DEVELOPMENT OF AN INTEGRATED SAFETY SISTEM FOR PRODUCTION FACILITIES: THE PROBLEM STATEMENT AND THE PROPOSED SOLUTION

Evgeny Gvozdev

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Moscow State University of Civil Engineering
evgvozdev@mail.ru

Abstract

The article focuses on explosion and fire hazards at production facilities of enterprises where flammable liquids and gases, categorized by explosion and fire risks, are processed, handled, transported, and stored. The goal to be attained and the tasks to be solved towards this end are formulated in the article. Consolidated areas of knowledge, accumulating results of research into risk assessment within systems of integrated safety implemented at production facilities, are considered by the author. A model for development of a novel set of research and methodological instruments (methods, techniques, software and hardware) is presented for its further practical application. The problem of developing integrated safety systems for industrial facilities, posing explosion and fire hazards, as well as the solution, are presented by the author for the first time. The novelty of the solution lies in the computation of validity of the practical application of a novel set of research and methodological instruments. A reduction in damage from accidents and fires at production facilities is demonstrated. Ultimately, the socio-economic problem of reducing damage from accidents and fires is solved not only by Russian production facilities, but also by government agencies, including the EMERCOM of Russia (Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters), Ministry of Labor and Social Protection of Russia, and Federal Environmental, Industrial and Nuclear Supervision Service of Russia.

Keywords: risk, explosion and fire hazard, integrated safety, integrated safety system, development model, target model

I. Introduction

Analysis of statistics on accidents and fires at production facilities shows that the share of combined hazardous events (accidents and fires) reaches about 20% of the total number of accidents. Damage from combined events reaches about 46% of the total damage from accidents. Such events may cause injuries and fatalities to in-house personnel and third parties [1-3]. *Explosion and fire hazards arising* at production facilities are understood as *the state of a facility characterized by the possibility of an explosion or a fire or, alternatively, the occurrence of fire followed by an explosion*[1]. These are the conditions for several types of damage (material and economic damage, calculated in *rubles*; injuries and fatalities, calculated in *units*). Production facilities posing fire and explosion risks (hereinafter -

[1] Federal Law No. 123-FZ of 22.07.2008 Technical regulations on fire safety requirements.

PFPFER) are enterprises where flammable liquids and gases are processed, handled, transported, and stored. Such production facilities are categorized by explosion and fire risks[2]; they are categorized according to computations made for production premises and buildings.

Substantial damage deals with combined hazardous events (accidents and fires) resulting from conditions triggering a fire or an explosion at a hydrocarbon processing facility. Thereafter, a secondary factor of explosion or fire is in place, and eventually large volumes of hydrocarbons (hydrocarbon gases) cause destruction and spread over the territory of a production facility (a gas spill). [4]. The article focuses on several types of damage (*economic, material, and social damage*) to the following three subsystems: the occupational safety subsystem (hereinafter - *OS*); the industrial safety subsystem (hereinafter - *InS*); the fire safety subsystem (hereinafter - *FS*), included in the integrated safety system (hereinafter - ISS) at PFPFER. The ISS at PFPFER should be understood as a set of interacting industry-wide subsystems (OS, InS, FS) needed to protect personnel, property, equipment and environment from accidents and fires. Integrated safety (hereinafter - IS) at PFPFER should be understood as industry-wide subsystems (OS, InS, FS) characterized by preventability of hazardous events (accidents and fires) that can damage the assets to be protected. According to item 15 of Article 2 of Federal Law 123-FZ of 22.07.2008 titled Technical fire safety regulations, assets to be protected are products owned by natural persons or legal entities, government agencies or municipalities (including property items located in settlements, as well as buildings, structures, vehicles, process plants, equipment, assemblies, products and other property), that are subject to FS requirements for fire prevention and protection of people in case of fire.

Reduction (elimination) of different types of damage depends on the availability of the required safety margin (figure 1), whose design value is determined using the following equation [5]

$$R_{(\tau)} = \frac{R_C(\tau)}{n_R}, \text{ where} \quad (1)$$

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

n_R is the safety margin value required to reduce (eliminate) the risk.

The *safety margin* is understood as a set of factors characterized by the sufficiency of actions required to solve problems arising as a result of dangerous events (accidents and fires).

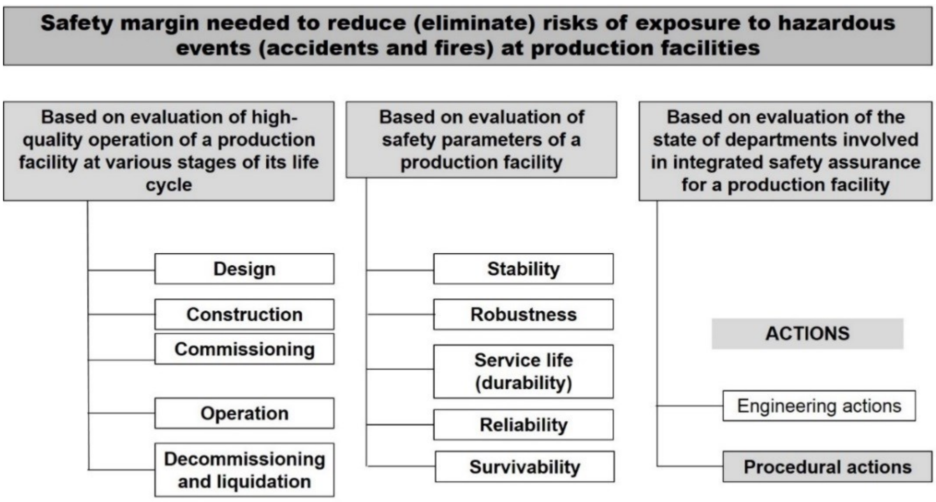

Figure 1: *Clustered focus areas for evaluation of factors affecting the safety margin needed to reduce (eliminate) risks*

[2] Code of Regulations CR 12.13130.2009 Categorization of premises, buildings and outdoor installations by explosion and fire hazards

The key idea aimed at reducing damage from hazardous events is to ensure the availability of a well-grounded safety margin designed to reduce (eliminate) various risks. Obviously, various applications and relationships determine the nature of the safety margin.

The focus areas listed above are highly relevant. The author conducted an analytical study to develop well-grounded solutions pre-compared with other well-known actions[3] aimed at improving the ISS at PFPFER to meet the principal requirement of point 10, Resolution 842, issued by the Government of the Russian Federation on September 24, 2013 “On Procedure for Awarding Academic Degrees".

II. 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*[4], 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 2).

Figure 2: *Findings used to solve problems of integrated safety management at industrial facilities*

Research Area 1 (see Figure 2) 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 [6]

$$R_{(\tau)} = F_R\{R_N(\tau), R_S(\tau), R_T(\tau)\}: \quad (2)$$

- developing a generalized model of risk assessment at industrial facilities that demonstrates changes, triggered by the factor values of risks $R(\tau)$, or probabilities $P(\tau)$ 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

[3] URL:https://docs.cntd.ru/document/499047147 (Date of access: July 1, 2023)
[4] 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.

technogenic sphere (T), that make up a single complex system, consisting of humans-nature-infrastructure, during time t [6].

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

$$R_{(\tau)} = F_R\{P(\tau), U(\tau)\}; \quad (4)$$

$$U_{(\tau)} = F_U\{U_N(\tau), U_S(\tau), U_T(\tau)\}: \quad (5)$$

- 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 $I(\tau)$ [7]

$$R_{(\tau)} = F_R\{E(\tau), W(\tau), I(\tau)\}: \quad (6)$$

- complying with the fundamental requirement concerning the non-exceedance of acceptable risks by calculated values of risks (formulas 2-6) in the process of implementing a risk-oriented approach [8].

$$R_{(\tau)} \leq \left[R_{(\tau)}\right], \text{ where} \quad (7)$$

$\left[R_{(\tau)}\right]$ 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]

$$R_{(\tau)} = \frac{R_C(\tau)}{n_R}, \text{ where} \quad (8)$$

$R_c(\tau)$ 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 3).

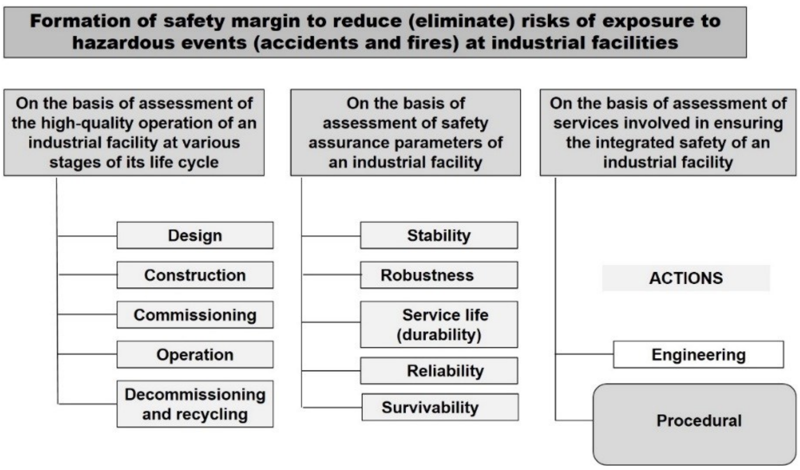

Figure 2: *Assessment of factors, affecting the safety margin needed to reduce (eliminate) risks*

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 risks (Figure 3).

III. 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 build awareness of approaches and techniques used in practice, as well as to provide more information about Research Areas 2 and 3 (see Figure 1). Methods[5], 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 risk assessment methods, used to ensure practical integrated safety of industrial enterprises, and new methods, proposed and substantiated by the author of the article*

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)

[5] 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.

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.

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 of the risk priority (1;2;...; n) depends on damage*
Risk values ranging from negligible to higher than acceptable risk, *risk value (A; B; C; D)*		+	
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)*

IV. Purpose of the study

The purpose of the study is to substantiate the adequate practical use of a novel set of research and methodological instruments developed by the author and to make sure that the socio-economic effect of its application is higher than that of the ISS that are currently used by PFPFER, in other words, to confirm the feasibility of new methods (groups of methods) to be used to assess risks arising within this system. In this case, the assessment process will be based on the practical data backed by the experiments.

To achieve this purpose, the author employed a methodology comprising the awareness of procedures, whose core elements are *methods and methodology, contributed to the set of research and methodological instruments,* used to solve problems of research and practice [10]. The following tasks were to be solved:

1. Presenting the statement of and the proposed solution to the problem of the future development of ISS at PFPFER.
2. Presenting the case justifying the adequacy of this solution to confirm the practical applicability of the proposed set of research and methodological instruments.

Below is a model for selecting a new risk assessment methodology required to develop ISS at PFPFER (figure 4).

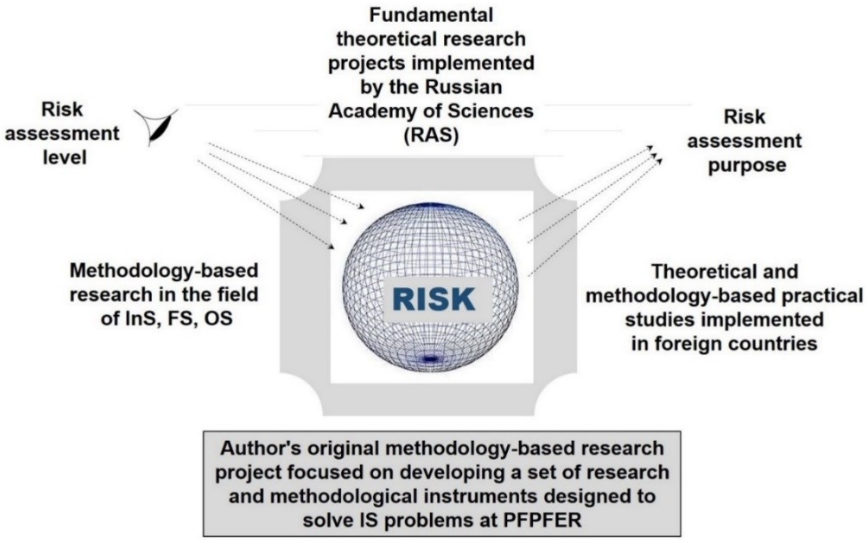

Figure 4: *Development model required for risk assessment at PFPFER*

The proposed model (see figure 4) is not considered as a model with the same assessment criteria. It allows looking beyond the horizon of unexplored risks, developing a new set of research and methodological instruments (models, methods, techniques) for practical use. Each new solution to a research problem has new features added to research and methodological instruments (for example, a solution to the new formulation of a problem can result in a new solution to this problem) [11]. It will open the way for a transition to development of ISS that are currently in operation at PFPFER enterprises.

V. Formulating and solving the problem of ISS development at PFPFER enterprises

The prospective development of ISS at PFPFER enterprises requires a safety margin composed of various resources (financial, material, information, energy, labor, and other types of resources) to be contributed to subsystems (OS; InS; FS) to reduce (eliminate) risks [12]. Figure 5 has a block scheme of the safety margin.

Given that material, economic, labor, time, information, and other resources are the main constituents of the corporate safety margin for enterprises under consideration, identification of the nature and extent of risks and coordination of subsystems (OS, InS, FS) support, adjustable to ensure the highest socio-economic effect, is a challenging task [13 – 21].

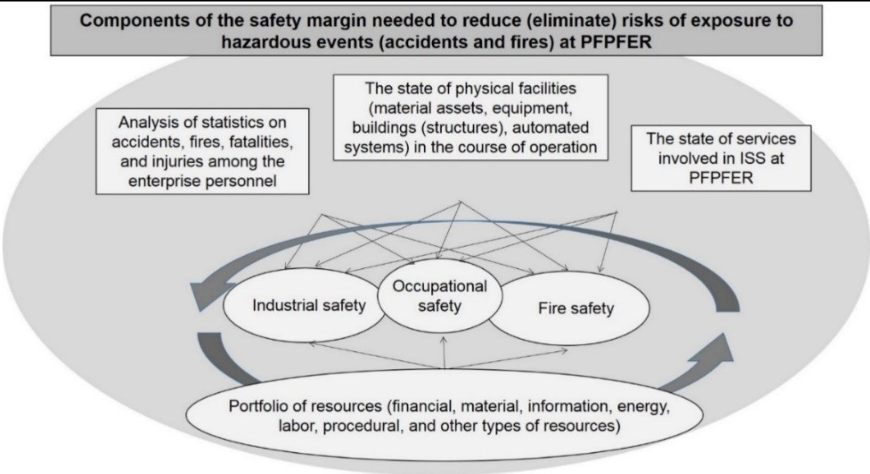

Figure 5. *The block scheme of the safety margin needed to reduce (eliminate) risks of damage from hazardous events (accidents and fires) at PFPFER enterprises*

Problem formulation. Assume that management teams of the enterprises under consideration make a decision to develop ISS at PFPFER or to bring its operation to a new qualitative level within a pre-set period of time. The management of these enterprises identifies a transition period, including the initial point of reference (t_0) and the point of goal achievement (t_1), included in the following model:

$$\sum_{i=1}^{N} P_{\varphi_{n1}}(t_0) \rightarrow \sum_{i=1}^{N} P^*_{\varphi_{n2}}(t_1), \tag{9}$$

where $P_{\varphi_{n1}}(t_0), P^*_{\varphi_{n2}}(t_1)$ are values, describing the state of subsystems (OS, InS, FS) at the beginning and at the end of the transition period;
$n_1; n_2$ are values of resources calculated for the initial point of reference (t_0) and the point of goal achievement (t_1).
If these values change and became equal to $P^*_{\varphi_{n2}}(t_1)$ during period (t_1), total changes will be calculated as follows:

$$\sum_{i=1}^{N} \left| P^*_{\varphi_{n2}}(t_1) - P_{\varphi_{n1}}(t_0) \right| = \Delta(t_1), \tag{10}$$

where $\Delta(t_1)$ is the total difference in changes for all values over period t_1;
| ... | is the sign showing the modulus of a number.
The task is to substantiate calculations of efficiency of the practical application of a set of research and methodological instruments and to demonstrate a reduction in damage to subsystems under consideration.
Solution. If the total difference $\Delta(t_1)$ showing changes in all values during period t_1 is available, the value of the development change $У(t_1)$ at the point of goal achievement (t_1) can be calculated using the following formula:

$$У(t_1) = \frac{\Delta(t_1)}{E_n}, \tag{11}$$

where E_n is the efficiency of the volumetric contribution of resources to $(1 - N)$ industry-focused subsystems (OS, InS, FS). It is the value whose calculation needs hundreds of different parameters.
The following calculations must be made to find effective contributions of resources to the $(1 - N)$ industry-specific subsystem (OS, InS, FS).
Assume that actual $(P^{Risk}_{\varphi_{n1}}(t_0))$ boundary and $(P^{Cp}_{\varphi_{n1}}(t_0))$ mean values of damage to subsystems (OS,

InS, FS) are available for the previous period. Further, the target damage reduction value is identified for the forecast period $(t_0 - t_1)$ with account taken of the deviation of the actual damage values from the mean ones

$$\sum_{i=1}^{n} \left| P_{\varphi_{n1}}^{\text{Cp}}(t_0) - P_{\varphi_{n1}}^{Risk}(t_0) \right|. \tag{12}$$

Further, the rational target value $P_{\varphi_{n1}}^{Prog}(t_1)$ of a reduction in damage to subsystems (OS, InS, FS) is found; it is subject to comparison as a ratio of values for current and projected periods $(t_0 - t_1)$, taking into account a deviation of mean values of damage from planned values of damage:

$$\sum_{i=1}^{n} \left| P_{\varphi_{n1}}^{Prog}(t_1) - P_{\varphi_{n1}}^{\text{Cp}}(t_0) \right|, \tag{13}$$

where n is the total number of values used in the calculations.

λ_n, the coefficient affecting a reduction in damage from accidents and fires at PFPFER, calculated for current values, can be written as follows:

$$\lambda_n(t_0) = \frac{\sum_{i=1}^{n} \left| P_{\varphi_{n1}}^{\text{Cp}}(t_0) - P_{\varphi_{n1}}^{Risk}(t_0) \right|}{\sum_{i=1}^{n} \left| P_{\varphi_{n1}}^{\text{Cp}}(t_0) \right|}. \tag{14}$$

λ_n, the coefficient affecting a reduction in damage from accidents and fires at PFPFER, calculated for the ISS development period, can be formulated as follows:

$$\lambda_n(t_1) = \frac{\sum_{i=1}^{n} \left| P_{\varphi_{n1}}^{Prog}(t_1) - P_{\varphi_{n1}}^{\text{Cp}}(t_0) \right|}{\sum_{i=1}^{n} \left| P_{\varphi_{n1}}^{\text{Cp}}(t_0) \right|}. \tag{15}$$

The achieved target value of the ISS development at PFPFER (conventional period) $\text{У}(t_1 - t_0)$ will be calculated using the difference between coefficients λ_n, affecting the reduction in damage from accidents and fires at these enterprises

$$\text{У}(t_1 - t_0) = \lambda_n(t_1) - \lambda_n(t_0). \tag{16}$$

The proposed theoretical models of ISS at PFPFER, designed for the present and future systems, are characterized by numerous parameters requiring computations to be made for all risks. Hence, there is a need to develop the ISS designed for PFPFER, meaning that there is a need to develop ***a set of research and methodological instruments*** to ensure the availability of the safety margin to ensure the maintenance and development of subsystems (OS, InS, FS), and to improve the efficiency of ISS at the enterprises considered in this article.

VI. The case substantiating ISS improvement at PFPFER through the use of a set of research and methodological instruments

Let's analyze the calculation made within the framework of an experiment to make verifications using formula (8) together with the data obtained using methods contributed to the software registered with the Federal Service for Intellectual Property[6] (figure 6).

[6] Certificates of state registration of computer software:
№ 2022614215 RF Calculator for evaluation of industrial and fire safety actions at oil and gas enterprises of Russia; published 17.03.2022, by E.V. Gvozdev, B.S. Sadovsky, N.R. Ruppa, P.A. Butovchenko;
RF № 2023611653. Rater for assessment of industrial and fire safety at oil and gas enterprises of Russia; published 24.01.2023 E.V. Gvozdev, N.M. Migalchinsky, T.E. Koldin, D.S. Sinyakin.

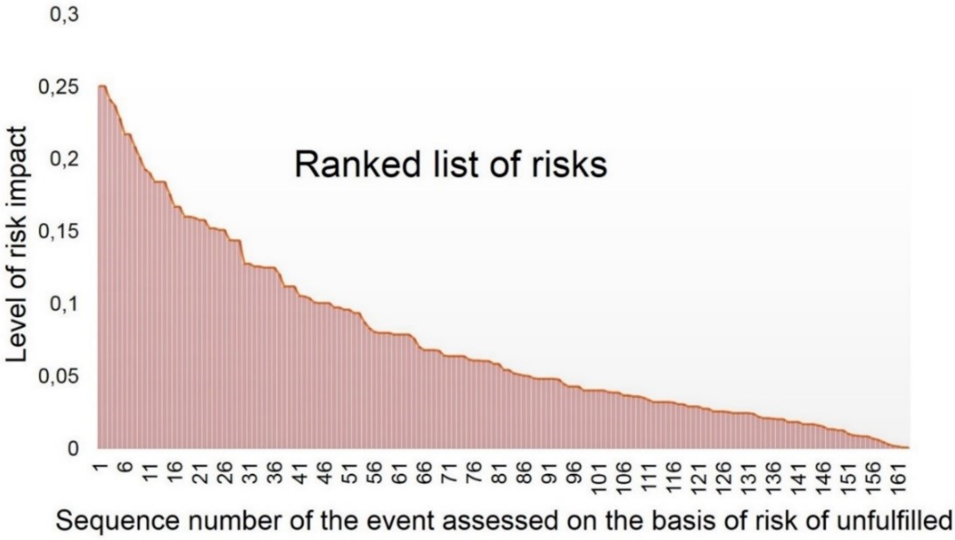

Figure 6. *Ranked list of unfulfilled activities assessed by risk*

The sampling has minimum (from 0,001) and maximum (0,250) limit values of risk calculated for unimplemented actions, extracted from statistics of accidents and fires for the period of 9 years[7].

In the present-day environment Corporate Decision Makers (hereinafter - DMs) use their practical experience to distribute resources between ISS subsystems (OS, InS, FS). Thus, DMs rise the probability of errors in prioritizing factors of damage from accidents and fires on the ranked list of risks.

In the course of experiments some factors were randomly disregarded (about 25% in total) according to the following procedure: every 2nd factor was disregarded for the 1st experiment; every 3rd factor was disregarded for the 2nd experiment; every 4th factor was disregarded for the 3rd experiment (figure 6). As for the sampling analyzed using a set of research and methodological instruments, factors 121 to 161 (about 25% in total) were disregarded. Calculation formulas are presented for each experiment in the form of a system of equations:

$$\begin{cases} A_1 = \sum_{0,001}^{0,250}(n_1 + n_2 + \cdots + n_{161}) - (n_1 + n_3 + \cdots + n_{79}) \in (25\%) = \lambda_{nA_1}(t_0) \\ A_2 = \sum_{0,001}^{0,250}(n_1 + n_2 + \cdots + n_{161}) - (n_1 + n_4 + \cdots + n_{118}) \in (25\%) = \lambda_{nA_2}(t_0) \Rightarrow A_{\mathrm{PE3}}(t_0) \\ A_3 = \sum_{0,001}^{0,250}(n_1 + n_2 + \cdots + n_{161}) - (n_1 + n_5 + \cdots + n_{157}) \in (25\%) = \lambda_{nA_3}(t_0) \end{cases} \quad (17)$$

$$B = \sum_{0,001}^{0,250}(n_1 + n_2 + \cdots + n_{161}) - (n_{121} + n_{122} + \cdots + n_{161}) \in (25\%) = B(t_1)$$

Experimental results for present and future ISS at PFPFER are shown in figure 7.

The graph shows that the ISS can be improved at PFPFER, if a set of research and methodological instruments are employed. In other words, risks of damage from accidents and fires can be reduced by 18% during the period of the ISS development.

[7] Information about accidents and fires is available on the website of the Federal Environmental, Industrial and Nuclear Supervision Service of Russia at https://www.gosnadzor.ru/industrial/oil/lessons/index.php?sphrase_id=2569631, accessed 15.08.2023

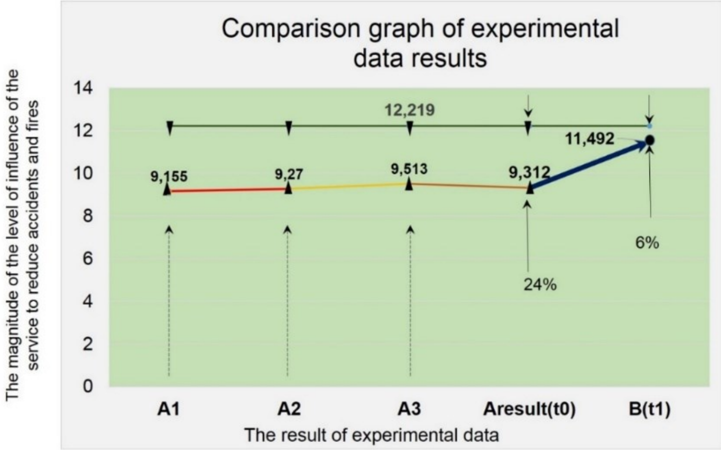

Figure 7. *Experimental data for present and future ISS at PFPFER*

Figure 5 shows the ratio of the present-day target value of ISS at PFPFER, equaling $У(t_0)$, to the achieved target development value of ISS at PFPFER, equaling $У(t_1)$. A positive trend towards the reduction in damage from accidents and fires can be formulated as follows:

$$m\lambda_{(1-n)} = B(t_1) - A_{\text{PE3}}(t_0) \approx 2{,}2\,, \tag{18}$$

where $m\lambda_{(1-n)}$ is the mathematical expectation of the total value, affecting the reduction in damage from accidents and fires, calculated using a set of research and methodological instruments; $A_{\text{RES}}(t_0)$; $B(t_1)$ are the final results based on the experimental data for the current and future ISS at PFPFER (figure 7).

The total calculated value, affecting the reduction in damage from accidents and fires and immediately related to all damage from accidents and fires reported on the website of the Federal Environmental, Industrial and Nuclear Supervision Service for the period of 9 years, is shown in table 3. The value applies to all Russian oil and gas companies.

Table 3. *Ratio of one unit of damage to total damage from accidents and fires at Russian oil and gas enterprises in 2014-2022*

Category	Total damage from accidents and fires according to reports	Ratio of total damage to one unit of damage according to experimental data
Fatalities, number of persons	49	4
Injuries, number of persons	122	10
Economic damage, billion rubles	19,7	1,615

Values of socio-economic damage can be reduced to a conventional unit based on the experimental data (table 1) using the ratio of total calculated damage from accidents and fires to different categories of assets to be protected (table 1), as well as to the total calculated value $\lambda_n const \approx 12{,}2$ (figure 5).

The socio-economic effect $E_{(1-n)}$ can be calculated as follows to rise the ISS at PFPFER in the course of the development period:

$$E_{(1-n)} = \frac{m\lambda_{(1-n)}}{У^{*}_{(t_1-t_0)}}, \tag{19}$$

where $У^{*}_{(t_1-t_0)}$ is the time frame (3 years and more) prescribed by the management of these enterprises for the development of ISS at PFPFER. A conceptual solution to the problem of the present-day ISS development at PFPFER is found. It will bring socio-economic benefits in the future in case of a reduction in the number of accidents and fires at these enterprises.

This case confirms the feasibility of the ISS development through the practical application of research and methodological instruments at PFPFER. The proposed approach to development of the current ISS at PFPFER, presented by the author in a formal form, can be applied at any other production facilities of the Russian Federation.

VII. ISS development at Russian production facilities: the proposal to be made to the management team

Executives of Russian production facilities can consider different ISS development periods for PFPFER. Below is the projected socio-economic effect attainable during one development period equaling one year (figure 8).

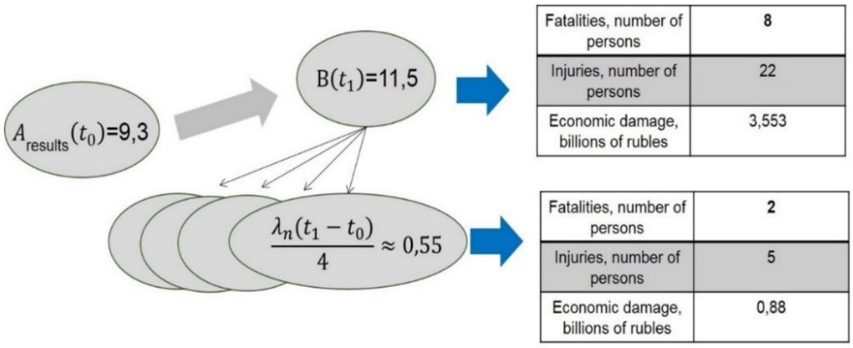

Figure 8. *Target model describing the achievement of the socio-economic effect during one year*

Schedules outline the time horizon needed to achieve the strategic objective, which sets the time frame for achieving sub-objectives at tactical and operational levels. The case of time horizons is presented for forecasting purposes (figure 9).

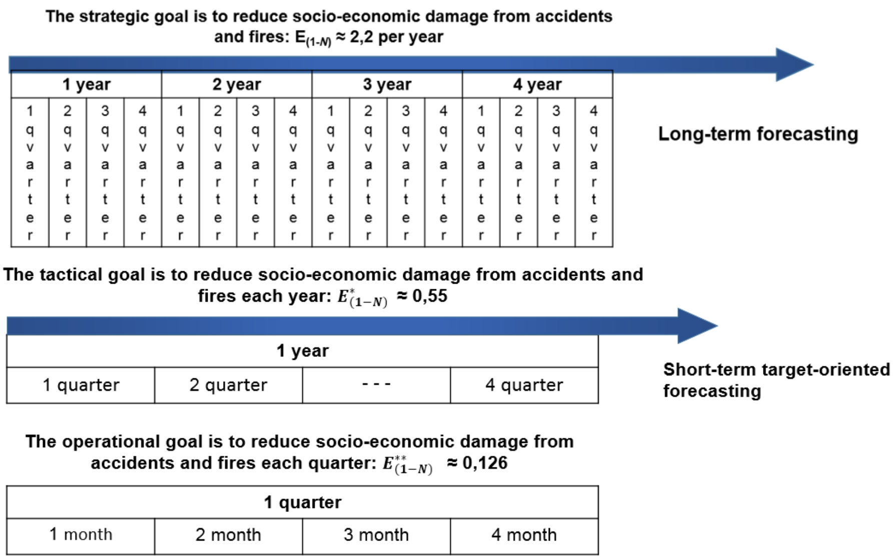

Figure 9. Time horizons for ISS development at Russian production facilities

The strategic objective is formulated by the management team for a long period of time, but its achievement should be broken down into steps (monthly or quarterly goals).
At the tactical level, the horizon for scheduling future activities is limited to one year.
At the operational level, all actions implemented within a month (a quarter) are taken and registered in the documents of target-oriented operational scheduling.
Production facilities should take advantage of the main items (models, methods, techniques, etc.) from the set of research and methodological instruments, developed by the author of the article, to achieve their targets at the strategic level, including a major reduction in damage from accidents and fires at Russian production facilities.

Conclusion

1. The relevance of the ISS development at PFPFER is substantiated by the author. In the future, ISS will be able to reach a qualitatively new level through the assessment of risks of damage from combined hazardous events (accidents and fires). Consolidated improvement areas are identified, and research results are available for practical application in this area of research.
2. The idea of a new category of combined risks of hazardous events (accidents and fires) is presented. Its originality lies in the fact that the adjustment of the required safety margin should take into account the state of subsystems and the effect of services (OS, InS, FS) on the state of ISS at PFPFER. The author of the article presents a new research area that requires expanding the range of methods used in practice to assess the state of subsystems (OS, InS, FS).
3. The formulation of and a solution to the problem of the future development of ISS at PFPFER is presented. Its uniqueness lies in the fact that this solution can present an individual risk as a quantitative value as a result of assessment of each action left unimplemented in the field of OS, InS, and FS.
4. The case substantiating the adequacy of results is presented. It proves the practical usability of a new set of research and methodological instruments, which (1) have a socio-economic effect for Russian production facilities, and (2) lead a positive trend towards a smaller damage from accidents and fires registered and reported by different government authorities, such as the Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters, the Ministry of Labor, and the Federal Environmental, Industrial and Nuclear Supervision Service of Russia.

References

[1] Gvozdev, E., 2021. Visualization and diagnostics of reliability of an object with changing functioning conditions. E3S Web of Conferences, Moscow, April 22–24. DOI 10.1051/e3sconf/202126302009

[2] Gvozdev, E.V., Matvienko, Y.G., 2021. About the evaluation of the state of integrated safety of industrial enterprises. Technosphere safety technologies 4(94), 76-95. DOI 10.25257/TTS.2021.4.94.76-95

[3] Gvozdev, E.V., 2022. About the evaluation of the state of integrated safety at enterprises of oil and gas industry of Russia. Fire and Explosion Safety, vol. 31, 1, 49-64. DOI 10.22227/0869-7493.2022.31.01.49-64

[4] Gvozdev, E.V., 2023. Formulating the problem of rational allocation of resources to ensure integrated safety. Real Estate: Economics, Management, 2, 50-55

[5] Makhutov, N.A., Pokrovskii, A.M., Dubovitskii, E.I., 2019. Analysis of Crack Resistance of an Oil Trunk Pipeline Considering the Varying Failure Viscosity in the Neighborhood of a Welded

Joint. Journal of Machinery Manufacture and Reliability, vol. 48, 1, 35-42. DOI 10.3103/S1052618819010126

[6] N. A. Makhutov, V. N. Permyakov, R. S. Akhmetkhanov, Risk analysis and security of critical facilities of the oil and gas industry (Tyumen, TyumNGU, 560 p., 2013)

[7] Gadolina, I. V. Varied approaches to loading assessment in fatigue studies / I. V. Gadolina, N. A. Makhutov, A. V. Erpalov // International Journal of Fatigue. – 2021. – Vol. 144. – P. 106035. – DOI 10.1016/j.ijfatigue.2020.106035

[8] Makhutov, N. A. Assessment of extreme thermo-mechanical states of engineering systems under operating loading conditions / N. A. Makhutov, M. M. Gadenin, D. O. Reznikov // Acta Mechanica. – 2021. – Vol. 232, No. 5. – P. 1829-1839. – DOI 10.1007/s00707-020-02920-3

[9] Makhutov, N. A. Analysis and management of strength parameters, resource and risks of safe operation of power plants with various types of energy resources / N. A. Makhutov, M. M. Gadenin // Problems of mechanical engineering and machine reliability. – 2022. – No. 1. – pp. 47-56. – DOI 10.31857/S0235711922010060

[10] Dissertation presentation alert. https://www.safety.ru/about/dissertation/obyavozaschite/031022-gvozdev-evgeniy-vladimirovich (August 14, 2023)

[11] Dolgov, A.I., 2013. Methodology of scientific research. DSTU, 161 p

[12] Abrosimov N.V., Aksyutin O.E., Aleshin, A.V., et al., 2019. Security of Russia. Legal, socio-economic and scientific-technical projects. Scientific foundations of industrial safety. Moscow, Znanie, 824 p. ISBN 978-5-87633-183-0

[13] Mileshko, L.P., 2023. Economics and safety management. Yurait, 99 p. ISBN 978-5-534-13764-4

[14] Fedortsov, A.B., Silivanov, M.O., 2021. Physiologically based control of the process of gentle light awakening. Journal of Physics. Conference Series 16. Moscow. DOI 10.1088/1742-6596/2127/1/012064

[15] Odintsov, B.E., Urintsov A.I., Mamedova, N.A., 2021. Business process performance management of enterprises in terms of inverse calculations AIP Conference Proceeding, Volgograd. DOI 10.1063/5.0067990

[16] Mkrtchyan, L., Straub, U., Giachino, M., Kocher, T., Sansavini, G., 2022. Insurability risk assessment of oil refineries using Bayesian Belief Networks. Journal of Loss Prevention in the Process Industries, 74. https://doi.org/10.1016/j.jlp.2021.104673

[17] Massel, A.G., Pesterev, D.V., 2017. Transformation of cognitive models into knowledge base of production expert system. Proceedings of the 19th International Workshop on Computer Science and Information Technologies. Germany, Baden-Baden. USATU, vol. 1, 121-124. ISBN 978-5-1030-8, ISBN 978-4-4221-1031-5

[18] Vladimirovich, G.E., Mikhailovna, C.V., 2019. The Modern Strategy to the Process of Managing Complex Security of the Enterprise on the Basis of Rational Centralization. International Journal of Innovative Technology and Exploring Engineering, 9(1), 4614–4620. https://doi.org/10.35940/ijitee.A4944.119119

[19] Qingsong, X., Leiguang, J., Xuedong, L., 2020. Decision-making optimization of complex product design task change perturbation based on prospect theory. Journal of Industrial Engineering and Engineering Management, 34(1). https://doi.org/10.13587/j.cnki.jieem.2020.01.020

[20] Bochkov, A. Reflections on Dual nature of risk. Toward a formalism / A. Bochkov // Reliability: Theory & Applications. – 2023. – Vol. 18, No. S5(75). – P. 44-74. – DOI 10.24412/1932-2321-2023-575-44-74.

[21] Arefyeva, E. Managing the risk of emergencies caused by groundwater flooding of the historical built-up areas / E. Arefyeva // Reliability: Theory & Applications. – 2023. – Vol. 18, No. S5(75). – P. 125-135. – DOI 10.24412/1932-2321-2023-575-125-135.