Scientific paper

Impact of The Buildings Areas on the Fire Incidence

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Dedicated to the memory of the late Prof. Dr. Valentin Koloini

Abstract

A survey of statistical studies shows that probability of fires is expressed by the equation $P(A) = KA^{\alpha}$, where A = total floor area of the building and K and α are constants for an individual group, or risk category. This equation, which is based on the statistical data on fires in Great Britain, does not include the impact factors such as the number of employees and the activities carried out in these buildings.

In order to find out possible correlations between the activities carried out in buildings, the characteristics of buildings and number of fires, we used a random sample which included 134 buildings as industrial objects, hotels, restaurants, warehouses and shopping malls.

Our study shows that the floor area of buildings has low impact on the incidence of fires. After analysing the sample of buildings by using multivariate analysis we proved a correlation between the number of fires, floor area of objects, work operation period (per day) and the number of employees in objects.

Keywords: Fire, structural model, probability, ignition, floor area of buildings

1. Introduction

The incidence of fire in objects is not only the concern of insurance companies but of all those dealing with fire risks, development of fire and its consequences. Incidence of ignition and its reasons have also been studied by some researchers dealing with accidents.[1,2] The interest in studying relationships between the incidence of fire ignition and floor area of buildings is some hundreds years old. At first, people were interested in the relationship between fire risk and floor area, and later on in correlation between the probability of fire and the floor area of the object. Johansen[3] in his study mentions some studies which were concerned with correlations between fire risks and floor area of objects. As early as 1835, Barrois[4] published a mathematical description of his findings related to fire risks and the floor area of objects. Later, his idea was taken up by Savitch[5] who constructed a theoretical model using smooth distribution of ignition frequency. Similar research along these lines was carried out by Eklund (1920) and Berge (1950), however, their research encompassed mainly statistical data from Scandinavian countries. Johansen,[6] drawing upon the data on fires in Danish farmhouses, redefined the model. In the late sixties of the previous century, Ramachandran[7] modelled the correlation between the incidence of ignition and the floor area of buildings. Ramachandran[8] set up foundations to modern correlation model, which was later used, and further developed by Rahikanen and Keski-Rahkonen[9] who used fire statistical data from Finland. Thus, looking for correlations between the incidence of fires and floor area of buildings has remained interesting for insurance companies.

Over the last fifteen years the number of fires has been growing in Slovenia. The growing trend of fires in industrial objects is smaller compared to residential objects, however, the costs of damage in industry have increased. Fire statistics in Slovenia has never been concerned in making correlations between the incidence of fires and floor area of buildings, which may be due to small parameter values (i.e. the population of the state which is approx. two million, with approx. 500 industrial fires). Relatively small number of fires is the reason that it is not possible to use only statistical data, as commonly used around the world, but it makes sense to investigate an accidental sample, obtained by further data collection.

2. Method for the Analysis of Fire Frequencies

The majority of analyses of the incidence of fires in buildings, probability of fires or fire risks are based on statistical data of fires over a certain time period. By using structural equation models (SEM)[10,11,12] on samples of randomly selected buildings (whether or not there has been fire) it is possible to analyse the impacts of situations and time of exposition for activities performed in buildings on the incidence of fires. This method is a completely statistical approach to studying the incidence of fires. If we obtain a reasonably large sample we can calculate the correlations between independent factors and dependent variables. These methods have been in use for several decades in social sciences, however research shows that they could be applied in technical sciences as well, e.g. in fire safety.[13]

3. Sample of Buildings in Slovenia

To obtain the data, a survey was carried out on 134 buildings (industrial objects, hotels, restaurants, warehouses, shopping malls) in order to find out a correlation between structural properties, activities being performed there and the number of fires. The selection of buildings was narrowed down to those in which the buildings are mainly occupied by employees with a small impact of "visitors" on the conditions in the building.

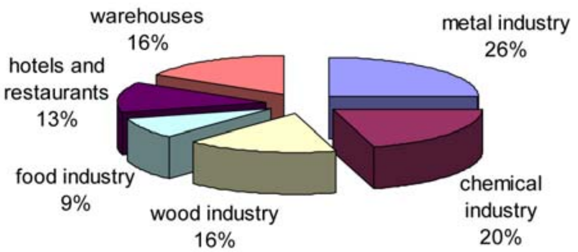

Figure 1. Distribution of the sample by activities

We collected the data on the activities of each company, floor area of the premises, and the volume of buildings, number of employees, types of construction materials (combustibles, non-combustibles), dust generated from technological process, housekeeping conditions, use of flammable cleaning agents, amounts of flammable substances used in technological processes, transport of flammable substances through buildings, use of open fire, hot surfaces, sparks, electrical installations (age of buildings, maintenance, failures), number of fires in the last five to ten years and the percentage of smokers among the employees. A lot of these variables are in no connection with the number of fires; they are independent, or in negative correlation with fires, and for this reason some variables were excluded from further research.

The sample encompassed buildings, where the average of the number of fires in a five-year period was greater than one (e.g.. period 1996–2000 *average*1 = 1.0672, and period 2001–2005 *average*2 = 1.2164). These figures include all registered fires which did not necessarily develop into larger fires.

The first step in processing the data was to find out the probability of fire occurrence, meaning that extreme values (more than 10 fires in a five-year period) were excluded from the sample. We focused on two five-year periods in the sample during which the floor area of buildings did not change and thus obtained a double size sample.

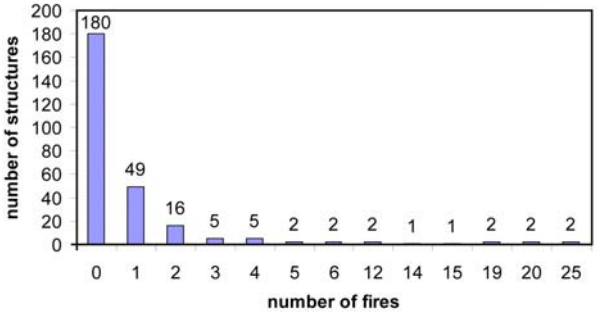

Figure 2. Distribution of the sample by number of fires

The data from the sample show that during a five-year period fires occurred in one third of the objects. In 7% of buildings fire occurred more than three times. The probability of the incidence of fire in a structure was distributed similarly to Poisson probability distribution, however due to a large number of buildings where no fires occurred, it was not possible to prove an adjustment hypothesis. The graph below shows a comparison between the sample and the Poisson distribution.

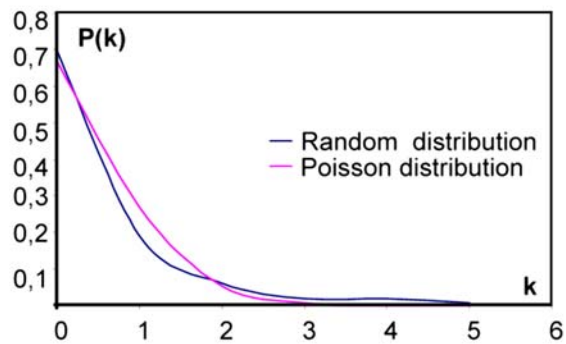

Figure 3. Sample and Poisson distribution of probability of fires (k)

4. Floor Areas of Buildings and Incidence of Fires

Ramachandran[8] set up a model stating that the probability of fire and the surface of a building are correlated by the equation:

$$P(A) = KA^{\alpha}, \quad (1)$$

where A = total floor area of the floor, K, α = constants for the type of building (with regard to fire hazards). The results are based on statistical data on fires in Great Britain. Ramachandran took the parameters from experimental data for industrial processing buildings: K = 0.0017 and α = 0.53. In European countries, in general, $\alpha \cong 0.5$. Of course, this equation is valid for any reason of fire in any part of the building, but it is very difficult to estimate the probability of fire by individual causes for a particular part of a building.

An example of parameters definion. Statistical data on fires in Great Britain for a certain period show the following figures: total number of fires 1.162, fires in warehouses 63, smokers' material in 15 cases. Conditional probability (by classical definition of probability) of fire due to smokers' material in a warehouse is calculated as a quotient 15/1162 = 0.0129. In this way we obtain conditional probability of fire due to smokers' material. If we want to obtain data for a more concrete probability, e.g. for a textile production industrial unit with floor area of 25.000 m^2, the probability of fire can be calculated by using parameters K = 0.0075 and α = 0.53. By equation (1) we obtain the result 0.116. This, of course, is a general probability of fire for any textile industry and for any reason of fire. If we want to obtain conditional probability of fire caused by smokers, we calculate the probability of fire under a particular condition. i.e. probability product:

$$0.0129 \cdot 0.116 = 0.0015$$

Equation (1) can be simplified to a linear equation if we take logarithmic values (the base of logarithms is 10) of variables and constants:

$$\log P(A) = \log K + \alpha \log A \quad (2)$$

Rahikanen and Keski-Rahkonen[9] made a step forward. They used statistical data on fires in Finland and applied the Barrois equation:

$$f''_{m} = c_1 A^r + c_2 A^s, \quad (3)$$

where f''_{m} = incidence of fires and A = floor area of the structure, and obtained the coefficient values presented in Table 1.

In studying correlations, and to test the equation for Slovenia, we made some exchanges: We could not use statistical data from fire statistics of Slovenia because some of data are not existing. So we used the data from our sample. In this way we encompassed different types of buildings, in many of which there has been no fire, and by using the structural equation model searched for a similar equation.

Table 1: Coefficient values in equation (3)

Coefficient	Non-residential
c_1	0.025
r	–1.5
c_2	1.3E-5
s	–0.15

5. Correlation Between the Floor Area of Structure and Probability of Fires

The first step in our research was to test the hypothesis that the floor area is related to the probability of fire. Using equation (2) we took logarithms of the values of surfaces to obtain the following contingency table:

Table 2: Number of buildings by floor area

logarithm of the surface	up to 2	up to 3	up to 4	up to 5	up to 6
minimum one fire in five years	3	28	38	9	1
no fires in five years	15	106	54	6	1

The independence hypothesis test with probability rate of 0.01 shows that the logarithm of surface and the number of ignitions are not independent variables. This relationship can also be supported by calculating the correlation coefficient, where the value COR(log(A), log(f)) = 0.3153458 (A = surface, f = incidence of fires) proves that both quantities are correlated. However, they are not linearly dependant and for this reason we cannot entirely prove validity of Equations (1) and (4).

The regression analysis of the data for the probability of fire and building floor area according to ANOVA shows the following relation:

$$\log(P(A)) = -1.06 + 0.17 \cdot \log(A) \quad (4)$$

which can be also written as:

$$P(A) = 0.025 \cdot A^{0.17} \quad (5)$$

From our sample we obtained coefficients K = 0.025 and α = 0.17. This would hold in a situation where there is no other influence for fire ignition and development of fire in a building.

6. Multivariate Analysis

However, it needs to be noted that the factors which influence the incidence of fires are primarily technological processes and activities performed in the building, and not the parameters of the building. Research on the impacts of work processes and object parameters has shown that the size of the building has very low impacts, while the impact of the exposure to ignition sources and time load of a structure due to the work process is greater (working periods in objects: 8 hrs, 12 hrs, 16 hrs, 24 hrs).

Since we frequently find poor correlation between variables in the analysis with structural equations (SEM analysis)[14,15] we doubled the sample and tried to find correlations between the floor area of objects, work-time period, number of employees and incidence of fires.

The symbols below have the following meanings:

A = floor area of the object,

t = time load of the object (working hours in the object),

f = incidence of ignition in a structure (over the period of 5 years)

The logarithmic values of the results were compared with Equation (2). Since f can be equal to 0, we took value $(1 + f)$ instead of f in order to avoid singular logarithmic values Thus, the symbol log(f) means log($1 + f$). The correlation matrix shows that all quantities are correlated, i.e. they are dependent.

Table 3: Correlation matrix of logarithms of variables, calculated by the LISREL program (Scientific Software International, Inc. 7383 N. Lincoln Avenue, Suite 100 Lincolnwood, IL 60712, U.S.A.)

log(*f*)	**log(*A*)**	**log(*t*)**	
log(*f*)	1.00		
log(*A*)	0.25	1.00	
log(*t*)	0.41	0.32	1.00

By multivariate analysis of the data we can find the dependence between one dependent variable and greater independent variables. In our case we were looking for dependence between the frequency of fires and the surface and time load of the object. If we calculate multiplate regression using the LISREL program, we obtain a correlation scheme of the variables.

From the dependence scheme of the random variable it is possible to draw regressive correlation:

$$st(\log(f)) = 0.37st(\log(t)) + 0.14st(\log(A)) \qquad (6)$$

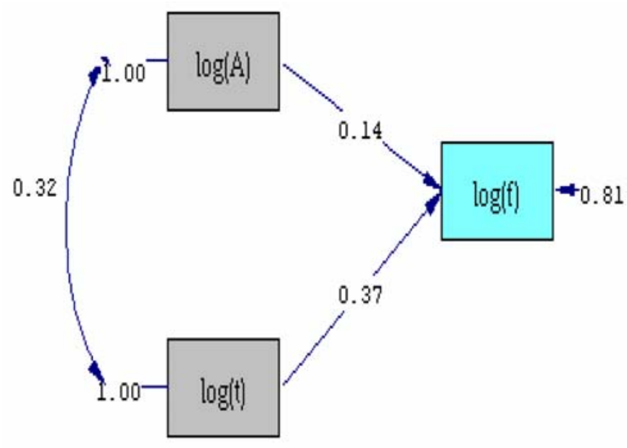

Figure 4. Dependence scheme of the incidence of fire and the surface and time load of the object

In the equation the symbol st stands for standardized values (without units). The equation shows that the incidence is correlated with the time load and the building surface. Non-standardised variables can be obtained by the following equation:

$$\frac{\log(f)-\overline{\log(f)}}{\sqrt{\mathrm{var}(\log(f))}} = 0.37\cdot\frac{\log(t)-\overline{\log(t)}}{\sqrt{\mathrm{var}(\log(t))}} + 0.14\cdot\frac{\log(A)-\overline{\log(A)}}{\sqrt{\mathrm{var}(\log(A))}} \qquad (7)$$

A simplified equation can be written down as:

$$\log(f) = C_1 \cdot 0.37 \log(t) + C_2 \cdot 0.14 \log(A) + D, \qquad (8)$$

where the coefficients C_1, C_2 and D are the coefficients calculated from the sample. Converting Equation (8) back to the potential form, the relationship between the incidence of fires in objects, floor area, and time load is written as:

$$1 + f = 10^{D} \cdot t^{0.37C} \cdot A^{0.14C} \qquad (9)$$

This equation gives more information than the equation (1), which only indicates probability. Equation (9) gives us information on most probable number of fires in a particular object over a five-year period.

7. Conclusion

The reliability of the equation (1) is small since it is based on classical definition of probability and takes into consideration only one impact on the incidence of fires in buildings. Of course, if the statistical sample was larger it would be possible to further develop the equation. The ignition of fires can not be understood as a consequence of only one parameter of the building. The processes in the building have more influence on fire frequency, therefore, it is reasonable to treat samples by using modern statistical methods to evaluate the relationships and the role of individual variables (impact factors) on fire risks.

The method of computation of links from the sample is useful where they are pure statistical information or wish to verify the results obtained from data on fires. Equation (9) gives us information about most probable number of fires and it is first stage for developing a better equation for connection between impact factors and frequency of fire. Applying the models of structural equations allows for simultaneous treatment of several factors and their relationships. Thus, the equation obtained could be useful for engineers in designing preventive measures in fire protection, as well as for insurance agents when deciding on premiums in insurance contracts.

8. References

1. M. D. Moosemiller, *Development of Algorithms for Predicting Ignition Probabilities and Explosion Frequencies*, 8th World congress of chemical engineering incorporating the 58th Canadian chemical engineering conference and the XXIV Interamerican congress of chemical engineering Montreal, Quebec, Canada, August 23–27, 2009 : WCCE8. [S. l.: s. n., **2009**],
2. C. Durand, *Introduction of Frequency in France following the AZF Accident*, 8th World congress of chemical engineering incorporating the 58th Canadian chemical engineering conference and the XXIV Interamerican congress of chemical engineering : Montreal, Quebec, Canada, August 23–27, 2009 : WCCE8. [S. l.: s. n., **2009**],.
3. P. Johansen, Early Models Describing the Fire Insurance Risk, The Astin Bulletin, **1979**, *10*, 330–334,
4. T. J. Barrois, *Memories de la société royale des sciences, de l'agriculture et des art de Lille*, **1834**, *11*, 85–282,
5. S. Savitsch, *Zeitschrift für die gesamte Versicherangs-Wisserschaft*, **1907**, *VII*, 215–243,
6. P. Johansen, *On Fire Insurance of Rural Buildings*, in Transactions of XVth International Congress of Actuaries, New York, **1957,** *II*, 211–218,
7. G. Ramachandran, *Fire Safety Journal,* **1979/80**, *2*, 125–145,
8. G. Ramachandran, *Fire Technology*, **1988**, *24*, 204–230,
9. J. Rahikanen, O. Keski-Rahkonen, *Fire Technology*, **2004**, *40*, 335–353,
10. B. H. Pugesek, in: B.H.Purgesek at al. (Ed.): Structural Equation Modeling, Cambridge University Press, Cambridge **2003**, pp. 42–59,
11. D. Seo, *Safety Science,* **2005**, *43*, 187–211,
12. J. Šrekl, J. Golob, *CABEQ*, **2009,** *23*, 309–315,
13. J. Šrekl, J. Golob, *New approach to calculate the probability of ignition*: [lecture]. V: 8th World congress of chemical engineering incorporating the 58th Canadian chemical engineering conference and the XXIV Interamerican congress of chemical engineering Montreal, Quebec, Canada, August 23–27, 2009 : WCCE8. [S. l.: s. n., **2009**, 1–6,
14. K. G. Jöreskog, A general method for estimating a linear structural equation system, Educational Testing Service, Princeton N. J., **1970**, pp.1–43,
15. P. M. Bentler, D. G. Weeks, Psychometrika, **1980**, *45*, 289–308.

Povzetek

Pregled statističnih študij kaže, da je verjetnost vžiga dana z enačbo: $P(A) = KA^{\alpha}$, kjer je A celotna površina stavbe in K ter α konstanti za posamezno skupino (kategorijo tveganja) stavb. Ta zaključek je nastal na podlagi statistike požarov v Veliki Britaniji in ne vsebuje vpliva števila ljudi in njihove aktivnosti na tem območju.
V slučajnem vzorcu smo pregledali 134 objektov od industrijskih objektov, hotelov, restavracij, skladišč do trgovin z namenom, da ugotovimo ali obstaja zveza med dejavnostjo v objektu, karakteristikami objekta in številom požarov. Površina objektov v našem vzorcu kaže da zelo šibko vpliva na pogostost požarov. Ob analizi vzorca objektov z multivariantno analizo smo potrdili korelacijo med številom požarov, površino objektov, dolžino delovnega časa na dan in številom zaposlenih v objektu.