supported, and 37% believed the opposite.

On the other hand, the miners were unanimous on the reliability of the powered roof supports. Only 10% of respondents believe that the current section control systems were reliable. As many as 82.5% of respondents were not satisfied with the reliability of the control systems. 60% of miners saw problems in relocating the powered roof support section. In addition, more than half of the respondents (65.5%) said that hydraulic system failures occur frequently. Miners responded with a majority of votes (73.5%) that powered roof supports required improvements and innovative solutions. As many as 81.5% of the respondents believed that reliable operation of the powered roof support could affect the increase in extraction.

#### **Stage 4 – technology development concerning powered roof support**

In the last stage, the opinions of miners on the scope of further directions of the development of powered roof supports were examined. The answers are presented in Figure 6.

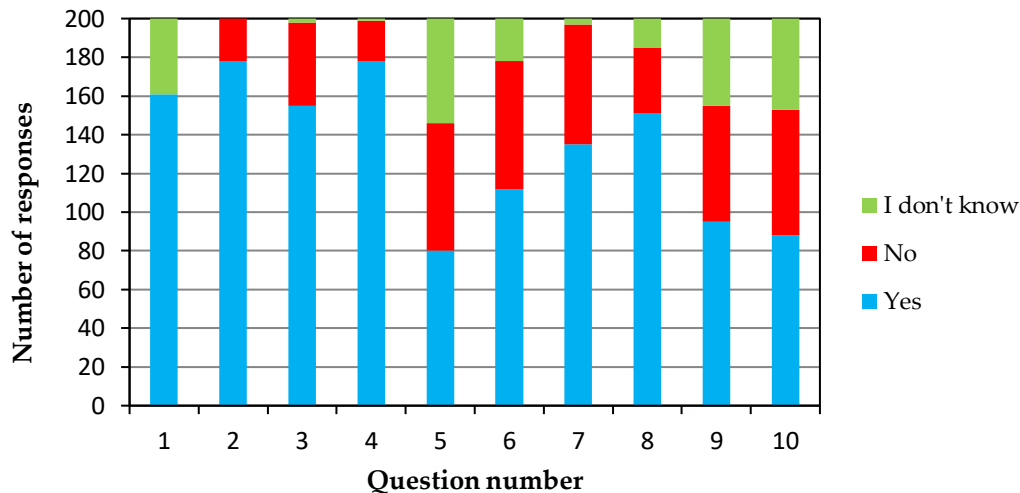


Fig. 6. Survey results for Area number 4 for table 4

Regarding the development of powered roof supports, the miners agreed on the need to strive to reduce their failure rate. This opinion was shared by (80,5%) of the respondents. The remaining 19.5% did not have an opinion on this subject. As many as 89% of miners also saw the need to improve the reliability of the powered roof supports.

The majority of the surveyed employees (77.5%) believed that the performance of the powered roof supports should be monitored. In addition, the vast majority of respondents (89%) saw the need to control whether the sections have been expanded to the initial load capacity.

Regarding the automatic relocation of sections, the opinions of miners were divided. 40% of respondents accept the possibility of using automatic relocation of sections. 33% of respondents believed that this solution is not possible, and 27% had no opinion on this subject. At the same time, miners expect the implementation of new solutions. 56% of respondents believed that the current section control systems should be improved. 67.5% of respondents expected support in the process of section expanding and obtaining the required load capacity.

According to the respondents, the time of relocating the section after a longwall panel was completed affected the amount of extraction. This opinion was shared by 75.5% of the respondents. At the same time, 47.5% believed that the process of section relocation could be accelerated, and 30% denied it. 44% of respondents said that new solutions should be sought to shorten the time of section relocation. 32.5% of respondents did not see such a need, and 23.5% of respondents remained neutral in this regard.

## Discussion

Figure 7 shows the answers for individual groups of respondents for each studied area. Manual workers from mechanical, electrical and mining departments as well as supervision employees, were noted here. In the end, each of the four studied areas was summarized. The percentage rates of responses for individual areas were shown.

The results of the study of the human factor in the development of the hydraulic system of the powered roof support			
Stage 1	Stage 2	Stage 3	Stage 4
Development of technology for underground mining in the era of Industry 4.0	Innovative solutions in mining	Current solutions in the field of powered roof supports	Development of technology in the field of powered roof support
<b>Mechanics</b> Yes 52,2% No 30,3% I don't know 17,5%	<b>Mechanics</b> Yes 66,9% No 12,5% I don't know 20,6%	<b>Mechanics</b> Yes 58,4% No 31,9% I don't know 9,7%	<b>Mechanics</b> Yes 72,2% No 13,8% I don't know 14,1%
<b>Electricians</b> Yes 46,8% No 35,0% I don't know 18,2%	<b>Electricians</b> Yes 60,4% No 32,1% I don't know 7,5%	<b>Electricians</b> Yes 49,3% No 31,1% I don't know 19,6%	<b>Electricians</b> Yes 66,4% No 23,6% I don't know 10,0%
<b>Miners</b> Yes 60,4% No 26,4% I don't know 13,2%	<b>Miners</b> Yes 61,8% No 30,9% I don't know 7,3%	<b>Miners</b> Yes 47,7% No 31,1% I don't know 21,3%	<b>Miners</b> Yes 58,8% No 27,3% I don't know 13,9%
<b>Supervision workers</b> Yes 63,3% No 22,7% I don't know 13,9%	<b>Supervision workers</b> Yes 74,6% No 13,9% I don't know 11,4%	<b>Supervision workers</b> Yes 61,2% No 26,3% I don't know 12,5%	<b>Supervision workers</b> Yes 69,9% No 21,0% I don't know 9,2%
<b>Stage 1:</b> Yes 58,4% No 26,7% I don't know 14,9%	<b>Stage 2:</b> Yes 67,8% No 21,0% I don't know 11,2%	<b>Stage 3:</b> Yes 55,3% No 29,2% I don't know 15,5%	<b>Stage 4:</b> Yes 66,7% No 22,0% I don't know 11,4%

Fig. 7. A summary of survey results

The responses of individual groups of respondents were very similar and did not differ significantly. Regardless of the position held, employees have similar views. Although the concept of Industry 4.0 was not widely known among mine employees, they believed that innovation generates economic growth and positively affected the competitiveness and success of the company. At the same time, they declared having trust in new technologies.

Employees noticed the need to intensify productivity and increase extraction. At the same time, they expected the implementation of innovative solutions in mines. Although more than half of the respondents felt safe in their workplace, employees believed that efforts should be made to improve safety.

Regarding the powered roof supports, over 40% of respondents expressed satisfaction with the currently used systems. They believed that the powered roof support fulfils its function well and that the excavation roof is properly supported. However, most respondents noticed the problem of frequent failures, including failures of the hydraulic system. Thus, mine workers expected innovative solutions that would improve the reliability of the operation of the powered roof supports. The respondents also saw the need to monitor the operating parameters of



the powered roof support. They noticed the need to control the required load capacity obtained in the sections. According to the respondents, reliable operation of the powered roof support could affect the increase in extraction.

### Conclusions

It can be concluded that one of the important aspects of the development of technology is the human factor. Technologies are used and operated by people, and their primary function is to serve them. Therefore, new technologies should respond to the needs of society. The aim of this study was to examine the human factor in the development of the hydraulic system of powered roof support. For this purpose, surveys were carried out. Mine employees who work with powered roof supports on a daily basis participated in this survey. The opinion concerning the field of Industry 4.0 and the development of new technologies in mining, including mainly powered roof supports, was examined.

Based on the assumed relationship in section two, the human factor should be used in order to increase the safety level of the powered support operation. The factor is defined as a general term used in a speciality that studies human-machine relations. To improve safety, both man and machine must be understood as one system. What is needed is the best possible adaptation of the mechanized longwall lining to cooperate with the man operating it.

The research shows that most mine workers see a need to develop technology and improve the currently used solutions in mining. The respondents support the idea of the introduction of automation and digitization in mines. Employees are interested in new technologies that will help them in their daily work, and that will increase safety. Employees relatively rarely answered "I do not know" (Fig. 7), which proves their high awareness.

The results of the conducted tests and their analysis indicate the need for further development of the powered roof support. The respondents' answers may be useful for constructors and producers of powered roof supports, as well as producers of control hydraulics. The presented conclusions may help to determine the lines of research for powered roof supports and the lines of their development. Respondents pointed out the need to develop the powered roof support in terms of bearing capacity. It is also necessary to improve reliability. Miners also expect to monitor and control the operating parameters of the powered roof support. In the future, the research may be supplemented with other aspects of the construction and operation of powered roof supports.

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