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A COMPARISON OF METHODS USED FOR FIRE SAFETY EVALUATION

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Abstract. The paper considers the problem of fire safety assurance by means of fire risk indexing and fire risk assessment. Attention is focused on the comparison of these two principal approaches and the possibilities of applying them in a combined set. The paper is aimed at defining, comparing and analyzing fire safety assessment by applying the aforementioned approaches. The practicability of both approaches is compared by means of an example considering fire safety of an existing office building. It is stated that fire risk indexing is more practicable than formal risk assessment despite all shortcomings of the former approach. It is highly probable that comprehensive decision-making concerning fire safety assurance will be based on fire risk indexing rather than on formal risk assessment.

Keywords: fire, safety, index, assessment, risk.

Introduction

The aim of analyzing building fire risk is to comprehensively understand and characterize fire-related risks to better inform the wide range of decisions that must be made as a part of building design, construction and operation. Specifically, fire risk is the possibility of an unwanted outcome in an uncertain situation where fire is the hazard that may induce the loss of or harm to one that is valued (e.g. life, property, business continuity, heritage, environment or some combination of these) (e.g. Rasbash *et al.* 2004).

Fire risk indexing is the link between fire science, fire safety and safety culture (Rasbash *et al*. 2004; SFPE 2002). Fire risk indexing is evolving as a method of evaluating fire safety that is valuable to assimilating research results. Indexing can provide a cost-effective means of risk evaluation that is both useful and valid. Fire risk indexing systems are heuristic models of fire safety. They constitute various processes of analyzing and scoring hazard and other system attributes to proceed with a rapid and simple estimate of relative fire risk. There are numerous approaches to fire safety evaluation that can be constructed as risk indexing (Watts 2002).

Contrary to fire risk indexing, detailed risk assessment can be an expressive and labour-intensive process. On the other hand, the assessment of fire risk employing formal statistical means allows a highly individual characterization of building fire safety.

The paper presents a short review of input variables used for calculating fire risk indices and assessing such risk. The discussion embraces an application of both fire risk index and fire risk assessment for a specific building. Attention in focused on the comparison of these approaches and the possibilities of applying them. The findings presented in the paper are viewed as knowledge that could facilitate decision-making with respect to fire risk.

Fire Safety Assessment by Fire Risk Indexing. Description of the Approach

Fire risk indexing is considered to be a link between fire science and fire safety (SFPE 2002). A risk index is defined as a single number expressing fire risk associated with a building. It is difficult to describe a typical method for indexing fire risk. A practical necessity of trying to assess multifaceted fire risks with limited resources has led to creating several fire risk indices. Representative examples of fire risk indices selected from literature are summarized in Table 1. They provide some idea of the types of variations involved with modelling and quantifying fire risk.

Four fire risk indices most frequently mentioned in literature on fire safety assessment are summarised in Table 1. The common feature of all four methods is that:

- all of those apply a predefined list of variables (attributes) to specify input;
- the calculation of fire risk indices yields a single number representing the magnitude of risk; however, this value is neither frequency nor consequence severity;

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Table 1. The main components of four basic types of sprinkler systems

Index	Mathematical expression of the index	Expression of tolerable risk	Reference
Gretener's index $I_G^{(1)}$	$I_G = \frac{P(\boldsymbol{x}_1, \boldsymbol{x}_2, \boldsymbol{x}_3) \times A(\boldsymbol{x}_1, \boldsymbol{x}_2, \boldsymbol{x}_3)}{N(\boldsymbol{x}_3) \times S(\boldsymbol{x}_2) \times F(\boldsymbol{x}_2)}$	$I_G \leq 1{,}3$	Kaiser (1979)
FRAME index I_{FR}	$I_{FR} = \frac{P(\boldsymbol{x}_1, \boldsymbol{x}_2, \boldsymbol{x}_3)}{A(\boldsymbol{x}_1, \boldsymbol{x}_2, \boldsymbol{x}_3)\ D(\boldsymbol{x}_2, \boldsymbol{x}_3)}$	$I_{FR} \leq 1{,}0$	F.R.A.M.E. (2008)
Dow's fire and explosion index (F&EI) $I_D^{(2)}$	$I_D = x_0 \cdot \sum_{i=1}^{6} x_{i1} \cdot \sum_{i=1}^{12} x_{i2}$	$I_D \leq 96$	Dow (1994)
Fire safety evaluation system (FSES) index $I_F^{(3)}$	$I_F = \prod_{i=1}^{5} x_{i1}$	$I_F \leq \sum_{j=1}^{3}\sum_{i=1}^{12} \mathbf{1}_{jk}(x_{i2}) x_{i2}$	Rasbash *et al.* (2004)
Hierarchical approach (HA)index $I_H^{(4)}$	$I_H = \sum_{i=1}^{n} w_i x_i$	$I_H \leq I_{H,tol}$	Rasbash *et al.* (2004), SFPE (2002)

(1) $A(\cdot)$ is probability that a fire will start (the risk of activation); $P(\cdot)$ is possible dangers (potential risk); $N(\cdot)$ refers to standard measures; $S(\cdot)$ refers to special protection measures and $F(\cdot)$ is the fire resistance factor of the building; the components of vectors $\boldsymbol{x}_1, \boldsymbol{x}_2, \boldsymbol{x}_3$ are explained in the paper written by Kaiser (1979).
(2) The values from 1 to 96 of I_D embrace the categories of light and moderate hazard (potential damage); intermediate, heavy and severe hazard is represented by intervals $I_D \in [97, 127]$, $I_D \in [128, 158]$, and $I_D \geq 158$ (Dow 1994); the components of vectors $\boldsymbol{x}_1, \boldsymbol{x}_2, \boldsymbol{x}_3$ are explained in Table 3.
(3) $\mathbf{1}_{jk}(x_{i2})$ = an indicator (zero-one) function related to fire safety parameter x_{i2}; the components of vectors $\boldsymbol{x}_1, \boldsymbol{x}_2, \boldsymbol{x}_3$ are explained in Table 2.
(4) Symbol w_i denotes the weights of normalized attributes x_i; $I_{H,tol}$ is a tolerable value of index I_H (not specified in literature).

– the calculation of fire risk indexing can be compared with some tolerable or target value different for each index.

Input variables used for calculation applying Gretener's method are presented by Kaiser (1979). Input variables of FSES and hierarchical methods used for calculation as listed in Table 2. The variables represent partially physical characteristics and partially abstract quantities. For example, if variable x_i represents the presence and type of fire alarm, it can take on values 0, 2, 3, 4, 5; the lowest value (0) stand for the absence of any alarm system, whereas the highest one (5) means a total coverage of the entire building floor area by the alarm system (SPFE 2002). It is obvious that assigning one of these values to x_i is rather an outcome of agreement than a result of same measurement for observation.

The indices calculated by means of the methods listed in Table 1 can be compared to some tolerable values, for instance, value 1.3 in case of Gretener's method. Although these values are some answer to the well-known question *How safe in safe enough?* both indices and tolerable values are a sort of an agreement rather than statistically or economically substantiated characteristics of fire safety.

The methods used for calculating fire risk indices use a considerable amount of information. However, this information is not directly related to statistical data on fires. Thus, the values of fire risk indices cannot be used verified by statistical data on fire accidents.

Table 2. Input variables (fire safety attributes) used for calculating FSES index I_F (variables $x_{12}, x_{22}, \ldots, x_{12,2}$ are also used for calculating HA index I_H) (Watts and Kaplan 2001)

Variable	Value	Min.	Max.
Occupancy risk variables			
Patient mobility	x_{11}	1.0	4.5
Patient density	x_{21}	1.0	2.0
Zone location	x_{31}	1.1	1.6
Ratio of patients to attendants	x_{41}	1.0	4.0
Patient average age	x_{51}	1.0	1.2
Fire safety variables			
Construction	x_{12}	-20	10
Segregation of hazard	x_{22}	-7	0
Vertical openings	x_{32}	-10	1
Automatic sprinklers	x_{42}	0	12
Smoke detection	x_{52}	0	4
Fire alarm	x_{62}	-2	4
Interior finish	x_{72}	-3	2
Smoke control	x_{82}	0	4
Exit access	x_{92}	-2	3
Exit system	$x_{10,2}$	-6	5
Corridor/room separation	$x_{11,2}$	-6	4
Occupant Emergency Program	$x_{12,2}$	-3	2

Table 3. Input variables (fire safety attributes) used for calculating the Dow's index I_D (Dow 1994)

Variable	Value
Dimensionless variables representing general process hazards	$x_{11}, x_{21}, \ldots, x_{61}$
Dimensionless variables representing special process hazards	$x_{12}, x_{22}, \ldots, x_{12,2}$
Dimensionless variable representing the intrinsic rate of potential energy release from fire or explosion	x_0

Numerical Example

To illustrate the use of fire indices for the quantification of fire risk, FRAME index I_{FR} will be calculated for a three-storey office building with open-plan floors shown in Fig. 1. The total are of three floors is 8400 m^2. The value of one square meter of compartment and content is €1440. This amount to the total value of the building equals €7 mln. The average number of people staying in each floor of the building during the workday is equal to 250. It is assumed that the building is used without standard fire protection measures (sprinklers and fire alarm).

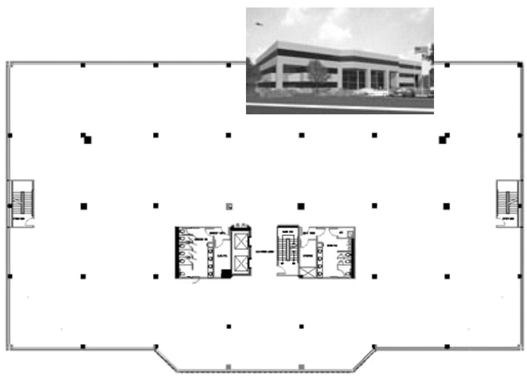

Fig. 1. A three open-plan office building with one area of fire origin in each floor

The general expression of the index under consideration, I_{FR}, is represented by the inequality

$$I_{FR} = \frac{\text{Potential risk}}{\text{Acceptable risk}} = \frac{\text{Probability of occurence} \times \text{Severity}}{\text{Acceptable risk}} = \frac{1/D(\mathrm{x}_2, \mathrm{x}_3)\, P(\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3)}{A(\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3)} \le 1.0, \qquad (1)$$

where input vectors are explained in the paper written by Kaiser (1979). The values of the components of these vectors are listed in Table 4. Detailed expression used for calculating quantities $P(\cdot)$, $A(\cdot)$, $D(\cdot)$ are given in FRAME technical guide (F.R.A.M.E. 2008). The inverse value of quantity $1/D(\cdot)$, that is, $D(\cdot)$, is called a protection level.

FRAME index I_{FR} can be calculated for three categories of potential fire risk: risk to a building and content, a risk to occupants and a risk to activities carried out in the vicinity of the building. Correspondingly, there are three expressions for calculating $P(\cdot)$, $A(\cdot)$ and $D(\cdot)$. In the present example, the values of I_{FR} were calculated first to the categories of fire risk:

$$I_{FR,B} = \frac{P_B(\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3)}{A_B(\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3) \times D_B(\mathrm{x}_2, \mathrm{x}_3)} = 0.61, \qquad (2)$$

$$I_{FR,O} = \frac{P_O(\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3)}{A_O(\mathrm{x}_1, \mathrm{x}_2, \mathrm{x}_3) \times D_O(\mathrm{x}_2, \mathrm{x}_3)} = 1.27, \qquad (3)$$

where subscripts "B" and "O" stand for a building and its content and occupants. The values of $P(\cdot)$, $A(\cdot)$ and $D(\cdot)$ related to respective cases were calculated by means of formulas given in the manual F.R.A.M.E. (2008):

$P_B(\cdot) = 2.25$; $A_B(\cdot) = 1.336$, and $D_B(\cdot) = 2.762$,

$P_O(\cdot) = 1.86$; $A_O(\cdot) = 1.09$, and $D_O(\cdot) = 1.33$.

Table 4. Input vectors $\boldsymbol{x}_1$, $\boldsymbol{x}_2$, and $\boldsymbol{x}_3$ (set of fire safety attributes) used for calculating F.R.A.M.E. index $I_{FR,B}$ and $I_{FR,O}$

Notation of a variable in the F.R.A.M.E manual	Comp.	Value	Notation of a variable in the F.R.A.M.E manual	Comp.	Value
Geometry data (vector $\boldsymbol{x}_1$)			k	$x_{18,2}$	0.008
h	x_{11}	5	f_s	$x_{19,2}$	90
H^+	x_{21}	15	f_f	$x_{20,2}$	0
l	x_{31}	70	f_d	$x_{21,2}$	15
b	x_{41}	40	f_w	$x_{22,2}$	0
Fire-specific data (vector $\boldsymbol{x}_2$)			u_1	$x_{23,2}$	0
Q_i	x_{12}	100	u_2	$x_{24,2}$	0
Q_m	x_{22}	400	u_3	$x_{25,2}$	8
M	x_{32}	1	w_1	$x_{26,2}$	0
T	x_{42}	150	w_2	$x_{27,2}$	0
a_1	x_{52}	0	w_3	$x_{28,2}$	0
a_2	x_{62}	0.1	w_4	$x_{29,2}$	1
a_3	x_{72}	0	w_5	$x_{30,2}$	0
a_4	x_{82}	0.1	Method-specific data (vector $\boldsymbol{x}_3$)		
a_5	x_{92}	0	Z	x_{13}	3
p	$x_{10,2}$	1	m	x_{23}	0.3
X	$x_{11,2}$	0.1	E	x_{33}	3
x	$x_{12,2}$	4	c_1	x_{43}	0
K	$x_{13,2}$	4	c_2	x_{53}	$12 \cdot 10^6$
s_1	$x_{14,2}$	0	n_1	x_{63}	0
s_2	$x_{15,2}$	3	n_2	x_{73}	0
s_3	$x_{16,2}$	0	n_3	x_{83}	2
s_4	$x_{17,2}$	14	n_4	x_{93}	0

The obtained results show that indices $I_{FR,B}$ and $I_{FR,O}$ take on the following values: $I_{FR,B} = 0.61$ and $I_{FR,O} = 1.27$. They suggest that a risk to building and content is acceptable, whereas a risk to occupants is too high. A sprinkler system and/or fire alarm may be necessary to install. This will allow to increase protection level $D_O(\cdot)$ and thus to decrease the value of I_{FRO}.

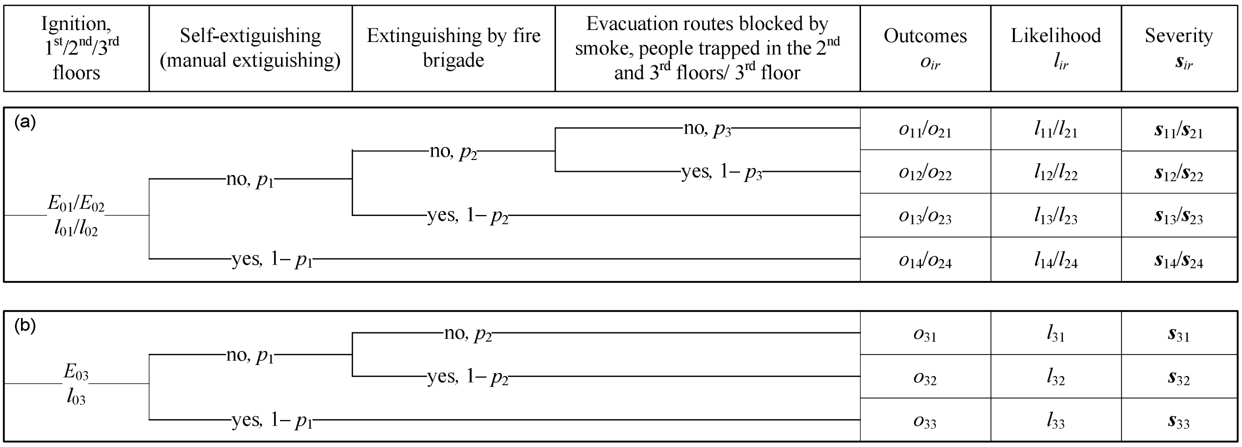

Fig. 2. Event tree diagrams developed for the initiation of fire in three floors of the building shown in Fig. 1: (a) diagrams of fire initiation in the 1st and 2nd floors (i = 1, 2); (b) diagrams of fire initiation in the 3rd floor (i = 3)

The Pros and Cons of the Approach

The obvious advantage of fire risk indices is a relative simplicity of their calculation. Input information on this calculation (values of fire safety attributes) can be specified with relative ease. The mathematical expressions of the indices themselves are trivial in terms of computational effort. Some indices are widely used in some countries and bring the influence of fire safety culture in these countries (e.g. Kaiser 1979). Fire risk indices allow a simple comparison of fire safety of individual buildings without a formal quantification of fire risk.

On the other hand, fire risk indices are relatively different models and are obviously far from those that should prevail against others. The use of a specific fire index seems to be a sort of a tradition of a particular country (group of countries), rather than a choice based on some scientific reasoning.

Fire Safety Assessment by Risk Analysis. Description of the Approach

A very comprehensive measure of fire safety is the risk defined in line with quantitative risk assessment, that is, in the form of likelihood-outcome pairs (Kumamoto and Henley 1996). In the context of the present paper, the risk due to exposure to fire i (fire originating in area i or, in terms of quantitative risk assessment, the ith initiating event) will consist of possible outcomes (consequences) o_{ir} of the fire and likelihoods l_{ir} of these consequences.

Generally, each o_{ir} is represented by several measures of significance or, in brief, significances (e.g. Kumamoto and Henley 1996). Each o_{ir} can be characterised by several, for example, n significances of different nature and with different measurement units. They can be grouped into the vector

$$\mathbf{s}_{ir} = (s_{ir1}, s_{ir2}, \dots, s_{irj}, \dots, s_{irn}). \tag{4}$$

Natural candidates for the components of $\mathbf{s}_{ir}$ are direct monetary losses due to fire i (s_{ir1}), the numbers of people killed and injured in this fire (s_{ir2} and s_{ir3}), the time of business interruption due to fire (s_{ir4}), etc.

With l_{ir}, o_{ir}, $\mathbf{s}_{ir}$, the risk related to fire i takes the following form:

$$\text{Risk}_i \equiv \{ (l_{ir}, o_{ir}, \mathbf{s}_{ir}),\ r = 1, 2, \dots, n_i \}. \tag{5}$$

In general, the total number of outcomes n_i may vary from one fire to another. Let us consider the three-storey office building shown in Fig. 1. Fire can originate in each floor (i.e., three fires are possible, i = 1, 2, 3). Fig. 2 shows simplified event trees developed for these fires (initiating events E_{0i}). In this example, $n_1 = n_2 = 4$ and $n_3 = 3$.

Risk (5) may express fairly diverse information, especially when the severity of each o_{ir} is represented by more than one significance measure. In the latter case, the risk of fire i will be associated with the matrix of significances

$$\begin{bmatrix} \mathbf{s}_{i1} \\ \mathbf{s}_{i2} \\ \vdots \\ \mathbf{s}_{ir} \\ \vdots \\ \mathbf{s}_{in_i} \end{bmatrix} = \begin{bmatrix} s_{i11} & s_{i12} & \cdots & s_{i1j} & \cdots & s_{i1n} \\ s_{i21} & s_{i22} & \cdots & s_{i2j} & \cdots & s_{i1n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ s_{ir1} & s_{ir2} & \cdots & s_{irj} & \cdots & s_{irn} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ s_{in_i1} & s_{in_i2} & \cdots & s_{in_ij} & \cdots & s_{in_in} \end{bmatrix}. \tag{6}$$

With this matrix, one can calculate an n-dimensional vector of the expected significances associated with fire i and apply this vector to, for example, a multi-attribute comparison of consequences of potential fires, namely,

$$\mathrm{c}_i = \left(\sum_{r=1}^{n_i} l_{ir} s_{ir1}, \sum_{r=1}^{n_i} l_{ir} s_{ir2}, \ldots, \sum_{r=1}^{n_i} l_{ir} s_{irj}, \ldots, \sum_{r=1}^{n_i} l_{ir} s_{irn} \right). \quad (7)$$

The corresponding components of vectors $\boldsymbol{c}_i$ can be summed up and this will yield the vector

$$\boldsymbol{c} = \left(\sum_{i=1}^{n_{\mathrm{f}}} \sum_{r=1}^{n_i} l_{ir} s_{irj}, \; j = 1, \ldots, n \right), \quad (8)$$

where n_{f} is the number of potential fires. The vector can be used as a multi-attribute measure of fire safety calculated by means of quantitative risk assessment.

The expected significances in (7) contain likelihoods l_{ir}, which in many cases, can be estimated independently of s_{irj} (this independence should be assumed with caution, see Kumamoto and Henley 1996). Each l_{ir} can be expressed as annual frequency (number of occurrences per year).

The frequency of relatively rare occurrences of fires and thus of outcomes o_{ir} can be estimated by means of the classical Bayesian approach to quantitative risk assessment (Aven and Pörn 1998; Vaurio and Jänkälä 2006; Vaidogas and Juocevičius 2009). In the context of this approach, likelihoods l_{ir} will be estimated in the form of epistemic uncertainty distributions related to true values of l_{ir} (Zavadskas and Vaidogas 2009). Such estimating is usually carried out by propagating epistemic uncertainties through such logical models of quantitative risk assessment as the event trees shown in Fig. 2.

Input information on calculation considering the event tree diagrams are the likelihoods of fire initiation (l_{0i}) and branching probabilities p_k. Both l_{0i} and p_k can be uncertain in the epistemic sense, and therefore can be outcome likelihoods l_{ir} of outcomes o_{ir}. The calculation of the risk defined by Eq. (5) consists of estimating l_{ir} and the assessment of severities $\boldsymbol{s}_{ir}$. The use of input information on calculating the risk consists mainly in hard statistical data and expert knowledge when this data is scarce or not available at all.

Fire risk assessment is similar to general engineering risk analysis. Summation (7) indicates the 'total' risk from multiple scenarios. This type of fire risk analysis, commonly referred to as probabilistic risk assessment (PRA) or quantitative risk analysis (QRA), is widely used in the process of chemical industry and for fire safety assessments of nuclear facilities (Apostolakis 1993), and is beginning to see broader application in fire protection engineering applications (SFPE 1999 and 2000; Magnusson *et al.* 1995; Magnusson 1995; Frantzich 1998).

Numerical Example

Let us return to the building shown in Fig. 1. In the case where the fire safety of this building is measured by means of a risk profile (5), fire scenarios leading to some specific and generally adverse outcomes must be identified. A simplified graphical representation of such scenarios is given in Fig. 2. These diagrams assume that fire can be initiated in each of the three floors and thus $i = 1$, 2, 3. The likelihoods of the outcomes of these scenarios are given by

$$\left.\begin{aligned} l_{i1} &= l_{0i} \cdot p_1 \cdot p_2 \cdot p_3 \\ l_{i2} &= l_{0i} \cdot p_1 \cdot p_2 \cdot (1 - p_3) \\ l_{i3} &= l_{0i} \cdot p_1 \cdot (1 - p_2) \\ l_{i4} &= l_{0i} \cdot (1 - p_1) \end{aligned}\right\} \quad i = 1,2; \; n_i = 4, \quad (9)$$

$$\left.\begin{aligned} l_{31} &= l_{03} \cdot p_1 \cdot p_2 \\ l_{32} &= l_{03} \cdot p_1 \cdot (1 - p_2) \\ l_{33} &= l_{03} \cdot (1 - p_1) \end{aligned}\right\} \quad n_3 = 3. \quad (10)$$

One can see that the input information required to calculate likelihoods l_{ir} consists of fire initiation likelihoods l_{0i} as well as branching probabilities p_k ($k = 1$, 2, 3). Initiation likelihoods l_{0i} can be estimated from the annual frequency calculated for the total floor area A = 8400 m^2 by means of the generalised Barrois model (Hasofer *et al*. 2007):

$$\begin{aligned} f(A) &= c_1 \cdot A^r + c_2 \cdot A^s = \\ &\quad 0.056 \cdot 8400^{-2} + 3 \cdot 10^{-6} \cdot 8400^{-0,05} = \\ &\quad 1.910 \cdot 10^{-6} \text{ per square metre per annum.} \end{aligned}$$

Then, this frequency of fire initiation related to A will be equal to

$$A \cdot f(A) = 8400 \cdot 1.91 \cdot 10^{-6} = 0.016 \text{ per annum.}$$

Consequently, fire can be exported every 62.3 years in average. As long as all three floors are used for identical occupancy, fire initiation frequency $0.016\mathrm{a}^{-1}$ related to the entire floor area can be A and divided by the number of floors and likelihoods l_{0i} obtained:

$$l_{0i} = 0.016/3 = 0.00533 \text{ a}^{-1} \; (i = 1, 2, 3).$$

Further numerical input into the problem is branching probabilities p_k, the hypothetical values of which are given in Table 5. Putting these values in expressions (9) and (10) along with fire initiation likelihoods l_{0i} yields the likelihoods of individual outcomes, l_{ir} (Table 6).

Table 5. Input information on the quantification of the risk represented by the event tree diagram shown in Fig. 2

Event	Symbol	Value
Self-extinguishing of fire	p_1	0.1
Extinguishing of fire by fire brigade	p_2	0.87
Blockage of evacuation routes	p_3	0.07

The vectors of severities, $\boldsymbol{s}_{ir}$, assumed in this example consist of three components, namely, direct monetary losses due to fire i, (s_{ir1}), the number of fire victims (s_{ir2}) and the time during which the use of a building is interrupted (s_{ir3}). The illustrative values of components $\boldsymbol{s}_{ir}$ are summarised in Table 6. Taking into account these values and likelihoods l_{ir}, one can calculate the vectors of the expected severities defined by Eq. (7) and related to three individual fire, namely, vectors $\boldsymbol{c}_i$. In this example, vectors $\boldsymbol{c}_i$ consist of three components:

$\boldsymbol{c}_1$ = (105.77 €/a; 0.19 victims/a; 0.0083 months/a),

$\boldsymbol{c}_2$ = (134.32 €/a; 0.14 victims/a; 0.0079 months/a),

$\boldsymbol{c}_3$ = (149.06 €/a; 0.046 victims/a; 0.0095 months/a).

As all three fires lead to the outcomes characterised by the same triplet of severities, the expected severities $\boldsymbol{c}_i$ can be gathered up into one vector characterising all possible fires in the building:

$\boldsymbol{c}$ = (389.15 €/a; 0.38 victims/a; 0.0025 months/a)

The latter vector can be seen as the final result of fire safety assessment by means of formal QRA. This vector implies that one building is characterised by three attributes having different units of measurement. In principle, the number of such attributes can be increased by adding an additional component to severity vectors $\boldsymbol{s}_{ir}$. Decisions and actions concerning fire safety can be directed towards reducing some or each of them. The calculation of the expected severities $\boldsymbol{c}$ is straightforward given values l_{0i} and p_k as well as components $\boldsymbol{s}_{ir}$. Unfortunately, the specification of these values is the most problematic part of QRA; especially, this applies to branching probabilities p_k. On the other hand, fires in buildings similar to the one considered in the present example are relatively frequent and well-investigated phenomena. One can suggest that branching probabilities can be estimated by a combined application of data on similar fires, computer simulation of the fire process and evacuation as well as expert judgement.

The Pros and Cons of the Approach

The advantage of applying QRA methods to fire risk assessment is obvious. Fire safety measures calculated on the basis of the risk defined by Eq. (5), for instance, the vector of expected significances, $\boldsymbol{c}$, express the level of fire safety in a very comprehensive way. On the other hand, the comprehensiveness of QRA creates stumbling blocks for applying this methodology to a practical assessment of fire risk. An accurate risk assessment requires a great deal of expertise, first and foremost, in the use of hard data and expert knowledge. QRA is, to a large degree, a process of estimating the probabilities and frequencies that are transformed eventually into a risk profile. This process may include a subtle use of subjective information in combination with sparse empirical data. As compared to the calculation of fire risk indices, the estimation of probabilities and frequencies involved in fire-related QRA may be a demanding and tedious task.

Conclusions

1. The possible ways of evaluating building fire risk have been considered. The problem of such evaluation is as ubiquitous as the hazard of fires in buildings itself. Attention was focused on two principal approaches to the quantification of fire risk: the application of fire indices and a formal assessment of the risk posed by fires when applying methods of quantitative risk assessment (QRA). These two principal approaches offer two polar extreme

Table 6. Illustrative values of the severities related to individual fire scenarios represented by the event tree diagram shown in Fig. 2

Fire i	Outcome likelihoods l_{ir}, a^{-1}	Scenario r	Severities s_{ir}		
			s_{ir1}, €	s_{ir2}, no of victims	s_{ir3}, months
$i = 1$	3.2×10^{-5}	$r = 1$	580 000	600	12
	43×10^{-5}	$r = 2$	180 000	400	7
	69×10^{-5}	$r = 3$	17 000	10	2
	479.7×10^{-5}	$r = 4$	1800	0	1
$i = 2$	3.2×10^{-5}	$r = 1$	440 000	400	11
	43×10^{-5}	$r = 2$	260 000	300	6
	69×10^{-5}	$r = 3$	18 000	15	2
	479.7×10^{-5}	$r = 4$	1500	0	1
$i = 3$	46×10^{-5}	$r = 1$	306 000	100	10
	69×10^{-5}	$r = 2$	16 000	7	2
	479.7×10^{-5}	$r = 3$	1500	0	1

possibilities of fire risk evaluation. The risk indices are simple measures of fire risk that can be calculated with relative ease for most buildings. However, the indices are considered to be non-scientific means of fire risk evaluation. The formal evaluation of the risk posed by potential fires is a rigorous scientific procedure allowing relating the event of fire initiation to the potential outcomes of fire.

2. Fire risk indexing and formal fire risk assessment have their own pros and cons. The addressed question Which of these approaches suits better for decision-making related to fire safety, insurance and design of buildings? Requires detailed discussions to be properly answered. One can only say that the use of risk indices is more practicable that formal risk assessment.

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GAISRINĖS SAUGOS VERTINIMO METODŲ PALYGINIMAS

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Santrauka

Gaisrinės rizikos indeksai ir formalus rizikos vertinimas yra du pagrindiniai metodai, taikomi vertinant gaisrinę saugą. Šiame straipsnyje yra trumpai apžvelgiami šie metodai, pateikiami jų privalumai bei trūkumai ir jie tarpusavyje palyginami. Pateikiamas pavyzdys, iliustruojantis gaisrinės saugos indeksų ir rizikos vertinimo pritaikymą biuro pastatui. Nustatyta, kad gaisrinės rizikos indeksai yra paprastai skaičiuojami ir lengvai pritaikomi praktikoje, tačiau jie turi esminių trūkumų. Jų taikymas yra greičiau susitarimo reikalas ir jie nėra pagrįsti griežta moksline metodologija. Be to, įvairiose šalyse taikomi įvairūs indeksai. Gaisro rizikos vertinimas grindžiamas kiekybine rizikos vertinimo metodologija. Toks vertinimas atliekamas taikant griežtas tikimybinio skaičiavimo taisykles ir išnaudojant statistinius duomenis bei ekspertų nuomones. Tačiau formalus rizikos vertinimas yra santykinai sudėtingas ir reikalauja aukštos matematinės kvalifikacijos. Tikėtina, kad priimant kompleksinius sprendimus, susijusius su pastato gaisrine sauga, jos užtikrinimas bus grindžiamas gaisro rizikos indeksais, o ne formaliu rizikos vertinimu.

Reikšminiai žodžiai: gaisras, sauga, indeksas, vertinimas, rizika.