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Applying Multi-Criteria Analysis Methods for Fire Risk Assessment

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Abstract – **The aim of this paper is to prove the application of multi-criteria analysis methods for optimisation of fire risk identification and assessment process. The object of this research is fire risk and risk assessment. The subject of the research is studying the application of analytic hierarchy process for modelling and influence assessment of various fire risk factors. Results of research conducted by the authors can be used by insurance companies to perform the detailed assessment of fire risks on the object and to calculate a risk extra charge to an insurance premium; by the state supervisory institutions to determine the compliance of a condition of object with requirements of regulations; by real state owners and investors to carry out actions for decrease in degree of fire risks and minimisation of possible losses.**

Keywords – **Effectiveness, decision, fire risk, priority, risk factors.**

I. Introduction

Experts' information is important for the process of fire risk assessment both at the stage of identification of factors influencing risk level of an object and at the stage of determination of each risk factor priority. The authors consider the application of methods of the multi-criteria analysis in order to differentiate risk factors by degree of their importance for the purpose of optimisation of further fire risk management process. The main direction of practical use of the model after its construction is as follows: by substituting concrete values of the defining factors in the model, the level of fire risk of object is calculated. The calculation allows ranging factors according to the level of their importance and influence on the level of fire risk. The calculation provides an opportunity to estimate the level of ensuring fire safety and guarantees that fire risks of object are reduced or supported at the admissible level.

II. Identification of Fire Risk Factors

A. Fire Occurrence Factors

One of the most important stages of fire risk assessment process is the identification of risks of fire occurrence. At this evaluation stage of fire risk, an expert identifies all essential factors of fire occurrence and investigates the measures taken for their elimination or control. It means that it is necessary to consider all potential sources of ignition and a situation which can lead to fire. The causes of fire occurrence are based on technologic, natural or social factors.

The technologic causes of fire occurrence, first of all, are related to properties of technological process, engineering communication systems, exothermic chemical reactions (self-ignition), electric processes (static electricity) and so forth [4].

The causes of fire occurrence can have a natural basis. Those are thunder-storms, fires on natural objects (forest, peat). A separate group of fire occurrence causes is related to social factors. The considerable number of fires arises because of careless handling of people of fire, non-compliance with norms of operation of devices, malicious arsons [9].

Within these three main groups of fire occurrence factors, there are many sub-factors, the number of which depends first of all on experts' qualification and experience, characteristics of an object and practice of assessment of fire risks in the concrete state (requirements of regulations).

There is a set of classifications of fire risk factors, including the model offered by the authors that classifies risks using the analysis of causes and effects and creation of the chart [5].

As a result of risk factor identification, a vast amount of information is created. The analysis and processing of the information requires the involvement of substantial financial and human resources that can make the risk assessment process inefficient at all. It is necessary to optimise large amount of information that means differentiation of fire risk factors and sub-factors by the degree of their importance, reduction in the number of those factors, whose influence on the object risk degree is little [6]. The authors review an example of practical application of analytic hierarchy process in order to determine the priority of three fire risk factors. All three factors are included in the general category of technologic factors.

It is important to note that the qualitative result can be reached only by involvement of the qualified and competent experts who reveal risk factors by performing the survey of an object and studying technical documentation (fire safety audit of object) [7].

B. Determination of Fire Risk Factors and Sub-factors

The authors review an example of practical application of analytic hierarchy process in order to determine the priority of three risk factor groups – A, B, C:

Group A– existence of technical means of fire-prevention protection at the object;

Group B – building characteristics;

Group C – fire-prevention management at the object.

In each group (A, B and C), sub-factors have been identified (Tables I, II, III):

Group A – 14 sub-factors (A1–A14);

Group B – 15 sub-factors (B1–B15);

Group C – 8 sub-factors (C1–C8).

TABLE I

SUB-FACTORS OF GROUP A – EXISTENCE OF TECHNICAL MEANS OF FIRE-PREVENTION PROTECTION IN A BUILDING

No.	Factor	Factor description
A1	The building is equipped with an automatic fire extinguishing system	Functional characteristics for automatic fire extinguishing system are set.
A2	Automatic fire extinguishing system is fault-free	It is checked for automatic fire extinguishing system operating period, which affects the automatic fire extinguishing serviceability. Expert assessment should be based on the automatic fire extinguishing system design documentation.
A3	Technical services of automatic fire extinguishing system are carried out	Technical services and maintenance of automatic fire extinguishing system, its regularity and influence on fire risk are surveyed. If during the survey it is established that the technical services are carried out (a technical service contract is in force, there are equipment passports, passport marks on the object), expert assessment of this factor can be positive. The assessment may be negative if all of the above-mentioned documents are prepared, but during the expert survey it is stated that technical services and maintenance have not been carried out.
A4	The building is equipped with an automatic fire alarm system	Fire alarm systems must be installed in facilities where hazardous fire factors can lead to personal injury and (or) death. Categories of buildings, in which the alarm system has to be installed, are established in state regulations.
A5	Technical services of automatic fire alarm system are carried out	Technical services and maintenance of automatic fire alarm system, its regularity and influence on fire risk are surveyed.
A6	Fire extinguishing means comply with the category of object	The compliance of fire extinguishing means with the category of fire danger of object is investigated.
A7	Manual firefighting equipment complies with state requirements	Experts should determine the existence of the fixed fire-fighting equipment in the building and its functional characteristics.
A8	There is fire alarm and evacuation control system in the building	The existence of fire alarm and evacuation control and management systems is surveyed. Risk of influence of fire dangerous factors on people during evacuation from the building is estimated.
A9	Alarm and evacuation management system is in order	Experts should consider functional characteristics of alarm and evacuation management system that affects the hazards of fire effects on people during evacuation.
A10	Distance from firefighting hydrants to the building complies with fire safety requirements	Experts should check the correctness of installation of firefighting hydrants that affect the risks of fire extinguishing.
A11	There is an external water supply for fire extinguishing in the building	Experts should evaluate external supply of water that affects the risks of fire extinguishing.
A12	External water supply is capable to provide amount of water sufficient for fire extinguishing	The adequacy of firefighting water characteristics is considered. Firefighting water supply network is checked by special instruments in accordance with the approved programmes and test methods.
A13	There is an internal water supply for fire extinguishing in the building	Requirements for internal water supply are established in state regulations and in construction documents of building.
A14	Firefighting equipment driveway to hydrants, water sources are free	Experts evaluate the possibility of free and fast access of firefighting equipment to hydrants and water sources. Fire alarm and evacuation control and management system has to provide the round-the-clock access to water sources for firefighting equipment and fire brigade.

TABLE II

SUB-FACTORS OF GROUP A – BUILDING CHARACTERISTICS

No.	Factor	Factor description
B1	Building design facilitates fire fighting	Experts should check whether the project documents comply with the requirements of territorial planning of fire safety rules, which are associated with the division of the building into sections and fire compartments. Buildings are defined in various categories depending on their functional characteristics and the degree of fire safety. Spatial planning solutions provided in the process of construction of the building are largely dependent on the risk of the spread of fire in the building. Expert assessment should be based on data obtained in the project documentation and research centre at the time of the survey data. In case of non-compliance with the project documentation, expert assessment should be based on the survey data.
B2	Type of heating systems is fireproof	Experts estimate the fire risk of the heating material, heating equipment and its operating conditions.
B3	Electrical installation system was renovated within the last 15 years	The compliance of electrical installation system with fire safety requirements is checked. Expert assessment is based on the data obtained in the building construction documentation and research facility during the survey.
B4	There are not explosive areas in the building	The existence of explosive areas in the building is evaluated.
B5	The distance from a fire brigade to the building complies with the requirements	Placement of building servicing firefighting brigades and its impact on firefighting risks are surveyed.
B6	The distance between the buildings complies with the fire safety requirements	Existence and adequacy of distance between buildings are evaluated. If fire safety distance between buildings is insufficient, risk of spread of the fire from one building to another is increased.
B7	The opportunity of fire spread from adjacent areas is excluded	Expert assessment has to be based on a site inspection. The following information about adjacent areas could be provided: spatial planning and maintenance, functional use of buildings and structures, access control, permanently or seasonally used, whether the areas are fenced. Expert examines the presence of residues of dry grass in autumn and spring.
B8	Paths and driveways	Experts examine a possibility of free and fast

	of buildings are free for firefighting equipment	access of firefighting equipment to the building. Fire alarm and evacuation control and management system has to provide the round-the-clock access to the building for firefighting equipment and fire brigade.
B9	External fire stair is designed in the building	Experts should determine the existence of external fire stair, which ensures the fire brigade access to the roofing. Existence of fire stair affects the fire elimination speed.
B10	There are emergency lights in the building	Experts should determine the existence of evacuation lighting and its compliance with fire safety requirements. Evacuation lighting existence and availability affect the hazards of fire effects for humans. Evacuation lighting must provide sufficient initial evacuation illumination escape routes. Expert assessment must be based on project documentation and survey of the building.
B11	Access to the electricity supply system is limited	In order to reduce the risk of fire due to electrical causes, improper maintenance, negligent acts with electrical or terrorist act, access to electrical appliances by third parties or employees who do not have the appropriate skills, has to be limited. Expert assessment must be based on the findings of the energy service company and the time of survey data. If it is found that the access to electrical appliances is easy, expert assessment should be negative.
B12	High security category power supply is designed in the building	Experts should determine the existence of high security category power supply in the building. High security category electricity supply ensures reliable and continuous functioning of building fire protection system. Expert assessment should be based on data from the design documentation of the building, as well as data obtained from the company electricity supplier, the company which deals with maintenance of fire safety systems of the building.
B13	Measures to eliminate static electricity are taken	The static electricity is formed as a result of an inequality of electric charges (negative and positive) between two objects. Emission happens during a spark. During inspection the expert defines: - whether contact between the moving subjects is limited there; - whether there are “generators” of static electricity; - whether the footwear is appropriate; - whether there is sufficient air humidity. Each of these factors is essential and its influence has to be limited.
B14	There is emergency exit in the building	Experts should determine the existence of emergency exit and its compliance with fire safety requirements. Emergency exit from the premises and floors has to ensure human escape from the building, the rooms at a time when the main escape routes are blocked by fire.
B15	Exit from the building is not limited due to its mode of operation	Experts should survey the building area with limited access to staff and third parties, where access control systems, access systems and others are used. Most known cases of deaths are linked to the fact that it is not possible to evacuate due to the closed door, or staff does not have access to some premises.

TABLE III

SUB-FACTORS OF GROUP C – FIRE-PREVENTION MANAGEMENT AT THE OBJECT

No.	Factor	Factor description
C1	Fire safety training for staff is carried out	Experts check, how well staff is trained in fire safety regulations. Level of knowledge and skills of the staff influences risk of occurrence and spread of the fire in the building. Expert assessment is based on reports of safety measures manager of the object and tests of staff (selectively). The expert assessment is negative, if the survey of staff demonstrates that they have insufficient knowledge of fire safety rules, even if all the entries in the logs on staff mentoring have been made correctly and timely.
C2	Staff has practical skills of actions in case of fire	Experts check staff practical skills of actions in case of fire. Training regularity affects the spread of fire and dangerous factor effects on the human health. Expert assessment is based on reports of safety measures manager at the enterprise and tests of staff (selectively), the results of company’s internal fire audit. The expert may give a negative assessment if there is no regular staff training.
C3	Staff evacuation and safety training is carried out	Experts check staff practical skills of evacuation from the building in case of fire. Training regularity affects the spread of fire and dangerous factor effects on human beings. Expert assessment is based on reports of safety measures manager of the object and tests of staff (selectively), the results of company’s internal fire audit. The expert may give a negative assessment if there is no regular staff training.
C4	Location of mass of people in the premises is not allowed	It is considered that the building “is filled” with people during various periods of work of the company. If in the building at the same time is more than 50 people, this building is considered to be the one, in which there is a big mass of people.
C5	There are no people at night in the building	Experts should survey human presence in the building during the night. In the premises there can be such categories of staff as caretakers, on-call staff or working night shift. The presence of people at the company during the night affects fire occurrence and spread of risk.
C6	There are constantly people in the building who can notify about fire	Presence of people in the building, rooms or premises increases the probability of detection of fire and elimination before arrival of fire brigade. Expert assessment is based on reports of safety measures manager, HR manager and the results of company’s internal fire audit.
C7	There is quality management system at the object	Quality management system is the tool of company management to ensure high-quality management and customer service in the company. The system based on participation of all structural units and all personnel at all organisational levels is directed to long-term success in increasing the satisfaction of consumers, and also benefits of the organisation and representatives of the public. Thus, quality management system ensures more reliable protection and safety of the object.
C8	There is the plan of emergency service involvement at the object	Experts check whether there are contracts on cooperation with special emergency services, plans for involvement of additional resources in case of emergency situation.

III. Comparative Estimation of Factors Applying the Analytic Hierarchy Process Method

As the authors have noted above, as a result of research of the factors influencing the fire risks, three main groups of factors A, B, C have been distinguished. The group of experts has made comparative estimates of factors by the principle “everyone with everyone”. It is supposed that these groups of factors are poorly connected among themselves that allows considering them as independent groups at the initial stage of research. In this case to place the factors by the extent of their influence on fire risks it is possible to use the analytic hierarchy process method developed by the American mathematician T. Saati [1].

Realisation of this method consists of three stages:

- Formation of hierarchies;
- Paired comparison of factors;
- Calculation of priorities – importance of factors [2], [3].

The following hierarchical structure of risk factors is supposed by the authors (Fig. 1).

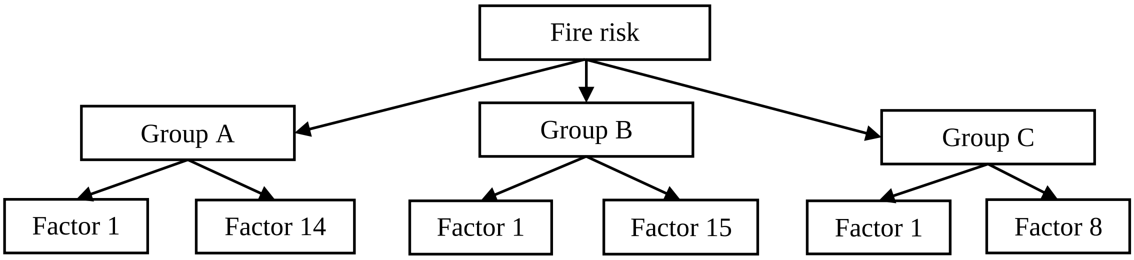

Fig. 1. Hierarchical structure of the factors influencing fire risks.

Paired comparison of factor groups A, B, C is carried out in the paper; the calculation results are shown in Table IV.

TABLE IV

Results of Paired Comparison of Factor Groups A, B and C

	A	B	C
A	1	1	2
B	1	1	3
C	0.5	0.33	1

The authors do not present the table of paired comparisons of factors, because they take up much space. As a result, for groups of factors and for factors in each group we will receive matrices of paired comparisons (1).

$$A=\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{pmatrix} \quad (1)$$

The authors have applied the following method to calculate the priorities:

- Matrix A is built at rather high degree of M (M > 30);
- the sum of S_i elements to every line of the matrix of $A^M(i = 1, 2,\dots,n)$ is calculated;
- total amount S of numbers S_i is calculated;
- priority size equal to S_i/S ($i = 1, 2,\dots,n$) is calculated for each factor.

TABLE V

Priority Size of Factor Groups A, B and C

	A	B	C	Σ	PV = Σ/Σ(Σ)
A	1	1	2	4	**0.369**
B	1	1	3	5	**0.462**
C	0.5	0.33	1	1.83	**0.169**
			Σ(Σ) =	10.83	**1.00**

The results of calculation of priorities of factors are shown in Table V. Group B – building characteristics – has the highest priority (0.462), the second place is taken by group A – existence of technical means of fire-prevention protection at the object (0.369), and the third place is taken by group C – fire-prevention management at the object (0.169).

The calculation results of priorities of sub-factors of group A are shown in Table VI. Priorities are calculated using the elementary approach.

TABLE VI

Priority Size of Sub-factors of Group A

	A1	A2	...	A14	Σ	PV = Σ/Σ(Σ)
A1	1	2	...	9	78	0.151
A2	0.5	1	...	9	75.5	0.146
A3	0.25	0.25	...	8	43.7	0.085
A4	0.5	0.5	...	7	64	0.124
A5	0.2	0.25	...	5	35.28	0.068
A6	0.33	0.33	...	9	56.31	0.109
A7	0.17	0.17	...	9	42.51	0.082
A8	0.14	0.17	...	8	36.04	0.070
A9	0.14	0.13	...	8	33.08	0.064
A10	0.14	0.13	...	7	12.79	0.025
A11	0.13	0.13	...	5	16.39	0.032
A12	0.11	0.13	...	4	9.34	0.018
A13	0.13	0.13	...	5	9.78	0.019
A14	0.11	0.11	...	1	2.96	0.006
				Σ(Σ) =	515.68	

Using the indicator of coherence of factor assessment *CI* (2), it is possible to specify expert estimates of paired comparisons of factors.

Then the coherence indicator is closer to zero, especially expert estimates are carried out adequately (usually, *CI* < 10 %, if number of factors does not exceed 10, and *CI* < 10–20 %, if number of factors exceeds 10).

$$CI = \frac{\lambda_{\max} - n}{n-1} \qquad (2)$$

where n – the size of a matrix (number of investigated factors), λ_{max} – the maximum value of a matrix of A^M .

$\lambda_{max.}$ has been calculated using special computer programs. Maximum value of matrix A $\lambda_{max.}$ = 16.851; $n = 14$. As a result, *CI* has been calculated:

CI = 0.2193 = 21.93 %.

A more exact result can be obtained using the following method:

Step 1. Calculate matrix A A^M degree (degree M $\geq$ 32);

Step 2. Calculate the maximum eigenvalue γ_{max} for matrix A^M ;

Step 3. Calculate $\lambda_{\max} = \sqrt[M]{\gamma_{\max}}$;

Step 4. Calculate *CI*.

Realisation of the method

Step 1

Matrix A^M is calculated, M = 32, the results are shown in Table VII.

Step 2. γ_{max} = 1.7908E+39;

Step 3. $\lambda_{\max} = \sqrt[K]{\gamma_{\max}} = 16.852$;

Step 4. *CI* = 21.94 %.

Specified λ_{max} confirms the previous result (21.93 %). Therefore, it is sufficient to use the matrix eigenvalues to calculate *CI*.

TABLE VII

MATRIX A^32 CALCULATION

1.16E+38	1.28E+38	…	1.46E+39	3.62E+39
1.04E+38	1.14E+38	…	1.31E+39	3.24E+39
4.57E+37	5.01E+37	…	5.76E+38	1.42E+39
9.23E+37	1.01E+38	…	1.16E+39	2.88E+39
4.19E+37	4.60E+37	…	5.29E+38	1.31E+39
6.12E+37	6.71E+37	…	7.71E+38	1.91E+39
3.19E+37	3.50E+37	…	4.02E+38	9.95E+38
2.68E+37	2.95E+37	…	3.38E+38	8.37E+38
2.23E+37	2.45E+37	…	2.81E+38	6.96E+38
9.34E+36	1.03E+37	…	1.18E+38	2.91E+38
1.14E+37	1.25E+37	…	1.44E+38	3.56E+38
7.72E+36	8.48E+36	…	9.73E+37	2.41E+38
8.60E+36	9.44E+36	…	1.08E+38	2.68E+38
4.76E+36	5.23E+36	…	6.00E+37	1.49E+38

After carrying out all these calculations, it is possible to define final arrangement of priorities for all A, B and C groups of factors.

To determine sub-factor priorities of all groups A, B and C, it is necessary to use the priority vectors from Table V.

α = 0.369 (priority vector of group A);

β = 0.462 (priority vector of group B);

γ = 0.169 (priority vector of group C).

Multiplying vectors PV_A, PV_B and PV_C (Fig. 2) by corresponding figures α, β and γ, total priority vector of sub-factors is obtained:

$$(PV_A \cdot \alpha, PV_B \cdot \beta, PV_C \cdot \gamma).$$

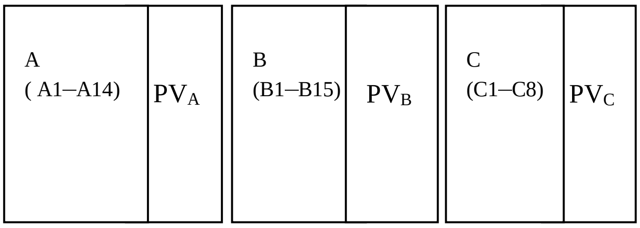

Fig. 2. Priority vectors of groups A, B and C.

The calculation results of total priority vector of sub-factors of group A are shown in Table VIII.

TABLE VIII

PRIORITY VECTOR OF SUB-FACTORS OF GROUP A

	A1	A2	...	A14	Σ	**PV = Σ/Σ(Σ)**	PV*α
A1	1	2	...	9	78	**0.151**	**0.0558**
A2	0.5	1	...	9	7.5	**0.146**	**0.0540**
A3	0.25	0.25	...	8	43.7	**0.085**	**0.0313**
A4	0.5	0.5	...	7	64	**0.124**	**0.0458**
A5	0.2	0.25	...	5	35.28	**0.068**	**0.0252**
A6	0.33	0.33	...	9	56.31	**0.109**	**0.0403**
A7	0.17	0.17	...	9	42.51	**0.082**	**0.0304**
A8	0.14	0.17	...	8	36.04	**0.070**	**0.0258**
A9	0.14	0.13	...	8	33.08	**0.064**	**0.0237**
A10	0.14	0.13	...	7	12.79	**0.025**	**0.0091**
A11	0.13	0.13	...	5	16.39	**0.032**	**0.0117**
A12	0.11	0.13	...	4	9.34	**0.018**	**0.0067**
A13	0.13	0.13	...	5	9.78	**0.019**	**0.0070**
A14	0.11	0.11	...	1	2.96	**0.006**	**0.0021**

After carrying out all these calculations, it is possible to define final arrangement of priorities for all factors. It gives the chance to choose such factors, which with sufficient degree of reliability will estimate risks.

IV. Conclusion

The authors suggest using the following algorithm for definition of a risk extra charge for concrete object of insurance taking into account risk factors:

1) identification of risk factors, which have significant impact (positive or negative) on fire safety of the object;

2) calculation of risk factor priority vectors and total priority vectors;

3) calculation of a risk extra charge to the main insurance premium depending on the degree of risk of individual object of insurance. If necessary, the calculated risk extra charge can be modified by the underwriter who considers non-formalised risk factors (for example, reputation of the client, a specific arrangement of object etc.).

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