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Assessment of the state of integrated security system at the enterprise using the priority setting method

The paper presents justification for using the priority setting method together with the Gaussian normal distribution functional to assess the state of the integrated security system of production enterprises. The justified method has a certain advantage over other methods of expert assessment due to the fact that it has no limit to expanding the boundaries in order to obtain adequate results in the form of quantitative values. The statistics of the occurrence of accidents and fires at enterprises of the oil and gas complex of Russia is analyzed, information is presented on the procedure for determining the primary factors initiating the occurrence of joint events (accidents and fires). An example is shown with the results of processing information received from experts. The developments presented in the paper will make it possible to solve in practice the problem of reducing damage from accidents and fires, i.e. solve a problem that has important socio-economic significance for Russia.
Keywords: *Integrated security system, priority setting method, Gaussian normal distribution, influence coefficient, expert decision*

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INTRODUCTION

The results of the analysis of statistics on the occurrence of joint dangerous events (accidents and fires) from which various damages are caused (*economic, material, damage to life or health of enterprise personnel and third parties*) at explosion and fire hazardous (hereinafter referred to as EFH) enterprises, which occur in the form of the following sequence of implementation: (accident → fire or fire → accident), are characterized by focusing on the primary event that occurred initially, it became the cause of the secondary event. However, the Department (industry structure), for example, (in the Ministry of Emergency Situations of Russia, or in Rostechnadzor) collects information with statistics on the occurrence of dangerous events (accidents, fires), and in the case under consideration, when a dangerous event began to cause damage as a secondary factor, it is recorded in the information statistics of the Department (industry structure) as a defect. A similar situation occurs at manufacturing enterprises, when the specialized services of Industrial Safety (hereinafter referred to as IS), Fire Safety (hereinafter referred to as FS), and labour protection (LP) perform their labour functions and collect data on the occurrence of hazardous events (accidents, fires), they are recorded in the enterprise statistics as an accident — in the IS service, as a fire — in the FS service, and the LP service in the event of damage to the life and health of the enterprise personnel or third parties, has to take upon itself such damage as a defect [1–5].

The information presented above confirms the need for further research taking into account the influence of subsystems (IS and FS, LP) on each other.

METHODS

The purpose of the presented paper is to substantiate the method for conducting a qualitative assessment of the state of the integrated security systems (hereinafter referred to as ISS) at the enterprise.

To obtain the quantitative value of the studied factors considered under conditions of uncertainty, when the control system is described from the point of view of its qualitative state, there is a need to resort to the use of expert assessment in the form of experts expressing their justifications in quantitative terms of the degree of preference, which allows us to talk about conducting a quantitative expert assessment.

The procedure for carrying out activities to assess the state of ISS at EFH enterprises is designed to present a logical conclusion based on the existing knowledge and personal experience of the expert. Whenever a problem is formulated by an expert, the following mandatory set of measures is carried out:

- modelling the measurement object from its decomposition into its component elements;
- identify factors that play a key role in determining quantitative assessment;
- taking into account the degree of influence of factors on determining the final quantitative assessment.

In subsystems (IS, FS, LP) various methods are used in practice to assess risks. To confirm the elements of novelty in the ongoing study, it was necessary to present information using different features proposed by the authors of the paper:

1) in Rostechnadzor, with using in practice order No. 387 of November 3, 2022[1], calculation methods are used: *analysis of the "Failure Tree"; analysis of the "Event Tree"; "What if?" "What — If";*

1 On approval of the safety manual "Methodological basis for hazard analysis and accident risk assessment at hazardous production facilities" : Order of Rostechnadzor dated 11.03.2022 No. 387. URL: https://kubancentr.ru/images/docs/Prikaz-Rostekhnadzora-ot-03.11.2022-N-387.pdf?ysclid=lr2dccjc55628540024 (accessed: 06.01.2024) (rus.).

analysis of “Hazards and Performance” (AOP); checklist (“Check-List”); “Hazard Identification”; HAZID (Hazard Identification); analysis of “Security Measures”; analysis of the “Mode and Consequences of Failures” (AVFO); quantitative assessment of accident risk;

2) in the Ministry of Emergency Situations of Russia, with using in practice order No. 404 of July 10, 2009[2], calculation methods are used — *logical event trees; determining the estimated evacuation time; determining the specific frequency of various types of pipeline depressurization; determining the time of blocking of evacuation routes as a result of the spread of dangerous fire factors to them;*

3) in the Ministry of Labour, with using Order No. 929 of December 28, 2021[3] in practice, calculation methods are used — *analysis of the “Decision Tree”; analysis of “Scenarios”; “What if?” (Swift); Bow-tie analysis; checklists; HAZOP (Hazard and Operability Study); “matrix” based on points; analysis of “Cause and Effect Relationships”; “Maintenance” aimed at ensuring reliability; analysis of “Levels of protection” (LOPA layers of protection analysis); analysis of the “Influence of the human factor” (HRA-Hyman Reliability assessment); assessment of the “Risk of getting an occupational disease”; cost-effectiveness analysis (cost-benefit analysis);*

4) the new method proposed by the author of the paper is the *method of prioritization*, which, together with the use of the *Gaussian normal distribution functionality*, becomes a powerful tool that has replenished the group of methods used for calculating individual weighting coefficients. Using the proposed method in practice will allow:

- by a group of experts, selecting a specific subsystem (IS, FS, LP) as well as the subsystem production structural units (hereinafter referred to as PSU) operating at the enterprise, deficiencies in which led to a joint dangerous event (accident and fire), which had an impact (direct; indirect; circumstantial);
- obtain a specific numerical value located in the interval (from 0.001 to 0.999) as an indicator of the level of influence of the subsystem (IS, FS, LP, PSU).

The information presented above clearly confirms the presence of elements of novelty in the paper, when compared with existing solutions used in practice.

RESULTS

Mathematically, the solution of expert problems can be described as the effectiveness of the assessed object in relation to another in the form of a directed graph (Fig. 1).

Each of the *n* — objects ($X_1, X_2, \ldots, X_n$) corresponds to a vertex of the graph, which expresses the result of the preference of one evaluated object over another.

Solving such a problem of determining the preference of one object over a group consisting of n objects using a drawing presents certain difficulties; in this case, it is necessary to build matrix $A = \|a_{ij}\|$;

$$A = \begin{vmatrix} a_{11} & a_{12}\cdots & a_{1j}\cdots & a_{1n} \\ a_{21} & a_{23}\cdots & a_{2j}\cdots & a_{2n} \\ \cdots & \cdots\cdots & \cdots\cdots & \cdots \\ a_{i1} & a_{i2}\cdots & a_{ij}\cdots & a_{in} \\ \cdots & \cdots\cdots & \cdots\cdots & \cdots \\ a_{n1} & a_{n2}\cdots & a_{nj}\cdots & a_{nn} \end{vmatrix}.$$

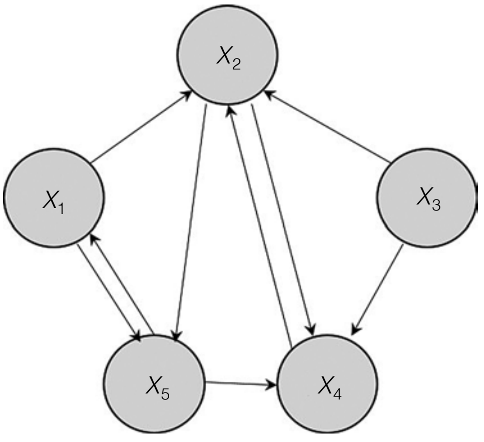

Fig. 1. Graph of the evaluation result of n-objects

And in this case:

$$a_{ij} = \begin{cases} 1, \text{ if } X_i > X_j; \\ 0.5, \text{ if } X_i = X_j; \\ 0, \text{ if } X_i < X_j, \end{cases}$$

where $i = j \to \{1, 2, \ldots, n\}$; $a_{ij} = 0.5$;

$X_i > X_j$ means the priority of one assessed object over another;

$X_i = X_j$ means equal importance of the objects being evaluated.

The justification presented above largely corresponds to the *method of prioritization* [6–10], which has a certain advantage over other methods of expert assessment due to the fact that it allows:

- establish relationships for the elements that make up the structure;
- present quantitative assessments where possible (subjective, expert);
- formulate and transform the problem into a logical-structured one;
- expand the capabilities of this *method* by using together with it the functionality of mathematical modelling and selecting optimal solutions.

Considering that the experts will give a non-numerical and qualitative characteristic, here, when determining the quantitative value for each qualitative value presented above, then using the Gaussian normal distribution functional (three sigma rule for a Gaussian random variable) [11–13], a specific the maximum value from the specimen for each of the presented qualitative characteristics (Fig. 2).

Using the graph it becomes possible to assign quantitative values for the following qualitative characteristics:

- *directly* related to the emergence and growth of conditions for causing damage from accidents and fires in volumetric terms, the value is ≈ 68.2 %, or ≈ 0.682, this indicator is assigned to a specific subsystem (IS, FS, LP, PSU);
- having an *indirect* relationship of ≈ 27.2 %, or ≈ 0.272, this indicator is assigned to a specific subsystem (IS, FS, LP, PSU), even that subsystem, which, during the assessment, was previously assigned a characteristic as having a direct relationship;

2 Approval of the methodology for determining the estimated values of fire risk at production facilities : Order of the Ministry of Emergency Situations of Russia dated 07.10.2009 No. 404. URL: torage/acts/173.pdf (accessed: 01.06.2024) (rus.).

3 Approval of recommendations for the selection of methods for assessing the levels of professional risks and for reducing the levels of such risks : Order of the Ministry of Labour of Russia dated 12.28.2021 No. 929. URL: https://normativ.kontur.ru/document?moduleId=1&documentId=411523&ysclid=lr2de60y5x667189787 (accessed: 01.06.2024) (rus.).

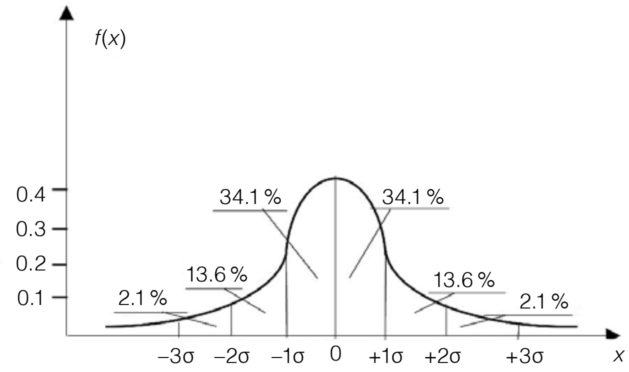

Fig. 2. The density distribution graph of a normalized value showing the volume ratio

- having a *circumstantial* relation of ≈ 4.6 %, ≈ 0.046, this indicator can be assigned to 1–2 specific subsystems (IS, FS, LP, PSU).

Then, in general mathematical form, the calculated value for determining the impact coefficient — k_i (IS, FS, LP, PSU), can be written by the equation:

$$k_i\{\text{IS, FS, LP, PSU}\} = 1 - \sum_{1}^{3} k_d\{\text{IS, FS, LP, PSU}\}, \qquad (1)$$

where k_d is a value representing the coefficient of deficiencies in the subsystem (IS, FS, LP, PSU) that is (*directly, indirectly or circumstantially*) related to the emergence and increase of conditions for causing damage from accidents and fires.

The overall resulting indicator of the operation of the subsystem (IS, FS, LP, PSU) for the period — *t* is calculated with reference to the functioning of the types of technological production process (*P — production; T — transportation; Ps — processing; S — storage; O — other*).

The final resulting indicator, which is the influence coefficient — k_{Inf} of the subsystem (IS, FS, LP, PSU) for the period — *t* (year, quarter, month, etc.) with reference to the functioning of the production technological process, can be represented by the equation:

$$K_{Inf\ (P;T;Ps;S;O)}\{\text{IS, FS, LP, PSU}\}\, t = \sum_{1}^{n} k_i / n, \qquad (2)$$

where *n* — numbered extreme value belonging to the specimen.

CONCLUSIONS

1. The rationale for the use of *the prioritization method*, with the help of which specific quantitative values are obtained, displayed in the form of a level coefficient, which indicates certain deviations and will allow adjusting the personnel management model (IS, FS, LP, PSU) is presented based on an analysis of methods used in practice.

2. *The method of prioritization*, together with the use of *the Gaussian normal distribution functionality*, becomes a powerful tool that has replenished the group of methods used for calculating individual weight coefficients.

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Оценка состояния системы комплексной безопасности предприятия с использованием метода расстановки приоритетов

Представлено обоснование по использованию метода расстановки приоритетов совместно с функционалом нормального распределения Гаусса для оценки состояния системы комплексной безопасности производственных предприятий. Обоснованный метод обладает определенным преимуществом по отношению к другим методам экспертных оценок в связи с тем, что он не имеет предела для расширения границ с целью получения адекватных результатов в виде количественных значений. Проанализирована статистика возникновения аварий и пожаров на предприятиях нефтегазового комплекса России, представлена информация о порядке определения первичных факторов, инициирующих возникновение совместных событий (аварий и пожаров). Показан пример с результатами обработки информации, полученной от экспертов. Представленные в статье разработки позволят на практике решать проблему по снижению ущерба от аварий и пожаров, т.е. решать проблему, имеющую важное социально-экономическое для России значение.

Ключевые слова: *система комплексной безопасности, метод расстановки приоритетов, нормальное распределение Гаусса, коэффициент влияния, экспертное решение*

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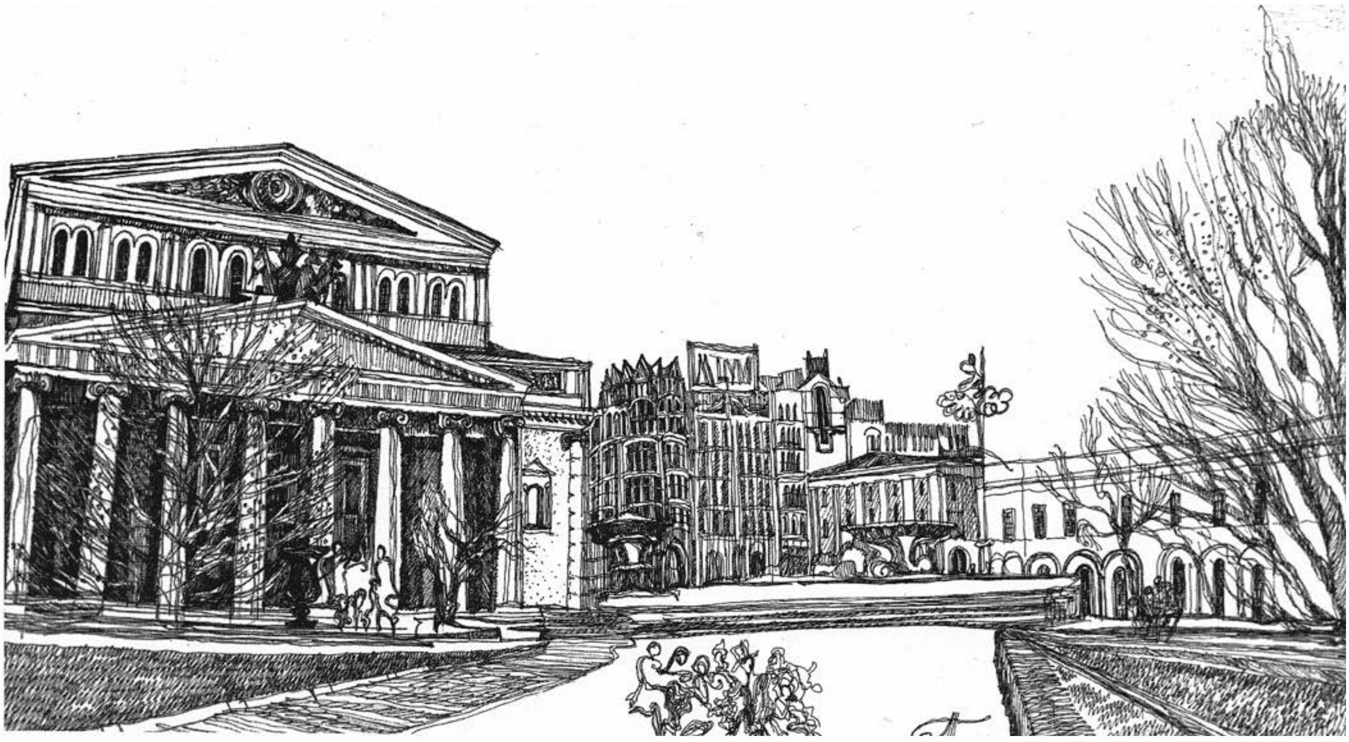

Л.И. Павлова. Москва. Театральная площадь. Рисунок, тушь, перо.