TECHNOSPHERE SAFETY

Original article
UDC 614.84
https://doi.org/10.23947/2541-9129-2022-3-4-11

Study of Death and Injury Risks Dynamics of the Federal Fire-Fighting Service Personnel Using Time Series Smoothing

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Introduction. Studies of risks dynamics of death and injury of the Federal Fire-Fighting Service personnel in the performance of official duties for a long period (from 2006 to 2021) have shown that difficulties often arise due to the heterogeneity of data, their significant fluctuations in different periods of time and the influence of random factors.

Problem Statement. In this paper, to study the risks of death and injury of personnel of the Federal Fire-Fighting Service of the State Fire Service in the performance of official duties, time series smoothing methods (the moving average method and the exponential smoothing method) were used, which made it possible to eliminate abnormal observations and reduce the influence of random factors.

Theoretical Part. To identify trends in the risks of death and injury of personnel of the Federal Fire-Fighting Service of the State Fire Service in the performance of official duties, the method of time series smoothing was used. The methods of moving average and exponential smoothing are considered. The distribution of the risks of injury and death of the personnel of the Federal Fire-Fighting Service of the State Fire Service in the performance of official duties for the period 2006-2021 is shown, the average annual levels of injury and death risks for this period are determined, the dynamics of the ratio of the number of cases of injury and death in these years is considered.

Conclusions. The number of registered cases of injuries has decreased due to the improvement of the occupational safety management system. During the period from 2006 to 2021, there was a reduction in the risk of injury to personnel by 4 times. The ratio of the number of injured and dead has significantly decreased (by more than three times) - from 31.5 to 9.4. In addition, as a result of occupational safety management system improvement, the number of injuries with severe and moderate damage has decreased due to their transition to the category of injuries with light damage.

Keywords*:* time series, moving average, exponential smoothing, injuries, death, Federal Fire-Fighting Service.

For citation*:* Mashtakov V. A., Kondashov A. A., Bobrinev E. V., Shavyrina T. A., Udavtsova E. Yu. Study of Death and Injury Risks Dynamics of the Federal Fire-Fighting Service Personnel Using Time Series Smoothing. Safety of Technogenic and Natural Systems, 2022, no. 3, pp. 4–11. https://doi.org/10.23947/2541-9129-2022-3-4-11

Introduction. When studying various indicators characterizing the activities of fire units, difficulties often arise due to the heterogeneity of data, their significant fluctuations in different time periods [1]. The distribution of

indicators on the time scale can be considered as a time series [2]. The most important task in the study of time series is to identify and statistically assess the main trend in the development of the process under study and deviations from it.

When studying time series, a systematic and random component is distinguished. The systematic component is the result of the influence of constantly acting factors. An example of a systematic component of a time series is a trend, which can be characterized as a smoothly changing component describing the net influence of long-term factors, i.e. a long-term trend of a feature change.

The random component reflects the influence of random factors and can be considered as random noise or error affecting the time series irregularly.

One of the most common methods of studying time series is smoothing [3], which consists in replacing the actual values with calculated ones, which are characterized by less variability. Smoothing is used in cases where the trend is not sufficiently clear. For a smoothed time series, the trend usually manifests itself more clearly. Smoothing of time series is also used to eliminate anomalous observations.

Among the most common methods of time series smoothing, the moving average method and the exponential smoothing method can be distinguished.

The moving average method [4] consists in replacing the actual values of a time series with the average values for a group of data for a certain period, and each subsequent group is formed by shifting by one unit of time. In the presented study, a year is used as a unit of time.

To calculate the moving average, the formula is used:

$$\widetilde{w}_i = \frac{1}{3}(w_{i-2} + w_{i-1} + w_i)\,, \tag{1}$$

where w_i — the initial value of the time series in the i-th year. The disadvantage of this method is the exclusion of the first two values of the time series from the smoothing procedure.

The exponential smoothing method doesn't have such a disadvantage [5], in which the weighted values of the series in previous years are used in the smoothing procedure, and the weight decreases as we move away from the year for which the smoothed value is determined. To calculate the smoothed value by exponential smoothing, the formula is used:

$$\widetilde{w}_i = \begin{cases} w_i, & i = 1 \\ \widetilde{w}_{i-1} + \alpha(w_i - \widetilde{w}_{i-1}), & i > 1 \end{cases}, \tag{2}$$

where α — the smoothing coefficient. In the presented study, it is chosen to be equal to 0.5.

Problem Statement. The aim of the research was to study the impact of improving the occupational health management system (OHMS) on reducing the risks of death and injury of the personnel of the Federal Fire-Fighting Service of the State Fire Service (FFS SFS) in the course of duty. In this work, using the methods of time series smoothing, the risks of death and injury of personnel in the line of duty were studied. Death and injury rates of the personnel of the FFS SFS for 2006-2021 are taken from the statistical data bank on morbidity, injury, disability and death of personnel of the units of the Ministry of Emergency Situations of Russia in the performance of official duties [6].

Theoretical Part. The risk of death is determined by the following formula:

$$R_{\text{гиб}} = \frac{N_{\text{гиб}}}{N_{\text{л.с.}}}, \tag{3}$$

where $N_{\text{гиб}}$ — the number of personnel killed in the line of duty for the year, people, $N_{\text{л.с.}}$ — the average annual number of personnel, people.

The risk of injury is determined by the formula:

$$R_{\text{трав}} = \frac{N_{\text{трав}}}{N_{\text{л.с.}}}, \quad (4)$$

where $N_{\text{трав}}$ — the number of personnel injured in the line of duty for the year, people.

Figure 1 shows the distribution of the risk of injury to the personnel of the FFS SFS in the performance of official duties from 2006 to 2021.

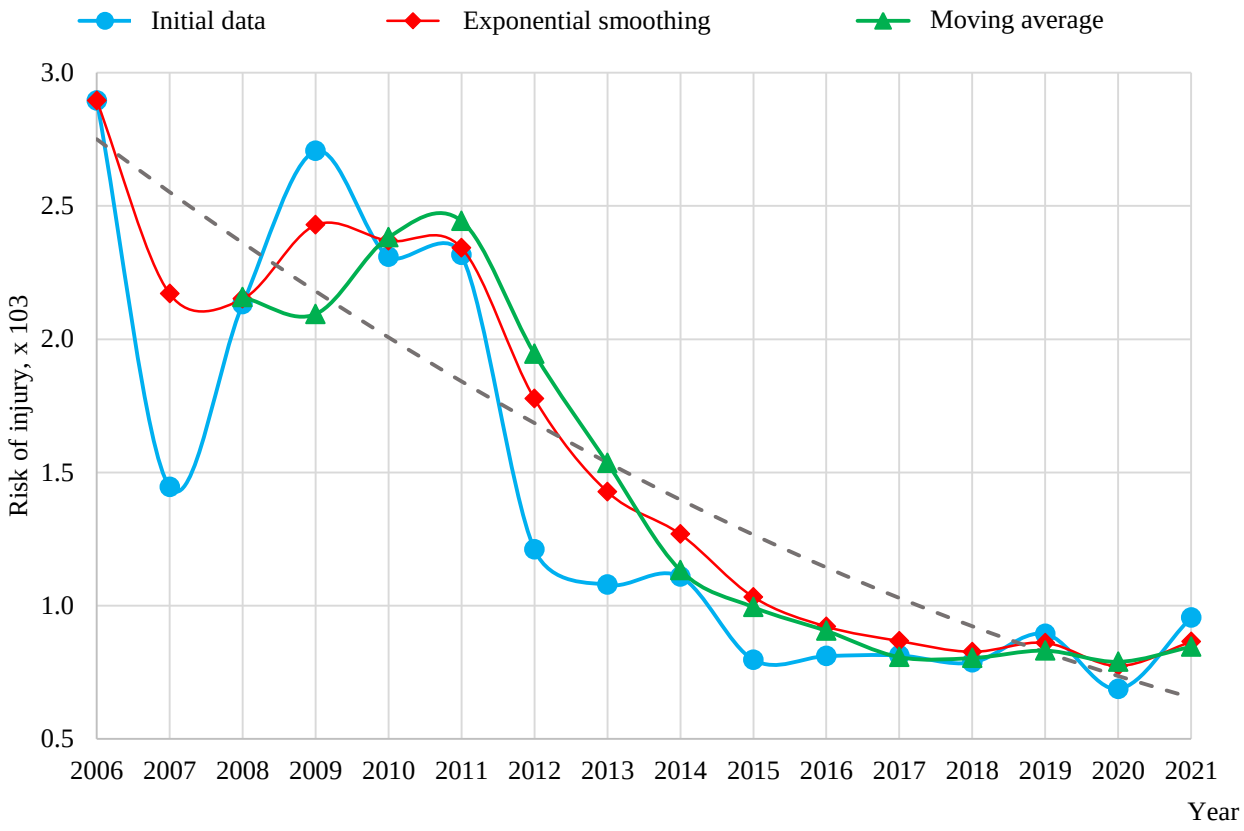

Fig. 1. The risk of injury to the FFS SFS personnel in the performance of official duties from 2006 to 2021. Dashed curve — least squares approximation

The average annual risk of injury is 1.43×10^{-3}. From 2006 to 2011, the risk of injury to the FFS SFS personnel varied significantly from year to year. The average annual risk of injury during this period was 2.30×10^{-3}. From 2011 to 2015, there was a sharp decrease in the level of injuries. In subsequent years, the risk of injury remained approximately at the same level — on average 0.82×10^{-3}.

Smoothing of the injury risk distribution was performed using the moving average method (shown in green in Fig. 1). As it can be seen from the figure, the smoothed distribution at certain points is quite different from the original distribution (for example, in 2009, 2012 and 2013). The distribution obtained by exponential smoothing (shown in red in the figure) reproduces more accurately the original distribution. Therefore, this particular smoothing method was used further.

The smoothed distribution is approximated by the least squares method [7] using a polynomial function of the 2nd order. The risk of injury is described by the function:

$$R_{\text{трав}} = (0.0042x^2 - 0.211x + 2.962) \times 10^{-3}, \quad (5)$$

where x — the ordinal number of the year ($x = 1$ corresponds to 2006), the coefficient of determination $R^2 = 0.86$. As follows from dependence (5), from 2006 to 2021 there was a 4.2-fold reduction in the risk of injury – from 2.75×10^{-3} to 0.66×10^{-3}.

Figure 2 provides the distribution of the risk of death of the FFS SFS personnel in the line of duty from 2006 to 2021.

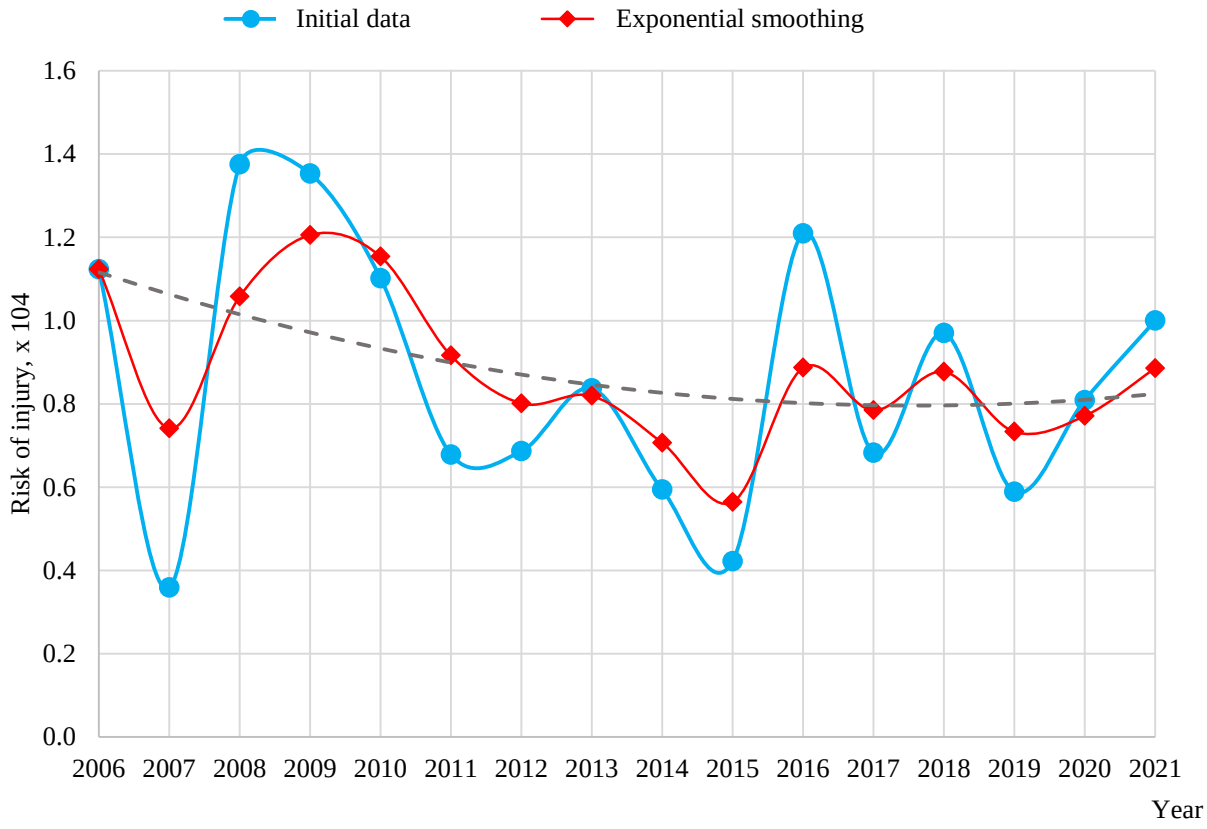

Fig. 2. The risk of death of the FFS SFS personnel in the line of duty from 2006 to 2021. Dashed curve — least squares approximation

The average annual risk of death is 0.86×10^{-4}. The risk of death was highest in 2008 and 2009, when its value reached 1.38×10^{-4}. Then there was a reduction in the risk of death to 0.42×10^{-4} in 2015. In subsequent years, the risk of death increased and reached values from 0.6×10^{-4} to 1.2×10^{-4}.

As it can be seen from Figure 2, the distribution of the risk of death has a significant random component, which leads to significant fluctuations in its magnitude in different years. To reduce the influence of random factors and highlight the prevailing trend, exponential smoothing was performed (shown in Fig. 2 in red). The smoothed distribution is described by a 2nd-order polynomial function obtained by least squares approximation:

$$R_{\text{гиб}} = (0.0024x^2 - 0.046x + 1.015) \times 10^{-4}. \quad (6)$$

The coefficient of determination $R^2 = 0.34$. In accordance with dependence (6), over the period from 2006 to 2021, the risk of death decreased by 24% from 1.12×10^{-4} to 0.82×10^{-4}.

In international and domestic practice for the study of occupational injuries, the concept of "pyramid of accidents" is used, when for 1 case of injuries with severe damage there are about 10 cases of injuries with average damage and 100 cases of injuries with light damage [8, 9]. The analysis of injuries of the FFS SFS personnel in the performance of official duties showed [10] that on average, for 1 case of injuries with light damage, there are 8 cases of injuries with medium damage and 10 cases of injuries with severe damage. This ratio can be explained by the fact that

the victims mostly go on sick leave after receiving moderate and severe injuries. Therefore, light injuries are practically not registered.

In this regard, the ratio of the number of cases of injury and death of the FFS SFS personnel in the line of duty is of interest:

$$D = \frac{N_{\text{трав}}}{N_{\text{гиб}}}. \quad (7)$$

Figure 3 shows the dynamics of this ratio from 2006 to 2021. The red color shows the distribution obtained as a result of exponential smoothing. The smoothed distribution is approximated by a 2nd-order polynomial function:

$$D = 0.038x^2 - 1.89x + 27.57 \quad (8)$$

The coefficient of deter mination $R^2 = 0.85$.

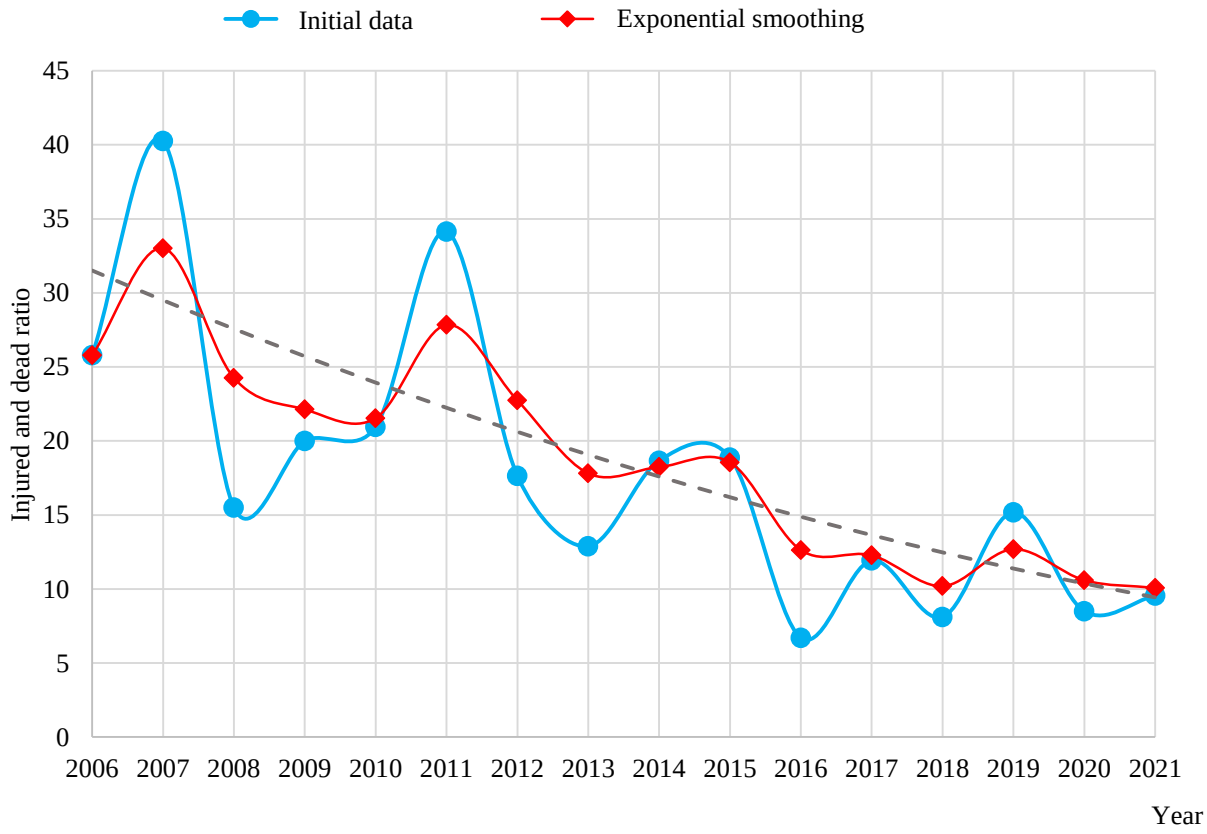

Fig. 3. Ratio of injured and dead FFS SFS personnel in the line of duty from 2006 to 2021. Dashed curve — least squares approximation

Over the period from 2006 to 2021, the ratio of injured and dead decreased by 3.3 times — from 31.5 to 9.4. Such a decrease can be explained by the fact that as a result of the improvement of the occupational safety management system, namely, the adoption of regulatory legal acts, including Order of the Ministry of Labor and Social Protection of the Russian Federation of 13.12.2014 No. 1100N "On approval of the Rules on Occupational Safety in the Units of the Federal Fire Service of the State Fire Service"[1], the number of injuries with severe and average damage (injuries with minor damage without temporary loss of working capacity are not always recorded), as a result of which the number of reported cases of injuries has decreased.

[1] The document became invalid due to the entry into force of Order of the Ministry of Labor and Social Protection of the Russian Federation No. 881n of 11.12.2020 "On Approval of the Rules on Labor Protection in Fire Protection Units"; the use of personal and collective protection of workers (Article 3 of Federal Law No. 426-FZ of 28.12.2013 "On Special Assessment of Working Conditions").

Conclusions. Over the period from 2006 to 2021, the ratio of injured and dead decreased by 3.3 times — from 31.5 to 9.4. This decrease can be explained by the fact that as a result of improving the occupational safety management system, the risk of injury with severe and moderate damage to health has decreased. It is possible that this risk has decreased not to zero damage, but to the level of injury with light damage.

Thus, the study of the risks of death and injury of the FFS SFS personnel in the line of duty for the period from 2006 to 2021 has been carried out. To identify trends in the observed dependencies, the exponential smoothing method was used. In 2006–2021, the average risk of injury to the FFS SFS personnel in the line of duty was 1.43×10-3. During the period under review, the risk of injury decreased by more than four times. The risk of death of the FFS SFS personnel in the line of duty is characterized by significant fluctuations from year to year; the average value of the risk of death for the period under review was 0.86 × 10-4. The ratio of the number of injured and dead personnel of the FFS SFS in the line of duty decreased by more than three times, which can be explained by a decrease in the number of medium and severe injuries as a result of improving the occupational safety management system.

For further optimization of the occupational health management system, it is necessary to:

– implement constant monitoring by labor protection officials that personnel in the line of duty follow the instructions on labor protection;

– organize occupational safety classes among the personnel in the system of service training;

– regular monitor the state of injuries and deaths of personnel in the line of duty.

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Received 20.04.2022
Revised 26.05.2022
Accepted 26.05.2022

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Claimed contributorship:

V. A. Mashtakov — analysis of the research results, revision of the text, correction of the conclusions; A. A. Kondashov — formulation of the main idea and concept of the study, development of the purpose and objectives of the study, calculations, analysis and interpretation of data, participation in writing the text of the manuscript, formulation of conclusions; E. V. Bobrinev — academic advising, review of publications on the topic of the article, participation in the collection and processing of material, analysis of research results, participation in writing the text of the manuscript; T. A. Shavyrina — participation in writing the text of the manuscript, editing the text, making the final version of the article; E. Y. Udavtsova — development of research design, preparation of literature, participation in the collection and processing of material, participation in writing the text of the manuscript.