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Increasing Labour Safety on Coal Mines

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ABSTRACT

The article provides an overview of the main classifications and concepts of human error and human factor in relation to the coal industry. The main issues have been identified, the solution of which will reduce the probability of erroneous actions of the working staff to 70-90%. According to the authors, at the present stage of the development of the coal industry in the Russian Federation, an important issue is the introduction to manning tables of specialists in the study of human factors (ergonomics).Patent analysis of promising systems for controlling harmful production factors based on personal protective equipment for employees has been conducted. The results of theoretical and practical studies in the field of labour protection for the organisation of transparent remote control of workers are presented. Technical solutions are proposed for combining a system for monitoring the use of personal protective equipment (respirator, glasses, headphones) and a protective helmet. The graphical results of an anonymous survey of workers of coal enterprises of the Russian Federation concerning safety and labour protection, as well as the practice of using personal protective equipment, are presented. The results of a survey of employees concerning their attitude towards expanding the functionality of traditional personal protective equipment are summed up.

Key words: Industrial Safety, Occupational Safety and Health, Safety Helmet, Risk Assessment, Personal Protective Equipment, Hazard, Labour, Human Factor, Coal Mine.

1. INTRODUCTION

Human error has been a key factor in industrial accidents since the dawn of industrialisation, while before the industrial revolution it was a lesser problem [1]. This error is an unavoidable side-effect of being human and potential errors in safety-related situations can and must be controlled to mitigate their impact [2]. J. Rimmington, Chairman of the UK Health and Safety Committee, commented on the significance of human error: "Studies show that human error is the main secondary cause of 90% of major accidents, while 70% of them could be prevented through management actions" [3]; "The time when technical safety measures were of more importance has passed... Nowadays, we need to accept the significance of the human factor" [4].

It is necessary to include the position of a human factors (ergonomics) specialist in the manning tables of mining companies. The main functions of this specialist include the communication of information concerning workplace conditions and industrial safety status to company employees in a convenient form [5].

Human factors specialists will contribute to decision-making with regard to the following [6]:

- standardisation of new equipment,
- convenient use of best practices,
- employee training,
- investigation of the cause and effect of major breakdowns and accidents at the industrial site,
- consultations for operators and managers on the implementation of new technologies,
- support of controls and display devices.

Furthermore, human factors specialists can provide important information to help process operators to correctly understand a work process status [7]. The key aspect of human error that global science focuses on nowadays is the lack of control over a situation [8]. Control over a situation means that an operator or a team must be aware of what is going on around them and understand how events and their own actions impact their work [9]. Control over a situation can be restored by making the work zone informative [10]. First, the use of personal protective equipment (PPE) must be controllable. Second, employees must be informed of the current environmental status (air temperature, concentration of harmful substances, electromagnetic radiation level, etc.) [11]. Being informed of the situation in the work zone is a way towards significant safety improvement during mining operations [12].

1.1 Promising Systems of PPE-Based Production Hazards Controls

Russian labour laws stipulate that an employer must control workplace conditions (Article 212 of the Labour Code of the Russian Federation). There are many advanced means that help to control environmental parameters, an employee's condition or any potential hazards in the immediate vicinity of the worksite. There are sensor systems developed that are attached directly to employees, their clothes or PPE [13], as well as bands able to monitor the user's health [14].

Let us consider the Nand Logic Smart Helmet, intended for people engaged in extreme sports [15]. It consists of a safety helmet and an inbuilt electronic device. The electronic device contains many modules, such as a wireless Bluetooth connection, GPS receiver, SD-card slot, stereophonic speakers, battery, cameras to record the visual environment around the user, accelerometer, gyro sensor, light, temperature and humidity sensors, as well as LEDs for information display. The audio system of the helmet can be used to listen to audio information generated by a smartphone. The information from humidity and temperature sensors is assessed to automatically control fans integrated in the helmet to maintain a comfortable microclimate. A noise-cancelling system is provided. Smart bicycles and crash helmets can be equipped with sensors to monitor the situation on the road and to timely warn users of an imminent danger [16]. Such systems are of great interest, but they are not designed for use at industrial sites.

Gas analysers are used to control air during mining and mine rescue operations. They are portable continuous-action devices that ensure permanent control over gas content in the workplace air [17, 18]. However, they are not provided to all employees and in case of an emergency, those who do not have them might be notified with a great delay [19].

Some authors suggest that sensors and information process systems should be placed in the underhelmet space of a miner safety helmet [20]. This method has several drawbacks. The main drawback is the positioning of an electronic system in the space between the user's head and safety helmet, which impairs the protective properties of the design by reducing the space required for the free movement of the helmet's internal gear to absorb the shock when the helmet hits an external object [21].

PPE combined with advanced controls allowing to monitor the industrial environment and the employee's physical condition is a promising solution. It is worth noting that employees do not wear PPE on many occasions, thus violating safety requirements [22].

1.2 Control over the Use of Head Protection

Structural unit managers appointed by the employer and occupational health and safety specialists control the correct use of PPE, its timely replacement, inspection and testing [23-25].

In reality, the use of PPE, including safety helmets, involves a number of formalities and compromises related to human factors. Responsible employees are not always conscientious enough and do not report others for not using PPE and so on.

A relevant occupational safety challenge is to have transparent remote control over employees and to prevent human factor impact on performance. This requirement is an important area for method improvement and hardware upgrade aimed at ensuring employee safety in the environment presenting increased hazards for human health. An effective solution will ensure continuous control over compliance with mandatory requirements for PPE usage, thus increasing the level of employee safety in the workplace.

The employee's head and a safety helmet together form an information space, which is the aggregate of two sources that contain the information required to control safety compliance when wearing a safety helmet in the industrial environment. The worker's head as a type 1 source of information is regarded as a physical object with specific geometrical proportions, mechanical properties, volume and substances filling this space [26].

The sources of information that consider the employee/safety helmet system as a physical object include:

- changes of dielectric properties of the object;
- changes in the optical conditions in the object;
- changes in the characteristics of an ultrasound signal passing through the object.

The information on the presence of this physical object in the internal space of the safety helmet can be extracted with sensors that respond to changes in the characteristics. The following information can be recorded:

- changes in the dielectric permanent environment in the safety helmet space when the said object is present;
- interruption of a light beam by the object's geometry;
- changes in the characteristics of an ultrasonic transmitter caused by the impact of mechanical properties and substances in the object, etc.

The benefit of the considered method of control over safety compliance is the relative simplicity of head identification in the safety helmet space using such sensor systems. However, the method disregards a subjective factor, such as the possibility of an unprincipled worker to impact a control result artificially by substituting a physical object. This requires an additional source of information (type 2) that would reduce the probability of a false control result.

The second proposed source of information is the information generated by an employee as a biological being and a work process participant.

The sources that characterise the details of the employee/safety helmet status as a biotechnical system include:

- changes in the rhythmic activity of body systems in the biological object;
- changes in heat exchange conditions between the biological object and the environment;
- spontaneous and organised motor activity of the biological object.

In this case, the required assessment control criteria generated based on the review of type 1 information are complemented with adequate factor-based criteria, which are significantly harder to imitate. The type of recorded information is selected based on its value and potentially convenient implementation of the recording process (which does not affect productivity) [27].

It may include:

- rhythmic activity of core functional body systems (cardiovascular system and external respiratory system);
- main vital constants (body temperature, oxygen blood content, etc.);
- electrical brain activity;
- spontaneous and organised (professional) motor activity;
- heat exchange with the environment, etc.

Since these processes are hard to imitate, it is almost impossible to generate false information about the use of a safety helmet.

Furthermore, in accordance with the theory of reliability of technical systems, two technical systems used simultaneously and independently for the same purpose are properly backed up and significantly improve sustainability.

The reliable recording of required information forms a basis for its reliable assessment. The basis for this assessment is the generation of decision rules and their relevant algorithms. Type 1 information can be presented in the analogous and discrete form. A change in the dielectric permanent environment inside the safety helmet caused by the employee's head inside it is analogous information and entails a change in the electric capacity formed by the dielectric material and capacitor coating inside the safety helmet’s structural element. The electronic circuit of the impulse generator where the condenser in question is a time-setting element can change an impulse sequence period. It is an informative sign used in the decision rule. If an optoelectronic method is used to identify the employee's head inside the safety helmet, assessed information is discrete. In both cases, the result of assessment must be discrete (e.g., $Y1 = 1$ means that the employee's head is not inside the safety helmet; $Y1 = 0$ means that the employee's head is inside the safety helmet).

The decision rules used to analyse biomedical information are normally more complex but are eventually transformed into a discrete code (e.g., $Y2 = 1$ means that the employee's head is inside the safety helmet; $Y2 = 0$ means that the employee's head is not inside the safety helmet).

The assessment, which includes decision rules obtained during the review of type 1 and type 2 information, forms the aggregate of logic equations solved to obtain more reliable additional information on the employee/safety helmet system (e.g., $F1 = Y1 \wedge Y2 = 1$ corresponds to the double confirmation that the safety helmet is on; $F2 = Y1 \wedge Y2$ corresponds to the double confirmation that the safety helmet is off).

The assessment of mandatory safety helmet wearing rules cannot be adequate enough if not tied-in with the work process stages. In such conditions, it is crucial to record the astronomical time at the point when the safety helmet is put on (tpoi) (where i=1,2,3…n corresponds to the number of time intervals of active safety helmet use) and the time when its use ends (the safety helmet is taken off) (ttoi). The review of safety helmet use time intervals (€ = f (tpoi, ttoi)) helps to establish control over the adequate use of/failure to use head protection (stipulated by the rules and regulations in specific process areas) during working hours. Therefore, the aggregate of decision rules must be complemented with the continuous generation of a time sequence, which helps to export to the decision rule information on the legality of the employee/safety helmet system status at different stages of the work shift.

When the safety helmet is used in the wrong way, the situation is corrected in two ways. Firstly, an employee is informed on the current violation as soon as possible with a sound message generated as a verbal or sound alarm. This message motivates the employee to correct the situation. Secondly, the time intervals corresponding to the employee/safety helmet system status during the work shift are saved. Additional social and disciplinary measures can be taken by relevant control departments based on the posterior evaluation of saved information.

This control system combined with controls allowing to monitor the industrial environment and an employee's health is likely to become a promising solution for improving employee safety and reducing injuries in the workplace.

2. PROPOSED METHODOLOGY

We conducted a two-stage survey among the employees of Russian coal mining companies. The first stage revealed the overall status of PPE provision to employees and the second stage was conducted to investigate employees’ attitudes towards the use of smart PPE.

At the second stage of the survey in May 2018, we directly polled miners at the Shaktoupravleniye Sadkinskoye Ltd. The respondent groups were formed through a purposive sample. Positions occupied by the surveyed employees were as follows: ten shaft men, eight underground mine workers, six mining face workers, three operators of rock removal machines, three electrical technicians and nine other workers [28, 29].

The questionnaire consisted of 13 questions about the respondents’ attitudes towards the implementation of smart PPE and general information about the employee: job, length of service in the job and overall length of service in the coal mining industry. The questionnaire consisted of semi-closed questions. A respondent could answer the questions by ticking "Yes", "No" or "Neither Yes or No (own option)". Questionnaires with the highest and lowest scores were omitted. Scoring was as follows: "Yes" – 1 point, "Neither Yes or No (own option)" – 2 points, "No" – 3 points. The maximum possible number of points was 39 and the minimum – 13. Lack of an answer scored 0. Therefore, numerical limits were set at 16 points and less, as well as 34 points and more. Questionnaires, which were not within the limits, were omitted (four questionnaires).

3. RESULTS AND DISCUSSIONS

3.1 Results of the first stage

Let us consider the results of the first stage of the anonymous survey among the employees of a Russian coal company. More than 350 workers and 150 engineers completed questionnaires. The questionnaire consisted of five sections with one of them dedicated to PPE. Questions in this section were split into five subsections: provision, adequacy, use, inconvenience and protective properties. Questions in the subsections had overlapping values to exclude false answers.

The Provision subsection contained the following questions: "Do you receive all necessary PPE?" More than 27% of respondents answered that they did not receive all PPE they needed and offered their own answers (Fig. 1). When asked, "Do you think that additional/other PPE is necessary to maintain your health?" almost 47% of employees answered that they needed additional PPE to perform some activities and even provided their own answers expanding on the topic (Fig. 2).

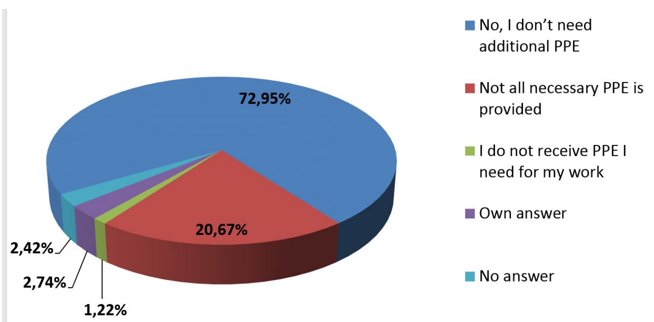

Figure 1: Provision of PPE to employees

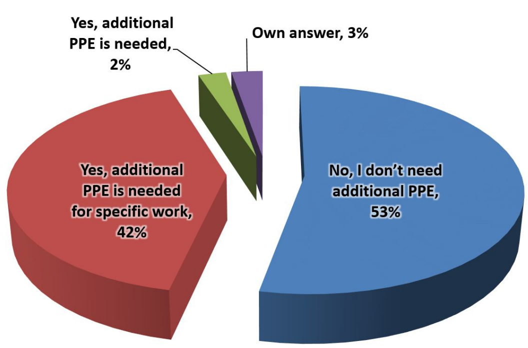

Figure 2: Provision of additional PPE to employees

Adequacy subsection contained the question "Please, determine if the size of the PPE you receive is adjusted to your personal parameters". One of four employees confirmed they had PPE with unsuitable anthropometric measurements (one or more sizes larger or smaller) (Fig. 3).

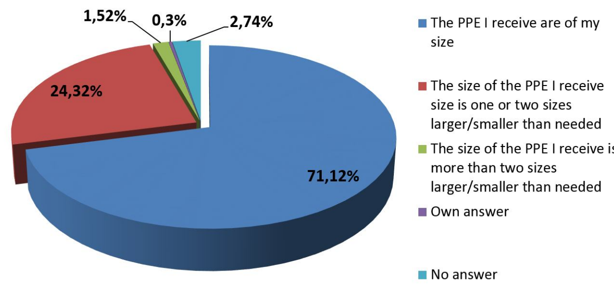

Figure 3: PPE sizes aligned with employee's personal parameters

The *Use* subsection showed that 21% of employees did not have training in PPE use, 51% of respondents take off PPE on a permanent or short-term basis as it is inconvenient, 41% of people take off PPE on a permanent or short-term basis since it provides low protection, while 35% of employees are not satisfied with its aesthetics (colour pattern) (Fig. 4).

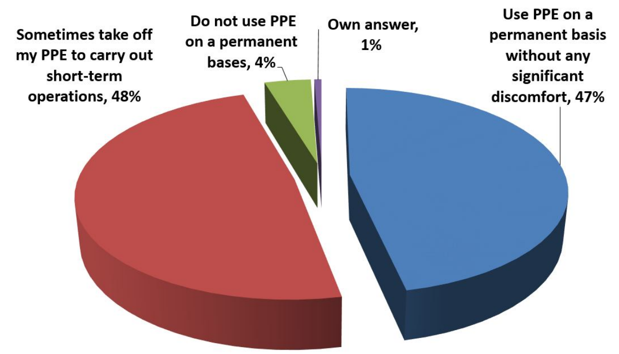

Figure 4: Use of PPE by employees

The *Inconvenience* subsection revealed the failure to wear PPE in summer or when employees carry out physically demanding work. When asked, "Do you have to take off special clothes due to high temperature or humidity in your workplace?" more than 200 out of 350 people answered that they had to take off PPE due to significant discomfort (Fig. 5).

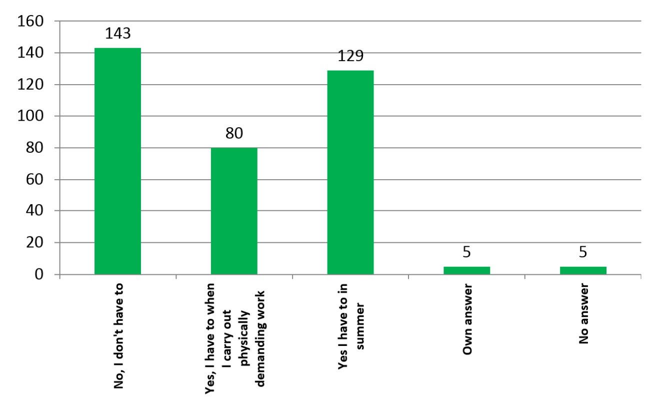

Figure 5: Influence of climatic conditions on the use of PPE

The *Protective properties* subsection showed that 47% of employees were not satisfied with the protective properties of the PPE they received. When asked, "Do you think the period of PPE use meets its useful life?" only 57% of employees confirmed that the period of PPE use was in line with its useful life while its protective properties were still effective (Fig. 6).

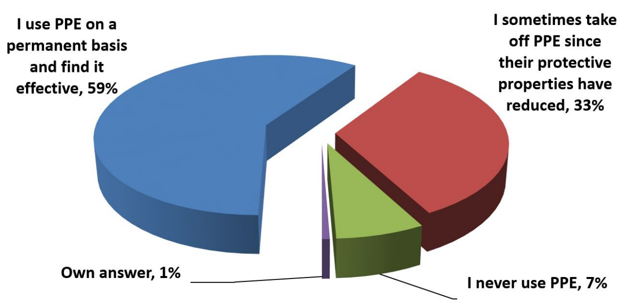

Figure 6: Duration of PPE use

Let us summarise the first stage of the survey among coal mining employees:

1. More than 27% of employees did not receive sufficient PPE.

2. Almost 47% of employees commented that they needed additional PPE to carry out specific work.

3. One out of four employees had PPE with unsuitable anthropometric measurements (one size or more larger or smaller than needed).

4. A total of 21% of employees did not have training in PPE use.

5. Almost 51% of employees stated that they take off PPE on a permanent or short-term basis as it is inconvenient, 41% of people take off PPE on a permanent or short-term basis since it provides low protection, while 35% of employees are not satisfied with its aesthetics (colour).

6. A total of 6% of respondents did not use any PPE.

7. More than 200 out of 350 respondents answered that they had to take off PPE due to significant discomfort caused by increased temperature and humidity in summer and when carrying out physically demanding work.

8. A total of 47% of employees were not satisfied with the protective properties of the PPE they received and a mere 57% of employees answered that the PPE period of use corresponded to the useful life.

9. Additional PPE was found necessary by 44% of respondents.

10. Only 66% of employees were satisfied with the appearance and colour of their PPE.

3.2 Results of the second stage

The mean number of points is 22.8. The questions, which scored most of all possible 102 points (all 34 respondents answered negatively – 3 points) are as follows:

- "What will be your attitude towards an audio/video device attached to your helmet or coat?": 9 out of 34 people were positive about this and others gave a negative answer (84 out of 102 points).
- "Is it necessary to complement the positioning system with the capability to read the employee's health status?": 10 out of 34 people answered "Yes" while the rest answered "No" (79 out of 102 points).
- "Do you find it necessary to maintain your health, get additional control devices to promptly assess workplace conditions (e.g., a gas analyser or a noise meter)? If yes, list them": 11 out of 34 people answered "Yes", while the rest answered "No" (77 out of 102 points).

The analysis of the results showed some mistrust expressed by most respondents to innovative approaches and additional technical means even if they improve personal safety. None of the nine respondents who were positive about the questions "What will be your attitude to an audio/video device attached to your helmet or coat?" showed singularity in terms of age (the respondents' mean overall length of service was ten years). Shaft men mainly had a positive reaction.
The questions, which had about the same number of "Yes" and "No" responses, scored 63 out of 71 points:

- "Would you like to have PPE with additional capabilities (environment monitoring or employee health monitoring)?" (63 points).

- Would you benefit from the information on your current health status in the work process and monitoring of your vital signs (pulse, blood pressure and body temperature)? (64 points).

- Do you need feedback from a dispatcher? (Possibility to report on the current situation without a delay)? (67 points).

- Is it necessary to expand the signal functions of a lantern or support all commands with sound signals? (71 points).

Employees were of different opinions regarding the new capabilities of PPE, such as environment and employee health monitoring. Probably, some employees are not ready to efficiently use new safety improvement tools in their working routine. The questions related to technical alarms and notification systems did not interest the respondents. It means that these changes and new capabilities of available hardware are basically sufficient.

The questions, which had more positive than negative answers, scored 34 out of 55 points (34 points – 34 "Yes" responses of 34 and 55 points – 23 "Yes" responses out of 34):

- "Does your employer provide you with PPE?" (34 points).

- "Is an employee positioning system efficient?" (44 points).

- "Are you satisfied with the quality and protective properties of the PPE you receive?" (45 points).

- "Is it necessary to have instant communication between employee groups in the work process?" (52 points).

- "Is it necessary to improve communication quality (suppress noise) between the employees in a team in the work process?" (55 points).

It should be noted that the traditional employee protection systems in place at the industrial site (PPE, multifunctional safety systems and mine communication systems) satisfy employees and are not challenged. However, there is a demand for instant communication between employees when performing their work and for better performance of existing communication channels [30-32].

The results of the second stage characterise the employees' attitude to the implementation of smart PPE among mining workers at the Shaktoupravleniye Sadkinskoye Ltd.

5. CONCLUSION

According to statistics, 10-15% of all fatal injuries occur due to the absence, non-use or technical imperfection of PPE. The result of the research is the identified need and support of more than 30% of coal company employees in creating scientifically-based solutions – smart PPE aimed at improving human security in a working environment using a transparent control system combined with a personal head protection device – a protective helmet. Such a decision will be aimed at the development of a safety culture of production and will increase the consciousness, initiative, rigour and interest of workers in the prevention of accidents and occupational diseases.

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