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QUANTITATIVE EVALUATION OF FIRE SAFETY FACTORS INFLUENCE FOR BUILDINGS USING COGNITIVE MAP AND ANP APPROACH

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ABSTRACT

Fire safety of buildings is influenced by numerous and interacting factors. Assessment of their influence delivers vital information which facilitates selection of proper solutions of different kinds for buildings. The paper deals with an approach which facilitates such assessment. The approach is based on identification of multi-dimensional relations between fire safety factors. A proven multi-criteria decision analysis tool is finally applied for deriving final evaluations.

Keywords: building, fire, safety, factor, influence, feedback, cognitive map, ANP.

INTRODUCTION

Fire safety evaluated for buildings and building occupants depends on numerous risk factors. These risk factors correspond to technical, economic, social and environmental merits. Complexity of material, structural, functional and formal solutions which are applied in contemporary buildings results in complexity of relations between fire risk factors.

Possible inter-relations between fire risk factors make assessment of their influence a difficult task. Application of special tools is therefore required to facilitate such evaluation. Such tools are nevertheless available, although they are rather rarely applied for fire safety analysis. Details about these tools can be found in several papers by Ginda & Maślak (2012, 2012a).

Successful assessment of influence of fire risk factors requires reliable data. Expert opinions are usually utilised with this regard due to a complex nature of fire risk issues. A two-level approach is presented in the paper for evaluation of fire risk factors influence on fire safety for buildings and for occupants.

The first level is devoted to identification of inter-relations between fire risk factors. Cognitive map (Kosko, 1986) is utilised for presentation of direct influence between fire risk factors. Proven equivalence of cognitive maps with linear transition function and DEMATEL (Tzeng et al., 2010) facilitates identification of structure of interactions between fire risk factors. The second approach level is devoted to assessment of influence of fire risk factors. Information provided at the first level is utilised with this regard. Analytic Network Process - ANP (Saaty, 1996) is applied for deriving final priorities for fire risk factors.

COGNITIVE MAP

A concept of a cognitive map emerged from modelling political problems (Axelrod, 1976). Kosko (Kosko, 1986) applied fuzzy information and developed a concept of a fuzzy cognition map (FCM). Fuzzy cognition maps proved an interesting universal decision support tool.

They are, therefore, applied in many diverse areas. FCMs are also called fuzzy decision maps (FDM) nowadays.

FCM is based on the application of a tuple consisting of the following 4 components:

1. A set of *n* objects.
2. A connection matrix **E**.
3. A state matrix **C**.
4. A threshold function *f*.

E is an *n* by *n* quadratic matrix. It expresses a structure of influence between considered objects. This structure can be also expressed by a digraph expressing influence relations between objects.

C has the same size as **E**. It is initially identical with an identity matrix **I**:

$$\mathbf{C}^{(0)} = \mathbf{I}\,. \tag{1}$$

Application of a threshold function *f* makes distinction between different objects clearer. We can adjust a threshold function to obtain reliable FDM analysis results. Sensitivity analysis is usually applied to justify an assumed threshold function.

A terminal state matrix $\mathbf{C}^{(T)}$ defines structure of influence between the considered objects. We apply a step-wise approach to derive the matrix:

$$\mathbf{C}^{(t+1)} = f\left(\mathbf{C}^{(t)} \cdot \mathbf{E}\right), \tag{2}$$

where: $t = 0, 1, \ldots, T$.

The terminal state matrix $\mathbf{C}^{(T)}$ can corresponds to 2 distinct cases:

1. A lack of changes in $\mathbf{C}^{(T)}$ between subsequent steps:

$$\mathbf{C}^{(T+1)} = f\left(\mathbf{C}^{(T)} \cdot \mathbf{E}\right). \tag{3}$$

2. A permanent limit state cycle with repeating sequence of subsequent state matrices for $t = T, T+1, \ldots, T+i\cdot(c-1), T+i\cdot c, T+i\cdot(c+1) \ldots$:

$$\mathbf{C}^{(T)} = \mathbf{C}^{(T+i\cdot c)}, \tag{4}$$

   where: *c* is a cycle length and $i = 1, 2\ldots$

FDM analysis results in a final set of weights *w* expressing influence of considered objects:

$$\mathbf{w} = \overline{\mathbf{z}} + \overline{\mathbf{C}}^{(T)} \cdot \overline{\mathbf{z}}, \tag{5}$$

where: $\overline{\mathbf{z}}$ denotes standardised vector z of non-negative weights expressing the importance of considered objects, $\overline{\mathbf{C}}^{(T)}$ is a row-wise standardised terminal state matrix:

$$\overline{\mathbf{z}} = \frac{\mathbf{z}}{\sum_{i=1}^{n} z_i}, \quad \overline{\mathbf{C}}^{(T)} = \frac{\mathbf{C}^{(T)}}{\max_i \left\{ \sum_{j=1}^{n} c_{ij}^{(T)} \right\}}. \tag{6}$$

DEMATEL PROCEDURE

DEcision MAking Trial and Evaluation Laboratory is a recognised and universal decision support tool. It is generally aimed at identification of cause-effect chain components in the case of n considered objects (Fontela & Gabus, 1976). A concept of direct influence is applied to express cause-effect relations between the objects. The direct influence of the objects on other objects is evaluated in a pair-wise manner. An ordinal measurement scale is applied in this regard. The scale consists of the bottom-most level that pertains to a lack of direct influence between the compared objects and N other levels that conform to gradually rising direct influence intensity of the first compared object on the second compared object. The highest scale level N_D corresponds to an extreme direct influence intensity of the first compared object on the other one. Number of applied scale levels depends on actual needs of a decision maker. An evaluation scale can look as follows:

- 0 – a lack of direct influence between compared objects,
- 1 – a slight direct influence,
- 2 – a big direct influence,
- 3 – an extreme direct influence.

A digraph is utilised to represent direct influence relations between the objects. Such digraph is called a direct influence digraph $G(V,E)$. Nodes V express the objects while weighted arcs E denote intensity and direction of direct influence relations. The considered digraph is represented by a matrix of direct influence $\mathbf{X}$. This matrix consists of rows and columns devoted to consecutive objects. Components x_{ij} correspond to direct influence intensity of the i-th subsequent object on the j-th consecutive object ($i, j = 1...n$).

Structure of direct influence relations between objects results in the indirect influence. Combination of indirect and direct influences gives the structure of total influence. A normalised matrix of direct influence $\overline{\mathbf{X}}$ is utilised in this regard:

$$\overline{\mathbf{X}} = \frac{1}{\lambda}\mathbf{X}, \tag{7}$$

where λ denotes the largest row-wise and column-wise sum of direct influence matrix components:

$$\lambda = \max\left\{ \max_{i\in[1,n]}\left\{\sum_{j=1}^{n} x_{ij}\right\}, \max_{i\in[1,n]}\left\{\sum_{j=1}^{n} x_{ji}\right\} \right\}. \tag{8}$$

Structure of total influence is represented by a matrix of total influence $\mathbf{T}$:

$$\mathbf{T} = \overline{\mathbf{X}}\left(\mathbf{I} - \overline{\mathbf{X}}\right)^{-1}, \tag{9}$$

where $\mathbf{I}$ denotes an identity matrix.

Values of two special indices, namely a relation s_i^- and a prominence s_i^+ are derived for each object from $\mathbf{T}$. Row-wise and column-wise sums of $\mathbf{T}$ components are applied in this regard:

$$\underset{i\in[1,n]}{\forall} \quad s_i^- = \sum_{j=1}^{n} t_{ij} - \sum_{j=1}^{n} t_{ji}, \tag{10}$$

$$\underset{i\in[1,n]}{\forall} \quad s_i^{+} = \sum_{j=1}^{n} t_{ij} + \sum_{j=1}^{n} t_{ji}\,, \tag{11}$$

A relation expresses causal (or effect) nature of objects. Clearly positive value confirms causal object role while clearly negative value corresponds to effect role of an object. A position tells us about an overall role of a considered objects in the identification of cause-effect chain components.

DEMATEL delivers two main measures for presentation of decision analysis outcomes. The first measure is a digraph of total influence $T(V,E_T)$. Digraph nodes V represent considered objects again while weighted digraph arcs E_T denote intensity and direction of total influence between the objects. It is worth noticing that a resulting total influence structure represented by $\mathbf{T}$ is often unclear. This is because it consists of a lot of rather unimportant total influence relations between objects. Application of a positive total influence threshold δ can help therefore in leaning it considerably to obtain reduced structure $\overline{\mathbf{T}}$. A threshold makes it possible to remove unimportant total influence relations from original structure $\mathbf{T}$:

$$\underset{i\in[1,n]}{\forall} \; \underset{i\in[1,n]}{\forall} \quad \bar{t}_{ij} = \begin{cases} t_{ij} & \text{for} \quad t_{ij} \geq \delta, \\ 0 & \text{for} \quad t_{ij} < \delta. \end{cases}, \tag{12}$$

Applied threshold δ value should deliver appropriate means for discriminating total influence intensity to a needed extent.

A relation versus a position graph provides another means for presentation of DEMATEL analysis outcomes.

ANP APPROACH

Analytic Network Process is an universal multi-criteria decision analysis method capable of including influence feedback while prioritising objects. It is also a vital extension of a well known Analytic Hierarchy Process (AHP) (Saaty, 1980). It benefits, therefore, from numerous AHP merits e.g. ability to include both intangible and tangible features, clear rules for pair-wise evaluation of considered decision making problem, enforcement of input data consistency.

ANP applies pair-wise comparisons to assess influence of decision problem model components. A typical 1-9 ordinal scale is utilised in this regard. Odd scale levels comprise basic parts of a scale and denote:

- 1 – a lack of difference in influence,
- 3 – a slight advantage of the first compared component over the second component,
- 5 – a big advantage of the first compared component,
- 7 – a very big advantage of the first compared component,
- 9 – an extreme advantage of the first component.

Even scale levels express hesitation related to choice of a scale level from consecutive odd scale levels. For example, we would select scale level 4 if we were unsure whether a first compared component influences solution of a considered decision problem slightly more or even more considerably than a second compared component.

A simple reciprocal of evaluation of an advantage of a first compared model component over a second compared model component is applied for evaluating an advantage of a second model component over a first model component.

A network structure is applied to express relations between decision making problem components in ANP. This network defines necessary evaluations making deriving overall priorities for all decision making model components possible. Related decision making problem components are therefore gathered in distinct clusters. Both cluster components and whole clusters are then compared in a pair-wise manner. Pair-wise comparisons result in evaluations of problem model components. Such evaluations enable us to prioritise decision making problem model components according to an assumed influence structure given by an applied network.

A special matrix **S** called a supermatrix is applied for deriving final priorities for all decision making problem model components. Consecutive supermatrix rows and columns are devoted to subsequent problem model components. A column pertaining to a given problem model component consists of priorities for all problem model components resulting from influence of that component. All columns should be normalised i.e. the sums of their components should be equal to 1.

The following rising to powers is applied to derive final priorities for decision making problem model components:

$$\mathbf{S}_{\lim} = \lim_{k \to \infty} \mathbf{S}^k , \tag{13}$$

where $\mathbf{S}_{\lim}$ is a limit supermatrix.

Rising to powers according to Eq.(7) stops when assumed absolute $\mathbf{S}_{\lim}$ estimation accuracy ε is obtained:

$$\underset{i=1,\,2...}{\forall} \quad \left| \mathbf{S}^i - \mathbf{S}^{i-1} \right| \le \boldsymbol{\varepsilon} , \tag{14}$$

where $\boldsymbol{\varepsilon}$ denotes a vector consisting of $\varepsilon > 0$ values.

A limit supermatrix yields convergent priorities for considered decision making problem model components.

It is evident that application of appropriate network influence structure is critical for obtaining reliable ANP results. Application of DEMATEL seems to be appropriate in this regard.

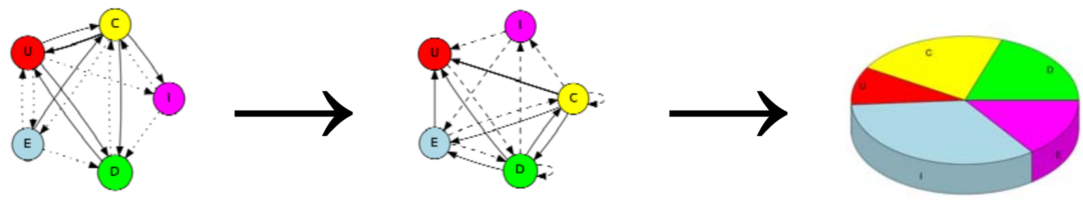
QUANTITATIVE ASSESSMENT OF INFLUENCE OF FIRE SAFETY FACTORS

Fire safety for buildings results from different factors. These factors are related to building design, construction and occupation. We therefore consider respective general fire safety factors: D, C and U in this regard. These factors are man-controllable.

Buildings function in a dynamically changing environment. We should, therefore, take into account influence of accidental factors too. Such factors correspond to both internal (I) and external (E) influences. Internal accidental factor can be for example applied for expressing uncertainty with regard to material performance while external accidental factor can be utilised for addressing uncertainty in surrounding environment influence. These factors are man-uncontrollable, undoubtedly.

We intend to assess influence of considered fire safety factors quantitatively. We apply, therefore, a two-stage approach presented in Fig.1. A cognitive map is proposed by an appointed expert. Direct Influence of factors is then evaluated by an appointed expert according to DEMATEL rules and a structure of a total influence is derived. Obtained structure provides appropriate means for addressing influence between fire safety factors while including feedback among them. An appointed expert applies ANP rules for evaluating intensity of such influence. We finally obtain, therefore, priorities expressing overall influence of considered fire safety factors.

CM DEMATEL ANP



(a) (b) (c)

Fig.1 A combined CM-DEMATEL-ANP approach

An appointed expert uses a 0-3 DEMATEL evaluation scale while evaluating influence of fire safety factors to define a cognitive map. An expert assumes that:

1. Design factors D considerably influence effects of construction C and building utilisation U factors (evaluations equal to 2). They slightly affect effects of internal accidental factors I (evaluation equal to 1) and extremely influence effects of accidental external factors E (evaluation equal to 3).
2. Construction factors considerably affect effects of design, internal and external accidental factors (evaluations equal to 2). They also extremely influence effects of building utilisation factors (evaluation equal to 3).
3. Building utilisation factors considerably affect effects of design factors (evaluation equal to 2). They slightly influence effects of construction and internal accidental factors (evaluations equal to 1).
4. Internal accidental factors slightly affect effects of design, construction and building utilisation factors (evaluations equal to 1). They considerably influence effects of external influence factors (evaluation equal to 2).
5. External accidental factors slightly affect effects of design and internal accidental factors (evaluations equal to 1). They considerably influence effects of construction and utilisation factors (evaluation equal to 2).

A resulting DEMATEL direct influence structure is presented in Fig.3. Different line patterns are applied to express a direct influence intensity evaluations:

- a dotted line expresses a direct influence intensity equal to 1,
- a solid line denotes a direct influence intensity equal to 2,
- a bold line expresses a direct influence intensity equal to 3.

It is worth noticing that an assumed direct influence structure includes feedback between different factors.

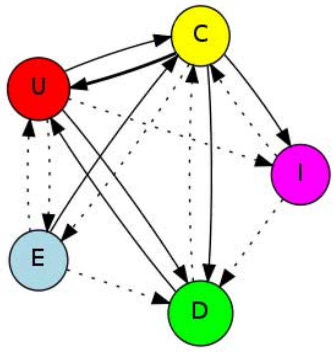


Fig.2. Direct influence structure for fire safety factors

A matrix of direct influence looks, therefore, as follows:

$$\mathbf{X} = \begin{bmatrix} 0 & 2 & 2 & 1 & 3 \\ 2 & 0 & 3 & 2 & 2 \\ 2 & 1 & 0 & 1 & 0 \\ 1 & 1 & 1 & 0 & 2 \\ 1 & 2 & 2 & 1 & 0 \end{bmatrix}. \tag{15}$$

We apply formulae (7-10) to obtain a matrix of a total influence:

$$\mathbf{T} = \begin{bmatrix} 0.4257 & 0.6056 & 0.7267 & 0.4526 & 0.7102 \\ 0.6403 & 0.4428 & 0.8313 & 0.5572 & 0.6579 \\ 0.4294 & 0.3368 & 0.3041 & 0.2990 & 0.2844 \\ 0.3745 & 0.3771 & 0.4526 & 0.2292 & 0.4818 \\ 0.4377 & 0.5046 & 0.6056 & 0.3771 & 0.3418 \end{bmatrix}. \tag{16}$$

Matrix **T** corresponds to a structure of total influence presented in Fig.3. We apply line patterns to express differences in such total influence:

- a dotted line expresses a total influence intensity smaller than 0.4,
- a dashed line denotes a total influence intensity at least equal to 0.4 and less than 0.6,
- a solid line expresses a total influence intensity at least equal to 0.6 and less than 0.8,
- a bold line denotes a total influence intensity at least equal to 0.8.

We apply an identified structure in ANP analysis. A structure suggests that we should always compare influence of factors D, C, U, I, E in a pair-wise manner while considering an exclusive influence of these factors.

An expert assumes, therefore, that according to influence of design factors D:

1. Influence of factors D on fire safety is slightly larger than influence of construction factors C (ANP evaluation equal to 3), slightly or even considerably larger than influence of building utilisation factors U and influence on external accidental factors E (evaluations equal to 4), the same as influence of internal accidental factors I (evaluation 1).

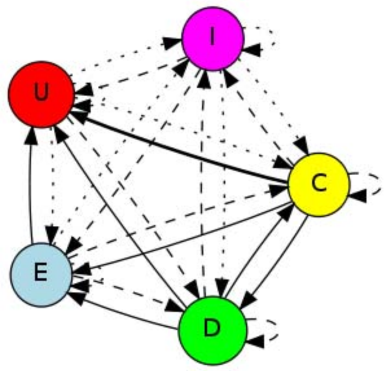


Fig.3. Total influence structure **T** for fire safety factors

2. Influence of construction factors on fire safety is slightly larger than influence of building utilisation factors and influence of external accidental factors (evaluations equal to 3). It is also slightly smaller than influence of internal accidental factors (evaluation 1/3).
3. Influence of building utilisation factors on fire safety is slightly or even considerably smaller than influence of internal accidental factors (evaluation equal to 1/4) and the same as influence of external accidental factors (evaluation equal to 1).
4. Influence of internal accidental factors on fire safety is slightly or even considerably larger than influence of external accidental factors (evaluation equal to 4).

Hence, obtained judgement matrix $\mathbf{A}_D$ is consistent ($c.r.$ = 0.024 < 0.10) and looks as follows:

$$\mathbf{A}_D = \begin{bmatrix} 1 & 3 & 4 & 1 & 4 \\ \frac{1}{3} & 1 & 3 & \frac{1}{3} & 3 \\ \frac{1}{4} & \frac{1}{3} & 1 & \frac{1}{4} & 1 \\ 1 & 3 & 4 & 1 & 4 \\ \frac{1}{4} & \frac{1}{3} & 1 & \frac{1}{4} & 1 \end{bmatrix}. \tag{18}$$

Matrix $\mathbf{A}_D$ corresponds to following local priority vector:

$$\mathbf{p}_D = \begin{bmatrix} 0.3465 \\ 0.1598 \\ 0.0736 \\ 0.3465 \\ 0.0736 \end{bmatrix}. \tag{19}$$

This vector confirms a considerable advantage in influence on fire safety of design factors D and internal accidental factors I over construction factors C according to influence of design factors D. Influence of building utilisation factors U and external accidental factors E proves rather small.

An expert assumes that according to influence of construction factors C:

1. Influence of design factors D on a fire safety of a building is slightly smaller than influence of construction factors C (ANP evaluation equal to 1/3), slightly larger than

influence of building utilisation factors U (evaluation equal to 3), the same as or even slightly smaller than influence on internal accidental factors I (evaluation equal to 1/2) and the same as influence of external accidental factors I (evaluation 1).

2. Influence of construction factors on fire safety is considerably larger than influence of building utilisation factors (evaluation equal to 5), the same as or even slightly larger than influence of internal accidental factors (evaluation equal to 2) and slightly larger than influence of external accidental factors (evaluation 3).
3. Influence of building utilisation factors on fire safety is slightly or even considerably smaller than influence of internal accidental factors (evaluation equal to 1/4) and slightly smaller than influence of external accidental factors (evaluation equal to 1/3).
4. Influence of internal accidental factors on fire safety is the same as or even slightly larger than influence of external accidental factors (evaluation equal to 2).

A resulting consistent judgement matrix $\mathbf{A}_C$ (*c.r.* = 0.013) and a vector of priorities $\mathbf{p}_C$ look as follows:

$$\mathbf{A}_C = \begin{bmatrix} 1 & \frac{1}{3} & 3 & \frac{1}{2} & 1 \\ 3 & 1 & 5 & 2 & 3 \\ \frac{1}{3} & \frac{1}{5} & 1 & \frac{1}{4} & \frac{1}{3} \\ 2 & \frac{1}{2} & 4 & 1 & 2 \\ 1 & \frac{1}{3} & 1 & \frac{1}{2} & 1 \end{bmatrix} \quad \Rightarrow \quad \mathbf{p}_C = \begin{bmatrix} 0.1434 \\ 0.4052 \\ 0.0583 \\ 0.2497 \\ 0.1434 \end{bmatrix}. \tag{20}$$

Hence, it is evident that influence of construction factors C on fire safety is noticeably larger than influence of internal accidental factors I according to influence of construction factors. Influence of internal accidental factors I is larger than influence of design factors D and external accidental factors E. Building utilisation factors influence fire safety only slightly.

An expert assumes that according to influence of building utilisation factors U:

1. Influence of design factors D on fire safety is the same as or slightly smaller than influence of construction factors C (ANP evaluation equal to 1/3) and slightly smaller than influence the remaining factors (evaluations equal to 1/3).
2. Influence of construction, building utilisation and both accidental factors is the same (evaluations equal to 1).

We obtain, therefore, a consistent judgement matrix $\mathbf{A}_U$ (*c.r.* = 0,004) and a resulting vector $\mathbf{p}_U$. They look as follows:

$$\mathbf{A}_U = \begin{bmatrix} 1 & \frac{1}{2} & \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \\ 2 & 1 & 1 & 1 & 1 \\ 3 & 1 & 1 & 1 & 1 \\ 3 & 1 & 4 & 1 & 1 \\ 3 & 1 & 1 & 1 & 1 \end{bmatrix} \quad \Rightarrow \quad \mathbf{p}_U = \begin{bmatrix} 0.0844 \\ 0.2154 \\ 0.2334 \\ 0.2334 \\ 0.2334 \end{bmatrix}. \tag{21}$$

It is evident that all factors influence a fire safety of a building considerably, besides design factors D, according to influence of building utilisation factors.

An expert assumes that according to influence of internal accidence factors I:

1. Influence of design factors D and construction factors C on a fire safety of a building is the same as influence of construction factors C (ANP evaluation equal to 1), the same as or slightly larger than influence of building utilisation factors U and external accidental factors E (evaluations equal to 2). It is also slightly smaller than influence of internal accidental factors (evaluation equal to 1/3).
2. Influence of building utilisation factors on a fire safety is slightly smaller than influence of internal accidental factors (evaluation equal to 1/3) and the same as influence of external accidental factors (evaluation equal to 1).
3. Influence of internal accidental factors on a fire safety is slightly, or even considerably larger than influence of external accidental factors (evaluation equal to 4).

We obtain a consistent judgement matrix $\mathbf{A}_{\mathrm{I}}$ ($c.r.$ = 0.012) and a resulting priorities $\mathbf{p}_{\mathrm{I}}$ for considered factors:

$$\mathbf{A}_{\mathrm{I}} = \begin{bmatrix} 1 & 1 & 2 & \frac{1}{3} & 2 \\ 1 & 1 & 2 & \frac{1}{3} & 2 \\ \frac{1}{2} & \frac{1}{2} & 1 & \frac{1}{3} & 1 \\ 3 & 3 & 3 & 1 & 4 \\ \frac{1}{2} & \frac{1}{2} & 1 & \frac{1}{4} & 1 \end{bmatrix} \Rightarrow \mathbf{p}_{\mathrm{I}} = \begin{bmatrix} 0.1810 \\ 0.1810 \\ 0.1040 \\ 0.4359 \\ 0.0981 \end{bmatrix}. \tag{22}$$

Internal accidental factors I influence a fire safety for a building at most. Design factors D and construction factors C influence a fire safety more than the remaining factors.

An expert finally assumes that according to influence of external accidental factors E:

1. Influence of design factors D on a fire safety is equal to or slightly larger than influence of construction factors C (ANP evaluation equal to 2), slightly larger than influence of building utilisation factors U (evaluation equal to 3) and the same as, or slightly smaller than influence of accidental factors (evaluations equal to ½).
2. Influence of construction factors on a fire safety is the same as, or slightly larger than influence of building utilisation factors (evaluation equal to 2) and slightly smaller than influence of accidental factors (evaluation equal to 1/3).
3. Influence of building utilisation factors on a fire safety is slightly smaller than influence of internal accidental factors (evaluation equal to 1/3) and slightly, or even considerably smaller than influence of external accidental factors (evaluation ¼).
4. Influence of internal factors on a fire safety is the same as influence of external factors (evaluation equal to 1).

Hence, a consistent judgement matrix $\mathbf{A}_{\mathrm{E}}$ ($c.r.$ = 0.015) and priorities $\mathbf{p}_{\mathrm{E}}$ are obtained:

$$\mathbf{A}_{\mathrm{E}} = \begin{bmatrix} 1 & 2 & 3 & \frac{1}{2} & \frac{1}{2} \\ \frac{1}{2} & 1 & 2 & \frac{1}{3} & \frac{1}{3} \\ \frac{1}{3} & \frac{1}{2} & 1 & \frac{1}{2} & \frac{1}{4} \\ 2 & 3 & 2 & 1 & 1 \\ 2 & 3 & 4 & 1 & 1 \end{bmatrix} \Rightarrow \mathbf{p}_{\mathrm{E}} = \begin{bmatrix} 0.1862 \\ 0.1106 \\ 0.0730 \\ 0.3060 \\ 0.3242 \end{bmatrix}. \tag{23}$$

It is clear that accidental factors I and E influence a fire safety of a building at most according to influence of external accidental factor E. Design factors D influence a fire safety moderately. Influence of the remaining factors is rather small.

We can finally build an ANP supermatrix:

$$\mathbf{S} = \begin{bmatrix} \mathbf{p}_{\mathrm{D}} & \mathbf{p}_{\mathrm{C}} & \mathbf{p}_{\mathrm{U}} & \mathbf{p}_{\mathrm{I}} & \mathbf{p}_{\mathrm{E}} \end{bmatrix} . \tag{24}$$

It looks as follows:

$$\mathbf{S} = \begin{bmatrix} 0.3465 & 0.1434 & 0.0844 & 0.1810 & 0.1862 \\ 0.1598 & 0.4052 & 0.2154 & 0.1810 & 0.1106 \\ 0.0736 & 0.0583 & 0.2334 & 0.1040 & 0.0730 \\ 0.3465 & 0.2497 & 0.2334 & 0.4359 & 0.3060 \\ 0.0736 & 0.1434 & 0.2334 & 0.0981 & 0.3242 \end{bmatrix} . \tag{25}$$

We assume an accuracy $\varepsilon = 0.0001$ for limit supermatrix estimation. Hence, we obtain a limit super matrix according to formula (14) for $k = 16$:

$$\mathbf{S}_{\mathrm{lim}} = \begin{bmatrix} 0.1969 & 0.1969 & 0.1969 & 0.1969 & 0.1969 \\ 0.2185 & 0.2185 & 0.2185 & 0.2185 & 0.2185 \\ 0.0958 & 0.0958 & 0.0958 & 0.0958 & 0.0958 \\ 0.3387 & 0.3387 & 0.3387 & 0.3387 & 0.3387 \\ 0.1501 & 0.1501 & 0.1501 & 0.1501 & 0.1501 \end{bmatrix} . \tag{26}$$

Each column of $\mathbf{S}_{\mathrm{lim}}$ defines final ranking of considered factors according to the influence on fire safety of a building. This ranking is presented in Fig.4. It is evident that fire safety of a building is mainly influenced by internal accidental factors I. Construction factors C and design factors D influence fire safety considerably too. Such fire safety is also moderately affected by external accidental factors E. Influence of building utilisation is rather small.

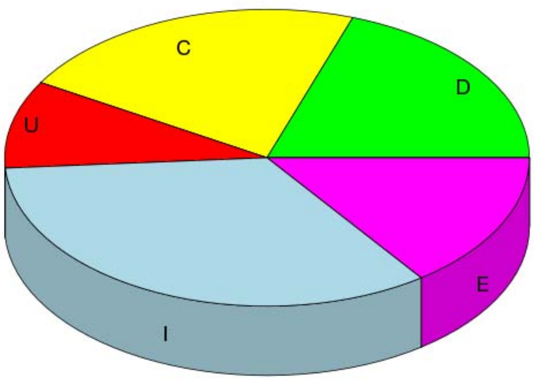


Fig.4. Final ranking of considered fire safety factors

CONCLUSIONS

Possibility of DEMATEL application to facilitate utilisation of cognitive maps and ANP analysis have been recognized only recently. Sequential application of these three approaches enables us to combine benefits of qualitative and quantitative analysis effectively. Results of a sample analysis confirm that.

Obtained results pertain to single expert opinions and deal with a set of arbitrarily selected and rather general fire safety factors. The presented approach is flexible enough to be easily adapted to actual needs with regard to included factors, application of multiple expert opinions etc. We are going to exploit these possibilities in future research.

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