Nataliya Kyrylaha
PhD (Physics and Mathematics), Associate Professor,
Kremenchuk Mykhailo Ostrohradskyi National University
20 Pershotravneva Str., Kremenchuk, 39600, Ukraine
natalykiril582@gmail.com
ORCID ID: http://orcid.org/0000-0002-2629-8867

UDC 330.43:614.84

Varvara Chernenko
PhD (Physics and Mathematics), Associate Professor,
Kremenchuk Mykhailo Ostrohradskyi National University
20 Pershotravneva Str., Kremenchuk, 39600, Ukraine
cher.var.petr@gmail.com
ORCID ID: http://orcid.org/0000-0002-2728-6876

Fire risk assessment in light of socio-economic factors

Absract
Introduction. The analysis of fire statistics is one of the most important tasks in making managerial decisions by the State Fire Service. Ensuring fire safety in the state is a vital factor in adequate prediction of the number of fires. Therefore, the problem of qualitative mathematical modelling of fire statistics arises.
The purpose of this article is the construction of adequate econometric models to forecast the number of fires in the different countries of the world.
Results. Based on the latest statistics provided by the Centre for Fire Statistics of the International Association of Fire and Rescue Services (CTIF) for 2003-2015, the authors of the article conducted a multivariate analysis of variance analysis and examined the key factors affecting the number of fires worldwide, such as population size, the country's territory and gross domestic product (GDP) per capita. The use of cluster analysis has made it possible to distinguish five groups of countries that have similar risk factors for fire. With regard to the examined factors, the authors propose time series models with a distributed lag for two countries, Ukraine and France, and forecasted future values for the number of fires.
Conclusions. The factors affecting the number of fires in the country can be divided into two groups: objective (territory, natural and climatic conditions) and socio-economic (to reveal their impact, it is necessary to analyse such indicators as density of fires, population density and GDP per capita).
Analysing the worked out models which include socio-economic and objective factors, we can conclude that for Ukraine and France the influence of social and economic factors differs. For Ukraine, the low population density factor is positive, i.e. it contributes to lowering the density of fires. For France, the situation is the opposite. The density of GDP per capita, by contrast, greatly contributes to reducing the density of fire cases in France, however in Ukraine its effect is manifested in a negative way.
Keywords: World Fire Statistics; ANOVA; Fire Risk; Fire Case; GDP; Cluster Analysis; Model Distributed Lag; Forecast; France; Ukraine
JEL Classification: C32; C38; C51
DOI: https://doi.org/10.21003/ea.V166-07

Кирилаха Н. Г.
кандидат фізико-математичних наук, доцент, кафедра інформатики та вищої математики,
Кременчуцький національний університет імені Михайла Остроградського, Кременчук, Україна
Черненко В. П.
кандидат фізико-математичних наук, доцент, кафедра інформатики та вищої математики,
Кременчуцький національний університет імені Михайла Остроградського, Кременчук, Україна
Оцінювання стану пожежної небезпеки країни з урахуванням соціально-економічних факторів
Анотація
На підставі статистичних даних Центру пожежної статистики Міжнародної асоціації пожежно-рятувальних служб (CTIF) за 2003–2015 рр. виявлено чинники, що впливають на число пожеж у країнах світу. Виділено групи країн, схожих за дією факторів пожежної небезпеки. Для України та Франції побудовано моделі розподіленого лага для числа пожеж. Проведено прогнозування числа пожеж за побудованими економетричними моделями. Зроблено висновок про відмінність впливу тих самих соціально-економічних факторів на пожежну небезпеку в країнах, що досліджуються.
Ключові слова: світова пожежна статистика; дисперсійний аналіз; кластерний аналіз; модель з розподіленим лагом; прогноз; Франція; Україна.

Кирилаха Н. Г.
кандидат физико-математических наук, доцент, кафедра информатики и высшей математики,
Кременчугский национальный университет имени Михаила Остроградского, Кременчуг, Украина
Черненко В. П.
кандидат физико-математических наук, доцент, кафедра информатики и высшей математики,
Кременчугский национальный университет имени Михаила Остроградского, Кременчуг, Украина
Оценка состояния пожарной опасности страны с учетом социально-экономических факторов
Аннотация
На основании статистических данных Центра пожарной статистики Международной ассоциации пожарно-спасательных служб (CTIF) за 2003–2015 гг. выявлены факторы, влияющие на число пожаров в странах мира. Выделены группы стран, сходных по действию факторов пожарной опасности. Для Украины и Франции построены модели распределенного лага для числа пожаров. Проведено прогнозирование числа пожаров согласно построенным эконометрическим моделям. Сделан вывод о различии влияния одних и тех же социально-экономических факторов на пожарную опасность в исследуемых странах.
Ключевые слова: мировая пожарная статистика; дисперсионный анализ; кластерный анализ; модель с распределенным лагом; прогноз; Франция; Украина.

1. Introduction

Various aspects of social life have negative anthropogenic and technogenic impacts on the ecological state of the surrounding world. The problem of fires is one of the most serious challenges. Diverse and not always well-organised economic activity, climatic and natural conditions, high population density in some regions and human negligence - all these factors lead to a high risk of fires.

A reduction in the number of fires in a country does not bring direct income to the economy, but it has an impact on the country's economic growth. Therefore, accounting for costs and efforts to ensure fire safety in the country is one of the components of economic analysis, both at the macroeconomic and microeconomic levels. Detailed quantitative data on fires in various socio-economic facilities, the causes of their occurrence and information on deaths are needed for such an analysis. Therefore, econometric modelling of fire statistics should actively develop as a separate branch of modern science.

2. Brief Literature Review

A large number of studies have been devoted to the analysis of fire statistics and modelling. Among the Russian authors, one can list the works of N. N. Brushlinsky (2000) [1], B. M. Pranov (2015) [2], N. P. Tretiyakov (2009) [3]. Various approaches to econometric modelling and prediction of the number of fires are proposed in their scientific works. Hence, B. M. Pranov offers a method to construct approximate mathematical dependencies for fire statistics of a number of European countries by using the Cobb-Douglas function [2]. In the article by N. P. Tretyakov (2009), the identification of groups (clusters) of countries similar to each other in their general fire circumstances is realised [3].

The analysis of fire statistics and their consequences in Ukraine is concentrated on the study of the Ukrainian authors among whom are M. V. Biloshitsky, R. V. Klymasya et al (2013) [4]. The authors focus on the problems in organising the work of firefighting services and query why, with a much larger number of fixed fires in European countries close in size to Ukraine, there are much more fire victims and injured in Ukraine. In this connection, we find it essential to refer to the article by I. P. Ivanchenko (2015), in which the author considers the features of organisation and principles of the work of firefighting services in such European countries as Poland, Germany and France [5]. The author pays special attention to the economic aspect of the problem.

Among the foreign authors who are engaged in modeling fire statistics depending on demographic, climatic and socio-economic indicators, we can distinguish the work by E. Chuvieco, L. Giglio and C. Justice (2008) [6]. The authors conclude that a high level of GDP and population density contribute to high density and duration of fires. In the article by W. Lizhi, R. Auzhi (2008) based on the K-medium clustering method, a model for automatic classification of various risks of urban fires is proposed [7]. In the work by D. Tuia, F. Ratle (2008), the authors present a methodology of spatio-temporal clustering of forest fires with an example of one Italian region, which shows the significance of spatio-temporal regularities [8]. A. Hasofer and I. Thomas, who in their work (2006) focus on identifying a group of factors that lead to death and injury to people in fires in buildings, were involved in the analysis of fire statistics in buildings [9]. In the work by Y. Lizhong, Z. Xiaodong et al. (2002) [10] the authors analyse statistical data on fires in China with the aim of identifying the causes of fires in the country, taking into account factors such as the location of the facility, the time of year and the time of day.

However, the application of many methods is quite difficult in the context of a small amount of statistical data available, since the centralised publication of statistical reports on the number of fires in countries began only in 2003. Therefore, the problem of constructing fairly simple and effective modelling techniques that could be applied in a meagre statistical environment remains relevant.

3. Purpose

The purpose of this work is to determine the factors that affect the fire statistics in different countries of the world and offer fairly simple methods to construct econometric models of the risk of fire, which provide smaller errors for forecasting.

4. Results

The research is based on statistical data by the Centre for Fire Statistics of the International Association of Fire and Rescue Services (CTIF) for 2003-2015 [11], while GDP values are taken from the online resource [12].

One of the tasks set in the work is to identify factors that affect the fire situation in different countries of the world. According to the approach [2], it has been assumed that the factors affecting the number of fires could be: population, GDP in general or GDP per capita. However, these values cannot be considered in isolation from such an important factor as the territory of the country. Is it possible to say that the situation on fire danger is at comparable level in countries such as the UK, France, Italy and Russia, based only on the indicator of the number of fires. In 2015, it was 191,647; 300,667; 234,675, and 145,900, respectively. Such relatively good indicators of the number of fires can be referred to either different approaches to statistical recording of fires or really powerful and effective work of the state and society in providing fire safety.

The use of multifactorial variance analysis made it possible to emphasise which three factors exert a statistically significant influence on the number of fires. These are population, territory, GDP per capita. This analysis shows these factors modelled as statistically significant, accounting for 97.6% of the total variance (R^2 = 0.976). The impact of GDP in general is not confirmed.

It is suggested to take into account the territory factor indirectly, i.e. to begin with variables density of fires, population density and GDP per capita density. Further, we will investigate the dependence of the density of fires on population density and GDP per capita density.

After ranking the countries in descending order for each of the factors obtained (the lowest rank gets the object with the highest value of this factor) and carrying out the clustering procedure (by the K-means method), a diagram was constructed of the average values of the ranks of each variable for each cluster (Figure 1):

1 - population density,
2 - GDP in general density,
3 - GDP per capita density,
4 - fires density.

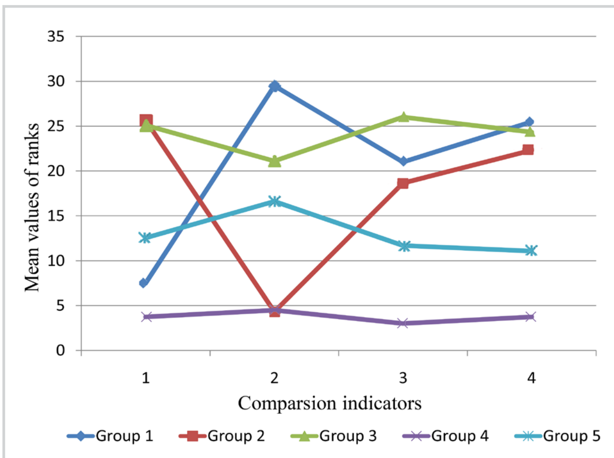

Fig. 1: **A diagram of the mean values of the ranks of the groups formed during clustering**
Source: Own research

Analysing the diagram shown in Figure 1, it is possible to single out a group of countries in which, with a rather low density of GDP per capita and low population density, the lowest density of fires is recorded (Group 3 which includes Russia, Kazakhstan, Belarus and Ukraine). The following two groups of countries, Group 1 (Moldova and Vietnam) and Group 2 (the USA, Finland and Norway), are completely different in GDP per capita density and similar in density of fires. The group of countries occupying an intermediate position is Group 5. It includes some European countries and Japan.

Finally, we can identify a group of countries (Group 4) with a high GDP per capita density and the highest level of fire density, covering prosperous and developed countries such as the United Kingdom, the Netherlands, Switzerland and Singapore.

Time series of the values of four variables were considered (density of fires, population density, GDP per capita density, GDP in general density) for each of the countries for which there are sufficiently complete statistics of CTIF reports for all 13 years of statistical periods [11]. Unfortunately, those are few: Russia, Ukraine, Estonia, the USA, Latvia and France. We calculated the correlation between the exponential variable of the density of fires and its lags, and factor variables and their lags. We introduced the levels of factors and the index itself into the model of the distributed lag, which gives the highest values of the correlation coefficient, and examined the statistical characteristics of the models.

Let us consider the example of two countries, Ukraine and France, in terms of the application of this technique. Such a choice can be explained, firstly, by objective circumstances - these countries are among the few whose information is almost complete, and, secondly, a comparison of such almost identical in territory but different in the degree of economic development countries may prove to be interesting.

Based on the results of the variance analysis and analysing the correlation coefficients, we can propose a specification of the model with a distributed lag in the form:

$$Y_t = a_0 + b_1 Y_{t-k} + a_1 X_{1,t-p} + a_2 X_{2,t-r}, \qquad (1)$$

where Y_t - the dependent variable, density of fires;
X_1 - the factor variable, population density;
X_2 - the factor variable, GDP per capita density;
$k, p, r \in \{0,1,2,...\}$ - the integers reflecting the shift of the variable relative to the current level.

Now it is possible to conduct a statistical study - a phased introduction of factors into the model and an analysis of the adequacy of each model.

Thus, in the case of building a model for Ukraine, after comparing the statistical characteristics of several models, it is suggested to consider the following:

$$Y_t = 0.52709 + 0.2193 Y_{t-2} - 6.21063 X_{1,t-4} + 2.63262 X_{2,t-4}, \qquad (2)$$
$$R^2 = 0.7063 .$$

In the case of analysis of statistical data for France, we come to the conclusion that the best model is:

$$Y_t = 1.140797 - 0.12645 Y_{t-3} - 1.06721 X_{1,t-2} - 12.51018 X_{2,t-4}, \qquad (3)$$
$$R^2 = 0.7993 .$$

Figures 2 and 3 show the statistical data and model values of the indicator of the number of fires in Ukraine and France, respectively.

Analysing the presented models, it can be noted that for these countries the influence of social and economic factors manifests itself in different ways. For Ukraine, the low population density factor is positive, i.e. it contributes to lowering the density of fires. For France, the situation is the opposite.

The density of GDP per capita, by contrast, greatly contributes to reducing the density of fire cases in France, but in Ukraine its effect is manifested in a negative direction. The variable ratio reflects the effectiveness of financial injections into the firefighting activities of the whole society. The free coefficient of the models reflects the possibility of occurrence of fire situations from factors not depending

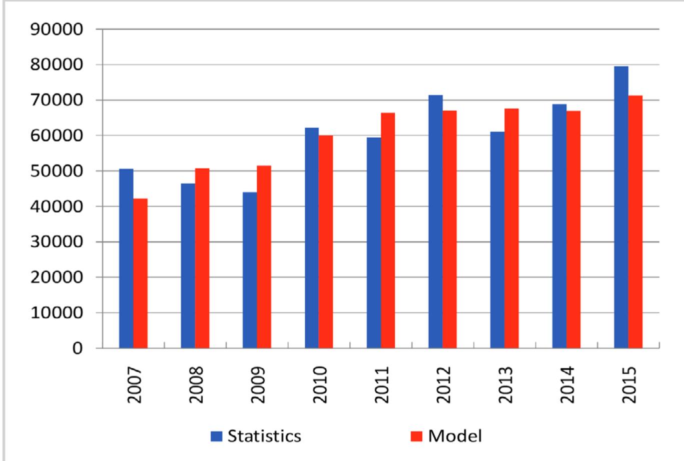

Fig. 2: **Statistics of the number of fires in Ukraine for 2007-2015 and the relevant model values**
Source: Own research

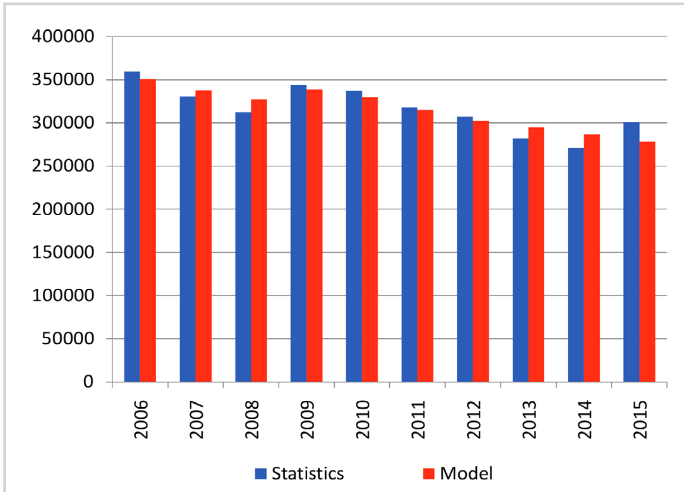

Fig. 3: **Statistics of the number of fires in France for 2006-2015 and the relevant model values**
Source: Own research

on society, in particular, the influence of natural and climatic conditions.

It should be noted that the obtained models can and must adaptively change when new statistics arrive. The main thing is that they are convenient for forecasting, because for this it is essential to know the values of factors that are several periods in the past.

The difficulty can be in finding fire statistics as a factor value, since the international journal CTIF [11] publishes its statistical reports with a delay of two years. For example, if we make a forecast for Ukraine for 2018 at the end of 2017, we need fire statistics for 2016, yet it may not be correct, as it will be published in the magazine in 2018. The possibility to predict the missing values by Model 1 itself can be the way out of this situation. Knowing the true value of the number of fires for 2014, you can get the predicted value of the indicator for 2016. Then, the confidence interval for the predicted value of the indicator at the level of reliability $p = 0.95$ will take the form: $0.14879 < Y < 0.15095$. This means that with a probability of 0.95 we should expect that the number of fires in Ukraine in 2018 will be from 89,801 to 91,107.

Similar arguments can be true for France. However, since Model 2 is different, other kinds of difficulties may arise, i.e. to forecast for the year 2018 it is essential to know GDP per capita for 2018. Here one can independently conduct a simple extrapolation of the trend of the time series of GDP per capita for France by using the available data [12]. Then we obtain a confidence interval for the indicator at the level of reliability $p = 0.95$: $0.36886 < Y < 0.3755$. This means that with a probability of 0.95 we should expect that the number of fires in France in 2018 will be from 237,337 to 241,640.

The outcomes of conducted research lead us to the next question: why is the number of fires almost five times higher in the economically developed and comparatively prosperous France than it is in Ukraine? Is there a different approach to the procedure for recording fires or is the result from efforts of society and the state?

With the weakening of preventive measures, the number of fires in the forecast year may be greater. Therefore, the latest achievements of science and technology should also contribute to the reduction in the number of fires. This is realistic and meets the desire of specialists and leaders in the field of fire safety to take measures to reduce the number of fires, and hence the number of human casualties caused by fires.

5. Conclusions

The paper considers various approaches to analysing one of the indicators of fire statistics, among which is the number of fires for the countries of the world. With the help of multivariate analysis of variance, it has been revealed that the number of fires is affected by three factors: the population of the country, the territory of the country and GDP per capita. Taking into account the territory factors indirectly, it is proposed to consider the density of fires, population density, GDP per capita density and the GDP in general density as variables. The use of cluster analysis has made it possible to distinguish five groups of countries that are similar in effect to fire hazard factors. We have studied the possibility of applying time series models, in particular, the distributed lag model. Models for Ukraine and France are demonstrated as exemplary models with the possibility of using the presented models to predict future values of the number of fires.

Further improvement of the presented apparatus lies in the direction of constructing structural-temporal models that allow one to take into account the influence of climatic conditions, as well as the role of the state in ensuring fire safety of the country.

References

1. Brushlinskii, N. N. (2000). *World Fire Statistics in the Late XXth Century.* Moscow: SFD Academy (in Russ.).
2. Pranov, B. M. (2015). On a method for modeling the European fire statistics. *Tehnologii Tehnosfernoy Bezopasnosti (Technologies of Technosphere Security), 61*(3). Retrieved from http://agps-2006.narod.ru/ttb/2015-3/21-03-15.ttb.pdf (in Russ.)
3. Tretiyakov, N. P. (2009). Application of Cluster Analysis to.World Fire Statistics. *Tehnologii tehnosfernoy bezopasnosti (Technologies of Technosphere Security), 24*(2). Retrieved from http://agps-2006.narod.ru/ttb/2009-2/08-02-09.ttb.pdf (in Russ.)
4. Biloshitsky, M. V., Klymas, R. V., Yakimenko, A. P., & Matviychuk, D. Y. (2013). Analysis of Statistical Data of Fires and Their Consequences in the Residential Sector in Ukraine. *Pozhezhna bezpeka: teoriia i praktyka (Fire safety: Theory and Practice), 14,* 9-14 (in Ukr.).
5. Ivanchenko, I. P. (2015). Foreign Experience of Organization of Civil Protection. Organizational-Economic Component. *Investytsii: praktyka ta dosvid (Investment: Practice and Experience), 23,* 156-159 (in Ukr.).
6. Chuvieco, E., Giglio, L., & Justice, C. (2008). Global Characterization of Fire Activity: Toward Defining Fire Regimes from Earth Observation Data. *Global Change Biology, 14*(7), 1488-1502. doi: https://doi.org/10.1111/j.1365-2486.2008.01585.x
7. Lizhi, W., & Aizhu, R. (2008). Urban Risk Clustering Method Based on Fie Statistics. *Tsinghua Science & Technology, 13*(S1), 418-422. doi: https://doi.org/10.1016/S1007-0214(08)70184-6
8. Tuia, D., Ratle, F., Lasaponara, R., Telesca, L., & Kanevski, M. (2008). Scan Statistics Analysis of Forest Fire Cluster. *Communications in Nonlinear Science and Numerical Simulation, 13*(8), 1689-1694. doi: https://doi.org/10.1016/j.cnsns.2007.03.004
9. Hasofe, A., & Thomas, I. (2006). Analysis of Fatalities and Injuries in Building Fire Statistics. *Fire Safety Journal, 41*(1), 2-14. doi: https://doi.org/10.1016/j.firesaf.2005.07.006
10. Lizhong, Y., Xiaodong, Z., Zhihua, D., Weicheng, F., & Qing'an, W. (2002). Fire Situation and Fire Caracteristic Analysis Based on Fire Statistics of China. *Fire Safety Journal, 37*(8), 785-802. doi: https://doi.org/10.1016/S0379-7112(01)00054-6
11. Brushlinsky, N. N., Hall, J. R., Sokolov, S. V., Ahrens, M., & Wagner, I. P. (2005-2017). *World Fire Statistics. Center of Fire Statistics of CTIF.* Reports No. 10-22. Retrieved from http://www.ctif.org/ctif/world-fire-statistics
12. SVSPB (2017). *Gross Domestic Product per Capita in the World.* Retrieved from http://svspb.net/danmark/vvp-stran-na-dushu-naselenija.php (in Russ.)

Received 1.06.2017