# Risk assessment methodology within the framework of integrated safety of industrial enterprises

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**Abstract.** The article outlines consolidated research areas that bring risk assessment results into the integrated safety of industrial enterprises. The author compares currently used methods for assessing *industrial safety, fire safety, and occupational safety* subsystems, included in the system of integrated safety of industrial enterprises, and a new method for assessing integrated safety. Three tasks must be solved to make industrial enterprises safer. To solve the first task, scientific research results, currently applied in Russia and worldwide, were analyzed. The conclusion is that the damage from hazardous events can be reduced using a reasonable safety margin, required to reduce (eliminate) various risks, the rational application of the safety margin using the approach stemming from a new vision of risks. When the second task was solved, current methods of assessing subsystems of industrial safety, fire safety, and occupational safety, included in the system of integrated industrial safety, were compared with a new technique used to assess integrated safety. The objective of the third task was to present a formalized description of a new model for improving and developing an integrated safety system for explosive and flammable production facilities. The purpose of risk assessment is formulated; new integrated safety assessment methods and results are presented. As a result, the three above-mentioned tasks are solved, and the conceptual model of an integrated safety system is developed for Russian industrial enterprises.

## 1 Introduction

The statistics of accidents and fires at explosive and flammable production facilities (hereinafter - EFPF) shows that each year combined hazardous events (accidents and fires) reach about 20% of the total number of accidents there. The damage from such events reaches about 46% of the total damage from accidents; combined hazardous events cause sanitary and irrecoverable losses to personnel and third parties [1-5]. *Explosion and fire hazards* at such facilities, which are understood as *the state of the facility characterized by the possibility of an explosion and fire or the occurrence of fire and subsequent explosion* are the conditions that can cause several types of damage (material and economic damage, calculated in *rubles*; casualties, also known as sanitary and irrecoverable losses, calculated

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in *units*). Such EFPFs include operating facilities engaged in the production, processing, transportation and storage of hydrocarbons, for example, at Russian oil and gas processing enterprises. A characteristic case of substantial damage from combined hazardous events (accidents and fires) encompasses conditions for a fire or an explosion at a hydrocarbons processing facility, further secondary explosion or fire, followed by the facility destruction and the spill of large volumes of hydrocarbons (hydrocarbon gases) over the area of the facility [6-8].

The author considers those hazardous events (*accidents combined with fires*), as a result of which damage (whether economic, material, or social) was caused to the following three subsystems: an industrial safety subsystem (hereinafter - *InS*); a fire safety subsystem (hereinafter - *FS*), and an occupational safety subsystem (hereinafter - *OS*).

The purpose of the article is to present a methodology for a risk-oriented approach to integrated safety (hereinafter - IS) management at EFPFs. The following tasks are to be solved to achieve the pre-set purpose:

1. Analyzing current methods of IS assessment at EFPFs; identify consolidated areas of research that demonstrate valuable research findings.
2. Considering risk assessment methods applied in industry-specific subsystems (InS; FS; OS), taking into account any contradictions that may arise; outlining a new focus for improving and developing IS systems at EFPFs, or formulating new methods (a new group of methods) of further research that may bring results of international significance.
3. Devising a model for demonstrating comparative results of current developments used in practice; presenting a conceptual model capable of bringing existing IS systems at EFPFs to a totally new level.

## 2 Analysis of fundamental areas for improving and developing integrated safety at industrial enterprises

Fundamental documents governing the vital activity of Russia, including its essential industrial infrastructure, include *National Security Strategies of the Russian Federation, approved by Decrees of the President of the Russian Federation*[2], which govern the development of comprehensive actions towards their implementation.

The outcome of a research project on IS problems, solved using the risk-oriented approach at industrial facilities, is consolidated areas of research that demonstrate valuable research findings (figure 1).


[2] Decree of the President of the Russian Federation № 1666 issued on 02.07.2021 On National Security Strategy of the Russian Federation; Decree of the President of the Russian Federation № 400 issued on 19.12.2012 On the Strategy of the State National Policy of the Russian Federation for the Period through 2025.

**Figure 1.** Findings used to solve problems of integrated safety management at industrial facilities

Research Area 1 (see Figure 1) considers theoretical fundamentals and their connection with the risk-oriented methodology and its implementation to ensure the IS of industrial enterprises; the following fundamental principles are formulated:

- using fundamental principles of risk analysis $R(\tau)$ in the three principal areas of vital activity (social (*N*), natural (*S*) and technogenic (*T*) activities), conducted as a single complex socio-natural-technogenic system of humans-nature-infrastructure during time τ [9, p. 228]

$$R_{(\tau)} = F_R\left\{R_N(\tau), R_S(\tau), R_T(\tau)\right\}; \quad (1)$$

- developing a generalized model of risk assessment at industrial facilities that demonstrates changes, triggered by the factor values of risks *R(τ)*, or probabilities *P(τ)* of dangerous events (accidents, fires, emergencies) and respective damage (economic damage, assessed in *rubles*; social damage assessed in the *number of people injured, killed, also known as casualties*). These types of damage are related to the main spheres of life, including the social sphere (*N*), the natural sphere (*S*), and the technogenic sphere (*T*), that make up a single complex system, consisting of humans-nature-infrastructure, during time $t$ [9, p. 228].

$$R_{(\tau)} = F_R\{P(\tau), U(\tau)\}; \quad (2)$$

$$R_{(\tau)} = F_R\{P(\tau), U(\tau)\}; \quad (3)$$

$$U_{(\tau)} = F_U\{U_N(\tau), U_S(\tau), U_T(\tau)\}; \quad (4)$$

- drafting scenarios of events, occurring in a complex system, and making a quantitative assessment of risks $R(\tau)$, using parameters of principal triggers and destructive factors of dangerous energies $E(\tau)$, substances $W(\tau)$, and information flows $I(\tau)$ [9, p. 228]

$$R_{(\tau)} = F_R\{E(\tau), W(\tau), I(\tau)\}; \quad (5)$$

- complying with the fundamental requirement concerning the non-exceedance of acceptable risks by calculated values of risks (formulas 1-5) in the process of implementing a risk-oriented approach [9, p. 228].

$$R_{(\tau)} \leq \left[R_{(\tau)}\right], \text{ where} \quad (6)$$

$\left[R_{(\tau)}\right]$ is the parameter that has a limit value of an assessed acceptable risk. Applicable regulations (RLA, or regulatory legal acts, and RD, or regulatory documents) of the Russian Federation set the limit value of an assessed risk.

Researchers from the Russian Academy of Sciences formulated the fundamental substantiation of acceptable risks $\left[R_{(\tau)}\right]$, whose calculated value is identified using the following equation [9, p. 229]

$$R_{(\tau)} = \frac{R_c(\tau)}{n_R}, \text{ where} \quad (7)$$

$R_c(\tau)$ is the threshold value of risk (critical, limit risk);

$n_R$ is the value of the safety margin used to reduce (eliminate) the risk considered above. The principle of choosing the reasonable *rational safety margin is sufficiency of compensatory actions aimed at reducing (eliminating) risks* (Figure 2).

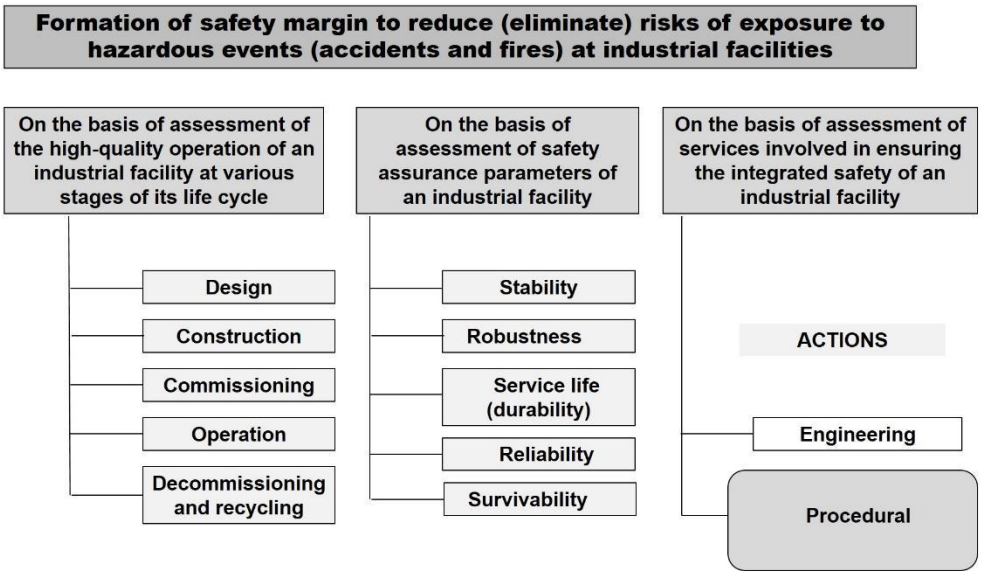


**Figure 2.** Assessment of factors, affecting the safety margin needed to reduce (eliminate) risks

The key approach to reducing damage from the impact of hazardous events encompasses a reasonable safety margin designed to reduce (eliminate) various risks. Obviously, the safety margin to be analyzed will be based on its application in different areas and considered using versatile methods of analysis in relation to risk (Figure 2).

## 3 Existing and new proposed methods of risk assessment in the field of integrated safety of industrial enterprises

In the course of solving the problem, it was necessary to (1) provide information describing approaches and techniques used in practice, (2) provide more information about Research Areas 2 and 3 (see Figure 1). Methods[3], including risk assessment procedures (recommendations) applicable by production facilities, were used to assess the risks arising within subsystems (InS, FS, OT). Information about the results of analytical comparison is provided in *Table 1*.

**Table 1.** Comparison between (1) risk assessment methods used to ensure the practical integrated safety of industrial enterprises and (2) new methods substantiated and proposed by the author of the article to obtain new results

[3] Order № 387 issued by Federal Environmental, Industrial and Nuclear Supervision Service of Russia on 03.11.2022 On Approval of Safety Guidelines Titled Methodological Fundamentals for Hazard Analysis and Accident Risk Assessment at Hazardous Production Facilities; Order № 404 issued by the EMERCOM of Russia (Ministry of the Russian Federation for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters) on 10.07.2009 On Approval of the Methodology for Determining Estimated Fire Risk Values at Production Facilities; Order № 929 issued by the Ministry of Labor of Russia on 28.12.2021 On Approval of Recommendations for Selecting Methods of Assessing Occupational Risk Levels and Reducing Levels of Such Risks.

| **Methods of risk assessment within the framework of integrated safety of industrial facilities** | | | |
|---|---|---|---|
| In the field of industrial safety | In the field of fire safety | In the field of occupational safety | Original methods proposed by E.V. Gvozdev |
| *Methods belonging to the group of logical-graphical methods* | | | |
| Event Tree Analysis; Failure Tree Analysis; "What - If" method | Logical event trees | Scenario Analysis; Decision Tree Analysis; Structured What-If Method (Swift) | Bayesian Trust Networks (BTN) method |
| *Methods belonging to the group of expert analysis methods* | | | |
| Check-List; Hazard and Operability Analysis (HOA); HAZID (Hazard Identification) method | - | Checklists; Bow-tie analysis; HAZOP (Hazard and Operability Study) method. | Analysis of hierarchies and pairwise comparisons method (MAI) |
| *Methods belonging to the group whereby characteristics are calculated using individual weighting coefficients* | | | |
| Failure Type and Consequence Analysis (FTCA); Safety actions analysis; quantitative accident risk assessment | Determining the time of blocking evacuation routes in case of fire; determining the estimated evacuation time | Cause-effect analysis; matrix method based on scoring; LOPA layers of protection analysis; HRA (Hyman Reliability Assessment); occupational disease risk assessment; cost effectiveness analysis (cost-benefit analysis) | Method of complex numbers (Symb method) |

The table presents consolidated groups of methods used in the subsystems (InS, FS, OS). Their practical application allows obtaining results in the form of final (qualitative or quantitative) estimated risk values.

## 4 Results obtained using existing and new methods of risk assessment within the framework of integrated safety of industrial enterprises

Comparative results of the practical application of methods were obtained in the format of final (qualitative or quantitative) estimated risk values (Table 2).

**Table 2.** Comparative results of final estimated risk values obtained in the course of risk assessment within the framework of integrated safety of industrial facilities

| ***Results of risk assessment within the framework of integrated safety of industrial facilities*** | | | |
|---|---|---|---|
| In the field of industrial safety | In the field of fire safety | In the field of occupational safety | Results obtained using methods proposed by E.V. Gvozdev |
| *Results presented as qualitative values* | | | |
| Risk prioritization based on categorization of hazards from accidents, *risk priority value (1;2;3)* | - | + | Prioritization of risk based on a general ranked list, *the value* |

| | | | |
|---|---|---|---|
| Risk values ranging from negligible to higher than acceptable risk, *risk value (A; B; C; D)* | | + | *of the risk priority (1;2;...; n) depends on damage* |
| Risk values with criticality of deviations, *risk value (high; medium; low)* | | + | |
| *Results presented as quantitative values* | | | |
| Risk values of the frequency of depressurization of engineering pipelines, *risk value* $10^{-n}/year$, *where n is a power value* | + | - | Risk values for the value of cause and effect relationships, *risk value of the probability of implementation (1-100%)* |
| Risk values of damage to people, *risk value of the probability of implementation* (1-100%), *risk value* $10^{-n}/year$, *where n is a power value.* | Risk values needed to determine the estimated evacuation time, *risk value (min.)* | - | Risk values based on the calculation of the impact factor of services, *risk value (0,001-0,475)* |

## 5 Discussion

Domestic and foreign experience should be applied to develop a risk-oriented approach to IS management at enterprises [10-21], and a new improved area of risk assessment must be developed using the obtained knowledge. In other words, risk must be considered from a different perspective. The proposed risk assessment model, designed for EFPFs, is provided in Figure 3. The model is considered not as a model, having the same evaluation criteria; rather, it allows analyzing unexplored risks, to develop a new research and methodology vehicle (models, methods, techniques) for its practical application to proceed to the development of IS systems that are currently in operation at EFPFs.

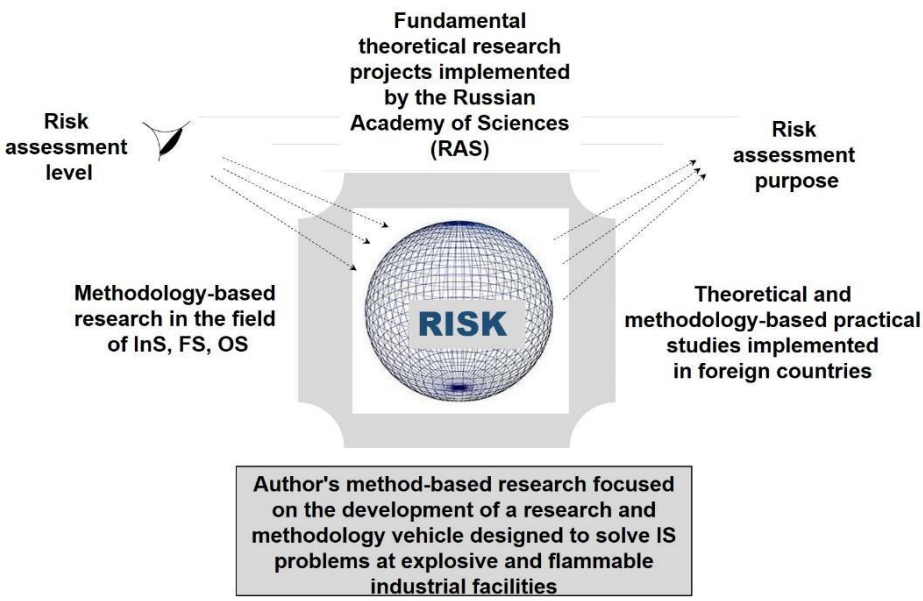

**Figure 3.** Choice of the area for assessing the risks to be reduced (eliminated) by using the safety margin designated to do away with hazardous events (accidents and fires)

The conceptual model of IS (integrated safety) system development at EFPFs (explosive and flammable industrial facilities of enterprises) is presented in Figure 4 [8].

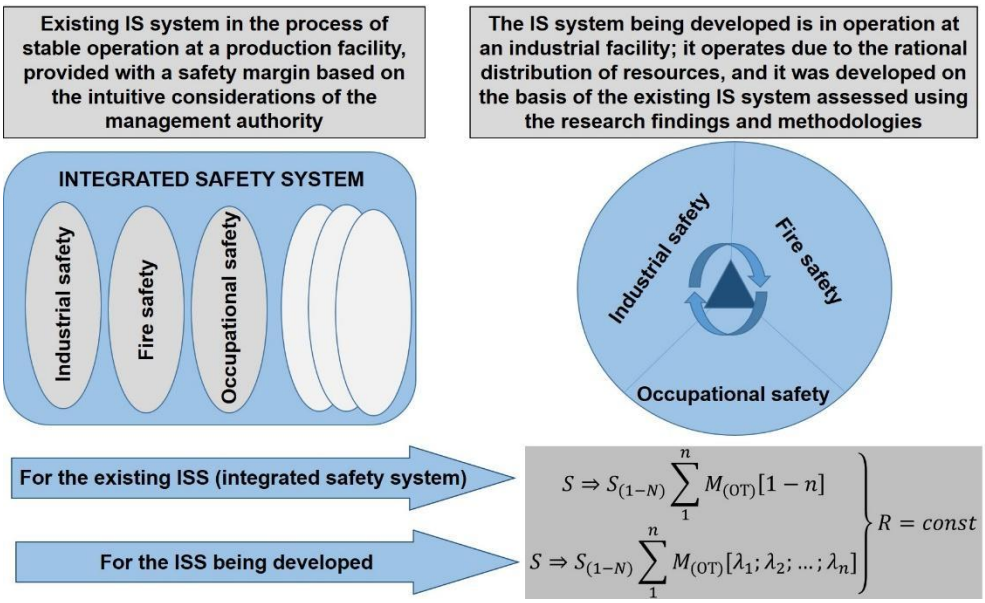


**Figure 4**. Conceptual model of IS system development at EFPFs

The model, designed for existing and future ISSs (integrated safety systems) at EFPFs, is based on (see Figure 4) a system of equations:

$$S \Rightarrow S_{(1-N)} \sum_{1}^{n} M_{(OT)}[1-n] \; S \Rightarrow S_{(1-N)} \sum_{1}^{n} M_{(OT)}\left[\lambda_1; \lambda_2 \dots \lambda_n\right] \} R = const, \text{ where} \quad (8)$$

$S$ is the IS system at EFPF;

$S_{(1-N)}$ are subsystems (InS, FS, OS, etc.) included in the IS system at EFPF;

$M_{(OT)}[1-n]$ are procedural and engineering actions (presented as a general ranked list) implemented in furtherance of intuitive considerations of the EFPF authority responsible for the ISS management;

$M_{(OT)}\left[\lambda_1; \lambda_2 \dots \lambda_n\right]$ are procedural and engineering actions (presented as a general ranked list with a weighting coefficient) implemented using the proposed research findings and the methodology.

The research finding is that the presented model (see figure 4) has limited resources for an IS system at an EFPF, which means a limited ability of an industrial facility to meet the need for the safety margin as requested by directors of departments, or supervisors of activities (InS, FS, OS).

The bottom expression in equation (8) confirms the need to develop the ISS at EFPFs, as well as to obtain advanced research findings and a methodology for the formation of the safety margin needed to deal with dangerous events (accidents and fires), and, hence, to maintain and develop the subsystems (InS, FS, OS).

## 6 Conclusions

1. The most recent achievements in the assessment of ISs at EFPFs are analyzed. Consolidated research areas, featuring respective research findings, are identified.
2. Methods used to assess risks in industry-specific subsystems (InS, FS, OS) are presented. Contradictions are taken into account to improve and develop a new research area for IS systems at EFPFs. Hence, the author defines new methods (group of methods) for further research that will generate research results of international significance.
3. The model allowing for the comparative analysis of practical findings is developed; the conceptual model that may bring existing IS systems at EFPFs to a new qualitative level of development is presented.

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