The analysis of factors of management of safety of critical information infrastructure with use of dynamic models

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Abstract. Based on the analysis of the dynamic model of panel data by region, including fire statistics for surveillance sites and statistics of a set of regional socio-economic indicators, as well as the time of rapid response of the state fire service to fires, the probability of fires in the surveillance sites and the risk of human death in The result of such fires from the values of the corresponding indicators for the previous year, a set of regional social-economics factors, as well as regional indicators time rapid response of the state fire service in the fire. The results obtained are consistent with the results of the application to the fire risks of the model of a rational offender. Estimation of the economic equivalent of human life from data on surveillance objects for Russia, calculated on the basis of the analysis of the presented dynamic model of fire risks, correctly agrees with the known literary data. The results obtained on the basis of the econometric approach to fire risks allow us to forecast fire risks at the supervisory sites in the regions of Russia and to develop management solutions to minimize such risks.

1. Introduction
Not only ensuring collecting statistical data on the happening fires, but also their analysis by results of which adoption of the administrative decisions directed to minimization of fire risks to the Russian Federation is possible is relevant for elaboration of long-term strategy of management of the level of fire risks on objects of supervision in regions of the Russian Federation, for the purpose of their minimization. Results of a complex research of fire risks are presented in works [1-8]. In this work the leading role of social factors among the causes of the fires in Russia is noted.

It agrees [1], the reasons of the fires connected with a human factor and relating to prevented by the Public fire service (PFS) of Emercom of Russia make more than 65% of total of the fires. Believing linear dependence of number of such fires on total of economic and administrative objects of supervision with violations of requirements of fire safety, expression for probability of emergence of the fires on such objects in a certain interval of time (year), taking into account statistical determination of frequency of the fires, according to the model presented in [9, 10] it is possible to write down as

\[ p = p_s + p_p = p_s + kC , \]

(1)

where \( k \) – regional coefficient of proportionality between probability of the fires on the objects of supervision caused by the prevented factors, and a share among objects which owners violate
requirements of fire safety: \( p_n \), \( p_p \) – probabilities of emergence of the fires in a year at the expense of respectively not prevented and prevented Public fire service of factors. Thus, probability of emergence of the fires at the expense of prevented Public fire service of factors is directly proportional to a multiplier which value is defined on the basis of economic model of the rational offender \([9, 10]\). The rationality of the offender means that violation happens only if the expected income from his commission exceeds possible, in case of fire and (or) loss punishments. When calculating level of violations on the basis of a hypothesis of the rational offender it is considered that the last, as the expected profit can consider economy on expenses on ensuring fire safety of objects, and as punishment can bear the following two types of losses: 1) losses at emergence of the fires on objects of supervision,

\[
    u = u_m + E_n \cdot R_{2n} / 10^2,
\]

where \( u_m \) – loss of property; \( R_{2n} \) – risk of death of the person at the fire on objects of supervision \([1]\), where unit of his measurement has an appearance [the victim / \( 10^2 \) fires]; \( E_n \) – material equivalent of human life on economic and administrative objects \([4]\); 2) losses from penalties for violations of requirements of fire safety, at the probability expected them for a unit of time \( f \). At the same time it is considered that the potential offender on the basis of the or others experience can estimate probability of emergence of the fire \( p \) in a year on objects of supervision.

Ignoring of requirements of fire safety in relation to the rational offender, taking into account possible penalties, happens only if the expected income of the offender meets a condition

\[
(1 - p) \cdot (b - fh) > pu .
\]

At the same time it is considered that the potential offender on the basis of the or others experience can estimate probability of emergence of the fire of \( p \) in a year on objects of supervision of the region.

On the basis of a hypothesis of the rational offender \([9, 10]\) in work \([10]\) the formula for definition of an economic multiplier has been received \( C \), the violation of requirements of fire safety reflecting economic idea of economic entities of expediency and defining a share of owners of objects, it is favorable to them to save means due to non-compliance with the called requirements. Expression for \( C \), at non-stationary social and economic and administrative and legal factors, taking into account delay time \( \tau \) between change of economic and administrative factors and change of \( C \), takes a form

\[
    C_i = \int_0^\infty \rho_{\mu,\sigma_u}(u)_{1,\tau} \int_{\frac{b_{f_i} - b_{f_{i-1}}}{1-p_i}}^{\frac{b_{f_{i+1}} - b_{f_i}}{1-p_i}} \rho_{\eta,\sigma_b}(b)_{1,\tau}, dbdu ,
\]

where

\[
    \rho_{\mu,\sigma_u}(u) = \frac{1}{\sqrt{2\pi \cdot \sigma_u u}} \exp \left[ -\frac{[\ln(u) - \ln(\mu)]^2}{2\sigma_u^2} \right],
\]

\[
    \rho_{\eta,\sigma_b}(b) = \frac{1}{\sqrt{2\pi \cdot \sigma_b b}} \exp \left[ -\frac{[\ln(b) - \ln(\eta)]^2}{2\sigma_b^2} \right],
\]

here \( \rho_{\mu,\sigma_u}(u) \) – density lognormal the distributed random variable of losses of owners of objects from one fire; \( \mu \) – median value for the corresponding distribution of size of losses from one fire; \( \sigma_u^2 \) – dispersion for normal distribution of a logarithm of size of losses from one fire \( \ln(u) \); \( \rho_{\eta,\sigma_b}(b) \) – density lognormal the distributed random variable \( b \) profits of owners of objects in a year from
economy on non-compliance with requirements of fire safety, with median value $\eta$ for the corresponding distribution and dispersion $\sigma^2$ for normal distribution $\ln(b)$; $f$ – probability of penalties for violators of requirements of fire safety in a year; $H$ – average value of size of the penalties inflicted on violators of requirements of fire safety; indexes $t$ and $t-\tau$ characterize time (for example, year) measurements of the corresponding characteristics.

At the same time regional coefficient of proportionality between probability and an economic multiplier $C$, and also probability $p_n$ can depend on a number of regional social and economic and administrative and legal factors which influence production discipline of personnel of economic and administrative objects, power loading at operation and also degree of wear of the equipment on the objects, that is from factors influencing fire risks.

For the characteristic of fire risks on economic and administrative objects of supervision in regions of Russia, besides the probability of emergence of the fires on such objects in a year measured as the relation of the number of fires on objects of supervision in the region in a year to quantity of such objects, with dimension [the fire / (object year)] it is possible to consider risk of death of the person, average on the region, from the fires on objects of supervision in a year which we will designate as $R_{gn}$, with dimension [victim / (object year)]. Integrated fire risk it is connected with probability of emergence of the fires on objects of supervision $p$ and integrated fire risk of death of the person at the fire on object of supervision $R_{2n}$ [1] formula:

$$R_{gn} = p \cdot R_{2n} / 10^2.$$ 

(5)

2. Analysis of panel data

Definition of determinants of fire risks on objects of supervision in regions of Russia, identification of their dependences on statistically registered socio-economic indexes and also from the indicators characterizing possibilities of the Ministry of Emergency Situations on suppression of the fires, such as indicators of time of rapid response to the fires is of practical interest. Use of the analysis of panel statistical data is relevant for the econometric analysis of the factors determining the level of fire risks on objects of supervision in regions of the Russian Federation. Panel data are observations of the same economic units which are carried out during the consecutive periods of time. In work [11], with use of statistical data on the Russian Federation, on the basis of the multidimensional regression analysis of dependence of number of the fires on a number of factors for which the coefficient of correlation has the highest value the dependence of the number of fires on 1 thousand people is received from number of the registered crimes per 100 thousand people of the population close to linear. Taking into account this result, assuming community of the socio-economic factors defining fire risks and crime rate in the Russian Federation, we will analyses empirical researches of influence of socio-economic factors on the different types of crime in regions of the Russian Federation executed on the basis of the analysis of panel statistical data in work [12]. In this work influence on crime of the following factors is revealed: average monetary per capita income of the population, Jeanie's coefficient (inequality measure in income), the level of abuse of alcohol among the population of the region, education level of the population of the region, average temperature of January in the region, the indicators connected with probability of criminal penalty for crimes. Then, carrying out the panel analysis of dependence of level of fire risks on objects of supervision in Russia from the socio-economic factors established in [12] as crime determinants, with replacement of the factors connected with probability and weight of criminal penalty for crimes by the factors connected with probability and weight of material and possible human losses is relevant for a research of the factors determining fire risks on objects of supervision. When carrying out the panel analysis, besides socio-economic factors, as the indicator characterizing possibilities of the Ministry of Emergency Situations on suppression of the fires also average time of arrival on the fire of the first fire divisions was considered.
For definition of influence of the considered factors on the level of fire risks on objects of supervision in regions of Russia the program has been used DPD98, written by Arellano and Bond [13]. It is necessary for asymptotic solvency of the received estimates that there was a sufficient number of the temporary periods ($T > 4$) and large number of objects ($N_{ob} > T$).

Information base for the analysis was made by panel data on 78 regions of the Russian Federation (autonomous areas as a part of areas, edges and also the regions which don't have a totality of data are excluded) for 2006-2016. Information on fire statistics and administrative and legal indicators has been received from these registered Public fire service of Emercom of Russia, in particular from [14], and social and economic indicators for regions and indicators of inflation have been taken from publications of Rosstat.

Believing that probability of the fires on objects of supervision in a year and risk of death of the person from the fires on objects of supervision in a year are linear functions from various factors, and aggregating on the population of the region, we will construct linear dynamic models for the description of fire risks, depending on a set of the set variables and also from a set of independent variables:

\[
\begin{align*}
\hat{p}_{\text{it}} &= a_{i}p_{\text{it}(-1)} + a_{2}R_{\text{mit}} + a_{4}U_{\text{mit}} + a_{4}S_{\text{it}} + a_{5}D_{\text{it}} + a_{k}V_{\text{it}} + \\
&+ a_{7}J_{\text{it}} + a_{9}A_{\text{it}} + a_{10}G_{\text{it}} + a_{1}T_{\text{it}} + a_{12}t_{\text{it}} + C_{1}, \\
R_{\text{git}} &= b_{1}R_{\text{guit}(-1)} + b_{2}U_{\text{mit}} + b_{3}S_{\text{it}} + b_{4}D_{\text{it}} + b_{5}V_{\text{it}} + \\
&+ b_{7}J_{\text{it}} + b_{9}A_{\text{it}} + b_{8}I_{\text{it}} + b_{10}G_{\text{it}} + b_{1}T_{\text{it}} + b_{12}t_{\text{it}} + C_{2},
\end{align*}
\]

where lower indexes $i$ and $t$ designate the region and year respectively; dependent variables: in the equation (6) $p_{\text{it}}$ – probability of emergence of the fire on objects of supervision in a year; in the equation (7) $R_{\text{git}}$ – risk of death of the person, average on the region, from the fires on objects of supervision in a year; the set variable in the equation (6) $R_{\text{mit}}$ – risk of death of the person at the fire on object of supervision; the set variables in the equations (6,7): $U_{\text{mit}}$ – taking into account inflation relatively 2006, accepting average material damage from one fire on objects of supervision in thousands of rubles for initial – average material damage in 2006; $S_{\text{it}}$ – the average penalty in thousands of rubles which is ordered to pay for violation of requirements of fire safety on objects of supervision taking into account inflation relatively 2006, accepting for initial – an average penalty in 2006; independent variables in the equations (6,7): $D_{\text{it}}$ – taking into account inflation relatively 2006, accepting average monetary income of the population in thousands of rubles for initial – average monetary income in thousands of rubles in 2006; $V_{\text{it}}$ – per capita in thousands of rubles, taking into account inflation relatively 2006, accepting a gross regional product for initial – a gross regional product per capita in thousands of rubles in 2006; $J_{\text{it}}$ – Jeanie's coefficient in regions (inequality measure in income); $A_{\text{it}}$ – number of the patients with for the first time in life the established diagnosis of the psychotic frustration connected with alcohol intake and a syndrome of dependence on alcohol put under dispensary observation by psycho neurological and narcological institutions on 105 people of the population of the region (according to arguments from work [15], this indicator can characterize the level of abuse of alcohol among the population of the respective region); $I_{\text{it}}$ – percent of students of educational institutions of higher education in the population of the region (this indicator can characterize education level in the region); $G_{\text{it}}$ – percent of urban population in the region; $T_{\text{it}}$ – average temperature of January in degrees Celsius in the region; $t_{\text{it}}$ – average time on the region (in minutes) arrivals on the fire of the first fire divisions; $C_{j}$ – the constant including unaccounted factors.
The results of the regression analysis of panel data received with use of the program are presented in table 1 for models on the basis of the equations (6) and (7) DPD98 [9]. Also values of their standard mistakes (in brackets) and their importance are presented in table 1, except values of coefficients and constants, (z), which are defined as the attitude of value of coefficient or a constant towards value of the corresponding standard mistake and also levels of credibility of coefficients and constants are given.

**Table 1.** Results of the regression analysis of panel data from 2006 to 2016 on dependence of level of fire risks on objects of supervision in regions of the Russian Federation from socio-economic factors and an indicator of time of rapid respon.

| Factors | Model 1 | Model 2 |
|---------|---------|---------|
|         | equation (6) for $p_{it}$ – probabilities of emergence of the fire on objects of supervision in a year [fire / (object year)] | equation (7) for $R_{git}$ – average on the region of risk of death of the person from the fire on object of supervision in a year [victim / (object year)] |
| $p_{it-1}$ [fire / (object year)] | 0.2607125 (0.0522585) $z = 4.99$ | 0.0645238 (0.0599118) $z = 1.08$ |
| $R_{g0-1}$ [victim / (10^5 person year)] | -0.000052974 (0.000085806) $z = -0.62$ | -2.83*10^{-8} (3.44*10^{-8}) $z = -0.82$ |
| $U_{git}$ [thousand rubles/fire] | -8.77*10^{-7} $z = -2.01$ | -2.83*10^{-8} (3.44*10^{-8}) $z = -0.82$ |
| $S_{git}$ [thousand rubles/penalty] | -0.0001907 (0.0000548) $z = -3.48$ | -7.86*10^{-6} (4.33*10^{-6}) $z = -1.82$ |
| $D_{git}$ [thousand rub] | -0.000275 (0.000282) $z = -0.97$ | -5.03*10^{-5} (2.19*10^{-5}) $z = -2.29$ |
| $V_{git}$ [thousand rub] | 1.23*10^{-8} (7.66*10^{-8}) $z = 0.16$ | 2.99*10^{-9} (5.93*10^{-9}) $z = -0.49$ |
| $J_{git}$ | -0.1006677 $z = -2.29$ | 0.0051511 (0.0036391) $z = 1.42$ |
| $A_{git}$ [patients /10^5 person] | 0.0000247 (0.0000128) $z = 1.93$ | -7.95*10^{-7} (1.04*10^{-6}) $z = -0.76$ |
| $I_{git}$ [%] | -0.001333 (0.0007409) $z = -0.18$ | 0.0000422 (0.0000575) $z = 0.73$ |
| $G_{git}$ [%] | 0.0005625 (0.000433) $z = 1.30$ | 0.000162 (0.000037) $z = 0.48$ |
| $T_{git}$ [degrees, C°] | 0.0000458 (0.0000568) $z = 0.81$ | 7.52*10^{-6} (4.43*10^{-6}) $z = 1.69$ |
| $t_{git}$ [minute] | 0.0002154 (0.0001258) $z = 1.71$ | 3.68*10^{-6} (9.79*10^{-6}) $z = 0.38$ |
| $C_{j}$ | 0.0088513 (0.0376075) $z = 0.24$ | -0.0022635 (0.0028878) $z = -0.78$ |

In the table 1 asterisks have designated levels of credibility: *** – 1%, ** – 5%, * – 10%.
Value of an economic equivalent of human life \( E_n \) for objects of supervision in Russia it is possible to estimate, having presented the equation (6) in the form:

\[
p_{it} = a_1p_{it-1} + a_3(\frac{a_2R_{2it}}{a_3} + U_{mit}) + a_4D_{it} + a_5J_{it} + a_6A_{it} + a_7Z_{it} + a_8G_{it} + a_9S_{it} + a_{10}T_{it} + a_{11}I_{it} + C_1.
\]  

Taking into account a ratio (2), the equation (6) can also be written down in a look:

\[
p_{it} = a_1p_{it-1} + a_3(\frac{E_n}{10} + U_{mit}) + a_4D_{it} + a_5J_{it} + a_6A_{it} + a_7Z_{it} + a_8G_{it} + a_9S_{it} + a_{10}T_{it} + a_{11}I_{it} + C_1.
\]  

(9)

Follows (8) and (9) from comparison that value of an economic equivalent of human life \( E_n \) on objects of supervision in Russia is determined by a formula:

\[
E_n = 10^2 \cdot a_2 / a_3.
\]  

(10)

Taking into account values and dimensions of coefficients and \( a_i \) from the table 1: \( E_n = 6040.36 \) [thousand rubles/victim], taking into account inflation relatively 2011.

The received assessment of an economic equivalent of human life on objects of supervision in Russia close will be coordinated with value of this indicator calculated for Russia by a technique of assessment of an economic equivalent of cost of the human life based that the economic equivalent of life of the average person is equal to the attitude of the average located monetary revenue towards average probability of death within a year [14–16]. From calculations of work [16], this value for Russia in 2013 was 12472 thousand rubles that there corresponded 9038 thousand rubles, taking into account official inflation relatively 2011. Such coordination of size \( E_n \), received from model 1, with value of the economic equivalent of human life received by a technique [16] confirms correctness of model 1 in application to assessment of probability of emergence of the fires on objects of supervision in regions of Russia and also it will be agreed with a hypothesis of the rational offender.

The results of the regression analysis presented in table 1 for quantitative dependence on various socio-economic factors of probability of emergence of the fires on objects of supervision in a year and an average on the region of risk of death from the fires on objects of supervision in a year will correctly be coordinated with the model of the rational offender given above. Really, according to model of the rational offender, on the basis of results of the work [17] performed for lognormality distribution of income of owners of objects [9, 10] and losses from the fires on objects ratios follow:

\[
\frac{dp}{d\ln(S)} < 0; \tag{11}
\]

\[
\frac{dp}{d\ln(U_{\mu})} < 0, \tag{12}
\]

where \( S \) – average value of a penalty for violation of requirements of fire safety on objects of supervision in the region; \( U_{\mu} \) – median value of size of losses from the fires on all objects of supervision of the region. Inverse relation follows from a ratio (11) \( p \) from \( S \), and from (12) inverse relation follows \( p \) from the factors determining the size of possible losses from the fires on objects of supervision: average values of loss of property \( U_m \) and \( R_{2n} \). It is also logical to assume that median value \( U_{\mu} \) distributions of size of losses from the fires of owners of objects of supervision increases or decreases in the same party, as median value of distribution of size of legal income of owners of objects from which investments accumulate in the cost of objects and can be lost at the fire. It is
possible to expect that the income of owners of objects of supervision in turn positively correlates with average value $D$ monetary income of the population of the region. Then signs of derivatives $\frac{dp}{d\ln(U_\mu)}$ and $\frac{dp}{d\ln(D)}$ have to coincide and be negative. Such negative dependence $p_{it}$ from factors $S_{it}$, $U_{it}$, $R_{zit}$, $D_{it}$, it is received on the basis of the regression analysis of panel data from 2006 to 2016 on regions of the Russian Federation and presented in table 1.

The presented results of the regression analysis of fire risks for objects of supervision in regions of the Russian Federation will be coordinated with results of the works [9, 10] executed on the basis of model of the rational offender about existence of economic determination of fire risks.

Follows from the results presented in table 1 that for probability of emergence of the fires on objects of supervision $p_{it}$ there is significant ($z = -2.29$) negative dependence on Jeanie’s coefficient $J_{it}$, with high level of confidence ($<1\%$): significant ($z = 1.30$) positive dependence from $G_{it}$ – percent of urban population in the region; significant ($z = 1.71$) positive dependence from $-\text{average time on the region of arrival on the fire of the first fire divisions}$.

Also follows from results of table 1 that for $R_{gat}$ – average on the region to risk of death of the person from the fires on objects of supervision in a year, the significant negative dependence takes place ($z = -1.82$) from an average on the region of a penalty $S_{it}$ for violation of requirements of fire safety on objects of supervision; significant negative dependence ($z = -2.29$) from $D_{it}$ – average monetary income of the population in the region with high level of confidence ($<5\%$); significant ($z = 1.42$) positive dependence on regional coefficient of Jeanie $J_{it}$; significant ($z = 1.69$) positive dependence from $T^c_{it}$ – the average January temperature in degrees Celsius in the region.

3. Conclusion
Results of the analysis of dynamic model of the panel data on regions of Russia from 2006 to 2016 including fire statistics on objects of supervision and statistics of set of regional socio-economic indexes and also indicators of time of rapid response of PFS Ministry of Emergency Situations to the fires allow to present quantitative dependences of probability of emergence of the fires in a year on objects of supervision in regions of the Russian Federation and an average on the region of risk of death of the person from the fires on objects of supervision in a year as linear functions from values of these indicators for the previous year, a set of regional social and economic and climatic indicators and also indicators of time of rapid response of Public fire service Ministry of Emergency Situations to the fires.

The received results correctly will be coordinated with results of application to fire risks of model of the rational offender. Assessment of an economic equivalent of human life, as of objects of supervision for Russia, calculated on the basis of the analysis of the presented dynamic model of fire risks, will correctly be coordinated with the values, known from literature, received on the basis of actuarial calculations. The results received on the basis of econometric approach to fire risks give information for the forecast of fire risks on objects of supervision in regions of Russia and administrative decisions on minimization of such risks.

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