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Risk-based automated system for prediction of fire safety in railway facilities

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Aim.*The development of the Russian railway industry is associated with the growing number of operated buildings, rolling stock, more complex business processes of infrastructure maintenance and client service. In this context, JSC Russian Railways (JSC RZD) needs to manage the fire safety of more than ten thousand units of traction rolling stock and hundreds of buildings, where potential fires may cause harm to passengers or interruption of service. Fire safety management of both fixed and mobile railway facilities is performed at all lifecycle stages from design to disposal. Implementing the processes of fire safety diagnostics and prediction requires the development of a man-machine system whose core would be an automated fire risk control system (ACS) that allows – basedon the fire risk prediction – makingdecisions regarding the requirement for the repairs, replacement or maintenance of railway facilities and fire safety systems.* **Methods.***The methods of the automatic control theory, expert assessment were used. The study aimed to develop an algorithm of automated auditing of railway facilities fire safety.* **Results.***It is established that the majority fire safety control systems use gas concentration sensors to detect symptoms of hazard before flame development. This approach is hardly effective in terms of fire safety of railway facilities. For railway facilities whose actual state has an effect on the probability of fire a fire audit algorithm was developed that is based on the existing service and repair system, as well as statistical data on the states of railway facilities that precede fire. In order to enable systematic risk management measures in a large number of railway facilities, the paper proposes the structure of an automated fire risks management system that includes a fire safety management center and a mobile hardware and software system for fire safety auditing.* **Conclusions.** *It shows the importance of developing a proactive fire safety management system based on fire risk assessment. It was identified that information on the states preceding fires in railway facilities can be obtained from both the existing automated failure reporting and risk assessment systems and the diagnostic results of the actual state of objects as part of scheduled preventive maintenance. A method of automated assessment of fire hazard is proposed for systematic management of fire risks in many railway facilities.*

Keywords: *fire risk, automate dauditing algorithm, pro active fire safety management system, automated fire risk assessment*

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Introduction

The first fire detection sensors were developed in the XIX century and were based on temperature detection, i.e., according to current existing classification were heat-sensitive alarms [1]. Sensors are at the core of most automated supervision and control systems. With the development of information technology, ensuring safety is becoming progressively more simple, yet it requires complex algorithms. Among today's fire safety technology we can note automated fire safety management systems, as well as the intelligent and robotized fire alarm and suppression systems. The design of buildings with automatic fire suppression systems involves computer simulation of the evacuation process. Automation and application of information technology are evident in each aspect of fire safety both in the fire prevention systems and fire safety systems. At the foundation of such automation are technologies that enable collection of statistical information on the cases of fire, analysis, investigation and proposal of solutions to prevent repeated incidents.

In order to ensure fire safety of large facilities various hardware and software systems are integrated into a single automated fire safety management system. A research of the software architecture of safety-critical systems is done in [2]. An event-driven system has a number of advantages that are valuable in terms of fire safety, i.e. a system can be easily extended with a new component, the components can react to any events. However, such architecture does not guarantee a reaction to an event, therefore, the reaction to an event must be confirmed explicitly. That requires an interface to external systems, human operator or an automated decision support system.

This paper examines the task of constructing the functional structure of an automated railway facility fire safety management system based on fire risk assessment and enabling the prediction of the probability of fires using information on the results of railway facilities diagnostics.

1. The problem of automated diagnostics of facility faults affecting fire safety

In accordance with the requirements of the code of practice [3] detecting the location of fire can be done using video cameras and matrix optical sensors with targeted indication of the source of fire, targeted automatic fire alarms, liquid flow detectors or sprinklers with start control. The efficiency of all actions following the detection of fire depends on the rate at which the alarm processes the incoming signals. For that purpose, various algorithms of processing the controlled ambient variables are in development [4]. Software dependability is another important factor. Matters of dependability of automated control systems, including those specific to fire safety, was examined by many researchers [5, 6, 7, 8]. In [9], the authors look at the problem of ensuring the protection of software from hardware faults, which is of special relevance in case of sensor-based systems. The high rate of sensor operation and dependability of automated systems components are essential, but not sufficient conditions of efficient fire safety management of complex technical facilities. Todays' systems must enable not only efficient suppression of detected fires, but prevent them as well. For this purpose, the fire alarm (FA) and public address and evacuation management system (PAEM) examined in [10] must be complemented with a circuit of early pre-fire detection of fire hazardous states (Fig. 1).

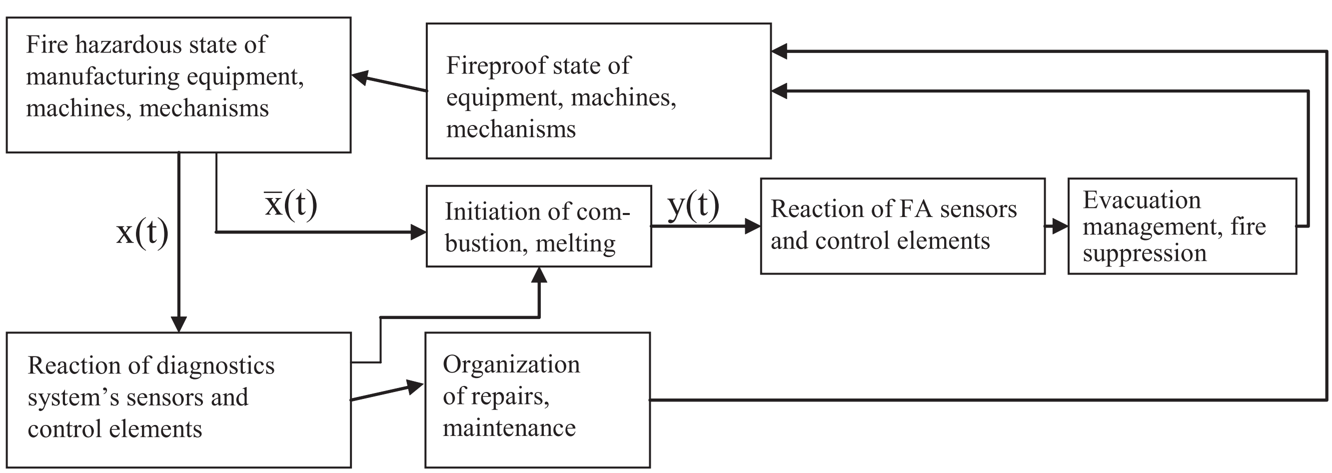

Figure 1. Operation diagram of FA and PAEM with a circuit of pre-fire detection of fire hazardous states

Table 1. Primary means of detection of pre-combustion signs of fire hazard

Facility	Technical facility	Controlled fire hazard state
Oil industry facilities [11]	Air pollution sensor	Dangerous level of explosive gas concentration
Sports facilities [12]	Combustible gases and ammonia vapors sensors	Dangerous level of explosive gas concentration, maximum acceptable concentration
Pipelines [13]	Pressure sensor	Elevated pressure
Peatlands [14]	Peat gas thermal probes	Temperature, gas concentration

Shown in Figure 1 are:

$x(t)$, the parameters of the object of evaluation (equipment/machine/mechanism) indicating the fire hazardous state of the facility, that can be identified by means of diagnostics, including, among other, human visual inspection of such facility,

$\bar{x}(t)$, the parameters of the object of evaluation (equipment/machine/mechanism) indicating the fire hazardous state of the facility, that cannot be identified by means of diagnostics, including, among other, human visual inspection of such facility,

$y(t)$, the environmental parameters registered by the fire alarm.

The majority of automated fire safety management systems contain only sensors that react to parameters $y(t)$. But currently, due to increasing costs of equipment, the requirement for round-the-clock operation, systems are needed that are capable of identifying signs of fire hazardous states before the appearance of fire. Such system will allow avoiding emergency interruption of manufacturing and business processes, as well as significantly reducing costs, including due to prevention of economic losses. Especially relevant is prevention of losses caused by emergency interruption of processes in railway transportation. Constructing a proactive fire safety management system requires designing methods and tools for diagnosing the parameters that indicate fire hazardous states of facilities. Based on the assessment of the fire risk of the identified states, the decision must be made regarding the modification of the state of the supervised facility before the onset of fire. Table 1 shows the technical facilities used for prediction of fire hazard in facilities before combustion

Today, proactive fire safety management systems are primarily used in the oil and gas industry and the primary parameter $x(t)$ they can observe is gas concentration. Gas alarm-based automated systems are also used in closed systems, e.g. submarines, warehouses. However, such diagnostics tools are not applicable in many other industrial facilities. That causes the requirement for the development of automated systems for monitoring faults affecting fire safety. This objective is especially important in the context of widespread automation of manufacturing and business processes and development of databases of actual states of facilities. For instance, JSC RZD operates an automated systems for recording technical facility failures [15], dependability and risks management systems [16]. Information from such systems should be used for purposes of various tasks. However, complete automation of diagnostics processes is not always necessary. Of high importance is the cost of sensors and other components, the availability of legacy manned facility inspection systems. The latter is especially important in case of facilities that undergo regular cycles of service and repair (S&R). In the railway industry, such facilities include: traction rolling stock, interlocking equipment, traction substations equipment, etc. In such facilities an efficient S&R system is already in place. The results of facilities diagnostics as part of S&R can be used in ensuring fire safety. It is obvious that the number of fire hazardous states of facilities is much smaller that the number of down or pre-failure states. For this reason, we should talk about fire audit of facilities whose criteria must be associated with the states that can actually cause a fire.

2. Diagnosing the faults of railway facilities that cause increased fire hazard

While auditing complex technical systems experts face two problems: limitations of human memory in terms of the number of the possible hazardous states of railway facilities (including "rote learning" of standard sets and ignoring the states outside of the expert's experience), as well as the time expenditures of coordination of the auditors' opinions. These problems are efficiently solved through the use of man-machine systems that enable real-time display of the list of auditing criteria for a specific technical system, recording the identified states, as well as using diagnostic tools.

Automated audit requires two modules, i.e. the module for railway facilities audit criteria and state classifiers development, the auditing module. The coordinated operation of these modules enables the algorithm of diagnostics of railway facility faults that cause increased fire hazard in facilities (Figure 2).

The module for audit criteria and state classifiers development must implement the following actions:

1. Source analysis for the causes of fire and results of EMERCOM inspections consisting in the composition of a list of fire safety violations identified as part of planned EMERCOM inspections, composition of a list of causes of fires.

2. Preparation of a list of standard fire hazardous states consisting in the statistics analysis of the fire safety violations and preparation of a list of typical violations, analysis of the causes of fire and composition of a list of typical fire hazardous states.

3. Ranking of typical fire hazardous states:

- preparation of the list of fire hazardous states of the 1-st category of hazard (states that cause fire),
- preparation of the list of fire hazardous states of the 2-nd category of hazard (states that lead to the onset of the causes of fire or states of facilities that were statistically sources of fire),
- preparation of the list of fire hazardous states of the 3-rd category of hazard (other states).

4. Agreement of the experts' opinions on the results of the ranking of fire hazardous states:

5. Quantitative estimation of the hazard of the 1-st category states:

- for the purpose of graph-based estimation of the fire probability, a graph and transition probability matrix are constructed,
- for the purpose of expert-based estimation of the fire probability, for each state the probability is estimated of the onset of fire hazardous events.

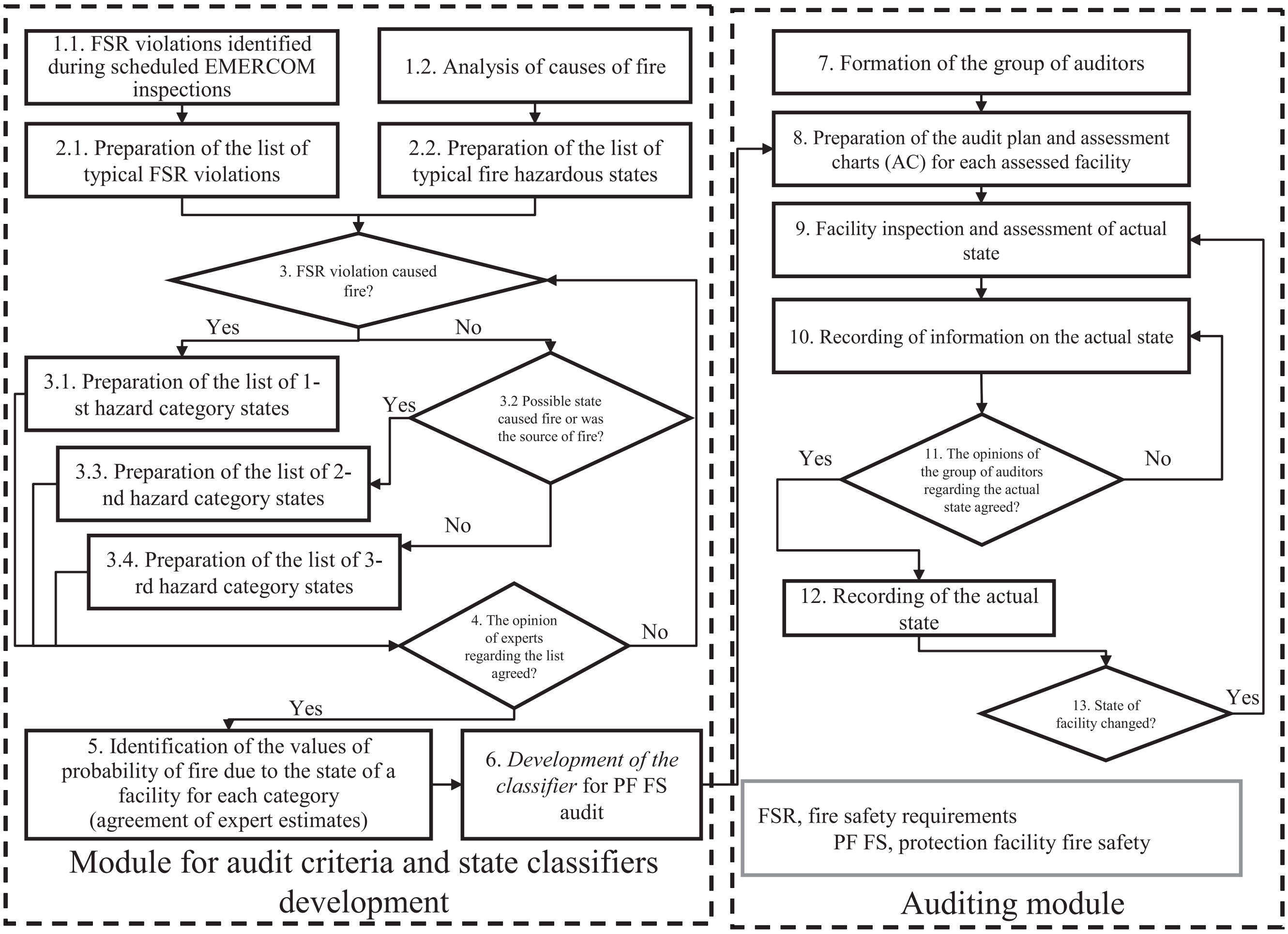

Figure 2. Algorithm of diagnostics of railway facility faults that cause increased fire hazard in railway facilities

6. Development of the classifier of fire hazardous states of fire safety auditing of railway facilities. The classifier includes the list of all possible states of a railway facility (taking into account the facility's design). The classifier, if necessary, indicates the tools that can be used to identify fire hazardous states. Using the developed classifiers, the auditing module operates and performs the following functions:

- formation of a group of auditors qualified in identifying fire hazardous states in railway facilities,

- preparation of the audit plan and assessment charts (AC) for each assessed facility. The audit plan describes the sequence of railway facility inspection. ACs contain a list of fire hazardous states that may be observed at the assessed facility. The AC also includes margins for notes on the actual state.

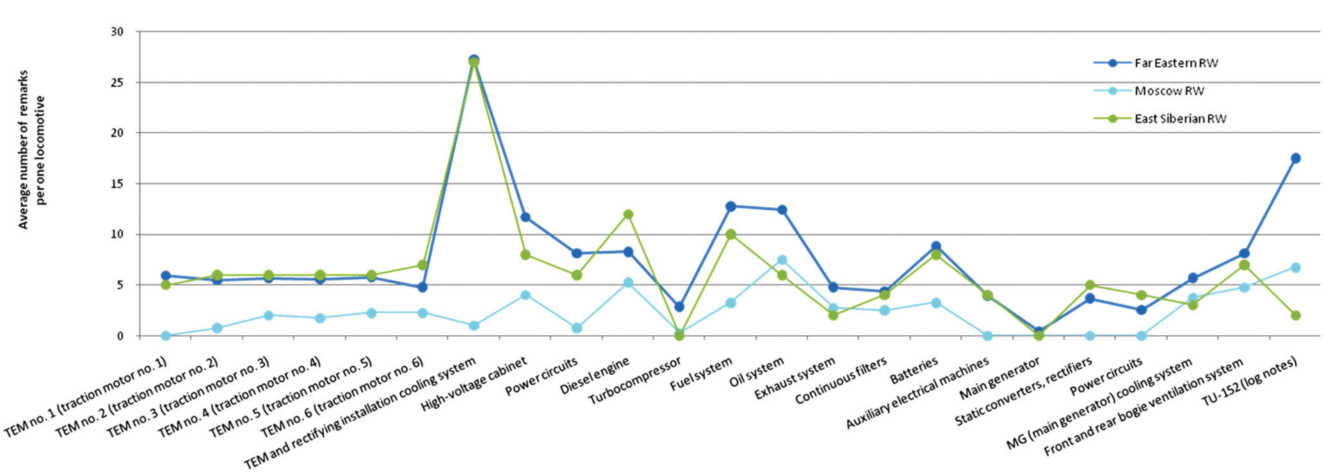

Figure 3. Fire hazardous state identification statistics in 3TE10-series traction rolling stock

7. Facility inspection, selection of the diagnostics tools, collection of data on the actual state.

8. Recording of information on the actual state.

9. Agreement of the auditors' opinions on the list of identified fire hazardous states

10. Registration of the facility's actual state.

11. Updating of the audit data in case of changes in the facility's state.

The algorithm shown in Figure 2 is iterated for each facility whose fire hazardous state is to be evaluated. Within the period of 2018 springtime inspection of the Far Eastern Traction Directorate 9761 fire hazardous states were identified in 221 units of TE10-series diesel-electric locomotives. Figure 3 shows data on the number of fire hazardous states identified as part of fire safety auditing of 3TE10-series locomotives of the Far Eastern, Moscow, East Siberian Traction Directorates.

3. Architecture of the automated railway facilities fire safety diagnostics and prediction system

Mathematical processing of the results of diagnostics railway facility defects that cause increased fire hazard are examined in [17, 18]. The result of such processing is the prediction of the fire risk of each assessed railway facility and decision-making regarding its clearance for operation. In order to enable systematic risk management measures in a large number of facilities an automated fire risks management system (AMS) is required. Such AMS must be developed taking into account the geographically distributed management system of the railway transportation. The following structure of the fire risks AMS in railway transportation will be efficient:

1) Fire safety supervision center that will collect information on the statistics of fires (e.g. through the integration with existing AMSs of JSC RZD). Such center must include the module for audit criteria and state classifiers development.

2) Mobile hardware and software system for fire safety auditing that enables the operation of the auditing module based on the data received from the fire safety supervision center.

Since the inspection of each facility requires visual monitoring, the use of mobile state recording systems will be optimal. Today, most sensors used in the diagnostics of the actual state of facilities (pressure, oil sensors, thermal imaging systems, etc.) are not part of a single network, therefore sensor readings must be taken individually. That is another argument in favour of mobile systems. Figure 4 shows the implementation diagram of the above method of railway facilities fire risk assessment.

The fire safety supervision center includes the central processor 1, whose inputs/outputs are directly connected

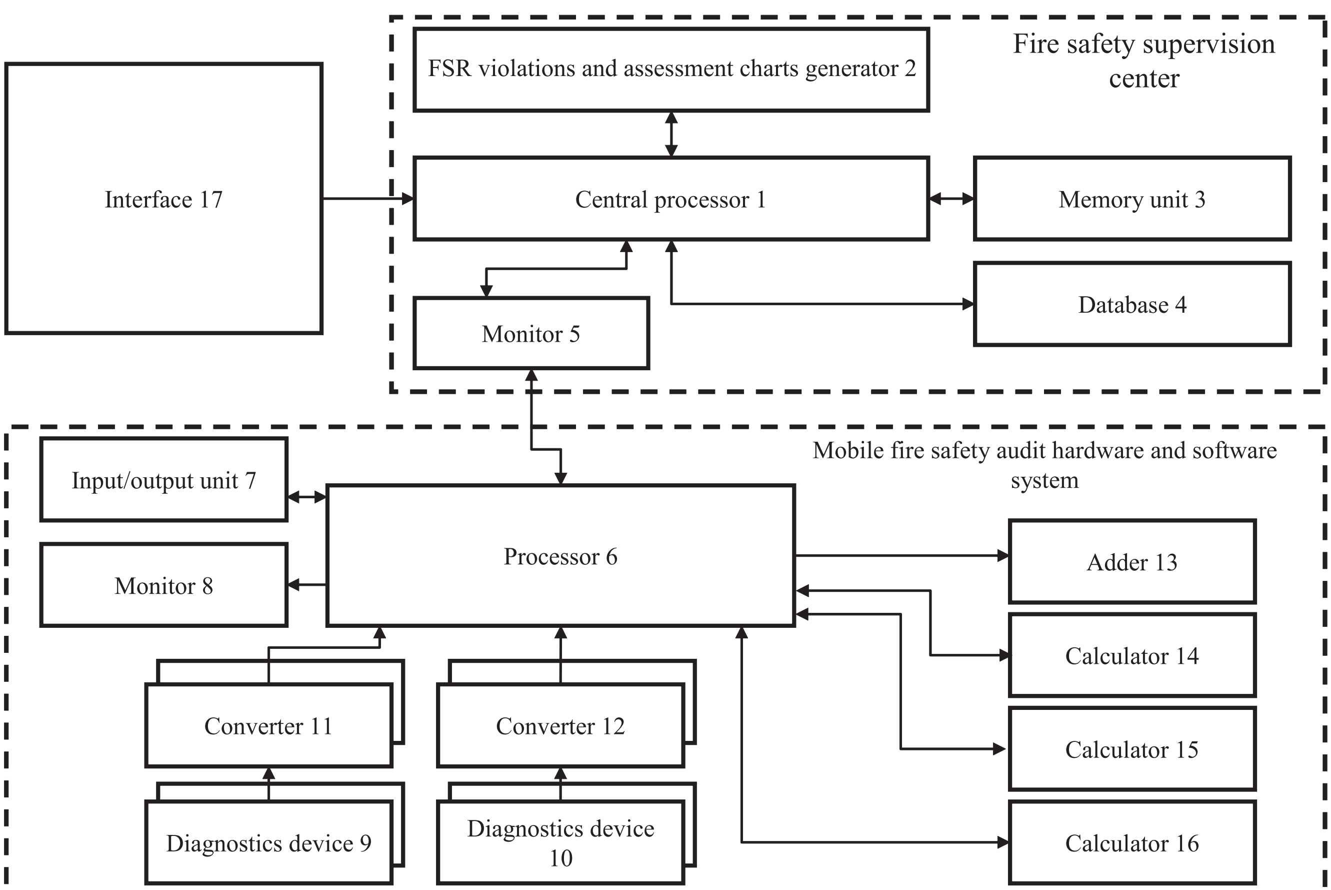

Figure 4. Implementation diagram of the above method of railway facilities fire risk assessment

directly to the outputs/inputs of the assessment chart generator 2 (module for audit criteria and state classifiers development), memory unit 3 and database 4, as well as the monitor 5. The mobile hardware and software system (MHSS) for fire safety auditing includes the processor 6 with the input/output unit 7 and monitor 8, diagnostic facilities in the form of appropriate supervision and diagnostics systems 9 and test instruments 10, converters 11 and 12, series-connected adder 13, first, second and third calculators 14, 15 and 16, the output of the latter of which is connected to the input of processor 6. The outputs of processor 6 are connected to adder 13 and communication interface 17 to ensure interaction of processor 6 with the central processor 1.

The output of each supervision and diagnostics system 9 and test instrument 10 through the appropriate converter 11 and 12 is connected to the input of processor 6, whose other inputs/outputs are connected to the outputs/inputs of calculators 14 and 15.

After the fire risk has been calculated using the data on the states of fire hazard submitted to MHSS, the elimination plan is developed taking into account the levels of risks created by such states. If the protected facility is cleared for limited operation, the elimination of fire hazardous states is done as part of scheduled S&R. If a facility is not cleared for operation, it is submitted to unplanned repairs.

Conclusion

The paper examines the problem diagnosing fire hazard states of railway facilities that precede fires. It shows the importance of developing a proactive fire safety management system based on fire risk assessment. It was identified that information on the states preceding fires in railway facilities can be obtained from both the existing automated failure reporting and risk assessment systems and the diagnostic results of the actual state of objects as part of scheduled preventive maintenance.

Selecting the parameters of facilities' actual states is proposed to be performed through an algorithm of diagnostics of railway facility faults that cause increased fire hazard allowing for the participation of a group of experts in the process of diagnostics. A method of automated assessment of fire hazard is proposed for systematic management of fire risks in many railway facilities. Taking into account the requirement of visual inspection of railway facilities, including the recording of the readings of geographically-distributed sensors, a mobile hardware and software system is proposed for auditing fire safety of facilities.

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