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Principles of providing safety, comprehensive analysis of the injury risk and the targeted impact on the traumatic factors as the instruments of increasing the efficiency of integrated safety management systems at mining enterprises of the Russian Federation

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ABSTRACT

The article analyzes the current state of industrial safety in the mining industry in Russia. The main reasons for today's accidents and injuries, as well as the specificities of modern systems of the industrial safety and labor protection control are presented. The results of the quantitative correlation-regression analysis of the traumatic factors and the expert-analytical assessment are given. The periodicity of preventive measures aimed at improving safety at coal mines is established. The features are described of a complex approach within the framework of realization of an integrated system of the industrial safety and labor protection control, which is the basis of formation of a "culture of industrial safety".

Keywords: coal mine, risk, injuries, safety, preventive measures.

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INTRODUCTION

Introduce the problem

In the Russian Federation, the problems of providing safety of the industrial complex and, as a consequence, the labor safety, became especially pressing by the end of the XX century as a result of decentralization of the state management of industry, elimination of the industry branch management structures in the production sector and the development of various forms of ownership.

With a general trend of reducing the workspace injuries in the coal industry in Russia, it remains higher in comparison with the best foreign coal enterprises. The increased injury risk and adverse working conditions in the mining industry enterprises are boosters of the individual and collective risks, which lead to a decrease in the labor productivity and an increase in the company expenditures on the work incapacity certificate payments, compensation payments, training of new employees and the purchase of equipment to replace the equipment failed due to accidents.

The issues of assessment of the state of industrial safety and labor protection, as well as the development of measures of their improvement are considered in the research of many scientists in this field. The research work has been mainly focused on the study of injuries in the underground mining operations. However, the injury problem in open cast mining is no less pressing. Therefore, the development of a complex methodology of analysis and forecast of the workplace injuries of the miners in coal mines on the basis of an integrated taking account of organizational, technological, technical and socio-economic factors, allowing developing in detail and applying with established periodicity the preventive measures is a topical research problem.

Analysis of the problem

In Russian mining industry, the state of the labor safety and the entire industrial safety is still a major concern. The overall level of accidents and injuries in the industry remains high; moreover, it is due not only to the technological specifics of the mining industry, but also to the general trends and conditions. Accidents often occur because of worn-out equipment, poor quality or late implementation of the maintenance and repair works. In some cases, the causes of accidents are ill-conceived design and technical solutions, lack of technological and labor discipline. The system of training and retraining of specialists and personnel for hazardous production facilities needs reforming, as well as the system itself of the management of industrial safety and labor protection in the mining industry (Subbotin, 2004).

A fair number of scientific works of Russian scientists are devoted to the study of systematic injuries of miners; however, the issue of individual cases of injury, which is quite complex, has not been given adequate attention. Therefore, on the background of the nationwide trend of the injury decreasing over the past 10 years, till the present time there are individual cases of injury in coal mines. In particular, this can be explained by the lack of a universal algorithm of integrated assessment of traumatic factors, which significantly reduces the effectiveness of safety management of coal companies.

From a systemic prospective, the safety management consists of the processes of preparation, adoption and implementation of the management decisions to ensure safety, preserve health and ability to work in the labor process. The content of these processes are realized through the following main functions (Ushakov, Kaledina, Kirin et al., 2008):

- implementation of the measures to ensure safety;
- realization of control over the state of safety;
- carrying out an analysis of the state of safety;
- stimulation of the safety works.

To successfully manage the labor safety, it is necessary to know the basics of management and be able to use them in practice. The production systems in the mining industry and, in particular, in the coal industry are complex technical systems, so to choose and interconnect the methods of their management is a

laborious task. To solve it, it is necessary to be able to quantify the impact of various hazardous and harmful workplace factors. For this purpose, nowadays the risk theory, one-factor and multivariate regression analysis, as well as the method of expert-analytical assessment are used (Bobrov, 1998; Bondar and Popov, 2007; Bugaev, 2011).

Each of the approaches in the evaluation of industrial safety has both advantages and shortcomings. In some cases, as practice shows, the statistical methods (such as correlation and regression) do not suffice for the objective assessment due to incomplete or unreliable source information. In such cases, the best option is to use a combined method, which integrates the expert-analytical and statistical components.

METHOD

Basic information about research methods

The work is performed using a complex of research methods, including a system analysis of the problem on the basis of research of Russian and foreign scientists, as well as the technical, statistical, probabilistic and expert methods of analysis of the industry injuries at surface coal mines. For the mathematical processing of data we used the following computer programs: Microsoft Excel, Statistica v.6.0 (Belyaev and Noskov, 1998).

Quantitative correlation-regression analysis

Workplace injury, like any complex random event, requires a multi-factor model. To identify the connection of the technological, organizational and economic factors with the injury level, we used the statistical data on two coal mines with the continuous mining technology of the OAO "SUEK-Krasnoyarsk" company ("Borodinsky", "Nazarovsky") and two coal mines with the cyclical mining technology of the OAO "SDS-Ugol" company ("Chernigovets", "Kiselevsky").

A quantitative correlation-regression analysis of traumatic factors in the coal mines with continuous technology has allowed identifying the most significant factors (3 of 15) and obtaining the predictive models of risk assessment (Table 1).

Table 1. Predictive models of risk assessment for "Nazarovsky" coal mine with continuous mining technology

Dependencies	Linear mathematical models of risk assessment	Determinancy coefficient
1. The dependence of the injury risk (R) on the coal mine productivity of extraction of the useful mineral (V_{UM})	$R = 11.55 \cdot 10^{-3} - 11.34 \cdot 10^{-6} \cdot V_{UM}$	0.64
2. The dependence of the injury risk (R) on the number of mineworkers (*Num. work.*)	$R = -24.78 \cdot 10^{-4} + 2 \cdot 10^{-6} \cdot \text{Num. work.}$	0.87
3. The dependence of the injury risk (R) on the expenditure on industrial safety and labor protection (Expend)	$R = 10.77 \cdot 10^{-4} - 11 \cdot 10^{-6} \cdot \text{Expend}$	0.74

As an example of multivariate regression analysis, we present a model of accidents risk in its dependence on the investment into industrial safety and labor protection and the productivity with respect to the useful mineral, built for two coal mines with continuous mining technology:

$$R = -1.2 \cdot 10^{-6} \cdot Z^2 + 1.4 \cdot 10^{-4} \cdot Z - 1.3 \cdot 10^{-10} \cdot D^2 - 1.6 \cdot 10^{-6} \cdot D - 3.7 \cdot 10^{-3},$$

where *Z* is the expenditure on industrial safety and labor protection per person per year, thousand rubles/year, *D* is the productivity with respect to coal per person per year, tons/year. This model can be taken with a significant probability of 90%.

By using these models, one can predict the risk zone for the occurring of accident at coal mines with continuous mining technology, adjusting it with the help of cash investment into industrial safety, productivity with respect to coal, and the number of miners.

These quantitative risk assessments are objective indicators of the emergency danger at an object. An analysis of these risk assessments is carried out in comparison with an acceptable risk value.

Acceptable risk

In the world, there are still no generally accepted (acceptable) threshold values of the level of individual risk for the risk assessment of potentially hazardous industries. The threshold values of risk, proposed by various foreign organizations and scientists, range from 10^{-3} to 10^{-8}. This spread is due to the attitude to risk (voluntary or forced), the level of industrial safety in the country, as well as the differences in the risk analysis methodology (Elokhin and Elokhina, 2004).

According to a leading specialist in the field of industrial safety W. Marshall (1989), the admissible risk value is the expected rate of loss of life $5 \cdot 10^{-5}$ in a year.

According to GOST R 12.3.047-98 "Fire safety of technological processes", the exploitation of technological processes is unacceptable if the individual risk is greater than 10^{-6} or the social risk is more than 10^{-5}. The exploitation of technological processes at the intermediate risk values can be allowed after carrying out an additional justification, which is to show that all possible and sufficient measures have been taken to reduce the fire hazard.

In the Declaration of the Russian Scientific Society for Risk Analysis (2006), the values of the maximum acceptable risk for the population in the Russian Federation are:

10^{-4} in a year, for the operating hazardous industrial facilities;
10^{-5} in a year, for the new (newly designed) hazardous production facilities.

Expert-analytical assessments

In the quantitative correlation-regression analysis of the risk of coal mines with the cyclical mining technology (OAO "SDS-Ugol": "Chernigovets", "Kiselevsky"), many linear models have turned out to be not significant. Moreover, the more factors were taken into account, the greater was the determinateness of the models. This fact testifies to the complexity of the connection between the risk level and the traumatic factors that define it. Because of this, it was decided to apply a qualitative analysis of traumatic factors with engaging the expert-analytical assessments (Beshelev and Gurevich, 1980), which allowed identifying the ways to improve the safety of coal mines.

With the help of a developed questionnaire consisting of 70 factors divided into 3 groups (the social-personal, social-organizational, organizational-technological ones), the experts of various management groups were interviewed (top-managers, middle managers). The experts were to meet the following requirements: completed higher education, work experience of at least 3 years; obligatory connection of the expert with the safety issues at the coal mines "Kiselevsky" and "Chernigovets" (department of labor protection, the control group, the security audit group) (Vanchikov, 2001).

To rank the factors affecting the injuries, the Pareto diagram was used. It is based on the 80/20 principle, according to which 20% of the causes lead to 80% of the problems; therefore the purpose of construction of the diagram is to identify these reasons to concentrate efforts to eliminate them. As a result of construction of the diagram, it was revealed that one can consider significant the factors from the first to the fifty first.

The concordance coefficient (consistency of the expert opinions) for the two coal mines is insignificant and equal to 0.125. This testifies to the opinion disagreement at the enterprises as a whole; however, if we consider the consistency in smaller social groups (Fig. 1), then a certain consistency is present. Also, Fig. 1 presents the first five traumatic factors, selected by some groups, which allow designing the first-priority measures inside the group.

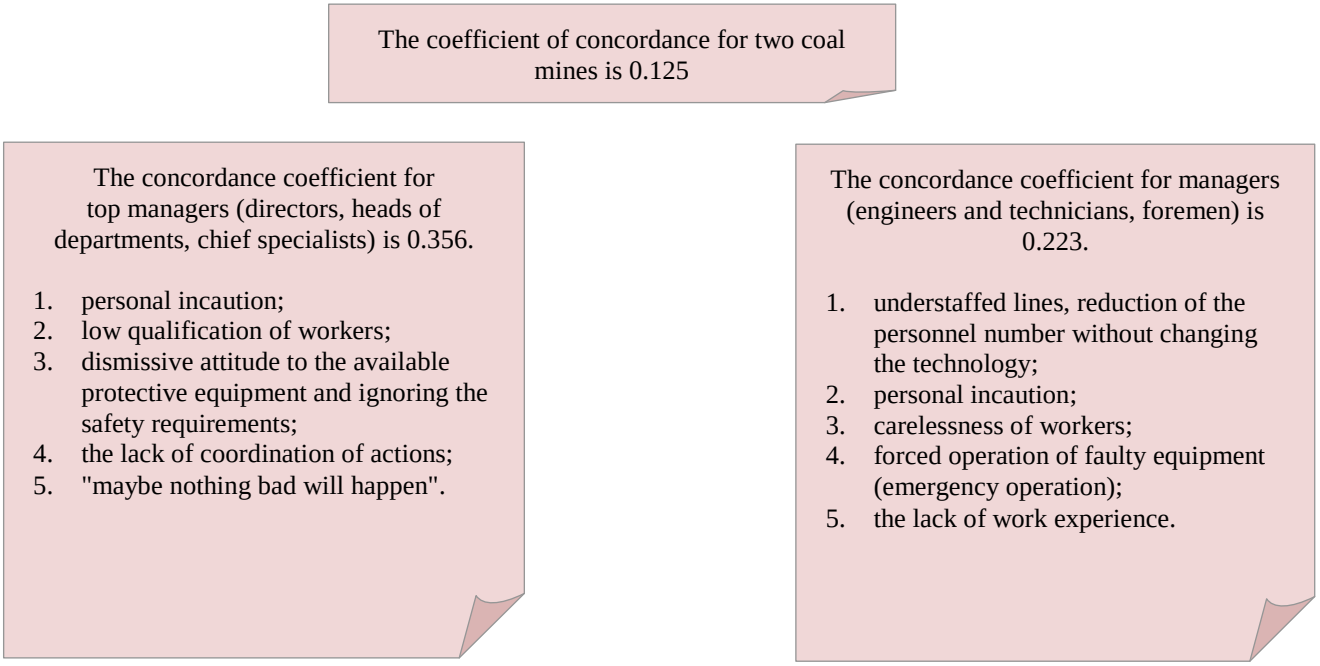

Fig. 1. Consistency of the opinions of the experts of coal mines with the cyclical mining technology

The periodicity of the first-priority prevention activities

A necessary condition in designing the plans of short-term activities is to establish the periodicity of preventive measures to reduce injuries.

On the basis of the discovered exponential law of distribution of injuries in open cast mining in the Russian Federation and the RSFSR over the past 50 years and using the formulas of reliability theory, the basic characteristics are determined of injuries in the coal mines with cyclical technology: the intensity of injuries, severity of injuries, the probability of an accident and the periodicity of preventive measures (Venetsky and Kildishev, 1975; Wentzel, 2009), which are partially reflected in Appendix A, table A1.

The developed plan of actions aimed at improving the safety of miners of the "Chernigovets" coal mine includes a program of activities for a year, as well as periodicity of short-term preventive measures to eliminate the organizational (70 shifts) and technical (220 shifts) causes of injuries.

It has been established that, with the introduction of short-term preventive measures in the next 5 years, the reduction in injuries of miners is expected from 20 to 80% (the dependence of the intensity of injuries is established with a confidence interval of $\pm$ 2 injuries per year).

In this case, a certain periodicity of preventive measures on the basis of the established exponential form of the distribution law for injuries allows planning and promptly implementing both the short-term and the medium-term activities. The developed algorithm of analysis and prediction of injuries on the basis of a comprehensive assessment of injury factors will improve the effectiveness of existing industrial safety management system at the studied coal enterprises.

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RESULTS

As the presented quantitative correlation-regression analysis has shown, the linear mathematical models of risk assessment are tenable, according to the determinacy coefficient, in the case of continuous mining technology (OAO "SUEK-Krasnoyarsk": "Borodino" and "Nazarovsky" coal mines).

In the case of cyclic mining technology (OAO "SDS-Ugol": "Chernigovets" and "Kiselevsky" coal mines), due to complex and multivariant connections between the risk level and its causes (Eliseeva and Yuzbashev, 2005), it is necessary to engage, besides the correlation-regression analysis, the expert-analytical assessments for the preparation of a plan of preventive measures (Dubrov, Mkhitryan, Troshin, 2008).

The expert analysis, as the applied mechanism, allowed determining the list of the most important factors, where the social-personal and organizational-technological factors are among the first. This fact indicates that the main factors affecting the injuries, one way or another, are connected with the human being. Thus, for the purposeful work in the field of prevention of work-place injuries and, as a whole, the industrial safety, proper prioritization is now required, where one of the key positions should be given exactly to the social-personal factors, the result of which will be more effective and efficient allocation of resources of the mining enterprise.

Moreover, the established periodicity of preventive measures on the basis of exponential distribution law for injuries allows planning and promptly implementing both the short- and long-term activities. The developed algorithm of comprehensive assessment of traumatic factors will improve the effectiveness of existing safety management system at a particular coal enterprise.

DISCUSSION

Obviously, the dangerous mining production is not profitable for employers, whereas the life and health of workers are clear priorities compared to other results of activity. Even the most up-to-date technologies and the latest equipment alone cannot exclude the dangerous human actions, whereas highly trained engineers in the role of managers are not always able to ensure production safety in the conditions of absence of consensus within the collective and of common understanding of the key goals, objectives and priorities. That is why, the updated economic mechanisms of production safety management, backed by progressive administrative methods, are so important in modern times (Subbotin, 2004; Buyko and Pantyukhova, 2010).

It should be noted that the human factor is the basis of management of any production, because even a combination of technological, organizational, economic connections will not ensure reliable operation of the production system, if it is not backed by the necessary social relations of the personnel. That is why, social policy is an indispensable component of business and an obligatory, necessary element of its sustainable development (Artemyev, Dobrovolsky, Salnikov, Galkin, Loginov, Kravchuk, Kilin, Nevolina, Fedorov and Zankov, 2010; Artemyev, Kilin, Azev, Kostarev, Shapovalenko, Yantsizhin, Ermak, Katychakov and Galkin, 2010).

The contemporary mining companies in Russia, in particular, the data for which were used in the study, setting the goal of steady reducing the production risks to a level corresponding to international standards, introduce a comprehensive approach to solving the problems related to the preservation of health and life of employees. Assuming a primary management objective, which is ensuring the operation and systematic development of production in accordance with the planned results and the technical-economic indicators, the ways of influencing the employees may be different and efficient to varying degrees of effectiveness, depending on the initial conditions:

- the organizational-administrative ones in the form of an oral or written order (command and so on). In addition, the orders must be not only legitimate, but also clear, precise and motivated;
- the socio-psychological ones, which involve the use of moral incentives (praise, criticism);
- the economic ones, including financial incentives of positive actions and financial responsibility for the caused damage;
- the motivational ones, which stimulate the internal motives of workers for good, accident-free work.

Currently, at the largest coal enterprises in Russia there are applied methods and specific control actions that meet their basic specificities. In addition, the following basic principles are adhered to:

- improving the work safety is an important socio-political task (for example, OAO "SUEK" is constantly implementing new programs in the framework of corporate social policy, in particular, the "Health" program and others);
- the effective management of the workplace safety is possible through a combination of comprehensive and systematic approach involving the advanced scientific methods (for example, evaluation of the LTIFR complex indicator, etc.);
- the improvement of the workplace safety should be systematic, permanent and continuous (there are needed the analysis and implementation of new technologies and methods in the field of industrial safety, used by the world leaders in the field of coal mining);
- the improvement of the workplace safety should have preventive character (the most effective are: forecasting of hazards, the conditions and causes of their origination, improvement of the staff work training; keeping to the schedule of preventive inspections and repairs of equipment; timely updating and improvement of material-technical base in the field of industrial safety and labor protection to the level of the world leaders in the field of coal mining, etc.).;
- any measures and actions in the field of industrial safety and labor protection management should be absolutely legitimate;
- the introduction of a radically new and safer machinery and technologies (an important aspect in this context is improving the level of training of the professionals working on new equipment);
- engaging into the work to ensure safety of all employees without exception (the regular "Safety Days", "Safety Weeks" etc. are very effective);
- work to improve safety should not be formal (a combination is very efficient of a system of rewards of different economic nature for the accident-free work with a system of sanctions for violation of safety rules);
- the control over the implementation of measures to improve the workplace safety should be systematic (in the framework of implementation of this principle, a "Unified information system of labor protection" is introduced in OAO "SUEK"). It should be noted that, in addition to the control levers internal for the enterprises, an external lever is currently active, which is regulated by a number of documents: under the RF Government order of January 24, 2012 No. VP-P9-1pr, together with Rostekhnadzor and Rostrud, periodic inspections are carried out of the implementation of measures for industrial safety and labor protection and the functioning of the system of training, retraining and advanced training of personnel, including the use of the personal protective equipment;
- economic levers to improve security should be thought-through and timely.

As a result of integrated application of these principles and the methods of influence, a "culture of production safety" is being gradually formed, which is characterized, according to the Corporate Social Report (Open Joint Stock Company "Siberian Coal Energy Company", 2009-2010), by the following key features:

1) ensuring workplace safety and industrial safety is an intrinsic need of the personnel;
2) all the requirements which provide an acceptable level of safety is an internal company standard;
3) all the requirements which provide an acceptable level of safety are fulfilled;
4) failure to comply with these requirements is an extraordinary incident, which is carefully analyzed.

It is obvious that it is possible to achieve the stated objectives in the field of industrial safety and labor protection only through specific management decisions and by virtue of daily assiduous work. Moreover, the formation and maintenance of the trend towards sustainable improvement of workplace safety is possible only with the active position of each individual employee who is aware that his/her actions are directed not only to ensure his/her own safety, but also directly related to the life and health of his/her colleagues.

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Table A1. Plan of measures aimed at improving the safety of miners of the "Chernigovets" coal mine

Type of the cause	Probability of appearance of an accident	Periodicity of preventive actions	Cause	Short-term and long-term activities
Organizational	0.32	70 shifts	Personal incaution	Short-term measures: 1. Limited access to particularly dangerous works for the risk-prone people; 2. The pre-shift monitoring of the health of miners; 3. Selective during-the-shift monitoring of the state of health of miners. Program of activities for a year: 1. Testing miners in terms of their risk proneness; 2. The introduction of additional questionnaire to the act in the form H-1 "Accounting for human factors in the accident"; 3. Creating a room of psychological relief; 4. Introduction of psychophysiological monitoring of miners.
			Low qualification of workers	Short-term measures: 1. Selective checking miners' knowledge of safety rules; 2. Miners' training of the safe methods of work; 3. Miners' training on the new (purchased) modern equipment. Program of activities for a year: The development of step-by-step job descriptions for miners (implementation of the approach: a staff member is an "operator" performing clear tasks).
			Dismissive attitude to the available protective equipment and ignoring the safety requirements	Short-term measures: 1. Selective inspection of miners' use of personal protective equipment; 2. Conducting a behavioral audit of miners to detect irregular labor practices; 3. Financial penalties for the "worst" offenders. Program of activities for a year: 1. Development of a system of fines for violations of the rules of industrial safety and labor protection; 2. Development of a behavioral audit plan.
			Staff turnover, understaffed lines, reduction of the personnel number without changing the technology	Short-term measures: Training mentors of effective methods of working with the young personnel members. Program of activities for a year: 1. Development of activities that raise the image of the miner profession to solve staffing problems; 2. Introduction of a graded wage system (competitive salary in the city); 3. Development of a social motivation program for potential young staff members and providing their training.
Technical	0.18	210 shifts	Forced operation of faulty equipment, emergency operation	Short-term measures: Evaluation of the technical condition by safety cards (excavators, loaders, drilling rigs). Program of activities for a year: 1. Removing the broken equipment from service; 2. Carrying out basic repairs; 3. Creating technical safety cards for the equipment; 4. Development of a plan of purchasing modern equipment.
	0.21	180 shifts	Traffic accidents related to the dumping trucks	Short-term measures: 1. Evaluation of the technical condition by safety cards (dumping trucks, technological vehicles); 2. Checking the technological roads in terms of compliance with the road regulations. Program of activities for a year: 1. Removing the broken equipment from service; 2. Carrying out basic repairs; 3. Creating technical safety cards for the equipment; 4. Development of a plan of purchasing modern equipment.
	0.12	270 shifts	Traffic accidents related to railroad	Short-term measures: 1. Evaluation of the technical condition by safety cards (traction units, railroad trains); 2. Checking railway in terms of compliance with the regulatory documents. Program of activities for a year: 1. Removing the broken equipment from service; 2. Carrying out basic repairs; 3. Creating technical safety cards for the equipment; 4. Development of a plan of purchasing modern equipment.

CONCLUSION

Most of today's major mining companies in Russia, engaged in open-cast coal mining, have now reached a point when the majority of easily noticeable causes of violations of safety regulations and labor protection are already eliminated. The focus only on the technical re-equipment does not bring a significant increase in safety either; and a system of penalties and rewards in the field of industrial safety is not always effective (Ivanov, Korshunov, Gridina and Pasynkov, 2011).

Thus, a systematic work, requiring continuous control, is further needed in the field of industrial safety and labor protection, in which one of the key positions should be given to the social-personal factor.

One of the prospective topics for further research is the development of an innovative element: a unified system of the labor and industrial safety management that, in real production activity of mining companies, will ensure the fulfillment of the requirements of the updated legislative and regulatory-technical documents, and become a part of a "rigid" organizational structure of industrial safety and labor protection, as well as improve the stability of the mining industry in the conditions of constantly changing internal and external environment.

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