Analysis and Evaluation of Risks, Associated with Fires

M V Grafkina*, E V Safronova, T Kazikyan

Moscow Polytechnic University, 38, BolshayaSemenovskayast., Moscow, Russian Federation, 107023

E-mail: marina.grafkina@rambler.ru

Abstract. Industrial activity is associated with the appearance of emergency situations, which are one of the common types of fires. In accordance with the existing legislation an independent fire risk assessment has been introduced and applied. However, a great number of fires makes it relevant to find solutions for use different methods of risk analysis and assessment allows us to develop optimal management decisions for fire protection of industrial buildings for different purposes to decrease individual fire risks and running simulation and prediction of fire indicators. The article presents the results of using different methods of risk analysis and assessment to improve fire safety.

1. Introduction

Any industrial activity is associated with the appearance of emergency situations, which realization are depends of the types and conditions of economic activity [1-5]. Flames- one of the most common types of emergency situations. In 2017 in the Federal act of December 21, 1994 N 69-FZ "About fire safety" introduced such definitions such “independent assessment of fire risk” and “ an expert in fire risk assessment”. These changes are bonded with the introduction of a risk-based method. At the same time as a result of fires in manufacturing workers are perished and get injuries of various severity, buildings, constructions and various material values are destroyed, damage is caused to the environment by pollution of the biosphere and the destruction of various materials, that require subsequent restoration by involving additional natural resources in the resource cycle. For example, By the data from Ministry of emergency situations in Russia in 2018 were 132074 fires, which killed 7913 people, 9650 people were injured, and direct material damage overall amounted to 15913505 thousand rubles [6]. For this reason, additional analysis and assessment of risks associated with fires on the workplace, and development of optimal management decisions to reduce the risks is a very actual problem.

Methods and various techniques in determining risks, create an opportunity for effective risk control. Firstly, fire risks can be categorized as economic risks, individual risks for employees (risks of death and injury of employees as a result of fires), environmental risks.

There are different methods for risks evaluation [7-9]: statistical method, analytical method, adept assessment method and etc. The statistical method is founded on the analysis of statistical information for previous years. In our case, using this method it is possible to determine the major focus to prevent different types damage from fires. The analytical method help to simulate and predict the development of the situation with mathematical models, including for certain periods

2. Results and Discussion

To use the statistical method for the analysis and evaluation of risks associated with fires, were used the information of the official statistical collections "Fires and fire safety" [6]. For research, the information were grouped by:

- number of fires;
- number of victims;
- direct material damage;
- the objects of the fires.
Using this method, we conducted a comparative analysis of economic risk and an environmental risk (in terms of effect on material natural resources) according to direct material damage from fires in industrial buildings and warehouses.

![Figure 1](image1.png)

**Figure 1.** Direct material damage from fires on buildings of various applicability

Comparative analysis shows that the economic risks (direct material damage) from fires in warehouses exceeds the damage from fires in industrial buildings, sometimes several times. With the exception of 2012, when the rates of direct material damage were almost equal.

A comparative analysis of the risk of death in buildings of these categories for the period from 2015-2017 (figure 2) shows that the loss of life in industrial buildings is several times higher than the relevant indicator in fires in warehouses.

![Figure 2](image2.png)

**Figure 2.** The number of deaths in buildings of various applicability

Consequently, the results obtained allow us to propose different management decisions that will be optimal for taking fire-prevention measures in buildings of different purposes. In warehouses with very high risks of economic losses, it is necessary to automate the system of accounting and movement of goods, in order to isolate the workplaces of workers from the places of storage. Then it will be possible to apply different fire-fighting methods and means of fire extinguishing for protection and rescue of
people in case of fire. And also to increase efficiency of methods and means for protection of material values which are concentrated in warehouse premises. For example, for places of storage it is necessary to apply automatic gas installations of fire extinguishing with use of various inhibitors, and creation of high concentration of fire-extinguishing substances in rooms where presence of people is not provided.

In industrial buildings, where there is a high probability of death and injury of people as a result of fires, it is necessary to minimize the individual risks of death. We believe that it is most effective to analyze individual risks at the stage of design and reconstruction of production facilities [10], when it is possible to make changes in ventilation and smoke removal systems, design additional emergency exits, plan the placement of equipment and workplaces, etc. Each change will affect the conditions of development of fires in buildings and premises, and, accordingly, the amount of individual risk to the people working in them. To select the most optimal options, it is better to use modern software tools for calculating individual risks (analytical method that allows you to model and predict the development of different situations). We used the Fenix+ program, which allows us to determine the calculated value of individual fire risk at production facilities, as well as to simulate possible evacuation options and the development of negative fire factors over time, depending on different design conditions.

The program was entered such information as:
- schedule of production premises;
- the class of functional fire hazard;
- availability of automatic fire extinguishing systems;
- automatic fire alarm installations;
- warning and evacuation control systems;
- smoke protection systems;
- deployment of fire protection units;
- equipment with primary fire extinguishing means;
- emergency exit device;
- compliance of escape routes;
- time, which people spent in the building.

At the design and reconstruction stage, necessary changes can be made to improve the fire safety of industrial buildings and reduce the individual risks of death of workers during the spread of fires.

On the figure 3-6 shows graphs of changes in fire hazards as a function of time in different design scenarios, for example, changes in visibility and oxygen content in production facilities in the presence or absence of smoke removal systems in production facilities.

| Name       | Temperature | Visibility | $O_2$  | $CO_2$ | CO | HCl | Thermal flow | $t_{block}$ |
|------------|-------------|------------|--------|--------|----|-----|--------------|-------------|
| Door 10    | 40.69       | 21.17      | 40.98  | Not blocked | Not blocked | No data | Not blocked | 21.17       |
| Recorder 1 | 64.05       | 30.44      | 102.77 | Not blocked | Not blocked | No data | 10.60        | 10.60       |

**Figure 3.** The graph of visibility of time (in the absence of a smoke removal system)

On the graph of visibility of time (figure 3) in the absence of a smoke removal system, the critical visibility value is reached after 20 seconds, and after 40 seconds falls to a minimum. On the graph of visibility of time (figure 4) in the presence of a smoke removal system, it is seen that the critical value is reached after 70 C. Therefore, the installation of a smoke removal system allows to increase the time required for workers who find themselves in the production premises during the development of the fire had more time for orientation and evacuation through emergency exits. Our analysis of data on industrial accidents during fires shows that often the loss of orientation in poor visibility makes it difficult to
Evacuate. As preventive preventive measures, it is also necessary to periodically repeat the training and familiarization of workers with the layout of the building and escape routes, training should be built in such a way as to bring the skills of action in emergency situations to automatism.

| Name      | Temperature | Visibility | $O_2$  | $CO_2$ | $CO$ | $HCl$ | Thermal flow | $t_{\text{back}}$ |
|-----------|-------------|------------|--------|--------|------|-------|--------------|-----------------|
| Door 7    | Not blocked | 70.03      | Not blocked | Not blocked | Not blocked | No data | Not blocked | 70.03           |
| Door 8    | Not blocked | 75.14      | Not blocked | Not blocked | Not blocked | No data | Not blocked | 75.14           |
| Recorder 2| Not blocked | 137.53     | Not blocked | Not blocked | Not blocked | No data | Not blocked | 137.53          |
| Recorder 2.1 | Not blocked | 137.53    | Not blocked | Not blocked | Not blocked | No data | Not blocked | 15.49           |
| Recorder 2.2 | Not blocked | 110.60    | Not blocked | Not blocked | Not blocked | No data | Not blocked | 10.60           |

**Figure 4.** The graph of visibility of time (in the presence of smoke removal system)

In case of fire in the air of industrial premises, the oxygen content is reduced, at its concentration below 17%, a person may lose consciousness. As the maximum permissible value of the oxygen content is accepted value equal to 0.226 kg/m³. From the graph of the dependence of oxygen content on time (figure 5) it can be seen that in various scenarios in the absence of a smoke removal system, the oxygen concentration reaches a critical value after 40 seconds, and in the graph (figure 6) in the presence and operation in the production building of the smoke removal system, the time of reducing the oxygen content to a critical value in the air of production facilities is increased several times.

Thus, the use of smoke removal system allows workers who find themselves in the zone of occurrence and development of the fire to get life-saving seconds for evacuation from the danger zone.

As means providing protection of respiratory organs of the person during development of fires it is also necessary to apply individual means of protection of respiratory organs both isolating, and filtering types.

| Name      | Temperature | Visibility | $O_2$  | $CO_2$ | $CO$ | $HCl$ | Thermal flow | $t_{\text{back}}$ |
|-----------|-------------|------------|--------|--------|------|-------|--------------|-----------------|
| Door 10   | 40.69       | 21.17      | 40.98  | Not blocked | Not blocked | No data | Not blocked | 21.17           |
| Recorder 1| 64.05       | 30.44      | 102.77 | Not blocked | Not blocked | No data | 10.60        | 10.60           |

**Figure 5.** The graph of connectivity of oxygen content of time (in the absence of smoke removal system)

The analytical method can also be used to model and predict for a given period the number of fires, the number of people affected by fires, changes in indicators of direct material damage, etc.

For modeling, determining the laws of the trend line and the value of the reliability of the approximation, as well as to predict changes in indicators in given periods, we used the possibilities presented by the program Microsoft Excel. The simplest mathematical models of the trend, widely used in the analysis of time series in Excel, are the following models:
- linear;
- logarithmic;
- polynomial;
- power-law;
- exponential.

| Name        | Temperature | Visibility | $O_2$  | $CO_2$ | $CO$  | $HCl$  | Thermal flow | $t_{\text{max}}$ |
|-------------|-------------|------------|--------|--------|-------|---------|--------------|-----------------|
| Door 7      | Not blocked | 70.03      | Not blocked | Not blocked | Not blocked | No data | Not blocked | 70.03           |
| Door 8      | Not blocked | 75.14      | Not blocked | Not blocked | Not blocked | No data | Not blocked | 75.14           |
| Recorder 2  | Not blocked | 137.53     | Not blocked | Not blocked | Not blocked | No data | Not blocked | 137.53          |
| Recorder 2.1| Not blocked | 137.53     | Not blocked | Not blocked | Not blocked | No data | 15.49       |
| Recorder 2.2| Not blocked | 110.60     | Not blocked | Not blocked | Not blocked | No data | Not blocked |                |

**Figure 6.** The graph of connectivity of oxygen content of time (in the presence of smoke removal system)

For modeling indicator of material damage the relative value characterizing material losses in monetary terms per unit of fire was calculated. (thousand rubles / unit of fire). The approximation for the period 2006-2011 was carried out using a polynomial model of the second degree. Analysis of the trend of material damage shows that in recent years there has been an increase in material losses, which can be explained including inflation and changes in the value of lost material resources and the saturation of buildings with expensive equipment. Prediction due to the small previous time series was carried out for one year. It should be noted that the reliability index of the approximation R2 is not high enough for industrial buildings, it is 0.7080, and for warehouses the indicator is high enough and is equal to 0.9015.

**Figure 7.** Modeling and prediction indicators of material damage in case of fires in industrial premises
Our experience in modeling and forecasting trends in the change of fire indicators such as: the number of fires, direct material damage characterizing losses in fires, the number of dead (injured) in fires using Microsoft Excel shows that the choice of indicators from statistical collections as initial statistical data does not allow to use this method to the full extent. The data presented in the compilations for the reporting period also contain figures for the previous four to five years, but they are not correlated with those of the previous compilations. In future studies, it is planned to search for statistical data from other sources. Promising in this direction, we think the data on various sectors of activity.

3. Conclusion
Fire safety is one of the main conditions for the safe operation of industrial buildings and structures. Fires at industrial facilities carry economic, environmental losses, the probability of death and injury of people. Reduce losses will help analysis and assessment of risks associated with fires, which allow you to identify additional reserves of enterprises to optimize management decisions to prevent emergency situations and reduce their negative consequences. It is especially effective for the analysis and assessment of risks associated with fires to use modern software that allows you to consider a variety of alternatives and determine the most effective scenario to improve the fire safety of production facilities.

References
[1] Jonathan Wahlqvist, Patrick van Hees. Influence of the built environment on design fires. // Case Studies in Fire Safety Journal, V. 5, May 2016, P. 20-33.
[2] Nakagawa Y. Recent development of flame retardant polymeric materials containing expandable graphite // Bulletin of Japan association for fire science and engineering, V. 56, 2006, P. 37-43.
[3] Rafi M.M., Aziz T., Lodi S.H. Mechanical properties of low-strength concrete at exposure to elevated temperatures // Journal of Structural Fire Engineering. V. 8, 2017, № 4. P. 418-439.
[4] Margrethe Kobesa, Ira Helsloot, Bauke de Vries, Jos G. Posta Building safety and human behaviour in fire // Fire Safety Journal, V. 45, Issue 1, January 2010, P. 1-11.
[5] E. Ronchia, F. Nieto, Uriz, X. Criel, P. Reilly. Modelling large-scale evacuation of music festivals // Case Studies in Fire Safety, V. 5, May 2016, P. 11-19.
[6] Fire statistics for 2018 year. Statistical compilation: Fires and fire safety in 2018. Under the General editorship Gordienko D. M.-M.: VNIIPo, 2019
[7] Jing Xin, Chongfu Huang Fire risk analysis of residential buildings based on scenario clusters and its application in fire risk management // Fire Safety Journal, V. 62, Part A, November 2013, P. 72-78.
[8] Brian J. Meacham Decision-Making for Fire Risk Problems: a Review of Challenges and Tools // Journal of Fire Protection Engineering, V. 14, 2004, First Published May 1, P. 149-168.
[9] Bhargava A., Van Hees P., Husted B., Junior A.R., Neumeister C. Performance analysis of a heat transfer and sub-grid chemical reaction distributed activation energy model for fire simulations // Journal of fire sciences, V. 37, 2019, № 1, P.: 18-46.

[10] Grafkina M.V., Sviridova E.Y., Sdobnyakova E.E. Improving ecological performance of design processes accounting for product life cycle // European Research Studies Journal. 2017. V. 20. № 2, P. 294-307.