Integrated Fire Risk Factors Analysis in the Residential Districts of Russian Federation Regions

A V Kalach¹, A Yu Akulov², E A Cherepanov²
¹ Voronezh Institute of the Federal Penitentiary Service of the Russian Federation, Voronezh
² Ural Institute Firefighting service of EMERCOM of Russian Federation, Ekaterinburg

E-mail: A_Kalach@mail.ru

Abstract. To develop a long-term strategy for managing the fire risks level at the sites of supervision in the Russian Federation regions, we collected, analyzed and summarized statistical data on fires occurring. Based on the obtained results, it is proposed to take management decisions aimed at minimizing fire risks in the Russian Federation. The article presents the results of a comprehensive study of fire risks.

In this study, special attention is paid to identifying the influence of social factors among the causes of fires occurring in Russia. Based on the panel data analysis for the regions of Russia, a quantitative dependence of the probability of fires occurrence at economic and administrative objects of supervision obtained. An assessment of the risk of death for a year because of such fires carried out. A comparative analysis of the values of the regional socio-economic factors corresponding indicators for the previous year carried out. A comparison of the results obtained with the rapid response time to fires rescue units of EMERCOM of Russia.

1. Introduction

In order to elaborate a long-term policy for management of the fire risks in the regions of Russian Federation for their minimization it is actual to organize the empirical examination of the effect on the integral fire risks of the regional social-economic factors and regional rates of time of the operative responses for the fire alerts of the State Fire Service (SFS) at the Ministry of Emergency Situations (MES) basing on the econometric analysis of available statistical data. In this case plotting of the linear dependence of the integral fire risks on the corresponding analyzed factors seems to be rather actual, with including of the quantitative estimation of the weight and significance of each factor. It is also interesting to compare the results of the factor dependence of the integral fire risks obtained because of econometric analysis with those ones obtained from dependence of the integral fire risks on the economic factors obtained because of the rational offender theory [1].

Results of the complex study of fire risks in Russia, presented in [2], show that the main part of fires and human tolls caused by fires occurs in the buildings of the residential sector. Note that a large part of such factors happened due to the “human” fault, i.e. due to a “social factor”.

Let us designate an integral fire risk connected with the probability for a man to meet a fire in the residential sector per time unit as $R_1$. In [3] it proposed to measure this risk in the units of $[\text{fire}/(10^3 \text{ human-year})]$. Hence, integral risk $R_2$ is connected with the probability for a human to die in the fire
in the residential sector and it is measured according to [3], in the units of [victim/(10^3 fires)]. Integral fire risk R_{sz} is connected with the probability for a human to die in a fire in the residential sector per time unit and it is measured according to [3], in the units of [victim/(10^3 human-year)]. It is obvious that for the fire risks the ratio R_{sz} = R_{iz}R_{2z} is true. So, risk R_{iz} characterizes a possibility of the fire realization in residential sector while risks R_{2z} and R_{3z} – some consequences of this realization.

Connection between the risk R_{iz} and probability of the fire initiation p_z per a year in the homesteads of the regional residential sector can defined by the correlation

\[ R_{iz} = p_z 10^3 \frac{N_z}{N} \]  \hspace{1cm} (1)

where N_z – is the number of homesteads in the region; N is the population size in a region.

Basing on the fact that the determining role in initiation of the fires in the residential sector is attributed to the “human factor”, particularly, casual handling with the sources of fire, for some other kinds of activity or inactivity resulting in the initiation of the fires in residential sector it is possible to write down the following relationship for the probability p_z of the fire initiation in the homesteads of the regional residential sector:

\[ p_z = p_{z0} + p_{zp} = p_{z0} + k_z K_p / K_0 = p_{z0} + k_z C_z , \]  \hspace{1cm} (2)

where p_z is a probability of the fire initiation in the homesteads of a region per year; p_{z0} is a component of the probability p_z is not directly connected with the human factor; p_{zp} – is the component of probability p_z connected with the violation the homestead members in the field of fire safety of their own homesteads. It means activity or inactivity of the individuals facilitating the possibility of fire initiation in the homesteads; k_z is the regional proportionality coefficient between the probability p_{zp} and multiplier \( C_z = K_p / K_0 \), determining the number of homesteads K_p violating requirements of the fire safety to the total number K_0 of homesteads in the residential sector of the region.

Since p_{zp} is a probability of the fire initiation caused by the human factor in the homesteads of the region per year is connected with the violations of the fire safety requirements by the homestead members then these violations can be considered as a variety of offences or crimes in the area of public security. At the same time for the analysis of the probability offences and crimes it is reasonable to apply theory of the rational offender by Bekcker [4].

In this situation the rational behavior of the fire safety offender in the residential sector means that an offence occurs only in the case if the expected additional usability V_z of its occurrence exceeds possible total damages in case of the fire in the homestead U_{sz}. It means validity of the following relation:

\[ (1 - p_z) V_z > p_z U_{sz} . \]  \hspace{1cm} (3)

It is considered that a potential offender can estimate the probability of the fire initiation p_z per a year in the homesteads of a region basing on its own or some other experience.

While estimating the probability of violations in the area of fire safety for his own dwelling basing on hypothesis of the rational offender it is necessary to account that the latter one can consider as the expected additional usability V_z: economy of the costs related with providing of the fire safety of the homestead, economic equivalent of satisfaction from alcohol intake or other habits provoking fire danger, and as a total loss U_{sz} under fire initiation in the homestead:

\[ U_{sz} = U_z + E_z R_{2z} / 10^2 , \]  \hspace{1cm} (4)
where $U_z$ are direct material losses as a result of the fire in the homestead; $R_{z}$ is a risk connected with the probability of the human death in a fire in the residential sector [3]; $E_{z}$ is an economical equivalent of the human life in the residential sector [5].

2. Relationship between determinants of the fire risks and criminality

Identification of determinants of the fire risks in the residential sector of Russian regions is of a practical interest as well as their dependence on the statistically registered social-economic indexes and also on the factors characterizing the capabilities of Emergency Situations Ministry concerned with fire extinguishing implying such factors as the time of operative response to the fire alerts. For the econometric analysis of the factors determining the level of the fire risks in the residential sector of Russia’s regions it is urgent to use the analysis of the panel statistical data. Panel data mean observations of the same economic units performed in consequent periods of time. In [6], with the use of statistical data obtained over Russian Federation basing on multi-dimensional regression analysis of the number of fires dependence on a set of factors characterized by the highest value of the correlation coefficient a close to linear one dependence of the number fires per 1 thousand of humans on the number of registered crimes recalculated per 100 thousands of the population. With the account of this result assuming a commonality of social-economic factors determining fire risks in the residential sector and criminal rate in RF let us analyze the empirical investigations of the effect of social-economic factors on the different kinds of criminality in the regions of Russian Federation performed on the basis of analysis of the panel statistical data presented in [7, 8]. In these works it was found the effect of such factors as average per capita cash income of the population, Jeeny coefficient (measure of inequality in the incomes), rate of alcohol abuse among the population of a region, educational level of the population in a region, mean temperature in January, indexes concerned with the probability of the criminal punishments for the execution of crimes. Then, in order to study the factors determining fire risks in the residential sector it is actual to perform panel analysis of dependence of the fire risks in Russia on social-economic factors identified in [7,8], as the crime determinants. However, factors connected with the probability and severity of the criminal punishment should be changed by the factors connected with the probability and severity of material and possible human tolls as well as the accounting for a specific factor for a certain residential sector as a percentage of a slum and hazardous dwelling in the regional residential sector. While performing the panel analysis the mean time for arrival of the first fire units was taken into account as an indicator characterizing ESM capability foe the fire extinguishing.

3. Results obtained basing on the panel data

To determine the effect of the accounted factors on the fire risks rate in the residential sector of the Russia’s regions let us analyze panel data on the basis of models with random effect [9]. Models with random effect are described by the equation $y_{it} = bx_{it} + u_{i} + c + \varepsilon_{it}$, where $y_{it}$ is the explained variable; $x_{it}$ is the explanatory variable; $u_{i}$ are random invariants in time for each of economical unit, $\varepsilon_{it}$ is an error of the model, and c is a constant value. In the models with random effect it is assumed that individual differences are of the casual type. In order to calculate models with the random effects generalized least-square (GLS) method should be applied that was realized in plm suite of the program R.

The information base for analysis comprised of the panel data for 82 regions of Russian Federation (1 region was excluded since it did not provide a complete data set) for the period of 2006 - 2016. Information on the fire statistics and indexes of the operative response for the fire alerts was obtained from the data that were registered by the State Fire Service of ESM in Russia, while social and economic indexes for the regions and inflation rates were taken from Rosstat publications.

Assuming that the risk of getting a human to the case of fire in the residential sector $R_{1z}$ and risk $R_{z}$ for a human to die in the fire per year in the residential sector to be linear functions of various factors and aggregating information over the population of the whole region let us develop a linear
model with a random effect for the description of fire risks in a dependence on a set of independent variables:

\[ R_{1it} = a_1 R_{2it} + a_2 U_{2it} + a_3 D_{it} + a_4 J_{it} + a_5 A_{it} + a_6 Z_{it} + a_7 G_{it} + a_8 S_{it} + a_9 T_{it} + a_{10} t_{it} + C_1. \]  

(5)

\[ R_{3it} = b_1 U_{2it} + b_2 D_{it} + b_3 J_{it} + b_4 A_{it} + b_5 G_{it} + b_6 S_{it} + b_7 T_{it} + b_{10} t_{it} + C_2. \]  

(6)

where subscripts i and t designate region and year, respectively; dependent variable in equation (5) \( R_{1it} \) is a risk for a man to get in the fire case in the residential sector; dependent variable in equation (6) \( R_{3it} \) is a risk for a human to die in a fire in the residential sector per year; independent variables in (5) and (6): \( U_{2it} \) is an average material damage from a fire in the residential sector, thousands of roubles, with the account of inflation relative to 2006 year and taking the mean material damage from a fire in the residential sector in 2006 as a reference value; \( D_{it} \) are average cash incomes of population in thousands of roubles with the account of inflation relative to 2006 year and taking the average cash incomes in thousands of roubles in 2006 as the reference value; \( J_{it} \) is Jeeny coefficient in the regions (measure of inequality in the incomes); \( A_{it} \) is the number of sick persons which were for the first time diagnosed to have a psychotic disorder connected with drinking and/or syndrome of alcohol addiction and which were taken to the regular medical check-up by psychoneurologic and narcological dispensaries per 10\(^5\) men of the regional population (according to [7], this index can characterize alcohol abuse rate in the population of the corresponding region); \( Z_{it} \) is a percentage of slum and emergency dwelling in a region; \( G_{it} \) is a percentage of the urban population in a region; \( S_{it} \) is a percentage of students of the educational institutions of the higher professional education in the population of a region (this index can show the education level in a region); \( T_{it} \) is an average temperature of January in Celsius degrees in a region; \( t_{it} \) is a mean time in a region (in minutes) for arrival of the first fire units after the fire alert; \( C_j \) is constant value including unsuspected factors.

Results of identification for the parameters of two models (equations 5 and 6) obtained on the basis of regression analysis of the panel data with the random effect are presented in Table 1; they were derived with the application of plm suite in the program R. Coefficients of the linear dependences of fire risks \( R_{1it} \) and \( R_{3it} \) on a set of independent variables were obtained. Besides the values of the coefficients the Table also represents the values of standard errors (in the brackets) and, correspondingly, validities \( z \) of these coefficients and the constants that are determined as the ratio of the coefficient or constant value validity to the value of the corresponding standard error.

**Table 1.** Results of analysis of the panel data basing on the model with the random effect, for the study of dependence of the fire risks in the residential sector of RF regions on social-economic regional factors and regional time rates of the operative response of the State Fire Service (SFS) at Emergency Situation Ministry (ES) for the fire alerts.

| Factors                        | Model 1 [fire/(10\(^3\) fire)] | Model 2 [victim/(10\(^5\) human)] |
|--------------------------------|---------------------------------|-----------------------------------|
| \( R_{2it} \) [victim/(10\(^2\) fires)] | \( -0.0179946 \) *** | \( 0.0040385 \) z = -4.46 |
|                                | \( -0.0001957 \) *** | \( -0.0066003 \) *** |
| \( U_{2it} \) [thous.roubles/fire] | \( 0.0000999 \) z = -1.96 | \( 0.0010674 \) z = -6.18 |
|                                | \( -0.0503379 \) *** | \( -0.4612459 \) *** |
| \( D_{it} \) [thous.roubles]  | \( 1.749431 \) *** | \( 12.20109 \) *** |
|                                | \( 0.2553084 \) z = 6.85 | \( 2.885301 \) z = 4.23 |
| \( J_{it} \)                   | \( 0.0023804 \) *** | \( 0.0237083 \) *** |
| \( A_{it} \) [sicks/10\(^5\)humans] | \( 0.0002213 \) z = 10.76 | \( 0.0024656 \) z = 9.62 |
Since generalized least-square (GLS) method was applied for estimation of the models with random effects then one should not bear on the value of R^2 for the interpretation of this model since in the regression estimated with the use of GLS it is not an adequate measure for estimation of the fitting quality. High values of Waald’s statistics mean adequacy of models 1 and 2 as a whole: 499.33 for model 1 and 492.89 for model 2. According to rho indexes individual effects accounted in these models form almost 88% for the variation of the dependent variable in the model 1 and 86% for the variation of the dependent variable in the model 2.

Expression corr(u_i,X)= 0, arranged in the upper part of the Table, represents an important hypothesis forming the base of the model. Regressors should not be correlated with non-observable random effects. Otherwise estimations for the model would not be valid.

The value of economical equivalent of the human life E_z for residential sector in Russia can be estimated by representing equation (5) in the form of:

\[ R_{1it} = a_2(a_1R_{2it}/a_2 + U_{zit}) + a_3D_{it} + a_4J_{it} + a_5A_{it} + a_6Z_{it} + a_7G_{it} + a_8S_{it} + a_9T_{it} + a_{10}t_{it} + C_1 \]  

With the account of the relationship (4) equation (5) can be also written as:

\[ R_{1it} = a_2(E_zR_{2it}/10^2 + U_{zit}) + a_3D_{it} + a_4J_{it} + a_5A_{it} + a_6Z_{it} + a_7G_{it} + a_8S_{it} + a_9T_{it} + a_{10}t_{it} + C_1 \]  

From comparison of (7) and (8) it follows that the value of economical equivalent of the human life E_z for the residential sector in Russia is determined by the formula:

\[ E_z = 10^2 \cdot a_1/a_2. \]  

With the account of the values and dimensionality of the coefficients a_1 and a_2 from Table 1: E_z=9195 [thous. roubles/victim], having in mind inflation relative to 2006 year.

The obtained estimation of economical equivalent for the human life in the residential sector of Russia is in a close agreement with the value of this factor, calculated for Russia according to the technique of estimation of the economical equivalent of the human life cost. The latter one is based on the fact that the economical equivalent of life for a typical man is equal to the ratio of disposable
average per capita annual income to the mean probability of human death during a year [10, 11]. From the calculations made in [11], this value for Russia in 2009 was of 12472 thous. roubles, that corresponded 9038 thous. roubles, with the account of official inflation relative to 2006 year. Thus, a consistency of $E_z$ value obtained from the model (1), with that one of the economical equivalent for the human life obtained accordi ng to the technique presented in [11], supports correctness of the model (1) in its application to the estimation of the risk for a man to get in case of fire per a year in the residential sector of the regions in Russian Federation and is in a good agreement with the model of rational offender.

Results of regression analysis presented in Table 1 for the quantitative dependence of $R_{1z}$ and $R_{3z}$ on different social-economic factors are quite correctly coincide with the model of rational offender presented above. Actually, according to the model of rational offender basing on the results of [1], from the expressions of (1) and (4), it follows that:

$$\frac{dR_{1z}}{d\ln(U_{sz\mu})} < 0,$$

(10)

where $U_{sz\mu}$ is a median value over all the homesteads of a region for the quantity of the total costs due to the fires.

From (10) it follows an inverse dependence of $R_{1z}$ on the factors determining the value of possible losses for the members of homesteads after a fire: mean values of $U_z$ and $R_{2z}$, as well as on the value of $D$ – average annual incomes of the population taking into account the value of inflation, assuming that these values must be in a positive correlation with the value of the average value of material damage $U_z$ caused by a fire in the residential sector. Just this negative (with the absolute value of significance coefficient $z > 1$) dependence of $R_{1z}$ on the factors: $R_{2z}$, $U_z$, $D$ was obtained on the basis of regression analysis for the panel data beginning from 2006 to 2012 over the regions of RF and is represented in Table 1. Positive dependence (with a significance coefficient $z = 6,85$) $R_{1z}$ on the Jeeny coefficient $J_u$, representing a degree of inequality in the incomes for the population of a region also correlates quite well with the model of a rational offender. Really, basing on the computation of [1], performed for lognormal distribution of the incomes of population [12] and material damages of the homesteads from fires [13] it follows that the integral fire risk in the residential sector $R_{1z}$ changes under the change of the variance $\sigma_u^2$ for normal distribution of the logarithm value for the amount of the incomes of the population $\ln(D)$ according to the expression:

$$\frac{dR_{1z}}{d\sigma_u} > 0, (1-p_z)V_{z\mu} < p_z U_{sz\mu},$$

(11)

where $p_z$ is a probability of the fire occurrence per a year in the residential sector; $V_{z\mu}$ is a median value of additional usability obtained from execution of the offences connected with the violation of the fire safety over all of the homesteads in the region; $U_{sz\mu}$ is a median value of the total losses caused by fires over all of the homesteads in the region. Since according to (4) total losses caused by fires, include the term $E_z R_{2z}$, connected with the possible victims as a result of the fires in homesteads, then accounting for a great value of the term $E_z R_{2z}$, condition (11) for the residential sector is executed. Since Jeeny coefficient $J = 2\Phi(\sigma_u / \sqrt{2}) - 1$, where $\Phi$ is a cumulative function for the standard normal distribution, then the relationship:

$$\frac{dR_{1z}}{dJ} > 0, \text{при} (1-p_z)V_{z\mu} < p_z U_{sz\mu},$$

(12)

is also executed that corresponds to a positive dependence of the integral risk $R_{1z}$ on $J_u$ –Jeeny coefficient for the regions, represented in Table 1.
The obtained results of regression analysis for the fire risks in the residential sector of RF regions are in agreement with the results of [14, 15], performed on the basis of the model of a rational offender concerned with the presence of economic determination of the fire risks.

Comparing the values of $R_{1ze}$ and $R_{3ze}$, obtained from the fire statistics for the residential sector of Russian Federation as a whole for 2012 year and the values of $R_{1zm}$ and $R_{3zm}$, calculated according to the models 1 and 2 basing on the economic statistical data of RF for the same year showed that the absolute value of the relative error for the model 1 in this case: $\Delta R_{1z} = \frac{|R_{1ze} - R_{1zm}|}{R_{1ze}} \times 100\%$ is of 10.5%, and for model 2: $\Delta R_{3z} = \frac{|R_{3ze} - R_{3zm}|}{R_{3ze}} \times 100\%$ is of 3.9%. The estimation of the most weighty contributions of the factorial terms into the calculated value of $R_{1zt}$ is characterized by relationships: $\frac{a_i G_{zi}}{R_{1zt}} = 1.406$; $\frac{a_i J_{zi}}{R_{1zt}} = 0.856$; $\frac{a_i D_{zi}}{R_{1zt}} = -0.795$; $\frac{a_i A_{zi}}{R_{1zt}} = 0.238$; $\frac{a_i R_{zi}}{R_{1zt}} = -0.199$. The estimation of the most weighty contributions of the factorial terms into the calculated value of $R_{3zt}$ is characterized by relationships: $\frac{b_i G_{zi}}{R_{3zt}} = 1.291$; $\frac{b_i J_{zi}}{R_{3zt}} = -0.815$; $\frac{b_i A_{zi}}{R_{3zt}} = 0.667$; $\frac{b_i A_{zi}}{R_{3zt}} = 0.265$; $\frac{b_i S_{zi}}{R_{3zt}} = 0.188$.

The relative contribution of factorial terms makes it possible to estimate the relative significance of different factors into determination of the fire risks.

While considering the contribution of different factorial terms into the fire risks it should be noted that according to the studies made in [2], $R'_{1r} > R''_{1u}$ and $R'_{3r} > R''_{3u}$ are true for Russia as a whole, where superscripts где верхние индексы "r" и "u" designate corresponding fire risks in the rural and urban area. This result can be explained by the fact that as for the urban as for the rural areas not only the difference in factor $G_{zi}$ is quite typical but it is also characteristic for a set of the other factors different by sign of their contribution into the values of the other corresponding integral fire risks.

4. Analysis of the capabilities for medium-term predictions of the fire risks
Let us consider the capabilities of econometric approach with the application of the models with random effect for providing of the medium-term prediction of the influence of determining factors on the integral fire risks in the regions of Russia. An information base for the investigations of these medium-term prediction models was ensured by the panel data over 82 regions of RF (one region was excluded since it did not provide a complete data set) for 2006 – 2010 years and similar data for 2006 – 2012 years. Information on the fire statistics and values of elapsed time for the operative responses to the emergency fire alerts was obtained from the data registered by the State fire service of the Ministry on Emergency Situations in Russia. Social and economic indexes for the regions and indexes of inflation were taken from the publications of Russian Agency of Statistics (Rosstat).

When performing integral fire risks for the regions of Russia it is reasonable to include in the models with random effect only those independent variables specifying the factors that cause fires which are themselves independent on the fire risks. They should be chosen in such a way that one can correctly estimate them or specify for the predictable year and region. So, it is unreasonable to include factors $R_{2z}$ and $U_z$ in a set of explanatory variables. Taking this into account let us formulate the following models for the prediction of integral risks for m years:

$$R_{1zt(t+m)} = c_1 D_{i(t+m)} + c_2 J_{i(t+m)} + c_3 A_{i(t+m)} + c_4 Z_{i(t+m)} + c_5 G_{i(t+m)} + c_6 S_{i(t+m)} +$$
\[ R_{3zi(t+m)} = d_1D_{i(t+m)} + d_2J_{i(t+m)} + d_3A_{i(t+m)} + d_4Z_{i(t+m)} + d_5G_{i(t+m)} + d_6S_{i(t+m)} + \]
\[ + d_7T_{i(t+m)} + d_8t_{i(t+m)} + C_3 \]

(13)

\[ R_{3zi(t+m)} = d_1D_{i(t+m)} + d_2J_{i(t+m)} + d_3A_{i(t+m)} + d_4Z_{i(t+m)} + d_5G_{i(t+m)} + d_6S_{i(t+m)} + \]
\[ + d_7T_{i(t+m)} + d_8t_{i(t+m)} + C_4 \]

(14)

Coefficients \( c_i \) and \( d_i \) in (13) and (14) can be determined basing on the retrospective panel data, while the values of factors are assumed to be equal to the estimated values of these factors for the predictable year.

Table 2 represents results of analysis of the panel data over the regions of Russia for 2006 – 2010 years and for 2006 – 2012 years on the basis of two models with random effect (equations 13 and 14), obtained with the use of plm suite of computer program R.

**Table 2.** Results of prediction for the integral fire risks \( R_{1z} \) and \( R_{3z} \) by the models with random effect for the regions of Russia in 2012 basing on the panel data for the period of 2006 – 2010 and panel data for the period of 2006 – 2012.

| Factors | Model 3 | Model 4 |
|---------|---------|---------|
|         | equation (13) for \( R_{1zi(t+m)} \) [fire/(10^3 men-year)] | equation (14) for \( R_{3zi(t+m)} \) [victim/(10^3 men-year)] |
| 2       | upper set of values was obtained from the panel for 2006-2010 (m=2); lower set of values was obtained from the panel for 2006-2012 (m=0) | upper set of values was obtained from the panel for 2006-2010 (m=2); lower set of values was obtained from the panel for 2006-2012 (m=0) |
| 1       | \( D_{i(t+m)} \) [thousands roubles] | \( J_{i(t+m)} \) |
|         | (0.0062484) \( z = -6.33 \) | (0.5056747) \( z = -10.86 \) |
|         | (0.0062484) \( z = -6.33 \) | (0.0046673) \( z = -3.33 \) |
|         | \( J_{i(t+m)} \) | (0.8112281) \( z = -9.5 \) |
|         | (1.786367) \( z = 6.94 \) | (2.572431) \( z = 6.94 \) |
|         | (0.0016536) \( z = -6.32 \) | (0.0185021) \( z = -6.32 \) |
|         | \( A_{i(t+m)} \) [sick persons/10^5 men] | \( Z_{i(t+m)} \) [%] |
|         | (0.0002426) \( z = 6.82 \) | (0.0060305) \( z = 0.32 \) |
|         | (0.0002426) \( z = 6.82 \) | (0.0006305) \( z = 0.32 \) |
|         | (0.0023161) \( z = 10.17 \) | (0.0019524) \( z = -0.28 \) |
|         | (0.0023161) \( z = 10.17 \) | (0.0022233) \( z = 10.37 \) |
|         | (0.0004308) \( z = 0.06 \) | (0.0066894) \( z = 0.06 \) |
|         | (0.0004308) \( z = 0.06 \) | (0.0004308) \( z = 0.06 \) |
|         | (0.00167498) \( z = 1.33 \) | (0.0170893) \( z = 1.33 \) |
|         | (0.00167498) \( z = 1.33 \) | (0.00167498) \( z = 1.33 \) |
|         | (0.0035004) \( z = 4.79 \) | (0.015856) \( z = 3.99 \) |
|         | (0.0035004) \( z = 4.79 \) | (0.003105) \( z = 5.11 \) |
|         | (0.015856) \( z = 4.79 \) | (0.0143899) \( z = 2.63 \) |
|         | (0.015856) \( z = 4.79 \) | (0.0143899) \( z = 2.63 \) |
|         | (0.0107893) \( z = 2.63 \) | (0.0107893) \( z = 2.63 \) |
|         | (0.0107893) \( z = 2.63 \) | (0.0107893) \( z = 2.63 \) |
In Table 1 asterisks mean confidence levels: *** – 1%, ** – 5%, * – 10%.

Adequacy of models 3 and 4 according to the panel data for 2006 – 2010 years and for 2006 – 2012 years is confirmed by the high values of Waald’s statistics. As it can be seen from the latter Table, for the models obtained by the panel data for 2006 – 2012 years the values of Waald’s statistics are higher that is connected with a greater amount of processed data from this panel. Expressions of $\text{corr}(u_i,X) = 0$ represent consistency of estimators for the models.

For the analysis of a possibility to apply models with the random effect for a medium-term prediction let us estimate explanatory variables held coefficients for stability taking coefficients from Table 2 as an example. Now let us consider independent variables that are most significant for the model. An estimator for the most significant contributions of factorial terms into the calculated values of $R_{1z(t+m)}$ derived from the panel data for 2006 – 2010 years is characterized by the relationships:

$$
c_2 G_{1z(t+m)} = 1,417; \quad c_1 D_{1z(t+m)} = -0,613; \quad c_2 J_{1z(t+m)} = -0,371; \quad c_1 A_{1z(t+m)} = 0,162.
$$
Estimator of the most significant contributions for the factorial terms into the calculated value of $R_{3zi(t+m)}$ from the panel data for 2006 - 2010 years is characterized by the relationships:

$$
\frac{d_3 G_{i(t+m)}}{R_{3zi(t+m)}} = 1.412; \quad \frac{d_1 D_{i(t+m)}}{R_{3zi(t+m)}} = -0.701; \quad \frac{d_2 J_{i(t+m)}}{R_{3zi(t+m)}} = -0.486; \quad \frac{d_3 A_{i(t+m)}}{R_{3zi(t+m)}} = 0.209;
$$

$$
\frac{d_3 t_{i(t+m)}}{R_{3zi(t+m)}} = 0.144.
$$

When analyzing the contribution of factorial terms into the calculated values of $R_{1i(t+m)}$ and $R_{3zi(t+m)}$ with the coefficients obtained from RF statistical data for the period of 2006 – 2010 years it should be noted for coefficient $c_2$ held by $J_{i(t+m)}$ confidence level was of 0.341, while for $d_2$ held at $J_{i(t+m)}$ confidence level was of 0.334, meaning their low correctness. Keeping this fact in a mind it is unreasonable to check coefficients $c_2$ and $d_2$ obtained from the panel data for the period from 2006 – 2010 years for their stability. Let us analyze for stability coefficients held at the independent variables with high levels of confidence. To do this let us calculate the relative change of the coefficients obtained from the panel data for the period of 2006 – 2010 years and for 2006 – 2012 years by the formula: $\delta k_i = \frac{k_i^{2012} - k_i^{2010}}{k_i^{2012}} \cdot 100\%$. Next, we find the following values: for the prediction of $R_{1i}$:

$\delta c_1 = 21.9\%$; $\delta c_3 = 28.6\%$; $\delta c_5 = 5.6\%$; for prediction of $R_{3z}$: $\delta d_1 = 17.4\%$; $\delta d_3 = 27.8\%$; $\delta d_5 = 7.0\%$; $\delta d_8 = 27.7\%$. In this situation the relative errors in the estimation of the coefficients themselves $\Delta k_i = \frac{1}{z} \cdot 100\%$, according to the factors $z$ in Table 2 are of: $\Delta c_1 = 15.7\%$; $\Delta c_3 = 20.8\%$; $\Delta d_1 = 17.6\%$; $\Delta d_3 = 14.6\%$; $\Delta d_5 = 25.0\%$; $\Delta d_8 = 21.0\%$ for the corresponding significant coefficients during the period of 2006 – 2010 years that is approximately agrees with the estimations obtained for $\delta k_i$. For the panel data during the period of 2006 – 2012 years relative errors $\Delta k_i$ are diminished: $\Delta c_1 = 9.2\%$; $\Delta c_2 = 14.4\%$; $\Delta c_3 = 9.6\%$; $\Delta c_5 = 19.5\%$; $\Delta d_1 = 10.8\%$; $\Delta d_2 = 26.8$; $\Delta d_3 = 9.8\%$; $\Delta d_5 = 23.6\%$; $\Delta d_8 = 15.5\%$.

Thus, the maximal relative errors: $\delta k_i$ and $\Delta k_i$ for coefficients of the models for medium-term prediction of $R_{1z}$ do not exceed 29% and for medium-term prediction of $R_{3z}$ they are lower than 28%.

Comparison of the experimental values of $R_{1ze}$ and $R_{3ze}$, obtained from the fire statistics for the residential sector of Russian Federation for 2012 year as a whole and the values of $R_{1zm}$ and $R_{3zm}$, obtained from the calculations by the models 3 and 4, demonstrated that in this case absolute values of the relative error for the models are expressed as: $\Delta R_{1z} = \frac{R_{1ze2012} - R_{1zm2012}}{R_{1ze2012}} \cdot 100\% = 12.6\%$; $\Delta R_{3z} = \frac{|R_{3ze2012} - R_{3zm2012}|}{R_{3ze2012}} \cdot 100\% = 2.8\%$; while the relative changes in the values of the integral risks for the period of 2010 to 2012 years were:
\[
\delta R_{1z} = \frac{R_{1z2012} - R_{1z2010}}{R_{1z2012}} \cdot 100\% = 13.6\% ; \quad \delta R_{3z} = \frac{R_{3z2012} - R_{3z2010}}{R_{3z2012}} \cdot 100\% = 13\% .
\]

So, from analysis of the relative errors for the coefficients in the medium-term prediction models and the relative errors of results for medium-term prediction models intended for the calculations of the integral fire risks in the residential sector \( R_{1z} \) and \( R_{3z} \) it follows that the value of prediction errors makes it possible to provide a relevant information in the case of sudden changes in the economic conditions and a correlated considerable change of the integral fire risks \( R_{1z} \) and \( R_{3z} \).

5. Conclusion

Results of analysis of the panel data over regions of Russia, including fire statistics for the residential sector and statistics over a set of the regional social-economic indexes as well as time metrics data concerned with the operative responses of State Fire Service of the Ministry on Emergency Situations in RF to emergency fire alerts using models with random effects make it possible to represent the quantitative dependences of risk for a man to get in fire in the residential sector per year; the same is true for the risk of a man to die in fire per year in the residential sector. Both of these kinds of risks are linear functions of a set of the corresponding regional indexes. The obtained results are in a quite good agreement with those ones related with the application of the model of the rational offender. Estimation of the economic equivalent for a human life in Russia calculated on the basis of analysis for the panel data using models with the random effect is consistent with the values known from literature obtained on the basis of the actuarial calculations. Analysis of the possibilities for using of the models with random effect for the medium-term prediction of the integral fire risks showed that the value of prediction errors provides relevant information in case of dramatic changes in the economic conditions and the corresponding considerable change of the integral fire risks \( R_{1z} \) and \( R_{3z} \).

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