DOI: http://doi.org/10.25728/cs.2022.2.1

PROBLEMS OF MANAGING THE FIRE SAFETY SYSTEM OF A FACILITY. PART II: MONITORING METHODS

D.V. Shikhalev

The State Fire Academy, the Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM), Moscow, Russia

✉ evacsystem@gmail.com

Abstract. This paper overviews fire safety monitoring methods for a facility and state assessment methods for socio-economic systems used in fire safety. As discovered, none of the existing fire safety monitoring systems has a decision support procedure for adjusting a parameter (or several parameters) deviating from a given range. The majority of fire safety monitoring systems only assess the state of fire protection systems and transmit information on their triggering to the operational services. Thus, fire safety monitoring is simplified to assessing the state of fire automation systems, which cannot objectively reflect the fire safety state of the facility. As established, the integrated rating procedure is a most developed tool for assessing the state of a complex socio-economic system. This procedure is widespread in the theory of active systems. Its application to fire safety assessment is described. The existing contradictions in the management of fire safety systems are revealed, and some ways to resolve them are presented.

Keywords: fire safety, management, assessment of the facility's state, fire safety system, monitoring.

INTRODUCTION

Presently, the concept of a fire safety system as a controlled object is absent: this procedure is not described, there are no criteria for assessing the efficiency of fire safety systems, and the heads of organizations do not understand what they need to manage. For details, see part I of the survey [1]. In addition, despite many approaches to fire safety assessment, they are difficult to implement for the facility's head: he or she needs deep knowledge of the subject matter and the availability of appropriate qualifications and tools (computer programs). Thus, the head cannot assess the safety of his or her facility without qualified specialists.

Monitoring is a method to assess the current state of a facility, including fire safety. It is defined as a system of continuous assessment, control, and management of the facility's condition depending on its environment [2]. Monitoring systems are widespread in various spheres of human activities [3–7], including the complex safety of buildings [8, 9].

Concluding the survey, part II considers methods to monitor the facility's fire safety and assess the state of socio-economic systems used in fire safety.

1. FIRE SAFETY MONITORING METHODS FOR FACILITIES

Fire monitoring has been developed quite recently. The first elaborated solutions are associated with the appearance of *Strelec-Monitoring*, a hardware-software complex (HSC) for emergency monitoring and warning. In the book [10], the concept of constructing a radio-channel fire safety monitoring system for facilities was proposed. The use of radio channels was justified, and their advantages over traditional telephone lines were shown. As noted, the main cause of severe consequences (mass deaths) is the inability of the existing fire detection systems to transmit signals about the fire directly to the fire departments (call delays). The requirements outlined therein concern reliability, noise immunity, and other technical parameters of monitoring systems. However, there is no clarity about the parameters to be monitored. Several fire monitoring problems in the Russian Federation were touched on, but they relate only to legal aspects of monitoring and not its type, tasks, or other technical characteristics. Thus, the proposed monitoring system is actually a system for transmitting information about the element(s) of the automatic fire alarm system triggered to the Federal Emergency Service and sending fire and rescue units based on this signal.

Another newly developed solution is *Prometheus*, the national unified analytical fire safety control system for buildings [11]. According to the official website, the system remotely controls fire protection systems in buildings, monitors their maintenance, and manages databases of all participants in the fire protection market. As supposed, *Prometheus* will form a fire safety rating of an organization. Based on the current system functionality, the rating will be formed by assessing the performance and maintenance of fire protection systems. However, it seems rash to judge the facility's fire safety by this indicator: fire safety and its state are much deeper and broader concepts. Scientifically grounded methods are implemented here; see part I of the survey [1]. This system may be considered a higher level of HSC *Strelec-Monitoring*. However, it merely controls and transmits information about the state of fire protection systems and cannot be called a monitoring system: there are no methods to control the parameters in real-time. Generally speaking, fire safety monitoring in this system is treated as the operational control of fire protection systems. Such an approach is rather superficial.

Nowadays, fire monitoring is the most elaborated area. The dissertation [12] described remote fire monitoring models with current fire state assessment in a building. When a fire occurs in a building, the task is to obtain actual data on its growth and dynamics to ensure the safety of fire and rescue units. The author developed a decision support method based on fire monitoring. It represents a multilevel procedure for analyzing and ranking decisions by preference. No doubt, the procedure is useful at the fire occurrence stage. But such a problem statement goes beyond the scope of this paper.

Another example is the logical and probabilistic approach to the state monitoring of a potentially hazardous facility, particularly scenario modeling of accidents, developed in [13]. The monitoring of potentially hazardous facilities was defined as the continuous collection of information and the observation and control of a facility, including risk analysis, measurement of technological parameters at facilities, emissions of harmful substances, and environmental conditions in the adjacent territories. Monitoring is based on the interaction of two blocks: informational (data acquisition, processing, and presentation) and expert (scenario processing, modeling, and (or) forecasting, including assessment of the results). As a monitoring indicator, the author used a set of parameters determining the facility's safety and describing the system state at a given instant. Despite the relevance of this work, its drawbacks are a general set of monitoring parameters and no information about their sources.

In addition, methods are developed to control the state of the fire environment within an automatic environmental monitoring system [14]. An approach was proposed to integrate fire alarm and extra-early detection sensors to control the gas contamination level of the premises. The ambient temperature in the control area, the level of carbon monoxide, and smokiness were monitored. Test results showed a 25% increase in the accuracy of fire detection and a 37% increase in the total reliability of the system. Despite the positive test results, the research is more about solving an engineering problem than a scientific one. As expected, increasing control means will improve the efficiency of fire detection; monitoring parameters are supposed known to fire safety experts.

Note another monitoring system used after fire occurrence and development [15]. It is intended to assess the safety of fire and rescue units while working at steel truss structures in fire. Monitoring is carried out by the structure failure index (the probability that the entire structure will collapse when one of its elements collapses). The idea is to install temperature control sensors only on the elements critical for the structure's stability. The significance of different elements for the structure's stability is calculated in advance. When a fire occurs, the sensors transmit the environmental parameters, and the structure failure index is evaluated. As demonstrated by computer simulations, the slab collapse can be predicted 180 s before its occurrence. This time is enough for the fire and rescue units to leave the hazardous area. The approach considered in [15] is valuable for fire monitoring but only at the fire occurrence stage (like the one proposed in [12]).

Modern technologies are actively introduced in monitoring. For example, we mention a conceptual fire-fighting monitoring system based on the Internet of Things (IoT) technology [16]. Using various sensors, the system monitors current information about the pressure in the fire-fighting system, the temperature and humidity of the environment, the voltage of electrical equipment, the position of control valves, and the triggering signal. An early fire detection model was proposed based on a neural network. However, the principles of its operation were not described. In addition, the five-point rating scale was introduced to assess the fire safety of a building, but the grading method was not specified. Based on the monitoring parameters, we suppose that the fire safety level is assessed by the current state of the automatic fire-fighting system. In general, the approach presented by the authors is interesting and needs development. Like in the previously considered publications, monitoring is carried out for the technical elements of fire protection systems.

There are several regulations and documents in the state standards on fire and emergency monitoring (e.g., the state monitoring system of critical and potentially hazardous facilities and dangerous cargos [17]). The object of monitoring is the safety state of such facilities and cargos. This concept does not distinguish any parameters to be monitored, defining control areas only. Its peculiarity is automated decision support to minimize the consequences of an emergency. In general, this concept describes in detail the functions, composition, and operation of the monitoring system. Despite the obvious relevance, this area has not been properly developed, remaining merely a concept.

Note the state standard [8] on the foundations and design principles of a structured system to monitor and control the engineering systems of buildings and installations structures (MSIS). Its functions, composition, information exchange procedure, and other aspects are defined. This system is designed for potentially hazardous and critical facilities. MSIS should forecast and prevent emergencies by monitoring and determining parameter deviations from the nominal values. The monitoring parameters include the following [8]:

– fire occurrence;

– failures in the heat and water supply systems;

– failures in the power supply system;

– gas supply failures;

– failures in elevator equipment;

– unauthorized entry into the premises;

– increased radiation, maximum permissible concentrations of chemically hazardous substances, etc.;

– flooding of premises, drainage systems, and technological pits;

– deviations of technological processes from standard modes;

– changes in the structural elements of the building;

– the state of fire and emergency protection systems;

– the state of engineering protection;

– the condition of areas with a high probability of dangerous natural processes (landslides, avalanches, etc.).

Structurally, MSIS consists of three subsystems: data collection and messaging, communication and crisis management, and monitoring of engineering structures. MSIS operates in the following way. The system continuously monitors factors affecting safety; in case of any deviation from the norm, it transmits information to the dispatcher for warning and decision-making. This system has no decision support modules that would suggest a set of alternative decisions. The MSIS function is to warn about changes in the facility's state.

The document [9] defines and regulates the construction of a system to monitor automatic fire protection systems and signaling on the centralized 01-112 service panel. This system should collect data on fires (accidents) and natural disasters; monitor the reliability and operability of fire protection systems. The system makes fire (fire, alarm, etc.) and service (malfunction, loop disconnection, etc.) notifications. Like MSIS, it provides no decision support during monitoring. The system's functions are limited to transmitting messages about the state of the fire protection systems to the authorized organization.

Thus, the monitoring systems considered above transmit information about the state of fire protection systems to the authorized organization (fire and rescue department). In addition, several parameters are simply monitored, and their values do not affect the control of the facility's state.

This situation can be explained by two expert opinions dating back to the late 1980s; see [18]. According to Acad. Yu.A. Izrael, monitoring is a system of observations to identify state changes under human activities, which includes observation, assessment, and forecasting of the environment state and does not include quality management for the environment and human activities [19]. His opponent, Acad. I.P. Gerasimov defined monitoring as a system of control, assessment, and management of the environment, which must be purposeful, interconnected, and efficient [20]. Moreover, the efficiency of management-free monitoring may cause some problems (the redundancy and insufficiency of information, no demand for information, etc.). As for fire safety, we accept Gerasimov's viewpoint in this paper. The primary problem in fire safety management (like in the management of any organizational system) is to monitor the system's current state, i.e., understand the starting point of management.

According to this analysis, fire safety monitoring methods for facilities are at the initial stage of development. As a rule, the state of fire protection systems is monitored, and data on their triggering are transmitted to the operational services. This is due to the following factors: no indicator characterizing the facility's fire safety state and, consequently, no technical solutions to obtain the values of monitored parameters. Moreover, none of the systems considered above monitors organizational measures (the observance of fire safety codes). Meanwhile, see part 1 of the survey [1], it is one of the most frequent reasons for fire occurrence. At the current development stage, fire safety monitoring systems for facilities need more parameters than those related to the operability of fire protection systems. The latter systems are designed for situations following fire occurrence. In addition, none of the monitoring systems in fire safety has a decision support procedure to adjust the values of parameter(s) deviating from the nominal range.

Based on the above considerations, we concretize the term "monitoring" for the facility's fire safety. Let us introduce the following definition. Fire safety monitoring for a facility is a regular purposeful activity that includes (a) assessing the facility's fire safety state based on a set of characteristic factors (in particular, organizational and technical measures), (b) control of this state by determining any deviations of the parameter values from the nominal range, and (c) decision-making in the case of such deviations. Thus, a topical problem is to identify a set of factors determining the state of fire safety and establish the relationship between them and the degree of their influence on the entire facility's state.

2. STATE ASSESSMENT METHODS FOR SOCIO-ECONOMIC SYSTEMS: APPLICATION TO FIRE SAFETY

Let us consider the existing state assessment methods for socio-economic systems. We begin with several terms.

Fire safety is the state of a facility characterized by the ability to prevent fire occurrence and development and the impact of fire hazards on people and property.[1]

Fire safety codes are special social and (or) technical conditions established to ensure fire safety by federal laws and other normative legal acts of the Russian Federation as well as regulatory documents on fire safety.[2]

Fire safety measures are actions to ensure fire safety, including the implementation of fire safety codes.[2]

Fire prevention is a set of precautionary measures to eliminate the possibility of fires and limit their consequences.[2]

Thus, no term currently characterizes the fire safety state. We define it in the following way: the facility's fire safety state is a set of organizational, social, and technical factors that determine the facility.

The state of most systems in the first approximation can be described by a set of factors (parameters) affecting their operation. The state assessment problem reduces to determining such factors (parameters), establishing their functional relationship, and obtaining qualitative or quantitative metrics of the factors. Assessment means both the process and result of measurement [21]. In this study, we comprehend assessment as the result of measuring the current state of a system. Consider several research works devoted to state assessment.

In the previous section, mechanisms for assessing the safety of potentially hazardous facilities have been described. They involve the theory of active systems. Let us consider this technology in detail.

The integrated rating procedure of complex socio-economic systems [22] is based on a hierarchical representation of the goal tree. The main idea is to disaggregate the tree vertices using the dichotomy method [23], convoluting vertex pairs up in the hierarchy. This procedure considers both quantitative (measurable or calculated) indicators and qualitative ones determined through expertise.

The procedure includes the following steps.

Step 1. Choosing n directions to assess the facility's state.

Step 2. Dividing all directions into subgroup 1 (objective estimates that can be measured, calculated, etc.) and subgroup 2 (expert estimates).

Step 3. Forming a unified rating scale for all n directions.

Step 4. Determining local estimates for the directions in subgroup 2.

Step 5. Determining the object's characteristic indicators for each direction in subgroup 2.

Step 6. Developing a scale to recalculate the indicators (Step 5) into local ratings.

[1] Federal Law of the Russian Federation of July 22, 2008, No. 123-FZ "Technical Regulations on Fire Safety Codes."

[2] Federal Law of the Russian Federation of December 21, 1994, No. 123-FZ "On Fire Safety."

Step 7. Determining the significance of the indicators (Step 6).

Step 8. Measuring or calculating the indicators of subgroup 2 (Steps 5 and 7).

Step 9. Recalculating the indicators in subgroup 2 into local ratings.

Step 10. Determining the facility's local estimates for the directions of subgroup 1.

Step 11. Determining a pair of directions to convolute the local estimates into a generalized one.

Step 12. Forming convolution matrices for the pairwise comparison of the local and generalized estimates.

Step 13. Forming the facility's integrated rating.

This procedure yields the integrated rating of a complex socio-economic system (organization, project, etc.). It was used for fire safety problems in several publications.

For example, the author [24] adopted the theory of active systems and the integrated rating procedure to develop models and mechanisms of fire safety management in a region. Fire safety in a region was characterized by three criteria: injuries and deaths in fires and the amount of material damage. The criteria were assessed using the four-point rating scale. In addition, the level of fire safety in the Voronezh Region was also assessed: as discovered, the level of fire safety decreased by 3% from 1996 to 2001. An appropriate program was developed to improve it.

This approach was further developed in [25]. The author proposed models and algorithms for fire safety management based on regional development programs. The three fire safety indicators of the previous study were supplemented by the number of fires. However, it was excluded at the next step due to exceeding the admissible relation with other indicators. Obviously, the number of fires is the main indicator affecting the others (the number of deaths, injuries, and the amount of material damage).

The approaches [24, 25] were an attempt to assess the level of fire safety, but the results seem debatable: the number of deaths and injuries and the amount of material damage are unacceptable and rather rough criteria. They can be used to assess fire safety measures in the first approximation but not the fire safety level.

The considerations presented above lead to the following conclusions. Currently, the integrated rating procedure, proposed by Prof. V.N. Burkov [22], is a most developed tool to assess the state of complex socio-economic systems. This procedure is efficient enough and can be adapted to assess the facility's fire safety system. At the same time, when the number of state indicators increases or their structural relations change, the procedure should be repeated, including expert assessment. This procedure was used to assess the fire safety level. However, the corresponding results are not applicable to assess the facility's fire safety state. Thus, fire safety state assessment methods for facilities require development.

CONCLUSIONS

Concluding part II of the survey, we note the following:

- According to the analysis, fire safety monitoring methods for facilities are at the initial stage of development. As a rule, the state of fire protection systems is monitored, and data on their triggering are transmitted to the operational services. This is due to the following factors: no indicator characterizing the facility's fire safety state and, consequently, no technical solutions to obtain the values of monitored parameters. Moreover, none of the systems considered above monitors organizational measures (the observance of fire safety codes), one of the most frequent reasons of fire occurrence. At the current development stage, fire safety monitoring systems for facilities need more parameters than those related to the operability of fire protection systems. The latter systems are designed for situations following fire occurrence. In addition, none of the monitoring systems in fire safety has a decision support procedure to adjust the values of parameter(s) deviating from the nominal range.
- Currently, the integrated rating procedure, proposed by Prof. V.N. Burkov [22], is a most developed tool to assess the state of complex socio-economic systems. This procedure is efficient enough and can be adapted to assess the facility's fire safety system. At the same time, when the number of state indicators increases or their structural relations change, the procedure should be repeated, including expert assessment. This procedure was used to assess the fire safety level for a region only, and the set of indicators was quite debatable. However, the corresponding results are not applicable to assess the facility's fire safety state. Thus, fire safety state assessment methods for facilities require development.

Let us summarize the problems of managing the fire safety system of a facility. This research area faces several serious challenges and contradictions:

- The head of a facility (organization) is charged with ensuring fire safety (managing the fire safety system), a criminal liability is stipulated for violating fire safety rules. However, no methods and algorithms are provided to manage such systems.

- The community of engineers and researchers has developed many methods to assess the facility's fire safety. Due to their complexity, the head of a facility (organization) cannot apply them without appropriate professional training to assess the current state of the fire safety system and make managerial decisions.

- Usually, studies of fire safety systems are focused on the strategic levels (region, state). At the basic level of a facility, there are still no technologies for managing fire safety systems (including problem statements and solutions) like, e.g., in the book [21].

We believe that the starting point for resolving the challenges and contradictions is the following set of problems:

– Conceptualizing the states of the facility's fire safety system at different operation stages of the system;

– Developing a methodology for assessing the state of this system at different phases of the facility's lifecycle;

– Developing methods, models, and algorithms for managing the state of the facility's fire safety system at different phases of the facility's lifecycle;

– Developing decision support methods for the head of the facility (organization) to manage the fire safety system;

– Developing an information-analytical system to support fire safety system management.

These problems should be solved in real-time.

Acknowledgments. *The author is grateful to the reviewers for careful reading of the manuscript and helpful remarks.*

REFERENCES

1. Shikhalev, D.V., Problems of Managing the Fire Safety System of a Facility. Part I: Assessment Methods, *Control Sciences*, 2022, no. 1, pp. 2–14.
2. *Grazhdanskaya zashchita: monitoring* (Civil Defense: Monitoring), Puchkov, V.A., Ed., Moscow: the All-Russian Research Institute for Civil Defense and Emergencies, 2015. (In Russian.)
3. Chepikov, N.A., A Model, Method, and Algorithm to Process Social-Hygienic Monitoring Data of a Road Transport Network for Health Risk Management, *Cand. Sci. (Eng.) Dissertation*, Kursk, 2013. (In Russian.)
4. Parashchuk, E.A., An Automated Air Monitoring System as Information Support for Making Managerial Decisions, *Cand. Sci. (Eng.) Dissertation*, Belgorod, 2014. (In Russian.)
5. Noritsa, V.A., Information Support for an Infrastructure Monitoring System of a Research and Education Institution, *Cand. Sci. (Eng.) Dissertation*, Moscow, 2013. (In Russian.)
6. Belov, A.V., Raster Models and an Algorithm to Visualize Spatial Data in Monitoring Systems for Natural and Anthropogenic Disasters, *Cand. Sci. (Eng.) Dissertation*, Kursk, 2013. (In Russian.)
7. Mikov, D.A., Information Risk Management in Remote Monitoring Systems for the Facility's State, *Cand. Sci. (Eng.) Dissertation*, Moscow, 2018. (In Russian.)
8. *GOST* (State Standard) *22.1.12-2005: Safety in Emergencies. A Structured Monitoring and Control System for the Engineering Systems of Buildings and Installations. General Requirements*, Moscow: the All-Russian Research Institute for Civil Defense and Emergencies, 2005. (In Russian.)
9. *GOST* (State Standard) *56935-2016. Production Services. Services on Constructing a System to Monitor Automatic Fire Protection Systems and Signaling on the Centralized 01-112 Service Panel*, Moscow: the Public Fire Safety Ministry, 2016. (In Russian.)
10. *Istoriya sozdaniya i sovershenstvovaniya besprovodnykh sistem monitoringa* (History of Creation and Improvement of Wireless Monitoring Systems), Zikov, V.I., Ed., Moscow: State Fire Academy of EMERCOM of Russia, 2015. (In Russian.)
11. *Prometheus. The National Unified Analytical Fire Safety Control System for Buildings*. URL: https://fortespro.ru. (Accessed January 14, 2021.)
12. Tarakanov, D.V., Multicriteria Models and Methods to Support the Management of Fire Departments Based on Fire Dynamics Monitoring in a Building, *Dr. Sci. (Eng.) Dissertation*, Moscow, 2018. (In Russian.)
13. Mosyagin, A., Monitoring of Potentially Hazardous Facilities Based on Logical and Probabilistic Modeling, *Cand. Sci. (Eng.) Dissertation*, Moscow, 2009. (In Russian.)
14. Glushko, V.S., An Integrated Environmental Monitoring System for Fire Prevention on Oil and Gas Facilities, *Cand. Sci. (Eng.) Dissertation*, Moscow, 2014. (In Russian.)
15. Jiang, S., Zhu, S., Guo, X., Chen, C., and Li, Z. Safety Monitoring System of Steel Truss Structures in Fire, *Journal of Constructional Steel Research*, 2020, no. 172, pp. 1–11.
16. Li, Y., Yi, J., Zhu, X., Wang, Z., and Xu, F., Developing a Fire Monitoring and Control System Based on IoT, *Proceedings of 2nd International Conference on Artificial Intelligence and Industrial Engineering*, 2016, pp. 174–178.
17. Decree of the Government of the Russian Federation of August 8, 2005, No. 1314-r "On Approving the Concept of the Federal Monitoring System for Critical Facilities and (or) Potentially Hazardous Infrastructure Facilities of the Russian Federation and Dangerous Cargoes," Moscow, 2005. (In Russian.)
18. Rychikhina, E.N., *Monitoring kak obshchaya funktsiya upravleniya* (Monitoring as a General Management Function), Uhta: Ural State Technical University, 2008. (In Russian.)
19. Izrael', Yu.A., The Concept of Biosphere Monitoring, in *Monitoring sostoyaniya okruzhayushchei prirodnoi sredy* (Monitoring of the Environment), Leningrad: Nauka, 1977. (In Russian.).
20. Gerasimov, I.P., *Struktura nauchnogo issledovaniya: filosofskii analiz poznavatel'noi deyatel'nosti* (Research Structure: Philosophical Analysis of Cognition), Moscow: Mysl', 1985. (In Russian.)
21. Novikov, D.A., *Control Methodology*, New York: Nova Science, 2013.

22. Burkov, V.N., Gratsianskii, E.V., Dzyubko, S.I., and Shchepkin, A.V., *Modeli i mekhanizmy upravleniya bezopasnost'yu* (Models and Mechanisms of Safety Management), Moscow: Sinteg, 2001. (In Russian.)
23. Anokhin, A.M., Glotov, V.A., Pavel'ev, V.V., and Cherkashin, A.M., *Tselenapravlenyi vybor: modeli, otnoshenia, algoritmy* (Purposeful Choice: Models, Relations, Algorithms), Moscow: Trapeznikov Institute of Control Sciences RAS, 1996. (In Russian.)
24. Polovinkina, A.I., Models and Mechanisms of Optimal Fire Safety Management in a Region, *Cand. Sci. (Eng.) Dissertation*, Moscow, 2003. (In Russian.)
25. Kuzovlev, A.V., Fire Safety Management Models and Algorithms Based on Regional Development Programs, *Cand. Sci. (Eng.) Dissertation*, Moscow, 2014. (In Russian.)

This paper was recommended for publication by V.V. Kul'ba, a member of the Editorial Board.

Received July 19, 2021, and revised November 1, 2021.
Accepted November 22, 2021.

Author information

Shikhalev, Denis Vladimirovich. Cand. Sci. (Eng.), the State Fire Academy, the Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM), Moscow, Russia
✉ evacsystem@gmail.com

Cite this paper

Shikhalev, D.V. Problems of Managing the Fire Safety System of a Facility. Part II: Monitoring Methods. *Control Sciences* **2,** 2–8 (2022). http://doi.org/10.25728/cs.2022.2.1

Translated into English by *Alexander Yu. Mazurov*,
Cand. Sci. (Phys.–Math.),
Trapeznikov Institute of Control Sciences,
Russian Academy of Sciences, Moscow, Russia
✉ alexander.mazurov08@gmail.com