Experience of creating a multifunctional safety system at the coal mining enterprise

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Abstract. The principles of creating multifunctional safety systems (MFSS) based on mathematical models with Markov properties are considered. The applicability of such models for the analysis of the safety of the created systems and their effectiveness is substantiated. The method of this analysis and the results of its testing are discussed. The variant of IFSB implementation in the conditions of the operating coal-mining enterprise is given. The functional scheme, data scheme and operating modes of the MFSS are given. The automated workplace of the industrial safety controller is described.

1. Introduction

The federal rules and regulations in the field of industrial safety “Safety Rules in Coal Mines” approved by Rostekhnadzor Order No. 550 of 19.11.2013 determine the composition of the safety systems included in the MFSS and also define the functions of this system – “monitoring and prevention of the conditions for occurrence of the hazard of geodynamic, aerological and technogenic nature; operative control of conformity of technological processes to the given parameters; application of emergency protection systems for people, equipment and structures” [1]. To solve the problem of providing the function of “operative control of the conformity of technological processes to specified parameters”, it is proposed to create an integrated class of automated systems [by analogy with the connection of APCS (automated process control system) – ASODC (automated system for operational dispatch control)]: II MFSS (integrated information multifunctional information safety system) – ASS (automated safety system).

The integrated information multifunctional safety system (II MFSS) is an analog of the ASODC, and this system, as an industrial safety controller, is designed to solve a range of tasks for timely response to emergencies and their prevention. The basis for the allocation of II MFSS from ASODC is:

- priority boost of dangerous situations and accidents over the overall control of technological processes and their separation into a separate category of production tasks;
- information flow in control of complex production exceeded the ability of a person to register minor safety rules failure (SR), which usually together lead to an emergency.

Proceeding from the foregoing, the creation of the MFSS is suitable for complex or dangerous technological industries, for example, a coal mining enterprise.
In describing the model of the MFSS and its implementation, it is proposed to use Markovian chains in combination with synergetic models due to the comparative simplicity and clarity of the mathematical apparatus, the high reliability and accuracy of the solutions obtained.

2. Modeling of a multifunctional safety system

Markovian chains are used to synthesize the model of the MFSS. Markovian chains use the general principles of the theory of stochastic processes for analyzing the discrete space of a state of objects group in time. Each object is at any time in one of the states from a bounded set.

The basic postulates of the MFSS model are:
1. Dangerous production – mine – is considered as a synergetic object with many internal states.
2. Transitions from one state to another are regarded as the Markovian process, that is, with independent probabilities.
3. Physical transition of an object from one state to another is displayed in the information space, as a given, expected event.
4. Each event generates a signal.
5. The signal is transmitted to the message by the II MFSS system.
6. The system has negative feedbacks on control, implemented by organizational and technical methods.
7. The task of the MFSS is to prevent the transfer of a dangerous object to the state of emergency.
8. When the object transit into the emergency state, the MFSS should minimize the damage and help restore the object to its normal state.

The model of the II MFSS (figure 1) can be represented in the form of system transitions from one state to another, generating an event and generating a signal; in the initial state of the system – normal operation of technological objects – “normal system operation” (S1); the quantized space of the system state can be represented in the form of such ranked states of severity as: violation of SR (S2), warning (S3), incident (S4), accident (S5). The operator’s task is to prevent the system from transition to the “emergency mode of the system” state (S6). This model can be referred to the class of Markovian processes with discrete states and continuous time.

![Graphical representation of the II MFSS](image)

**Figure 1.** Graphical representation of the II MFSS:
\( \lambda_{ij} \) – probability of transition from the state of \( S_i \) to the state \( S_j \).

The main problem in this model is a large number of states of the system and possible transitions between them. To optimize the operation of the system, the provisions of relational algebra are applied. Classification of events and their properties made it possible to identify groups of entities and
divide them into sets with small capacities. Optimization of the work of the model is achieved by synchronization of the directories of the II MFSS databases and automated safety systems (ASS). Classification of events occurs for each ASS according to the following principles:

1. Violation (damage) of the technical process environment (for example – rock fall, methane explosion, fire, flooding, etc.).
2. Violation (damage) of the means of the technical process (equipment), including power supply.
3. Failure of control systems, including damage to communications;
4. Deviation from the specified parameters of the technological process, including unscheduled stops.
5. Errors (including injuries) of personnel, other types of SR violations and warnings.

The event properties are:

1. Priority of the event (Accident, Incident, SR Violation, Confirmation or Prevention)
2. The place and time of the event;
3. Values of the event parameters (for example: the percentage of methane when the maximum permissible concentration is exceeded);
4. Personalization and acknowledgment of the event.

This approach offers the following advantages:

- MFSS directories contain all the events for all safety systems necessary and sufficient for safe operation;
- the system is universal and allows new events to be added;
- the business processes for officials to eliminate the safety threats are specified, as a given reaction to specific events;
- the time required to carry out the necessary instructions for personnel actions in emergency situations is shortened, and the accuracy and concreteness of these instructions increase.

3. Implementation of the multifunctional safety system

In the proposed model of the II MFSS collects and filters data from the ASS for its subsequent processing and storage. ASS can be a separately implemented specialized automated system, or be built into the process control system. The exchange of data from the ASS to the II MFSS is in the form of signals, the signals are converted into event messages. The data collection is organized in the II MFSS both by events (the initiator of the signal sending is the ASS) and by the timer – the external ASS is periodically fetched and signals are generated. The functional scheme of the interaction of systems is shown in figure 2.

![Functional diagram.](image)
Information coming from adjacent automated systems is accumulated in the database (DB) of the MFSS. The data schema is shown in figure 3.

![Figure 3. Data Scheme of the MFSS.](image)

Signals are decrypted into messages understandable to the industrial safety controller. The signals are transmitted in the coded form.

The software implementation of automated workplaces is based on the configuration of “1C: Enterprise 8. Industrial safety. Integrated”, designed to automate the tasks of ensuring labor safety, industrial, fire and environmental safety at enterprises. The choice of this solution is due to the wide possibilities for automation of the planning, accounting and control processes in various areas of fire and industrial safety, including the ability to keep records of technical devices used at hazardous production facilities, monitor the timeliness of routine maintenance and maintenance for equipment, to register the data of accidents and incidents at hazardous production facilities.

The appearance of the automated workstation (AW) of the operator is shown in figure 4.

The system can operate at any time in one of two modes:

*Normal operation.*
Under normal operating conditions, the operator receives reports of SR violations, incidents, accidents and from the self-diagnostic subsystem of the MFSS through the event log.

![Appearance of the operator’s workstation.](image)

The operator must necessarily confirm the message receipt (acknowledge it). If the message is not acknowledged within the specified time period, the system goes into emergency mode. When the message is registered in the system, it gets the status of active (unfinished).

After acknowledging the message, the operator, on the basis of the job description and regulatory documents, must make a decision to eliminate the violation of the SR or incident. When the cause of the event is eliminated, the message is automatically terminated and gets the archive status. It is also possible to terminate the event manually. But in this case, the message will be delayed for the period specified in the system setup, and will appear again, if in fact the factors that caused it are not eliminated.

When the operator enters the system or on demand, he receives a list of pending unfinished messages.

If the time for the completion of the event, that is set during the system setup and depends on the violation correction procedure, expires, this event is completed, and an event with a higher priority is generated instead (for example, a SR violation becomes an incident). In this case, additional automatic notification of the responsible officials from the alert list occurs.

When receiving an oral, telephone, written or other non-electronic message, the operator enters it through a special form in the MFSS.

**Emergency operation mode** – when the emergency response plan is activated.

In emergency operation mode the operator waits for the emergency mode to end and can generate reports on the occurred events. Emergency mode is used in the following cases:

- when an emergency message is received;
- on the initiative of the responsible head of the accident liquidation or the mining operator;
- if the message is not acknowledged within a specified period of time by the operator or by the person who replaces him.

In the emergency mode, system messages are acknowledged automatically.
4. **Technique of the analysis of industrial safety**
Accumulated information on messages for a long period makes it possible to calculate the transition probabilities from one state of the system to another, which allows the most probable ways of accident propagation to be predicted.

Analyzing the data it is possible to establish “bottleneck” places of the industrial safety system at the enterprise. That allows the possible accidents to be prevented by organizational and technical methods and safety systems to be optimized by increasing or, conversely, simplifying those that are responsible for the most traumatic and emergency areas of the technological process.

To automate this process it is possible to use the technologies of artificial intelligence systems – expert systems, neuron networks.

5. **Conclusion**
The economic efficiency of implementing the proposed models makes it possible to optimize the costs for the creation and operation of the safety systems included in the MFSS. Evaluating the effectiveness of technical systems, implementing safety systems, and determining the required “resolving power” of detecting the SR violations in these systems, that is, optimizing the number of signals generated by the system, the redundancy of these systems is eliminated, which leads to a decrease in the cost of acquisition and ownership.

Or the insufficiency of these systems is eliminated, thereby minimizing the costs and time for liquidation of the consequences of non-eliminated accidents. In addition, it is possible to build a digital simulation model of the MFSS enterprise for forecasting and experiments, for optimization, elimination of bottlenecks, and also to train the personnel preventing breakages and the danger from accidents for the real system.

Approbation of the methodology was started at the Chertinskaya-Koksovaya mine in 2016. Currently, the developed system is being implemented at this production facility.

**References**
[1] Rostekhnadzor Order No. 550 of November 19, 2013 “On Approval of Federal Norms and Rules in the Field of Industrial Safety “Safety Rules in Coal Mines”