Vol. 5, No. 1, 2018

https://doi.org/10.23939/eem2018.01.081

UDC 614.8

S. Kravtsiv
Teacher-methodologist

O. Sobol
Doctor of Technical Sciences, Professor
National University of Civil Defence of Ukraine

DEVELOPMENT OF MODEL F INTEGRAL FIRE RISK MANAGEMENT BY CORRELATION-REGISTRATION ANALYSIS

Abstract. This work is devoted to the construction of a mathematical model for controlling integral fire risk using correlation-regression analysis. On the basis of previous work, work is ongoing on developing a risk management method. For this purpose, the second cluster, which includes the Kharkiv region, was analyzed. In the field of initial data, included statistics for 2010–2017 on parameters such as the number of victims of fire in a year, the time of flight of fire and rescue units to the place of fire, the time of their localization of fire, the time of elimination of the fire and the number of people living in the study area. Using statistical data, the risk of death from a fire in a year was mathematically calculated and entered into the field of output data as a parameter to be investigated.

The study cluster includes 9 areas, therefore 63 events were received and analyzed. As a result, a regression equation was obtained, which makes it possible to predict a risk with a 95 % confidence. For example, the Kharkiv region conducted a forecast of the corresponding risk, with the actual result close to the forecasted, and lies within the permissible limits with a deviation of 5 %, which indicates the reliability of the developed mathematical model.

Key words: risk, correlation-regression analysis, factor, mathematical model, model adequacy.

The problem statement

The level of fire risk in our time is a normalized value, the value of which must be within acceptable limits. In accordance with the Concept of Risk Management for Man-made and Natural Emergencies [1] in Ukraine the value of the relevant risk should not exceed the value of 10^{-9}. This approach is in line with the practice applied in economically developed countries of the world. At the same time, the value of the calculated integral fire risk in all regions of Ukraine exceeds the permissible level. In this regard, there is a scientific and applied problem, which consists in reducing the specified level of risk to the admissible, that is, justified in the given socio-economic conditions. One of the tasks that will contribute to solving the problem is to identify the parameters that affect the integral fire risk, to develop models and methods of risk management, to predict the level of risk for the further development of substantiated recommendations regarding the establishment of security centers in the most problematic regions of our country.

The relevance of the chosen topic

In this paper we consider the process of constructing a model of management of integral fire risk R_3, namely the risk for a person to perish in a fire per unit time (in our case, per year), as well as forecasting this risk. In accordance with the Constitution of Ukraine [2], the fundamental right of every person is the right to life and the duty of the state is to protect human life. It should be noted that the specified risk characterizes the consequences of dangerous events, including fires. But at present, there are no models and methods for managing this type of risk, which indicates the relevance of this work.

An analysis of recent research and publications

In the previous articles, the foreign experience of the state regulation of acceptable risk level was analyzed [3] (this article contains the principles of risk regulation), the analysis of the main integral fire risks in the territory of Ukraine [4] was carried out, and the administrative-territorial units of Ukraine with high level of risk data were identified. In work [5] an estimation of the parameters influencing the integral fire risk is conducted. From this paper we can conclude that the investigated risk is directly proportional to the number of deaths from the fire, and has a significant dependence on the time of the fire and rescue units arrival and the time of fire localization.

Purpose and objectives

The purpose of this work is to develop a mathematical model of integral fire risk management, which will reflect the dependence of this risk on the parameters studied. To achieve the goal, it is necessary to conduct correlation-regression analysis with obtaining the coefficients of the corresponding function.

The main material of the research and the results obtained

One of the main directions of ensuring fire and technological safety in Ukraine is the introduction of a risk-oriented approach. One of the objectives of the risk-oriented approach is to develop the scientific basis of the concept of acceptable risk regarding the conditions of functioning of the national economy.

A risk-based approach [6] is a set of organizational measures that involves monitoring, analyzing, and assessing the risk of any entity based on a probabilistic safety analysis to prevent emergencies and manage risk in general. The transition to analysis and risk management should not only help to overcome the negative tendency to the increase of the number of emergencies, but also minimize their negative consequences: human losses, financial losses and environmental damage.

In order to manage risk it is necessary to find management levers that can be further influenced. We will conduct a correlation-regression analysis to find the necessary levers. Regression analysis is a method of studying the statistical relationship between one quantitative dependent variable and one or more independent quantitative variables. The dependent variable in the regression analysis is called the resulting, and the variable factors are the explanatory variables. In our case, the resulting variable is the integral fire risk R_3, and the explanatory variables are the number of victims $N_{victims}$, the time the fire and rescue units traveled to the place of fires N_{arrive}, the time of their localization T_{loc}, the time of the fire and the number of people living in the studied area T_{liq}.

Using the STATISTICA program, a correlation-regression analysis of the four clusters, as defined in the previous work [7], was performed. Using the Kharkiv region as an example, we will show the results of the calculations. Since the Kharkiv region belongs to the second cluster, we analyze it in the article.

The first stage of regression is to obtain a correlation matrix (Fig. 1).

Variable	Correlations (2_En)						
	N_{fire}	$N_{victims}$	T_{arrive}	T_{loc}	T_{liq}	N_{popul}	R_3
N_{fire}	1,000000	0,764915	0,031368	0,253070	0,013677	0,879360	0,060604
$N_{victims}$	0,764915	1,000000	0,088737	0,323689	-0,118355	0,937602	0,469821
T_{arrive}	0,031368	0,088737	1,000000	0,212499	0,575925	0,126764	-0,120900
T_{loc}	0,253070	0,323689	0,212499	1,000000	0,053396	0,235887	0,437409
T_{liq}	0,013677	-0,118355	0,575925	0,053396	1,000000	-0,024018	-0,272294
N_{popul}	0,879360	0,937602	0,126764	0,235887	-0,024018	1,000000	0,171210
R_3	0,060604	0,469821	-0,120900	0,437409	-0,272294	0,171210	1,000000

Fig. 1. Correlation matrix

The next step is to remove those parameters with which the risk has a strong correlation. In our case, there are no such parameters. A table with the values of significance was obtained (Fig. 2).

	Regression Summary for Dependent Variable: R_3 (2_En) R= ,92694742 R?= ,85923152 Adjusted R?= ,84414918 F(6,56)=56,969 p<0,0000 Std.Error of estimate: ,00000					
N=63	b*	Std.Err. of b*	b	Std.Err. of b	t(56)	p-value
Intercept			0,000058	0,000004	13,6670	0,000000
N_{fire}	0,20197	0,121943	0,000000	0,000000	1,6563	0,103257
$N_{victims}$	2,50990	0,175390	0,000000	0,000000	14,3104	0,000000
T_{arrive}	-0,08262	0,066501	-0,000001	0,000000	-1,2424	0,219264
T_{loc}	0,15390	0,058243	0,000000	0,000000	2,6423	0,010656
T_{liq}	0,00408	0,064797	0,000000	0,000000	0,0629	0,950075
N_{popul}	-2,38542	0,232631	-0,000000	0,000000	-10,2541	0,000000

Fig. 2. Levels of significance of the studied parameters

The level of significance of the studied parameters in Fig. 2 is shown by the criterion of p-value, which should not exceed 0.05. In our case, there are three such parameters at this stage, so we start with removing the greatest p-value. By deleting the parameter for the liquidation time T_{liq}, we will obtain a new table with the significance levels (Fig. 3).

N=63	Regression Summary for Dependent Variable: R_3 (2_En) R= ,92694205 R?= ,85922157 Adjusted R?= ,84687259 F(5,57)=69,578 p<0,0000 Std.Error of estimate: ,00000					
	b*	Std.Err. of b*	b	Std.Err. of b	t(57)	p-value
Intercept			0,000058	0,000004	13,9459	0,000000
N_{fire}	0,20289	0,120014	0,000000	0,000000	1,6905	0,096392
$N_{victims}$	2,50774	0,170475	0,000000	0,000000	14,7103	0,000000
T_{arrive}	-0,08021	0,053875	-0,000001	0,000000	-1,4888	0,142043
T_{loc}	0,15388	0,057731	0,000000	0,000000	2,6654	0,009986
N_{popul}	-2,38459	0,230221	-0,000000	0,000000	-10,3578	0,000000

Fig. 3. Levels of significance of the studied parameters without T_{liq}

The number of considered cases being analyzed equals the accepted valid ones and is 63, so it is not expedient to analyze again the matrix of correlations. In Fig. 3, we see that p-value of two more parameters is greater than 0.05, so we delete the arrival time T_{arrive} from the analysis and then again analyze the table with the levels of significance (Fig. 4).

N=63	Regression Summary for Dependent Variable: R_3 (2_En) R= ,92398428 R?= ,85374695 Adjusted R?= ,84366053 F(4,58)=84,643 p<0,0000 Std.Error of estimate: ,00000					
	b*	Std.Err. of b*	b	Std.Err. of b	t(58)	p-value
Intercept			0,0000535547565	0,000003	18,1675	0,000000
N_{fire}	0,25374	0,116252	0,0000000012181	0,000000	2,1826	0,033125
$N_{victims}$	2,57412	0,166258	0,0000005066851	0,000000	15,4827	0,000000
N_{popul}	-2,49578	0,220044	-0,0000000325992	0,000000	-11,3422	0,000000
T_{loc}	0,12870	0,055775	0,0000003677267	0,000000	2,3075	0,024615

Fig. 4. Levels of significance of the studied parameters without T_{liq} and T_{arrive}

Since all significance values of the parameters are less than 0.05, we will now proceed to the analysis of the residuals. To start with, we will construct the histogram of the residuals (Fig. 5).

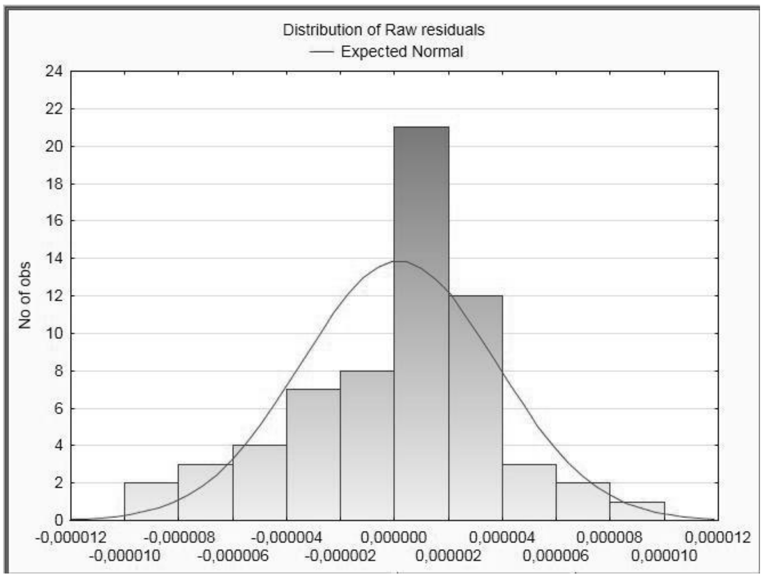

Fig. 5. Histogram of residuals

Let us check the residuals for normality. In general, Fig. 5 demonstrates the normality of the distribution, although there is one peak that would be less noticeable with the increase in the number of intervals. The hypothesis does not deviate from normality. The next step is to construct a normal probability plot of residuals (Fig. 6).

The systematic deviations of the actual data from the theoretical normal line are not observed, that is, the residuals are distributed normally. Now let us check whether there is or there is no dependence of the residuals on the predicted values and residuals. For this purpose, let us construct a scatter diagram to evaluate the acceptability of the results (Fig. 7).

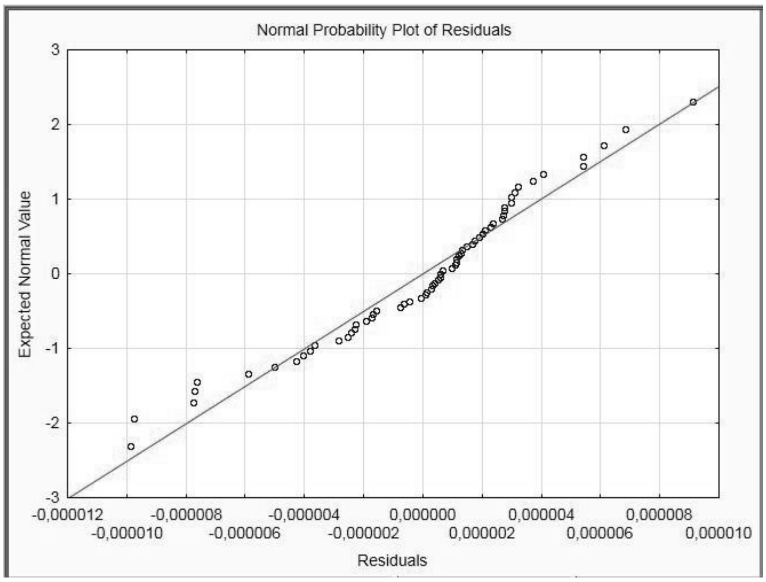

Fig. 6. Normal probability plot of residuals

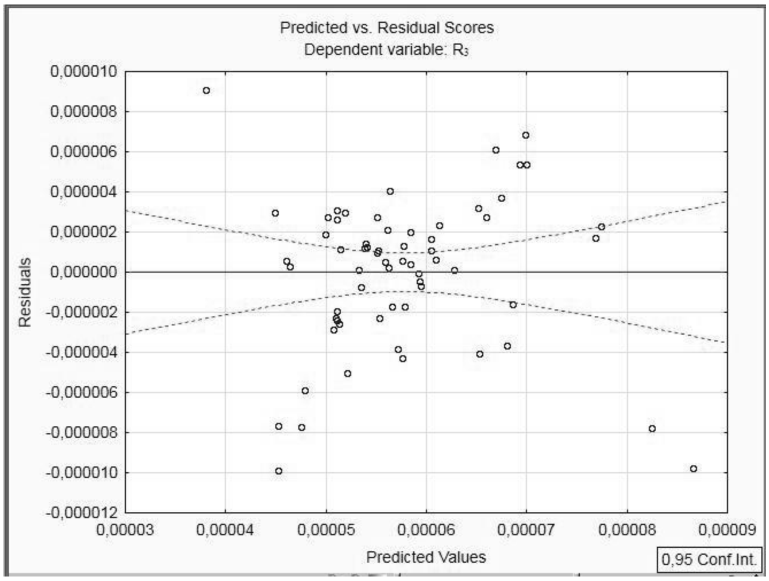

Fig. 7. The diagram of scattering the residuals from the predicted values

There is no consistency in the placement of points; they are located chaotically. Thus the residuals do not depend on the predicted values. Analysis of the residuals by two parameters indicates the adequacy of the model.

Let us move on to the stage of checking acceptability of the model as a whole. The level of significance must be between 0 and 0.05. From Figure 8, we determine that the level of significance is equal to 0. In this regard, the model can be considered acceptable.

The determination coefficient (R?) shows the adequacy of the selection of factors that influence the risk. Since this coefficient is equal to 0.85374695 (Fig. 4), which is more than 0.3, the selection of factors is adequate. The fact that the determination coefficient is close to one testifies to the quality of the model.

	Analysis of Variance; DV: R_3 (2_En)				
Effect	Sums of Squares	df	Mean Squares	F	p-value
Regress.	0,000000	4	0,000000	84,64323	0,000000
Residual	0,000000	58	0,000000		
Total	0,000000				

Fig. 8. Table of the results of dispersion analysis

Let us write the linear regression equation in the general case:

$$Y = b_o + b_1X_1 + b_2X_2 + \cdots + b_kX_k \quad , (1)$$

where Y is the dependent variable under study (factor, parameter), in our case it is R_3; b_0, b_1, b_2 ..., b_k are estimation of the parameters of the regression equation; X_1, X_2, ..., X_k are explanatory variables.

Let us write the equation of the received regression:

$$Y = 10^{-6} \cdot (53.5547 + 0.3677T_{loc} + 0.0012N_{fire;} + 0.5067N_{victims} - 0.0326N_{popul}) \quad (2)$$

Let us now consider the risk prediction using the resulting model. Fig. 9 shows all the parameters needed to predict the value of risk. Let us make a forecast for 2017 according to the data for the Kharkiv region, which are already known. The initial data are as follows: N_{fire} = 6430; $N_{victims}$ = 135 *people*; N_{popul} = 2718.5 *thousand people*; T_{loc} = 17 *min*.

Variable	Predicting Values for (2_En) variable: R_3		
	b-Weight	Value	b-Weight * Value
$N_{victims}$	0,000001	135,000	0,000068
N_{fire}	0,000000	6430,000	0,000008
T_{loc}	0,000000	17,000	0,000006
N_{popul}	-0,000000	2718,500	-0,000089
Intercept			0,000054
Predicted			0,000047
-95,0%CL			0,000045
+95,0%CL			0,000050

Fig. 9/ Risk forecast for 2017 made with the help of the developed model

Let us calculate the integral fire risk using the following expression [4]:

$$R_3 = \frac{N_{victims}}{N_{popul}} \quad (3)$$

$$R_3 = \frac{135}{2718.5} = 0.00004966 \frac{1}{year} \quad (4)$$

If we compare the values calculated by formula (3) with the predicted ones, then we can see that the actual result is close to the forecasted and lies within the permissible limits with a deviation of 5 %. This testifies to the reliability of the obtained mathematical model.

Conclusions

The paper presents a mathematical model of integral fire risk management constructed using a correlation-regression analysis. Having taken the Kharkiv region as an example there was made a forecast of the corresponding risk. The actual result turned out to be close to the forecasted one and was within the permissible limits with a deviation of 5 %, which indicates the reliability of the developed mathematical model. Further research will be aimed at developing a risk management method and working out well-founded recommendations for the establishment of security centers in the most problem regions of Ukraine.

References

1. *Order of the Cabinet of Ministers of Ukraine [Rozporiadzhennia Kabinetu Ministriv Ukrainy] (2014). On Approval of the Concept of Management of the Risks of Emergencies of Man-made and Natural Characteristics [Pro skhvalennia Kontseptsii upravlinnia ryzykamy vynyknennia nadzvychainykh sytuatsii tekhnohennoho ta pryrodnoho kharakteru]. Retrieved from http://zakon0.rada.gov.ua/laws/ show/37-2014-р [in Ukrainian].*
2. *The Constitution of Ukraine [Konstytutsiia Ukrainy] (1996). Retrieved from http://zakon2.rada.gov.ua/rada/show/254к/96-вр/page [in Ukrainian].*
3. *Kravtsiv S. Ya., Sobol' O. M. (2016). Analysis of foreign experience of state regulation of acceptable risk level [Analiz zakordonnoho dosvidu derzhavnoho rehuliuvannia rivnia pryiniatnoho ryzyku]. Bulletin of the National University of Civil Protection of Ukraine [Visnyk Natsionalnoho universytetu tsyvilnoho zakhystu Ukrainy], 2 (5), 297–302. Retrieved from http://repositsc.nuczu.edu.ua/bitstream/123456789/2037/1/Visnyk_NUCZU_41_2016_2%285%29.pdf [in Ukrainian].*
4. *Kravtsiv S. Ya., Sobol' O. M., Maksimov A. V. (2016). The analysis of integral risks on the territory of Ukraine. Problems of Emergencies [Problemy nadzvychainykh sytuatsii], 23, 53–60. Retrieved from http://repositsc.nuczu.edu.ua/bitstream/123456789/2031/1/Kravtsiv.pdf.*

5. *Kravtsiv S. Ya., Sobol' O. M., Tiutiunyk V. V. (2017). Estimation of parameters of influence on integral fire risk using factor analysis [Otsiniuvannia parametriv vplyvu na intehralnyi pozhezhnyi ryzyk za dopomohoiu faktornoho analizu]. Fire Safety [Pozhezhna bezpeka], 30, 99–104. Retrieved from http://repositsc.nuczu. edu.ua/bitstream/123456789/ 4899/1/30-13.pdf [in Ukrainian].*
6. *Piskunova L. E., V. A. Prylypko,. T. O. Zubok. (2012). Life Safety [Bezpeka zhyttiediialnosti]. Kyiv: PH "Academy" [in Ukrainian].*
7. *Kravtsiv S. Ya., Sobol' O. M. (2017). Grouping of administrative-territorial units of Ukraine on the level of integral fire risk by means of cluster analysis [Hrupuvannia administratyvno-terytorialnykh odynyts Ukrainy po rivniu intehralnoho pozhezhnoho ryzyku za dopomohoiu klasternoho analizu]. Problems of Emergencies [Problemy nadzvychainykh sytuatsii], 26, 79–86. Retrieved from http://repositsc.nuczu.edu.ua/ bitstream/123456789/6410/1/kravtsiv.pdf [in Ukrainian].*