Proceedings of the 2nd European Symposium on Fire Safety Science

Edited by:

Prof Bart Merci, Ghent University - Faculty of Engineering and Architecture

Dr Georgios Boustras, Center for Risk, Safety and the Environment (CERISE), European University Cyprus

<u>EUC Cultural Center, Nicosia June 16th – 18th 2015</u>

Acknowledgements

The editors would like to thank the organizing committee, the program committee and all those that worked to bring this symposium to success. In particular we would like to thank Mr Chris Bachtsetzis for the valuable help throughout and for helping us enormously with the proceedings.

Nicosia, June 2015.

ISBN 978-9963-2177-0-0

Table of Contexts

Keynote Lectures

Papers submitted and accepted for presentation

On the possibility of assessing fire protection levels

Vladimir Mozer*

Faculty of Security Engineering, University of Zilina, 1. maja 32, Zilina 010 26, Slovak republic

Abstract

The possibility of direct comparison of fire safety levels achieved through the implementation of various fire protection measures and systems has long been a topic of interest in the field of fire engineering. The difficulty usually lies with the selection of a comparability factor which would allow for a direct quantitative comparison. This paper deals with one aspect of the problem – comparing the economic impact of a fire based on the area damaged. By the utility of probabilistic fire modelling, a set of fire scenarios are evaluated with 16 different levels of fire protection. The fire safety measures considered are fire alarm system, portable fire extinguishers, sprinkler protection and compartmentation. Firstly, the area damaged by the fire was established the impact was evaluated in relation to the expected occurrence of fire, i.e. what yearly fire-related damage may be expected for each fire scenario/level of fire protection. Subsequently, mathematical relationships for fire protection system justification based on yearly cost of fire protection and fire loss reduction were established.

1. Introduction

In the process of fire safety design of a building a number of fire protection options may arise. Although the minimum required level is usually set in legislation and standards, there may be various approaches in addressing them or stakeholder(s) place an additional performance objective. This often includes property protection, business continuity and heritage protection. The fire safety engineer is then faced with a task of finding such a combination of fire protection systems which minimise potential fire loss and threat to life. The second selection criterion in the process is the cost of such a combination.

The economic justification of a fire safety design alternative may be a relatively complicated task which depends on an array of input parameters, some of which are not readily available [1]. Having said that, there are approaches which can be utilized to establish, on a probabilistic basis, how a given set of fire protection measures is expected to perform. Most often the event tree analysis (ETA) is applied to this type of problem as it is relatively simple and useful when little data is available on the outcomes of concern [2].

This paper will examine the utility of probabilistic fire modelling, namely the aforementioned ETA, in ranking fire safety levels for various fire protection alternatives.

2. Calculation approach

The modelled situation is represented in a series of nodal events ordered in a sequence. From the initiating event the nodal events are "branching" towards the individual outcomes, each representing a specific scenario.

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:

$$F_x = F.\prod P_x \qquad (1)$$

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.

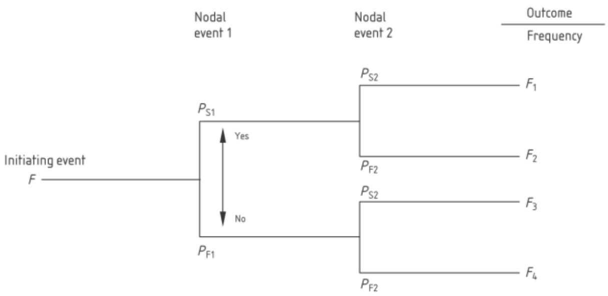


Figure 1 General form of an event tree [3]

The problem with this type of analysis, however, is the limited availability of statistical data of required detail and structure, confirmed by recent studies of Slovak fire statistics [4] [5]. Whereas the data for deterministic fire models may be acquired via various methods of testing in relatively shorts periods of time (e.g. [6] [7]), gathering the necessary statistical data is a long-term process. Engineering judgement and approximation have therefore often to be used.

3. Outcome interpretation

Since an event tree results in a number of potential outcomes it is very important how these results are interpreted and accounted for in the final analysis. There are two alternatives:

1. selecting the most probable outcome and its occurrence interval as the representative value;
2. accounting for each of the outcomes identified with respect to their occurrence intervals.

* Corresponding author: vladimir.mozer@fbi.uniza.sk
Proceedings of the 2nd IAFSS European Symposium of Fire Safety Science

The first alternative appears to be applicable only for cases when one of the outcomes has a significantly higher occurrence frequency compared to the others.

If fire damaged area is used as representative of an outcome, then it is possible to express the second alternative simply as:

$$S_{\mathrm{d}} = \sum_{i=1}^{n} \frac{S_{\mathrm{d,F}i}}{F_i} \tag{2}$$

where S_{d} is the average expected fire damage representative of a particular set of fire protection measures (nodal events) [$\mathrm{m}^2.\mathrm{yr}^{-1}$], $S_{\mathrm{d,F}i}$ is fire damaged area associated with the i-th outcome [m^2], and F_i represent the frequencies of the individual outcomes [$1.\mathrm{yr}^{-1}$].

The outcome is therefore expressed in m^2 of fire damaged area of the building per year for the purposes of this paper. It is also possible to express the outcome as a probability of a fire fatality or injury etc.

4. Model scenario definition

Lets consider a fabricated building which has a total floor area of 4000 m^2 and is divided into four identical fire compartments, each having a floor area of 1000m^2.

There are four fire protection measures available for this particular building: compartmentation, fire alarm system, fire extinguishers and sprinkler protection. These measures yield 16 potential alternatives of fire protection as listed in Table 1.

Table 1. Fire protection alternatives considered

No.	Fire alarm	Fire exting.	Sprinklers	Compartment
1	N	N	N	N
2	Y	N	N	N
3	N	Y	N	N
4	N	N	Y	N
5	N	N	N	Y
6	N	Y	N	Y
7	Y	N	Y	N
8	N	Y	Y	N
9	Y	Y	N	N
10	Y	N	N	Y
11	N	N	Y	Y
12	Y	Y	Y	N
13	Y	Y	N	Y
14	Y	N	Y	Y
15	N	Y	Y	Y
16	Y	Y	Y	Y

Obviously, for a real building the minimum requirement for each of the above measures would be set in legislation or standards, depending on the building type, size etc. This would lead to rejection of certain combinations from Table 1, however, for demonstration purposes they are all considered in our example.

5. Specification of nodal events and interactions

Having specified the building and fire protection levels an event tree was constructed; please, refer to Figure 1 at the end of the paper. The individual nodal events and associated probabilities are discussed below.

It should be pointed out that the probabilities and other data included are for demonstration purposes only, despite being extracted mostly from peer-reviewed or official sources. The purpose of their inclusion was avoidance of full use of fabricated values which could lead to skewed results.

Because the development of a fire is not solely driven by fire protection measures in place but also by fuel and ignition source configuration and other parameters the first nodal event after ignition was specified as spread beyond the first item ignited. Various sources [3] [8] [9] indicate that a relatively large proportion, approx. 40%, of fires actually never grow beyond the first item ignited. To err on the side of safety, due to high variability, the probability of fire spread from the first item ignited was selected to be 0.8, i.e. twice as probable as the studies indicate.

The second nodal event was automatic fire detection (Fire alarm), i.e. what is the probability that the detectors will activate and raise alarm to building occupants. Successful detection was assigned a probability of 0.85, from the interval of 0.8 – 0.9, as indicated in [3] [10] [11], and is representative of smoke detectors.

No automatic notification of the fire brigade was assumed, however, if the fire alarm system was not considered, the delay in discovering a fire was translated into a lower probability of successful fire suppression by portable fire extinguishers and a higher probability of a fire involving the entire compartment due to delayed fire brigade attendance (called by occupants).

The third nodal event was manual fire suppression by portable fire extinguishers (Fire exting.). The rate of successful fire suppression varies significantly from 25% to 95% [12]. The discussion provided in [12], which reviews a number of sources, led to a decision to discard the extreme values, leaving a range of 40 – 85%. From this the probability of successful suppression by fire extinguishers was taken as 0.6 when automatic detection was present and activated. When there was no detection or its activation failed, the suppression success probability was decreased by 50% to 0.3 due to the likely delay in discovering the fire resulting in a prolonged growth period.

The fourth nodal even was specified as sprinkler suppression. Sprinkler systems are well documented and the data available from various sources [3][11][13][14] indicate that the probability of successful fire extinguishment is approximately 0.9. This value is used in the event tree for cases where sprinkler protection is assumed.

The penultimate nodal event represents the capability of fire compartmentation to contain the fire within the compartment of origin for fire-fighting purposes. There is also an alternative of burnout, which was considered as an alternative fire extinction for when the fire brigade failed to extinguish the fire. The probability that compartment boundaries will contain the fire inside the compartment of origin was taken to be 0.8, deriving it from the values of 0.7 – 0.9 indicated in [3][15][16].

The final nodal event represents the success of fire-fighting operations performed by the fire brigade. There are four alternative probabilities specified, arbitrarily adjusted basing on [2][3][12][17][18]. These are 0.8, 0.6, 0.6 and 0.5, depending on the performance of fire detection and compartmentation.

When any of the fire protection means were not assumed in the calculation their probability of successful operation was set to 0.

The following areas were specified for the individual outcomes, mainly deriving from[2] [3][11]:
1 m^2 – fire contained to 1st item ignited
2.5 m^2 – fire suppressed by fire extinguisher
10 m^2 – fire suppressed by sprinkler system
500 m^2 – compartment and fire-brigade successful
1000 m^2 – compartment burnout
2000 m^2 – compartment failed / fire-brigade successful
4000 m^2 – complete burnout

The above difference between 10 m^2 and 500 m^2 may seem rather large, however, it would be difficult to specify further segmentation as no specific compartment layout – rooms – is considered in this study.

Following a review [19] of various sources of fire occurrence probabilities it was decided a value of 0.005 as the probability of the initiating event. The selected value represents an average absolute probability of a fire starting derived from 10 building occupancy types.

6. Results and discussion

The results of the above described ETA calculations are summarised in Table 2. For each level of fire protection an expected fire damage per year was determined. The yearly expected fire damage ranges from 0.2 m^2 for full protection to 12m^2 for no fire protection.

The results are divided into two groups sprinklered and nonsprinklered. For this particular case the yearly fire damage would indicate that having the building protected with a sprinkler system offers a very similar level of protection than having the building divided into fire compartments, fitted with a fire alarm system and portable fire extinguishers. Of course this result must not be generalised as it is valid only for the particular fabricated case.

It may be also concluded that without compartmentation the expected damage remains high; this is of course relative to the value density discussed below. This conclusion also correlates with the fact that sprinkler protection is often required in large uncompartmented buildings.

For the scenarios with sprinkler protection the decrease of fire damaged area achieved through the provision of additional fire protection measure is less pronounced. In relative terms, the fire damage for the case with all the fire protection measures in place is six times lower than for sprinkler protection alone, however, in absolute terms, the difference is about 1 m^2.

Table 2. Results of ETA calculations – fire damage for various levels of fire protection

No.	Fire alarm	Fire exting.	Sprinklers	Compartment	Damage [m^2/year]
1	N	N	N	N	12
2	Y	N	N	N	11.28
3	N	Y	N	N	8.4
9	Y	Y	N	N	4.88
5	N	N	N	Y	4.64
10	Y	N	N	Y	4.21
6	N	Y	N	Y	3.25
13	Y	Y	N	Y	1.83
4	N	N	Y	N	1.24
7	Y	N	Y	N	1.17
8	N	Y	Y	N	0.87
12	Y	Y	Y	N	0.51
11	N	N	Y	Y	0.5
14	Y	N	Y	Y	0.46
15	N	Y	Y	Y	0.35
16	Y	Y	Y	Y	0.2

One of the factors which affects the installation of any particular fire protection measure or their combination is the average value of protected property per unit of area; value density – V_d [€.m^{-2}].

Furthermore it is not just the direct loss, expressed as the product of V_d and S_d, but also an array of losses which could be for the purposes of this paper summed as indirect loss - L_i [€.yr^{-1}]. These would include business interruption, cost of fire brigade operation, environmental impact, etc.

The final factor is the cost of fire protection per year – C_p [€.yr^{-1}]. Considering solely the property protection objective, the increase in the yearly cost of fire protection measures should never exceed the expected reduction in yearly loss associated with fire. The justification criterion for the inclusion of a particular fire protection measure could be expressed through an efficiency factor c_e:

$$(S_{d1}.V_{d1} + L_{i1}) - (S_{d2}.V_{d2} + L_{i2}) = c_e.(C_{p2} - C_{p1}) \quad (3)$$

From Equation (3) the efficiency factor c_e can be expressed as:

$$c_e = \frac{(S_{d1}.V_{d1} + L_{i1}) - (S_{d2}.V_{d2} + L_{i2})}{(C_{p2} - C_{p1})} \quad (4)$$

$c_e \leq 1$ inclusion not justified
$c_e > 1$ inclusion justified

Where the subscript 1 indicates a design configuration without a particular fire safety measure and the subscript 2 indicates a design configuration in which the fire safety measure has been included.

The economic efficiency of a fire protection measure grows proportionally with c_e.

For selection of an appropriate level of fire protection, when a number of systems or measures are being considered in a particular building design, the combination with the highest value c_e of should be adopted, from the property protection point of view. Such a combination of fire protection systems has the highest economic efficiency of funds invested.

It should be reminded again, that property protection is not and, for most cases, cannot be the sole performance objective criterion to be considered when selecting appropriate level fire protection. In a real situation, some of the fire protection levels (measures combinations) would not be considered if they did not meet the minimum legislative or standard requirements for fire safety, which are usually concerned with life safety.

7. Conclusion

The purpose of this work was to analyse the potential of probabilistic fire modelling, using the event tree analysis approach, to assist the fire safety engineer in selecting an appropriate level of fire protection when multiple design alternatives are available.

For a model building 16 various level of fire protection were analysed, ranging from no protection to full protection, comprising a fire alarm system, portable fire extinguishers, sprinkler protection and compartmentation.

The focus of the comparison was property protection and the criterion evaluated was the expected yearly fire-damaged area.

As expected sprinkler protection was identified to have the greatest impact on reducing the fire damage, however, the combination of the other three measures offered a similar degree of damage reduction.

Analyses such as the one presented in this paper provide useful output for cost-benefit assessment. The final selection of an appropriate level of fire protection should be based on minimum life safety requirements and the most economically efficient combination of fire protection measures; the highest value of efficiency factor c_e.

Acknowledgement

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-0727-12.

References

[1] RAMACHANDRAN, G. *The economics of fire protection.* London: E & FN Spon, 1998. ISBN 0419207805.

[2] RAMACHANDRAN, G., CHARTERS, D. A. *Quantitative risk assessment in fire safety.* London, New York: Spon Press, 2011. ISBN 9780419207900.

[3] PD 7974-7. *Part 7 Probabilistic risk assessment.* London: BSI, 2003.

[4] CONEVA, I., PANÁKOVÁ, J.: *Požiare a ich následky na základe kategorizácie budov* In: Advances in fire and safety engineering 2014: recenzovaný zborník: Trnava: AlumniPress, 2014. - ISBN 978-80-8096-202-9.

[5] CONEVA, I., PANÁKOVÁ, J.: *Požiarovosť podľa kategorizácie stavebných objektov za obdobie 2008-2012* In: Bezpečnost, spolehlivost a rizika 2014 – Zborník konferencie, Liberec: Technická univerzita, 2014. - ISBN 978-80-7494-110-8.

[6] XU, Q., ZACHAR, M., MAJLINGOVÁ, A., JIN, C., JIANG Y.: *Evaluation of plywood fire behaviour by ISO tests* in: European Journal of Environmental and Safety Sciences Vol. 1(1) (2013)

[7] MARTINKA, J., CHREBET, T., BALOG, K.: *An assessment of petrol fire risk by oxygen consumption calorimetry* in: Journal of Thermal Analysis and Calorimetry Vol. 115(3) (2014)

[8] HASOFER, A. M., BECK, V. R., BENNETTS, I. D. *Risk analysis in building fire safety engineering.* Amsterdam, London: Butterworth-Heinemann, 2007. ISBN 075068156X.

[9] MÓZER, V., WILKINSON, P., SMOLKA, M., TOFILO, P. Probabilistic-deterministic modelling of fire spread [online]. *European Journal of Environmental and Safety Sciences.* 2014, 2(2), 79-83. Available from: http://www.sci-institute.com/2014_volume_2_issue_2/9a_mozer.pdf.

[10] BUKOWSKI, R. W., BUDNICK, E. K., SCHEMEL, C. F. Estimates of the Operational Reliability of Fire Protection Systems. *Third international conference on fire research and engineering,. Conference proceedings Chicago, Ill., October 4-8, 1999.* Bethesda, Md: Society of Fire Protection Engineers, 1999, pp. 87-98.

[11] RASBASH, D. *Evaluation of fire safety.* Chichester, England, Hoboken, NJ: John Wiley, 2004. ISBN 0471493821.

[12] GHOSH, B. *Assessment of the benefits of Fire Extinguishers as fire safety precautions in New Zealand Buildings.* Christchurch, New Zealand, 2008.

[13] BUKOWSKI, R. W., BUDNICK, E. K., SCHEMEL, C. F. Estimates of the Operational Reliability of Fire Protection Systems. *Third international conference on fire research and engineering,. Conference proceedings Chicago, Ill., October 4-8, 1999.* Bethesda, Md: Society of Fire Protection Engineers, 1999, pp. 87-98.

[14] FITZGERALD, R. W. *Building fire performance analysis.* Chichester: Wiley, 2004. ISBN 0-470-86326-9.

[15] TYLDESLEY, A., REW, P., HOULDING, R. Benefits of Fire Compartmentation in Chemical Warehouses. *Process Safety and Environmental Protection.* 2004, 82(5), 331-340.

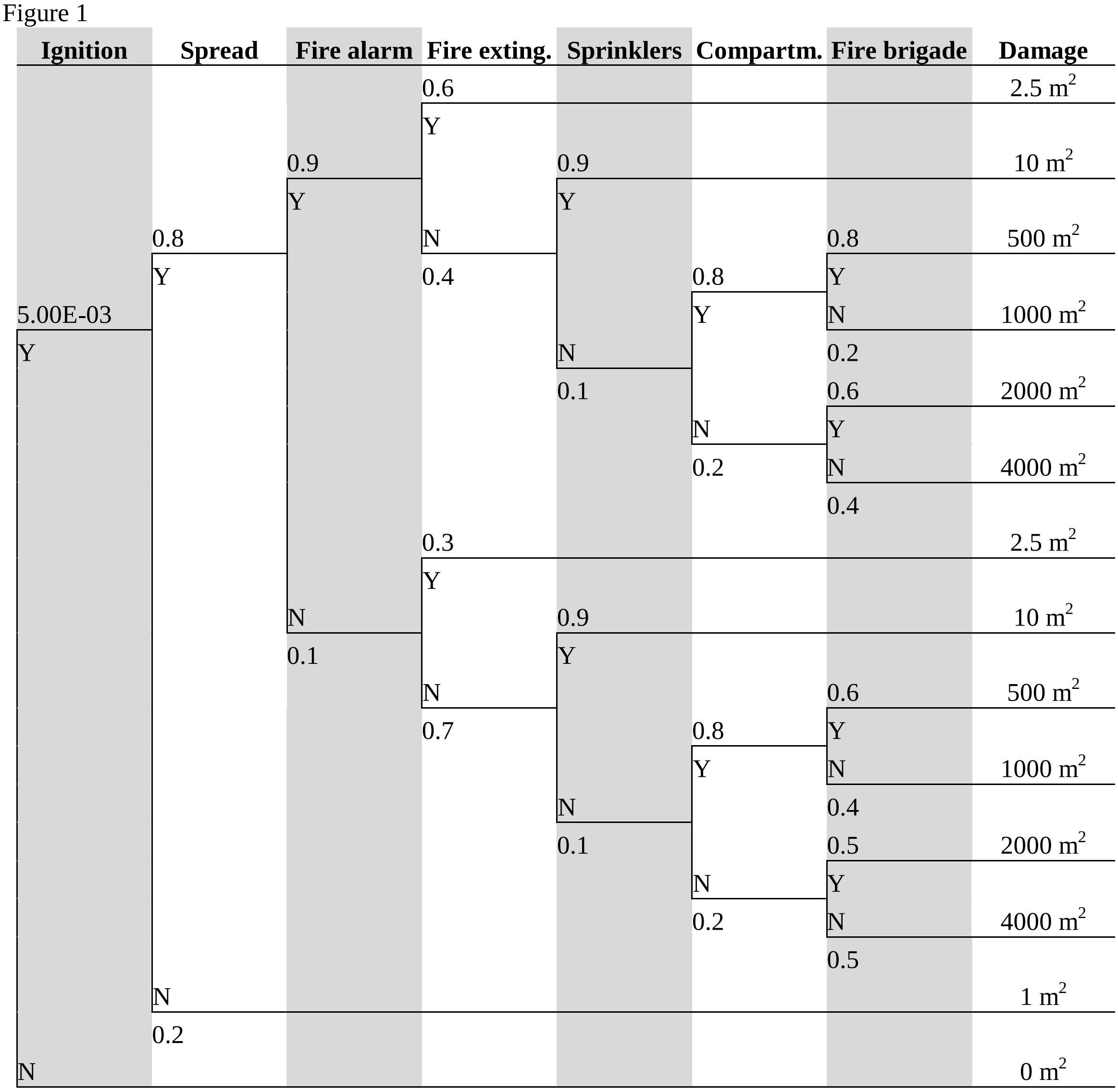
[16] HOULDING, R. C., REW, P. J. *Benefits of fire compartmentation in chemical warehouses. Research report 152.* Norwich, 2003.

[17] MELINEK, S. *Fire Fighting and Extent of Spread.* FRN 912. Borehamwood, 1972. Fire Research Notes.

[18] SÄRDQVIST, S., HOLMSTEDT, G. Correlation Between Firefighting Operation and Fire Area: Analysis of Statistics. *Fire Technology.* 2000, 36(2), 109-130.

[19] MÓZER, V., WILKINSON, P., TOFILO, P. Use of Statistical Data in Fire Engineering Design – an International Comparison. *Zeszyty Naukowe SGSP.* 2015, 53(1), 167-181.

Figure 1



Center for Risk, Safety and the Environment
(CERISE)
ISBN 978-9963-2177-0-0