Methodology for the Fire Safety Conditions Assessment at the Electric Power Enterprise

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Abstract: The article presents a methodologically described, sequential algorithm for obtaining an assessment of the fire safety conditions carried out at a large power enterprise in Russia. The article validates the choice of an analytic hierarchy process, which, by applying a pairwise comparison of factors and alternatives, makes it possible to determine the local priority indicator for each investigated element. The algorithm of sequential actions presented in the article, in the form of a detailed description, allows the quantifiable indicator for each event to be established. The formulation of the problem and its solution based on the established relationships between factors and indicators are presented. The final formula for obtaining quantitative values of the level directly related to the studied factors is presented.

Keywords: Fire safety, factor, appraisal ratio, conformity relation, expert.

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1 Introduction

Research in the area of fire safety (FS) is a scientific area that requires continuous improvement and development due to the human desire to minimize (eliminate) the conditions for the occurrence of fires not only in the facilities of the technosphere, but also in the natural environment. This desire is justified by the occurrence of various hazards in the technosphere, such as fires, resulting in enormous damage annually, not only through material, physical and economic losses, but also through the death and injury of people, suffer of the natural environment around us. It is clear that the current state of affairs associated with the occurrence of fires should be considered as a priority area requiring further research [1-5].

Although the processing of fire statistics at industrial enterprises shows a positive trend towards their gradual decrease, the solution of the tasks related to the identification of factors creating conditions for the occurrence of fires at present and further perspective will be a relevant and necessary aspect. In the analysis of fire statistics at industrial enterprises, a significant share of fires is related to the use of electric power (production, conversion, transformation, transmission, distribution, etc.), making up about 30% of the total indicator [6].

Mosenergo Public Joint-Stock Company (PJSC), one of the major generators of electricity in Russia and fire hazardous enterprise, served as an example for this study. The structure of the Mosenergo, PJSC is represented by power and heating plants (PHP), affiliated to the enterprises of the branch level of subordination.

The heads of any production enterprises of the Russian Federation, when planning measures aimed at improving the management and stable working processes, face the need to solve the following tasks of the enterprise operation safety:

1. Are the fire safety conditions at the enterprise acceptable and compliant?
2. What are the priority measures in solving security problems, what breakthrough modern approaches are effective (best) and what methods and techniques are available to assess the fire safety conditions at the enterprise?
3. Will the results of the assessment be able to develop a forward-looking program that will form a sustainable system of the enterprise operation, which will meet the fire prevention tasks?

In fire safety management of the enterprises, many proven methods aimed at minimizing (excluding) fire occurrence conditions are applied. However, in this direction, further studies are required to assess the state of the existing enterprise fire safety system operation.

2 Choice of Research Method

It has long been known that not only intuitive considerations should guide the choice of research method, it is necessary to focus on the choice of a directional vector in the researcher's a priori ideas of the physical essence and regularities of the studied object. The purpose of the performed paper is to present a methodological approach to the assessment of the fire safety conditions at the Mosenergo, PJSC for its further improvement.

Given the fact that the analyzed system is a complex mechanism, involving the electric power enterprise resources (personnel, financial, material, technical, etc.) with its links and relationships in the management hierarchy, it is proposed to use the analytic hierarchy process (AHP) developed by the American scientist Thomas Saaty [7].

The proposed method makes it possible:

1. to analyze the task to be solved. It is performed using the construction of data ordered hierarchically, which will represent the indicators and their relationship:

a) to achieve the main target indicator (main criterion) when assessing the fire safety rating,

b) to determine the factors affecting the rating,

c) to determine the characteristics of the ties between the elements under consideration, which affect the output characteristics of the studied indicators.

2. The AHP allows to determine the deviation values in the results obtained from experts, which requires a revision of judgments between experts.

3. The AHP solves the tasks of synthesizing the results, which significantly strengthens the results of the summary criteria indicator.

4. Through the AHP application, it is possible to organize a problem discussion and choose various options to reach a consensus.

5. The chosen method makes it possible to assess the importance of each decision and factor affecting the decision priority.

6. The AHP makes it possible to assess the sustainability of a decision as a characteristic of a promising development of the criteria target indicator.

Such immense potential of the proposed method allows to give specific numerical characteristics to the considered characteristic descriptions of the used factors.

3 Research Objective

In mathematical terms, it can be formulated as follows. It is necessary to find an output parameter in the form of an analytical expression (y) based on its determinants $(x_1, x_2, ...x_j, ..., x_n)$, that is, to find a function

$$y = f(x_1, x_2, ..., x_n) \quad (1)$$

with the help of which the data between the output and input indicators will be reproduced in the form of dependencies, where it will be possible to define and consider the characteristics of the influence of the arguments on the investigated function. To obtain the results of the influence, it is necessary to collect fire occurrence statistics for a certain period of time, for example, for several years. Then, on the basis of the data set for the study, it is necessary to form the enlarged blocks related to the causes of fire, approved in Appendix 2 of the Order of Ministry of Emergency Situations of Russia No. 625 dated 24 December 2018 “On the formation of electronic databases of fires and their consequences”. Next, it took a characteristic description of the blocks and their reduction to an unambiguous mutual correspondence in the form of a matrix denoted by A painted element by element, which looks like this:

$$A = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_n \end{matrix} \begin{bmatrix} A_1 & A_2 & \cdots & A_n \\ w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_1/w_2 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}, \text{ where} \quad (2)$$

$w_1, \cdots, w_n$ – they are related to weights calculated in the form of natural numbers (from 1 to 9) representing the exact numerical value;

n – - the total number of alternatives considered in the sample related to the rank of the matrix.

The importance of influencing the achievement of the objective by each element in the matrix sample is determined by solving the equation:

$$|A - \lambda E| = 0 \quad (3)$$

It is required to determine the maximum number and vector q

$$\lambda = \lambda_{\max} \quad (4)$$

$$|A - \lambda_{\max} E| \bar{q} = 0 \quad (5)$$

The represented (3-5) is solved by Newton's method, and the zero approximation is found as the geometric mean

$$\bar{q} = (q_1, q_2, q_3, ..., q_n) \quad (6)$$

$$q_1 = (q_{11}, q_{12}, q_{13}, ..., q_{1n}) \quad (7)$$
$$q_2 = (q_{21}, q_{22}, q_{23}, ..., q_{2n})$$
$$.....................................$$
$$q_n = (q_{n1}, q_{n2}, q_{n3}, ..., q_{nn})$$

The AHP application algorithm includes the following operations that are meaningful and step-related to the stages described below:

– an operation to form a hierarchy of key target indicators, where the main target criterion indicator is set at the top and key factor indicators are subordinated to it;

– an operation to determine the local and global priorities of the questionnaires analyzed and calculated in the content;

– an operation to check the obtained expert assessment results for consistency (i.e., the determination of the consistency index), which confirm the adequacy of the use of the obtained results;

– the final operation includes the calculation of criteria-factor indicators for the hierarchical top and peaks of the intermediate factor values based on the synthesis of local priorities.

To solve the given problem it is required to carry out a systematic analysis and synthesis of measures of requirements to ensure the required level of fire safety at each PHP separately and the Mosenergo, PJSC as a whole [8].

4 Problem Solution of the Fire Safety Conditions Assessment at the Enterprise

Through the application of MAI, it is possible to solve the problems of finding local and global priorities of the studied factors, practically the solution of the problem is realized in a series of following stages. At the initial *first stage,* the formulated problem statement should provide for the interconnection of the data set in a network or hierarchical form. The main purpose of the object under investigation, which is related to the obtaining of the result of the criterion indicator is placed at the top of the network hierarchical structure. The relationship to the main purpose and the subordinate, mutually related, downstream factors is built through the corresponding levels of factors presented as interim data. Such actions are conducted from the highest to the lowest levels.

At the *second stage*, there is a need for expert review and prioritization for each level of factors, taking into account the impact of each considered element on the intermediate target. The elements are compared in pairs, taking into account he peculiarities of the influence (more or less) on the higher target indicator. In this case, it is recommended to compare between the elements of the data set in matrix form. The consideration of elements as a symmetric matrix allows to provide a comparative analysis of the influence of the selected target factor on factors-arguments, resulting in a matrix of the following type:

$$A = \begin{pmatrix} a_{11}a_{12}a_{13} \cdots a_{1n} \\ a_{21}a_{22}a_{23} \cdots a_{2n} \\ a_{31}a_{32}a_{33} \cdots a_{3n} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ a_{n1}a_{n2}a_{n3} \cdots a_{nn} \end{pmatrix} \quad (8)$$

The matrix presented above relates to an inverse of symmetry category, thus satisfying the fulfillment of the property

$$a_{ij} = 1 / a_{ij} \quad (9)$$

where indices i is the row number and j is the column number associated with the intersection points. In this case, the pairwise comparison matrix takes the form

$$A = \begin{pmatrix} 1 & a_{12} & a_{13} & \cdots & a_{1n} \\ 1/a_{12} & 1 & 1/a_{13} & \cdots 1/a_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & 1 \end{pmatrix} \quad (10)$$

The work of experts on filling in the data of a set of indicators displayed in a matrix form is carried out as follows. At the top, it is written a target indicator that is relevant to all studied data in the matrix and with which the comparative analysis will be carried out in pairs. The names of the elements are written sequentially in both horizontal rows and vertical columns. The matrix blocks are filled only diagonally, where at the intersection of the blocks with the same name of the studied element horizontally and vertically the unit will be placed. The rest of the matrix set blocks are left blank and will contain the results of an expert who justifies them in terms of

the features of the influence (more or less) of each considered element on the target indicator recorded for the matrix.

For the expertise, a scale of objective comparisons was developed, in the content of which the characteristics of the influence of the compared elements are considered as a numerical indicator of assessment. In terms of the characteristic description of the influence on the target indicator of the pairwise compared elements, it is possible to establish the following levels of importance of the inter-element influence from the lowest to the highest (*equal importance; moderate superiority; substantial or strong superiority; significant superiority; very significant superiority), for which the superiority values are expressed as following indicators (1; 3; 5; 7; 9).*

The above levels of importance between the compared elements are represented as odd numbers 1;3;5;7;9, but they can also be expressed as level indicators of the number series 2;4;6;8, which indicates values falling within the interval between the odd importance indicators defined above.

At the third stage, there is a need to verify the adequacy of experts' use of a scale of preferences (relative importance). At this stage, the following condition needs to be taken into account, requiring the agreement of the obtained results from several experts due to possible errors expressed as substantial deviations. Given the fact that, in practice, there is no perfect consistency between several people on the same complex issue, the application of the AHP allows to calculate the assessment of the degree of consistency between experts. To this end, the following consistency characteristics should be taken into account:

– conformity ratio (CR);
– conformity index (CI);
– random index (RI).

The expression of the presented characteristics is written as:

$$CR = \frac{CI}{RI} \qquad (11)$$

(CI) is expressed using the expression

$$s_j = a_{1j} + a_{2j} + a_{3j} + ... + a_{nj},\ j = 1,2,3,...n \qquad (12)$$

The result using formula (12) is then multiplied by the *j*th exponent of the q_{ij} vector, and so on for subsequent columns

$$p_j = s_j \cdot q_{2j},\ j = 1,2,3,...,n \qquad (13)$$

The set of numbers as a sum of p_j reflects the proportionality of expert preferences

$$\lambda_{max} = p_1 + p_2 + p_3 + ... + p_n,\ j = 1,2,3,...,n \qquad (14)$$

The deviation from conformity results is expressed by conformity index

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad (15)$$

The conformity ratio (CI) to the mean of the random conformity index (RI) is called the conformity relation (CR), and a value less than or equal to 0.10 is considered acceptable [9].

5 Problem Solution Result of the Fire Safety Conditions Assessment at the Enterprise

As a result of the systems analysis and synthesis, the main factors and their indicators were identified in the assessment of the fire safety level of the enterprise.

Factors (F) to assess the fire safety level include:

F1 - assessment of the organizational and management activities of the enterprise in the field of fire safety;

F2 - assessment of the condition and functioning of physical facilities (structures);

F3 - assessment of the protection systems conditions during the operation of physical facilities;

F4 - assessment of the fire-fighting subsystem;

F5 - assessment of the condition and maintenance of the territory.

The evaluation factor - F1 includes the first-level influencing indicators:

P11(F1) - execution of fire safety management and reporting documents, provision of the enterprise personnel with information materials;

P12(F1) - training of the enterprise personnel in the field of fire safety.

The indicator P11(F1) content includes the following lower level indicators P111-P11(F1); P112-P11(F1); P113-P11(F1); P114-P11(F1); P115-P11(F1); P116-P11(F1); P117-P11(F1); P118-P11(F1); P119-P11(F1) with their assigned numbers corresponding to the sequential list of activities presented in the checklist.

The indicator P12(F1) content includes the following lower level indicators (P121-P12(F1); P122-P12(F1); P123-P12(F1); P124-P12(F1); P125-P12(F1); P126-P12(F1); P127-P12(F1) with their assigned numbers corresponding to the sequential list of activities presented in the checklist.

The factor - F2 includes the first-level influencing indicators:

P21(F2) – the presence of signs for access to the safe zone;

P22(F2) – in the area of fire safety, activities related to the space-planning solutions of buildings (structures).

The indicator P21(F2) content includes the following lower level indicators P211-P21(F2); P212-P21(F2); P213-P21(F2); P214-P21(F2); P215-P21(F2); P216-P21(F2), with their assigned numbers corresponding to the sequential list of activities presented in the checklist.

The indicator P22(F2) content includes the following lower level indicators P221-P22(F2); P222-P22(F2); P223-P22(F2); P224-P22(F2); P225-P22(F2); P226-P22(F2); P227-P22(F2), with their assigned numbers corresponding to the sequential list of activities presented in the checklist.

The factor - F3 includes the following indicators P31(F3); P32(F3); P33(F3); P34(F3); P35(F3);

P36(F3); P37(F3); P38(F3); P39(F3); P310(F3); P311(F3).

The factor - F4 includes the following indicators

P41(F4); P42(F4); P43(F4); P44(F4); P45(F4).

The factor - F5 includes the following indicators

P51(F5); P52(F5); P53(F5).

Further, the data were compiled in tabular form (Table 1):

Table 1: Pairwise element comparisons

	F1	**F2**	**F3**	**F4**	**F5**	**Priority vector**
F1	1	A_{12}	A_{13}	A_{14}	A_{15}	q_1
F2	$1/A_{12}$	1	A_{23}	A_{24}	A_{25}	q_2
F3	$1/A_{13}$	$1/A_{23}$	1	A_{34}	A_{35}	q_3
F4	$1/A_{14}$	$1/A_{24}$	$1/A_{34}$	1	A_{45}	q_4
F5	$1/A_{15}$	$1/A_{25}$	$1/A_{35}$	$1/A_{45}$	1	q_5

where A_{ij} – the values set by experts when completing the table, q_i – the priority vector value, calculated as geometric mean:

$$q_1 = \sqrt[5]{1 \cdot A_{12} \cdot A_{13} \cdot A_{14} \cdot A_{15}},$$

$$q_2 = \sqrt[5]{1/A_{12} \cdot 1 \cdot A_{23} \cdot A_{24} \cdot A_{25}},$$

$$q_3 = \sqrt[5]{1/A_{13} \cdot 1/A_{23} \cdot 1 \cdot A_{34} \cdot A_{35}},$$

$$q_4 = \sqrt[5]{1/A_{14} \cdot 1/A_{24} \cdot 1/A_{34} \cdot 1 \cdot A_{45}},$$

$$q_5 = \sqrt[5]{1/A_{15} \cdot 1/A_{25} \cdot 1/A_{35} \cdot 1/A_{45} \cdot 1}$$

After the local priority indicator is found, the *CR* represented by the formulas (11-15) is then determined.

The priority vector values for the first and second level indicators are calculated in the same way. To assess the fire safety level of the i th division, each expert completes a table of current indicator values with a numerical value in the range from 0 to 1.

As an example, we shall give the calculation fragments presented in Tables 2 and 3.

To obtain assessments of the first factor - $F1$.

Table 2: Assessments received from experts

No. of the analyzed influencing indicator	**Rating value from expert**
$P111$	r_{111}
$P112$	r_{112}

No. of the analyzed influencing indicator	Rating value from expert
$P113$	r_{113}
$P114$	r_{114}
$P115$	r_{115}
$P116$	r_{116}
$P117$	r_{117}
$P118$	r_{118}
$P119$	r_{119}
$P121$	r_{121}
$P122$	r_{122}
$P123$	r_{123}
$P124$	r_{124}
$P125$	r_{125}
$P126$	r_{126}
$P127$	r_{127}

To obtain assessments of the second factor - $F2$.

Table 3: Assessments received from experts

No. of the analyzed influencing indicator	Rating value from expert
$P31$	r_{31}
$P32$	r_{32}
$P33$	r_{33}
$P34$	r_{34}
$P35$	r_{35}
$P36$	r_{36}
$P37$	r_{37}
$P38$	r_{38}
$P39$	r_{39}

The fire safety assessment of the i th division (K_{PB_i}) of the Mosenergo, PJSC was determined using the formula:

$$K_{PB_i} = F_1 \cdot P_1 + F_2 \cdot P_2 + F_3 \cdot P_3 + F_4 \cdot P_4 + F_5 \cdot P_5 \quad (16)$$

where F_1, F_2, F_3, F_4, F_5 - numerical values of the assessed factors determined by experts using the AHP.

The results of the global priority values obtained as P_1, P_2, P_3, P_4, P_5 indicators were determined by the following formulas:

1. The assessment of the global priority P_1 was determined by the formula

$$P_1 = P_{11}(P_{111} \cdot r_{111} + P_{112} \cdot r_{112} + P_{113} \cdot r_{113} + \\ + P_{114} \cdot r_{114} + P_{115} \cdot r_{115} + P_{116} \cdot r_{116} + P_{117} \cdot r_{117}) + \\ + P_{12}(P_{121} \cdot r_{121} + P_{122} \cdot r_{122} + P_{123} \cdot r_{123} + P_{124} \cdot r_{124} + \\ + P_{125} \cdot r_{125} + P_{126} \cdot r_{126} + P_{127} \cdot r_{127})$$

2. The assessment of the global priority P_2 was determined by the formula

$$P_2 = P_{21}(P_{211} \cdot r_{211} + \Pi_{212} \cdot r_{212} + P_{213} \cdot r_{213} + \\ + P_{214} \cdot r_{214} + P_{215} \cdot r_{215} + P_{216} \cdot r_{216}) + \\ + P_{22}(P_{221} \cdot r_{221} + P_{222} \cdot r_{222} + P_{223} \cdot r_{223} + P_{224} \cdot r_{224} + \\ + P_{225} \cdot r_{225} + P_{226} \cdot r_{226} + P_{227} \cdot r_{227})$$

3. The assessment of the global priority P_3 was determined by the formula

$$P_3 = P_{31} \cdot r_{31} + P_{32} \cdot r_{32} + P_{33} \cdot r_{33} + \\ + P_{34} \cdot r_{34} + P_{35} \cdot r_{35} + P_{36} \cdot r_{36} + P_{37} \cdot r_{37} + \\ + P_{38} \cdot r_{38} + P_{39} \cdot r_{39} + P_{310} \cdot r_{310} + P_{311} \cdot r_{311}$$

4. The assessment of the global priority P_4 was determined by the formula

$$P_4 = P_{41} \cdot r_{41} + P_{42} \cdot r_{42} + P_{43} \cdot r_{43} + \\ + P_{44} \cdot r_{44} + P_{45} \cdot r_{45}$$

5. The assessment of the global priority P_5 was determined by the formula

$$P_5 = P_{51} \cdot r_{51} + P_{52} \cdot r_{52} + P_{53} \cdot r_{53}$$

6 Conclusions

The relevance of further research in the field of fire safety at Russian enterprises is presented. A reasonable option for choosing the AHP, the research method aimed at obtaining an assessment of the existing system conditions with the aim of its further improvement and development is presented. A sequence of calculations to obtain an assessment of indicators directly related to the ongoing fire safety measures at the Mosenergo, PJSC are formed.

References

[1]. Gvozdev, E. V., & Cherkina, V. M., 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

[2]. Gvozdev, E. V., Gribanova, E. B., Matvienko, Y. G., 2020. Methodology for Analysis of the Indicators of the Human Factor Effect on the Integrated Safety and Security of Electric Power Enterprises. *In Occupational Safety in Industry.*

[3]. Gvozdev, E. V., 2020. Methodology for the synthesis of an adaptive integrated security system at a regional life support enterprise. *In Fire and Explosion Safety.*

[4]. Gvozdev, E., 2020. On the probability determination of the reliability of a technosphere object under hazardous influence. *In IOP Conference Series: Materials Science and Engineering.* 869. p. 052043.

[5]. Gvozdev E.V., 2021. Rational allocation of the resource designated for comprehensive safety assurance at an enterprise: the problem statement. *Pozharovzryvobezopasnost/Fire and Explosion Safety*. 2021; 30(2):35-48. DOI: 10.22227/PVB.2021.30.02.35-48 (rus)

[6]. Makhutov, N. A., Gadenin, M. M., Buinovskiy, S. N., Grazhdankin, A. I., 2020. Scientific Fundamentals of Industrial Safety in the Multivolume Series "Safety of Russia. Legal, Socio-Economic and Scientific Technical Aspects". *In Occupational Safety in Industry".* 4. pp. 17-26.

[7]. Saaty, T., 1993. Decision Making. The Analytic Hierarchy Process. M.: "RADIO AND COMMUNICATION". p. 320.

[8]. Gvozdev, E. V., Rybakov, A. V., 2014. About the Methodology for Assessing the State of Fire Safety the Enterprise JSC "Mosvodokanal". *In Scientific and educational problems of civil protection.* pp. 68-80.