COAL MINE RISKS MANAGEMENT SYSTEM PATTERNS

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Abstract

The article defines a coal mine and associated stopes, panels and levels as an integral complex of hierarchically organized interdependent production facilities and physically heterogeneous material flows of coal, waste rock, water, and methane generated. The arguments follow that an efficient risk management should be based on the mine arrangement system patterns, as well as on the patterns of maintenance of safe conditions. It is important to represent the mine as a model, giving an integral notion both of these both patterns. The authors argue that because coal mining processes are interdependent in space and time, there is an interrelation between mining processes of adjacent stopes when the same panel is being mined, between mining processes of adjacent stopes when neighboring panels are being mined, and between mining processes of stopes of panels of neighboring levels. It is recommended to implement expenditure optimization mechanisms at the coal mine risk management systems in two stages: first an efficient structure of preventive and compensative costs of particular risks management at coal mine production facilities to be determined, and then an efficient amount of total expenditure on risk management at coal mine production facilities to be assessed.

Introduction

A coal mine is an integral complex of interrelated and interdependent artificial and natural production facilities of variable scale, involved by man in his purposeful activities aimed to safely excavate and produce the mineral. Such facilities can be categorized as the following upgrade sequence: stopes, panels, levels, underground mine operations, and, finally, the mine as a whole.

A stope, as the principal production unit of a coal mine, is an integral complex of interrelated and interconnected mining elements. These mining elements include the mined out space, mine workings confining this space, the coal seam face, the immediate and main roof and sole host rocks, stoping system, face support, and conveyor.

A panel, as the next in scale order coal mine production facility, incorporates an ordered assembly of sequentially mined out stopes combined by a common system of technical

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arrangement solutions. This system of technical arrangement solutions ensures safe and efficient mining operations within the panel. It serves as a system shell aggregating the stopes of the panel and ensuring the homeostasis of the panel as a system [2].

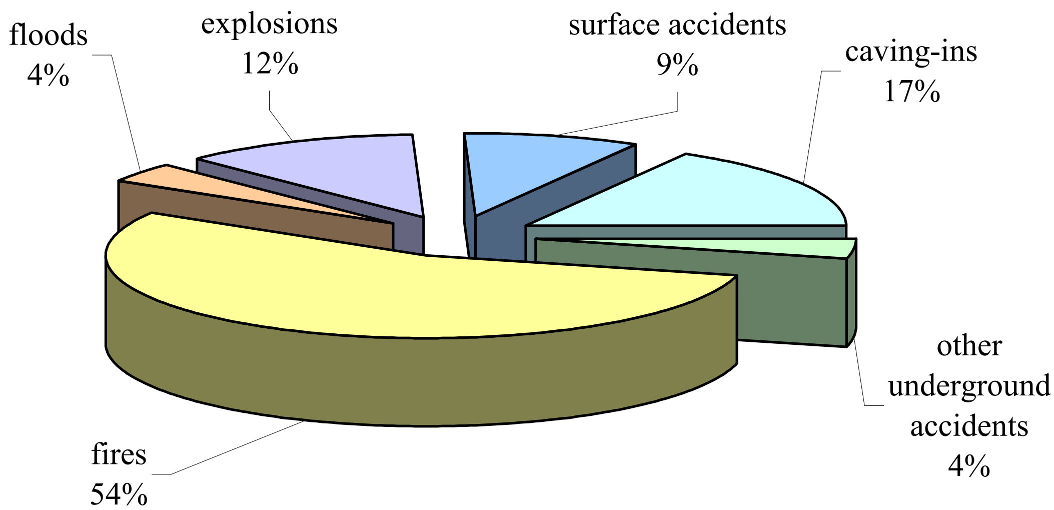
A level, being the next large in the scale sequence mine production facility, is composed of an ordered assembly of sequentially mined out panels, also combined by a common system of technical arrangement solutions. This system of technical arrangement solutions ensures safe and efficient mining operations within the level. It serves as a system shell aggregating the panels of the level and ensuring the homeostasis of the level as a system.

Similarly, the totality of coal mine levels is aggregated by the system shell of common technical arrangement solutions into the underground mine operations, being then aggregated into the mine a whole by the system shell of the mine general technical arrangement solutions.

Via this hierarchically arrayed system of coal mine production facilities, coal mining processes are being implemented. These mining processes produce physically heterogeneous material flows of coal, waste rock, water, dust, and methane. The intensity of the above flows is subject to the mine geological and mining conditions, and the intensity of mining processes initiating these flows.

All the mining processes in a mine are subject to the geological and mining conditions of implementation thereof. The coal mining conditions are subject to change, the same as the properties of mining elements of the principal coal mine production facility, the stope, and the interconformity these properties, with a consequential mismatching of mining processes. As a consequence, the intensity of the mine material flows produced by the mining processes is continuously subject to change.

Fig. 1. The structure of Russian coal mine accidents



The continuous change of the mine material flows and the low predictability of these flow are the reasons of coal mining liability to accidents. The structure of accidents at Russian coal mine is shown in Fig. 1.

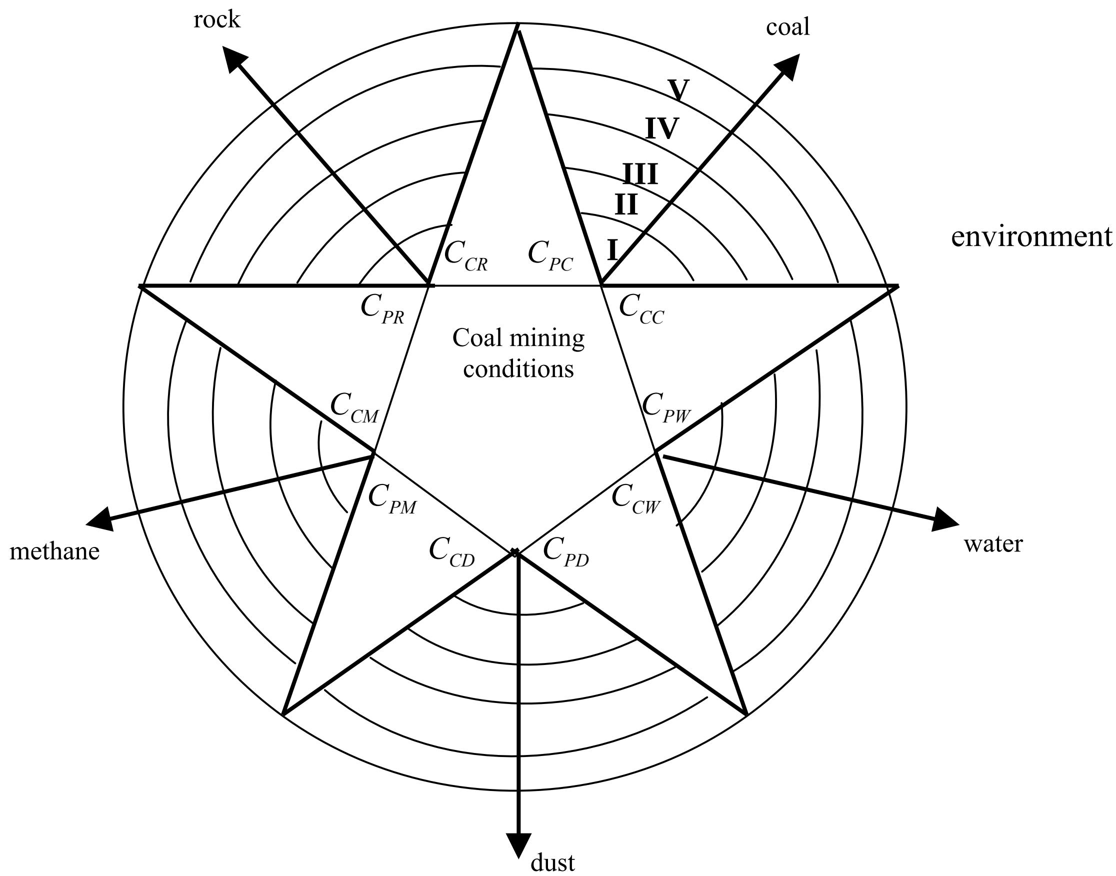
As it obvious from the above structure, fires are the predominant type of coal mine accidents. It is quite natural, as coal production is production of a principal energy carrier. Next in sequence are caving-ins, due to the energy carrier being produced from a rock massif composed of various rocks. The considerable percentage of explosions is due release in the process of coal mining of substantial quantities of methane occluded in coal and contained in coal dust. Methane and dust produce an explosive mix in contact with air oxygen. Floods and other accidents to which the underground mine operations are liable, are due to coal mining operations affecting aquifers and involving a high concentration of machines and mechanisms.

Theory

An effective management of the risks accompanying coal mining activities is subject to the systematic principles of a mine organization as a hierarchically arranged system of production facilities. Therefore, it is important to represent the mine as a model, giving to a person an integral notion both of the patterns of mine composition of production facilities and of the patterns of maintaining its safety.

Mine production facilities are based on the geological and mining conditions of the mineral production, and are organized in hierarchical levels.[1] Mine production processes generate material flows of coal, waste rock, water, dust, and methane toward the environment. These flows are formed according to the hierarchy levels of mine production facilities. Therefore, in order to find system patterns of mine risks management procedure, it is convenient to represent a coal mine structural model as the scheme shown in Fig. 2.

Fig. 2. A structural model of coal mine flows generation



Where I, II, III, IV, V – hierarchical levels of coal mine production facilities: I – stope; II – panel; III – level; IV – underground mining operations; V – mine as a whole;

C_{PC}, C_{CC}, C_{PW}, C_{CW}, C_{PR}, C_{CR}, C_{PM}, C_{CM}, C_{PD}, C_{CD} - the cost of preventive (P) and compensative (C) measures of mine safety ensuring for the respective flows generated.

All the mine safe operation measures can be subdivided into measures to mitigate risks inside and outside the mine[2]. The mine inside risk mitigation measures are related to occupational safety measures. The mine outside risk mitigation measures are related to the environment protection measures. Both the former and latter ones can be either preventive or compensative in character.

The preventive measures are aimed to decrease accident probability, while the compensative ones are aimed to mitigate accident consequences. Both category measures are to be implemented in advance of any actual accident. The preventive measures are to decrease the probability of simultaneous emergence of accident factors. The compensative arrangements are to influence the space and time incidence of emergency progress conditions, mitigating probable damages.

Implementation of preventive and compensative measures always involves costs. These costs are represented in Fig. 2 as the five-point star beams, being subject to the coal mining conditions. The five-point star beams cross all the hierarchical levels of coal mine production facilities. This means that preventive and compensative mine operation safety arrangements are to be implemented on each hierarchical level of its production facilities.

The accident prevention and consequences mitigation process at a coal mine is subject to a certain pattern. All the mine safe operation measures are to be designed and implemented pursuant to a certain procedure: from the maximum hierarchical level of coal mine production facilities, to the minimum hierarchical level thereof.[2] All accidents shall be suppress in the opposite sequence: from the minimum hierarchical level of coal mine production facilities, to the maximum hierarchical level thereof.

Method

Coal mining processes are interdependent in space and time. There is a close interrelation between mining processes of adjacent stopes when the same panel is being mined, between mining processes of adjacent stopes when neighboring panels are being mined, and between mining processes of stopes of panels of neighboring levels.

Therefore, implementation of mining processes safety measures in one stope, will inevitably affect the mining processes safety in another stope. Therefore, the costs of preventive and compensative measures for different coal mine production facilities are interrelated both within their mutual hierarchical level, and between themselves. Consequently, there is always available an efficient option of ensuring the necessary mine operation safety level due to selecting an optimal cost structure of the measures.

A coal mine risk management total expenditure making up model can be represented as follows:

$$E_i = p_i y_i + (1 - p_i) \cdot (C_{Pi} + C_{yi}), \quad (1)$$

Where

p_i - The probability of an accident due to the i-th mine flow implementation;

y_i - Assessment of consequences of an accident due to the i-th mine flow implementation;

C_{Pi} - preventive costs of decrease of the probability of an accident due to the i-th mine

Flow implementation;

C_{yi} - compensative costs of advance decrease of consequences of an accident due to the i-th mine flow implementation.

According to this model, the costs of coal mine risks management involve the costs of preventive and compensative measures and the risk assessment. The risk assessment in its turn involves the costs of accident control and consequences mitigation. The accident control procedure shall be implemented at the mine pursuant to the emergency control plan. The types and scales of likely accidents shall be determined in advance on the basis of previous experience of mining operations in similar mining and geological conditions, and using available statistical data.

An example of preventive costs of water environment protection are the costs of drainage and impervious screens arrangement, drill-holes grouting and waterproof bulkheads construction, fuel and greasing materials accounting and control system implementation; environmental instruction and personnel training expenditures.

An example of compensative costs of water environment protection are the costs of sewage treatment, sludge treatment and utilization, treatment works renovation and maintenance, and costs of other similar arrangements, including payments for third parties' sewage water treatment and hazardous waste utilization services.

An example of occupational safety preventive costs are the costs of advance degassing of the deposit in order to decrease gas ingress into mine workings and prevent gas blowouts; the costs of improvement of drill-and-blast operations procedure; of personnel training and professional examination; of occupational and industrial safety standards implementation; and of routine auditing of mine production processes.

An example of occupational safety compensative costs are the costs of concomitant degassing of mined coal seams and host rocks; costs of mine ventilation system improvement; costs of explosion-proof equipment application in mine workings of gaseous mines or extra costs involved due to the need to use pneumatic power.

The coal mine risk management costs optimization process shall be implemented in two stages. At Stage I, an efficient structure of particular risks management preventive and compensative costs shall be determined. At Stage II, an efficient amount of total risk management expenditure shall be assessed.

An efficient structure of preventive and compensative costs of particular risks management shall be determined upon the condition of risk minimization at a production facility of the examined hierarchical level, provided the preventive and compensative costs are invariable. A mathematical model of assessment of an efficient structure of these costs, is the following:

- Costs structure assessment criterion:

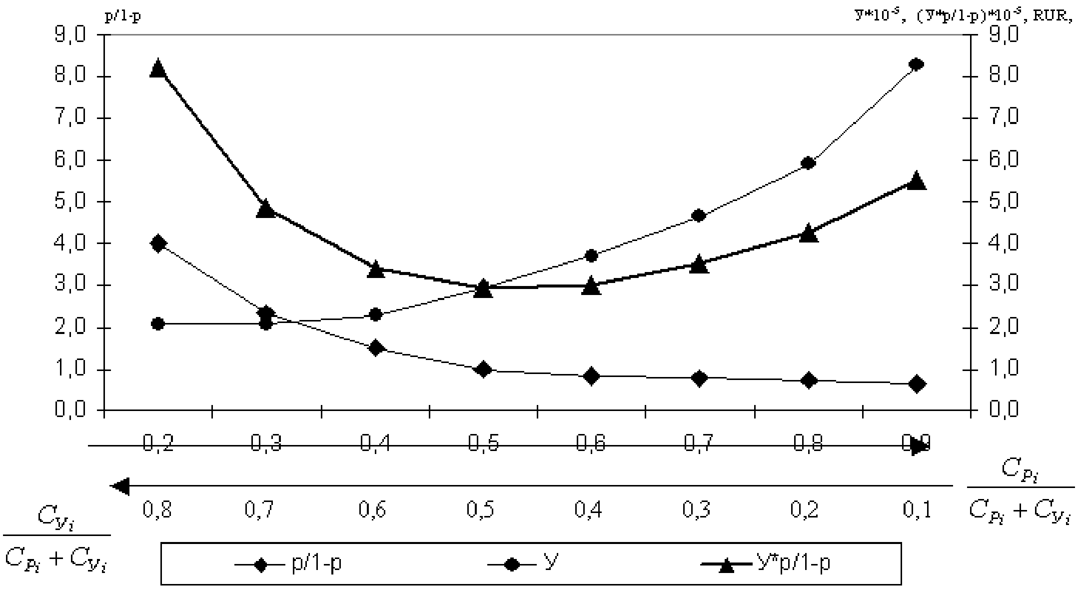
$$\frac{p_i}{1-p_i} \cdot Y_i \to \min \quad , \qquad (2)$$

- Limitation:

$$C_{Pi} + C_{Yi} = const \quad . \qquad (3)$$

Fig. 3. shows the process of formation of an efficient structure of risk management preventive and compensative costs.

Fig. 3. Formation of an efficient structure of coal mine risk management costs



As it is obvious from the above diagram, in case of a particular preventive and compensative cost structure, specific for each type of risk inherent to coal mine production facilities, a minimum risk is ensured.

An efficient amount of coal mine risk management expenses is determined upon the condition of minimization thereof, provided the structure of preventive and compensative costs is invariable. A mathematical model of assessment of an efficient amount of risk management costs is the following:

- expenses assessment criterion:

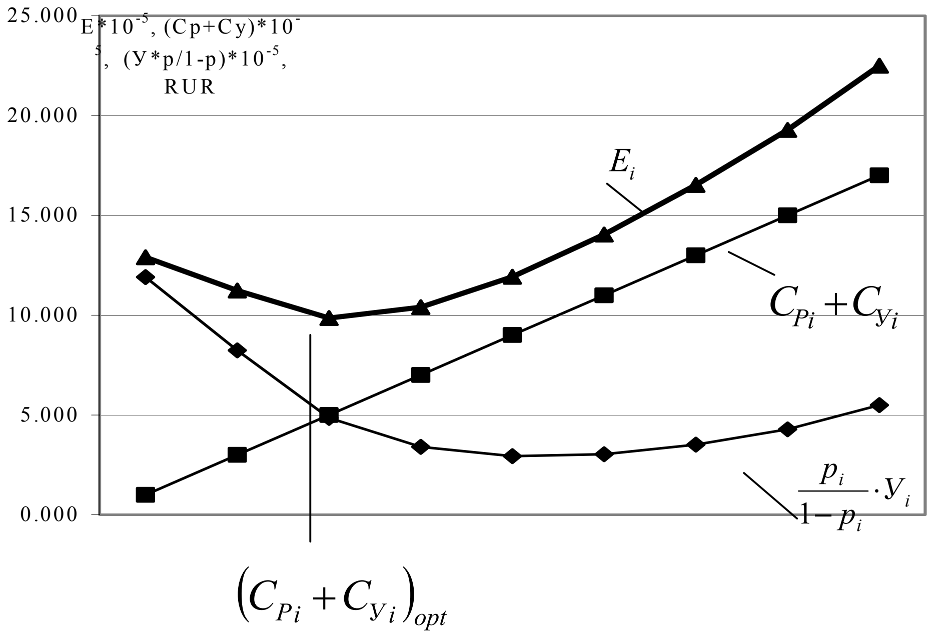
$$E_i = \frac{p_i}{1-p_i} \cdot Y_i + \left(C_{Pi} + C_{Yi}\right) \to \min \quad , \qquad (4)$$

- limitation:

$$\frac{C_{P\,i}}{C_{У\,i}} = const \qquad (5)$$

Fig. 4 shows the process of formation of an efficient amount of coal mine risk management expenses.

Fig. 4. Formation of an efficient amount of coal mine risk management expenses



As it is obvious from the above diagram, in case of a certain ratio of preventive and compensative costs to assessed risk, a minimum amount of the total expenditure on risk management at production facilities of the all the coal mine hierarchical levels is achieved.

Results

1. A coal mine is an integral complex of hierarchically organized interdependent production facilities, where mining processes are being implemented, and physically heterogeneous material flows of coal, waste rock, water, and methane are generated.
2. Mismatching of coal mining processes causes a continuous variation of intensity of material flows generated by these processes, and creates risks of accidents at the coal mine production facilities.
3. An efficient risk management at coal mine production facilities shall be based on the mine arrangement system patterns, and on the patterns of maintenance of safe conditions at these facilities.
4. Maintenance of safe conditions at coal mine production facilities is implemented via preventive and compensative measures. The costs of these measures are interrelated within each hierarchical levels of mine production facilities. Employment of this interrelation allows to minimize coal mine risk management expenses, provided an acceptable level of mine operation safety is maintained.
5. It is advisable to implement the coal mine risk management expenditure optimization procedure in two stages. At Stage I, an efficient structure of preventive and compensative costs of particular risks management at coal mine production facilities is to be

determined. At Stage II, an efficient amount of total expenditure on risk management at coal mine production facilities is to be assessed.

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