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ФАКУЛТЕТ ТЕХНИЧКИХ НАУКА НОВИ САД

TECHNICKÁ UNIVERZITA VO ZVOLENE

4. МЕЂУНАРОДНА НАУЧНА КОНФЕРЕНЦИЈА

БЕЗБЕДНОСНИ ИНЖЕЊЕРИНГ

ПОЖАР, ЖИВОТНА СРЕДИНА,
РАДНА ОКОЛИНА, ИНТЕГРИСАНИ РИЗИЦИ

И

14. МЕЂУНАРОДНА КОНФЕРЕНЦИЈА

ЗАШТИТЕ ОД ПОЖАРА И ЕКСПЛОЗИЈЕ

ЗОП 2014

НОВИ САД, 2-3. ОКТОБАР 2014.

ЗБОРНИК РАДОВА
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SAFETY ENGINEERING

FIRE, ENVIRONMENT,
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AND

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FIRE AND EXPLOSION PROTECTION

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NOVI SAD, 2-3. OCTOBER 2014.

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ОДСЕК ЗАШТИТЕ,
НОВИ САД, РЕПУБЛИКА СРБИЈА

ТЕХНИЧКИ УНИВЕРЗИТЕТ У ЗВОЛЕНУ
ТЕХНОЛОШКИ ФАКУЛТЕТ ЗА ПРЕРАДУ ДРВЕТА
ОДСЕК ЗАШТИТЕ ОД ПОЖАРА,
ЗВОЛЕН, РЕПУБЛИКА СЛОВАЧКА

УНИВЕРЗИТЕТ У НОВОМ САДУ, ФАКУЛТЕТ ТЕХНИЧКИХ НАУКА
ДЕПАРТМАН ЗА ГРАЂЕВИНАРСТВО И ГЕОДЕЗИЈУ
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Editors:
Prof. PhD Verica Milanko
Ass. Prof PhD Mirjana Laban
Ing. PhD. Eva Mračkova

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HIGHER EDUCATION TECHNICAL SCHOOL OF PROFESSIONAL STUDIES IN NOVI SAD

The Higher Education Technical School of Professional Studies in Novi Sad, Serbia, founded in 1959, fulfills its mission in higher education, fields of expertise and research in order to apply the acquired knowledge.
It educates engineers at four Departments in 20 accredited study programme of professional bachelor and specialist studies.
In the Department of Protection Engineering the following areas are studied:

- Fire protection,
- Occupational health and safety,
- Environmental protection, and
- Civil protection and emergency rescue.

Since 2010 Fire Protection and IT studies are accredited distance learning programme. The continual application of modern scientific, technical and technological processes of production and business increases the quality of activities in the School.

TECHNICKÁ UNIVERZITA VO ZVOLENE

The main mission of the Technical University from Zvolen is to provide university education in accredited study programme as well as to develop scientific research in different fields of industry. The Technical University in Zvolen comprises four faculties: the Faculty of Forestry, the Faculty of Wood Sciences and Technology, the Faculty of Ecology and Environmental Sciences, and the Faculty of Environmental and Manufacturing Technology.

The continual application of modern scientific, technical and technological processes of production and business increases the quality of activities at the University. Department of Fire Protection is at the Faculty of Wood Sciences and Technology.

UNIVERSITY OF NOVI SAD

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The Faculty of Technical Sciences in Novi Sad is an institution of higher education and scientific research founded in 1960, whose mission is to realize high quality educational programme, develop scientific disciplines and apply the acquired knowledge in economy and society.
There are four disciplinary-related science and educational fields implemented by the FTS:

- engineering and technology,
- natural science and applied mathematics and
- human sciences and applied art.

Faculty consists of 13 departments implementing 88 study programme at the undergraduate and postgraduate levels.
The Department of Civil Engineering and Geodesy offers a comprehensive study programme in the field of civil engineering, survey (geodesy) and disaster and fire risk management: Disaster management and Fire Safety B.Sc. Honours and M.Sc. Qualification levels. Disaster Risk Reduction Centre established in 2007, has the mission to promote and contribute to the culture of resilience by dissemination of the latest research results of hazard, vulnerability and risk-related indicators.

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PREFACE

The Higher Education Technical School of Professional Studies in Novi Sad, traditionally organizes scientific and professional conferences on the highest level in the country in the field of fire and explosion protection. We proudly emphasize our leading position in education when it comes to professions concerning fire protection.

In 1976, 1st Yugoslav conference of fire and explosion is held at the Faculty of Agriculture in Novi Sad. It gathers the most eminent experts in the field of fire of the former Yugoslavia. Then, there are two more conferences, also held in Novi Sad in 1984, at "SPENS", and in 1989 at the "Putnik" Hotel.

In 1994, when 4th Yugoslav and 1st International conference of fire and explosion is organized, this conference grows into an international meeting with the help of our colleagues and experts from Ukraine, Poland and Hungary. Since then, the conference is organized biannually, and in 2006, on its 10th anniversary, it grows into the congress of the profession.

In 2008 the conference is organized as an international scientific meeting prepared in cooperation with the Faculty of Technical Sciences from Novi Sad and the Technical University in Zvolen from the Slovak Republic, bringing together experts in the field of safety and protection from Serbia and abroad.

With the same team, 4th International scientific conference and 14th International conference on fire and explosion is organized this year at the Higher Education Technical School of Professional Studies in Novi Sad on 2nd and 3rd October 2014. The aim of the conference is the exchange of the latest scientific knowledge and experience of experts in the field of safety engineering, and the main topic of fire protection is complemented by topics in the field of environmental engineering, occupational health and safety, and civil protection.

In order to efficiently manage risk situations, it is necessary to identify conditions and hazards, study the causes of risk events and build a strategy for preventing their development and consequences.

Positive results can be expected by involving scientists and experts dealing with safety engineering and process management in the living and working environments. The exchange of opinions and knowledge is essential and one of the steps contributing to progress

Organizing committee

САДРЖАЈ:

БЕЗБЕДНОСТ ОД ПОЖАРА/ FIRE SAFETY ENGINEERING

ЦИВИЛНА ЗАШТИТА И СПАСАВАЊЕ У ВАНРЕДНИМ СИТУАЦИЈАМА
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БЕЗБЕДНОСТ ОД ПОЖАРА

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FIRE SAFETY ENGINEERING

Vladimir MOZER[1]
Jozef KLUCKA[2]

Original scientific paper

ESTABLISHING ECONOMIC IMPACT OF FIRE

Abstract: The main topic of this paper is the economic impact of a fire. By knowing what the expected damage is the stakeholders can take appropriate countermeasures. This may be an installation of a fire protection system, e.g. a sprinkler system, introducing a higher level of compartmentation to the building etc. However, in order to know what the expected fire loss, in monetary terms, is, one needs to know to what size the fire will grow. The solution to this task has two parts. Firstly, the size of the fire needs to be established and secondly, the expected damaged area must be converted into financial loss. Both of these tasks are introduced in this paper and a worked example is provided. In the worked example two scenarios with different levels of fire protection are compared. Probabilistic modeling is used for establishing the size of the fire and the extent of damage. Subsequently, adequate economic tools are applied to assign monetary value to the expected damage.
Key words: probability modeling, fire safety, economic loss, level of safety

ОДРЕЂИВАЊЕ ЕКОНОМСКОГ УТИЦАЈА ПОЖАРА

Апстракт: Главна тема овог рада је економски утицај пожара. Када се зна која је очекивана штета, актери могу да предузму одговарајуће противмере. То може бити инсталација система заштите од пожара, нпр. спринклер система, увођење вишег нивоа компартментације (издељености) у згради итд. Али, да би се знало шта је очекивани губитак у пожару, у финансијском смислу, мора се знати колики ће бити пожар. Решење овог задатка има два дела. Прво, треба одредити величину пожара и друго, мора се утврдити финансијски губитак за очекивану оштећену област. Оба задатка су обрађена у овом раду, а дат је и конкретан пример. У примеру се пореде два сценарија са различитим нивоима заштите од пожара. Пробабилистичко моделовање се користи за утврђивање величине пожара и степена оштећења. Затим се примењују одговарајући економски алати ради одређивања новчане вредности очекиване штете.
Кључне речи: пробабилистичко моделовање, безбедност од пожара, економски губитак, ниво безбедности

[1] Ing. PhD Department of Fire Engineering, Univeristy of Zilina, Faculty of Special Engineering, ul. 1. maja 32, 01026 Zilina, Slovak Republic, vladimir.mozer@fsi.uniza.sk
[2] Ing. PhD Department of Crisis Management, Univeristy of Zilina, Faculty of Special Engineering, ul. 1. maja 32, 01026 Zilina, Slovak Republic, jozef.klucka@fsi.uniza.sk

1. INTRODUCTION

Probabilistic fire modelling is a well established and widely recognised tool used in fire risk analysis and design [1],[2]. The main objective of this type of analysis is to calculate probabilities of occurence for selected scenarios or outcomes; this may be area damaged by fire, life loss, injury etc. Unlike in deterministic fire modelling, exact quantities, such as the smoke layer temperature, are not of primary interest. Instead, a more general objectives are used, such as: *What is the probability of fire spread beyond compartment boundaries?*.

There may be a number of aspects to a fire risk analysis, depending on the objectives of the individual stakeholders. For the enforcing authority, life safety is of primary importance, however, the investor may be more interested in the economic implications of the design, once the minimum life-safety criteria have been met. The standardised fire engineering design concept, incorporates these objectives, which, once formulated, have to be quantified and assessed for acceptability [3],[4].

Once the probabilities of interest are known, the stakeholders can make the decision, whether the level of risk is acceptable or countermeasures must be incorporated into the design. As mentioned above, some stakeholders may be interested in economic implications and potential fire loss for the proposed design; what level of safety – avoided loss and other benefits– will the funds ivnested in fire protection measures yield.

2. CALCULATION METHODOLOGY

For the analysis two calculation methods are employed; for risk estimation – the event tree analysis and for economic loss – cost per-area-damaged method.

2.1. Event tree analysis

The analysis is undertaken in the form of event trees. According to [2], event trees are most useful when there is little data on the frequency of outcomes of concern that are very infrequent, e.g. multiple fire deaths. A general form of an event tree is shown in Figure 1.

The frequency of each of the outcomes F_x is then expressed as:

$$F_x = F.\prod P_x \tag{1}$$

where F is the frequency of the initiating event – a fire starting in a given type of occupancy, and P_x represent the probabilities of nodal events occurring.

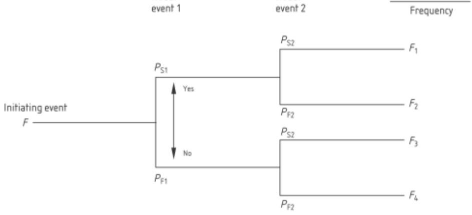


Figure 7 General form of an event tree [2]

The problem with this type of analysis, however, is the limited availability of statistical data of required detail and structure. Whereas the data for deterministic fire models may be acquired via various methods of testing (e.g. [5],[6]) in relatively shorts periods of time, gathering the necessary statistical data is a long-term process. Engineering judgement and aproximation have therefore often to be used.

The primary probability – Initiating event (Fig. 1) – is the probability of a fire starting. This probability is closely tied with the occupancy type – purpose group – of a building. In general, the probability of a fire starting may be expressed as overall or area-dependent. The overal probabilities for selected occupancy types are listed in Tab. 1. Tab. 1 also lists the calculation conostants for equation (2), which can be used for the calculation of area-dependent probabilities [2].

$$F_{\mathrm{i}} = a.A_{\mathrm{b}}^{b} \tag{2}$$

Where:

F_{i} - probability (frequency) of a fire starting [y^{-1}]

A_{b} - floor area of building [m^2]

a, b - probability (frequency) calculation constants for particular building type [–]

Table 1 Overall fire occurence probabilities and area-dependent probability calculation constants

Occupancy type	Overall probability of fire starting [y^{-1}]		Probability of fire starting calculation constants [2]	
	SK [7]	UK [2]	a	b
Education	$1{,}5 \times 10^{-3}$	$4{,}0 \times 10^{-2}$	0,0002	0,75
Hospitals	$3{,}0 \times 10^{-3}$	$3{,}0 \times 10^{-1}$	0,0007	0,75
Hotels	$1{,}9 \times 10^{-2}$	–	0,00008	1,0
Industrial	$8{,}1 \times 10^{-3}$	$4{,}4 \times 10^{-2}$	0,0017	0,53
Office	$4{,}1 \times 10^{-3}$	$6{,}2 \times 10^{-3}$	0,000059	0,9
Shops	$8{,}5 \times 10^{-3}$	–	0,000066	1,0
Warehouses	–	$1{,}3 \times 10^{-3}$	0,00067	0,5

2.2. Loss estimation – cost per area damaged by fire

In order to be able to estimate potential fire loss, the expected fire spread must be known. In addition to the area damaged by fire, fire loss is closely tied with value concentration; there is a vast difference between, say a 100 m^2, fire damaged area in an office and a warehouse.

Similarly to the probability of a fire starting based on the building's floor area (Eq. 2), [2] and [8], give a formula (3) for the calculation of damaged area within the building, based on its floor area; building-dependent constants *c* and *d* are given in Table 2.

$$A_{\mathrm{d}} = c.A_{\mathrm{b}}^{d} \tag{2}$$

Where:

A_{d} - probable area damaged by fire [m^2]

A_{b} - floor area of building [m^2]

c, d - fire damaged area calculation constants for particular building type [–]

Although this is a straighforward calculation, it does not give information about the potential mitigation effects of fire protection measures which may be installed above the minimum requirements; standard fire protection level, characteristic for a given type of occupancy is accounted for in coefficients *c* and *d*.

Table 2 Probable fire damaged area calculation constants

Occupancy type	Probable fire damaged area calculation constants [2]	
	c	d
Education	2,8	0,37
Hospitals	5,0	0,00
Hotels	5,4	0,22
Industrial	2,25	0,45
Office	15,0	0,00
Shops	0,95	0,50
Warehouses	3,5	0,52

As an alternative to the above, and the primary method of calculation, the fire-damaged area is established, together with its occurrence probability, as an outcome of the event tree analysis.

In both cases, the financial loss is then calculated as a product of the fire-damaged area and an arbitrary value density (cost) per unit of area [EUR/m^2] for the given type of building.

3. CASE STUDY

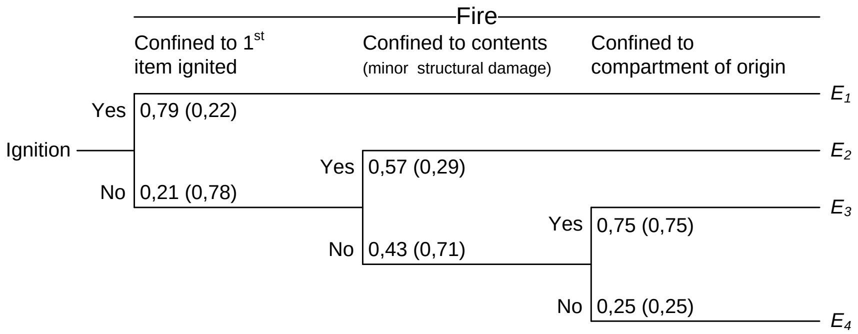
3.1. Descritpion of buildings and probabilty of fire starting

The building in question consists of two compartments, each having a floor area of 1000m^2; the total floor area of each building is 2000m^2. Each compartment is further subdivided into at least two rooms. Three various occupancy types are assumed: office, shop and industrial. There are two levels of fire protection: sprinklered and unsprinklered.

Since the probabilities of a fire starting calculated using Eq. (2) are the most conservative from the available options, they were used in all subsequent calculations and are as follows: *Industrial* – 0,096; *Office* – 0,052; *Shop* – 0,132.

3.2. Event tree analysis formulation

Due to the lack of available statistical data for the Slovak republic, the probabilities from [2] were used. The basic event trees for the sprinklered and non-sprinklered scenarios (values in brackets) with the probabilities for the individual nodal events are shown in Figure 2.



*values in brackets denote Unsprinklered scenario

Figure 2 Event trees for modeled fire scenarios

The probabilities of the final node – failure of a compartment boundary – are based on the reliability data for elements of fire protection from [2]. They represent the probability of that the compartment boundary will achieve at least 75% of the designated fire resistance.

Table 3 Extent of fire damage and outcome frequencies for defined fire scenarios

Fire scenario	Extent of damage	Outcome frequency	
		Sprinklered	Unsprinklered
Confined to 1st item E_1	max. $5m^2$	0,790	0,220
Confined to contents E_2	50% of compartment	0,120	0,226
Confined to compartment of origin E_3	100% of compartment	0,068	0,415
Spread beyond comparment of origin E_4	2x compartment area	0,023	0,139

3.3. Determining the probability, extent of fire damage and potential loss

Table 4 lists the probabilities and occurence intervals for the individual fire scenarios, E_1 – E_4; the values were obtained using Equation (1). The most probable outcome for each fire protection level is in bold. It should be realized that the occurence of a fire does not decrease for the individual fire scenarios E_x, but is rather divided among the possible outcomes.

It is also very important to take into account the expected lifespan of a building, in order to determine whether or not a fire scenario (event) is relevant to the buliding in question. Remoy [9] states that buildings in Europe and America have an expected lifespan of 50-70 years. This means it is rather unlikely that a fire will grow beyond the first item ignited – $5m^2$ for the sprinklered occupancies. On the other hand, with the exception of the office category, there is a possibility for even the most severe – fire spread beyond the compartment of origin – cosequences and damaged area.

Table 4 Probabilities and occurence intevals for individual fire scenarios

Occupancy	Fire starting		E1		E2		E3		E4	
	P	O	P	O	P	O	P	O	P	O
Sprinklered										
Industrial	$9{,}6.10^{-2}$	10	$\mathbf{7{,}5.10^{-2}}$	**13**	$1{,}1.10^{-2}$	87	$6{,}5.10^{-3}$	155	$2{,}2.10^{-3}$	464
Office	$5, 5.10^{-2}$	18	$\mathbf{4{,}4.10^{-2}}$	**23**	$6{,}6.10^{-3}$	151	$3{,}7.10^{-3}$	268	$1{,}2.10^{-3}$	803
Shop	$1{,}3.10^{-1}$	8	$\mathbf{1{,}0.10^{-1}}$	**10**	$1{,}6.10^{-2}$	63	$8{,}9.10^{-3}$	112	$3{,}0.10^{-3}$	336
Unsprinklered										
Industrial	$9{,}5.10^{-2}$	10	$2{,}1.10^{-2}$	48	$2{,}2.10^{-2}$	46	$\mathbf{4{,}0.10^{-2}}$	**25**	$1{,}3.10^{-2}$	76
Office	$5{,}5.10^{-2}$	18	$1{,}2.10^{-2}$	82	$1{,}2.10^{-2}$	80	$\mathbf{2{,}3.10^{-2}}$	**44**	$7{,}6.10^{-3}$	131
Shop	$1{,}3.10^{-1}$	8	$2{,}9.10^{-2}$	34	$3{,}0.10^{-2}$	33	$\mathbf{5{,}5.10^{-2}}$	**18**	$1{,}8.10^{-2}$	55

P – probability $[y^{-1}]$; O - occurence [y]

Taking the most likely outcomes into consideration, the fire-damaged area is $5m^2$ and $1000m^2$ for sprinklered and unsprinklered scenario, respectively, regardless of the occupancy type. In comparison, Eq. (2) yields $69m^2$ for industrial premises, $15m^2$ for offices and $50m^2$ for shops, regardles of the level of protection.

Table 5 provides information on economic implications of the fire scenarios and how sprinkler protection significantly decreases the potential total loss and loss per year, despite the seemingly illogical (exlained above) shorter time period between fires. These simplified fire scenarios give the stakeholder an overview of consequences, in the orders of magitude, that may be expected.

Table 5 Probabilities and occurence intevals for individual fire scenarios

Occupancy	Value density*	Likely damage	Likely loss	Occurence interval	Loss per year
	[EUR/m^2]	[m^2]	[EUR]	[y]	[EUR/y]
Sprinklered					
Industrial	300	5	1500	13	115
Office	100	5	500	23	22
Shop	200	5	1000	10	100
Unsprinklered					
Industrial	300	1000	300000	25	12000
Office	100	1000	100000	44	2272
Shop	200	1000	200000	18	11100

*Fabricated values – for demonstration only

3.4. Life safety

Although not as directly quantifiable as the potential for fire damage and loss, life safety implications may also be predicted. Logically, if the fire is most likely not to extend beyond the first item ignited for sprinklered buildings, the fire will not pose such a significant threat to the occupants as if it could grow further.

A study by Melinek [10] suggests that a 40% reduction in fatalities and 20% reduction in casualties could by achieved if all fires were sprinklered, however, available statistical data is not sufficient to make such a study for the building type in question.

4. CONCLUSIONS

Establishing economic impact of fire should form a standard part of the decision making process. Since there are often a number of ways of achieving the required / desired level of safety, the stakeholders should be able to make an informed decision as to which of them is the most economicaly effective.

Probabilistic fire modelling, the Event three analysis in particular, offers a relatively simple way of undertaking such an economic feasibility analysis.

The paper demonstrated an example analysis on a range occupancies, an the results are in favour of sprinkler protection. Although commonly acknowledged as an superior fire protection measure, initial and maintenance costs are a common reason for reluctance from the investor. The economical benefits benefits – significant drop in total and yearly fire loss- are often not enough, since they are only hypothetical in their nature, whereas the installation and maintenance costs are real. These costs should be compared with the benefits, however, were not available at the time of this study.

From a life safety point of view, sprinkler protection certainly represents an improvement, however, the lack of statistical data makes it difficult to quantify.

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