Dynamics of clustering of regions of Ukraine by the number of fires arisen

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***Abstract*—Under a cluster analysis of the regions of Ukraine by the number of emergencies of a natural and technogenic nature, the effectiveness of the functioning of the Unified State Civil Protection System (USCPS) is assessed. Considerig the uncertainty of the parameters affecting the conditions for the normal functioning of the state territory, it is proposed to create an effective information-analytical subsystem to manage the processes of prevention and liquidation of the emergencies when it is integrated into the current USCPS vertically from the object level to the state one, various functional elements of the territorial emergency monitoring system and the system of the situational centers.**

Keywords—cluster analysis; uncertainty of the information; Unified State Civil Protection System; territorial emergency monitoring system, the situational centers system.

I. INTRODUCTION

According to the reform strategy of the State Emergencies Service of Ukraine (SES of Ukraine) [1–4], among the urgent areas for improving the functioning of the USCPS, it is necessary to identify a number of problematic issues of a scientific, informational and technological nature regarding the optimal management of emergency prevention, localization and liquidation processes, namely, 1) improvement of the mechanism of interaction between the SES of Ukraine and other structures at all levels of national security by further developing the state emergency management center of the SES of Ukraine, the formation of relevant regional centers and the establishment of their interaction with the Main Situation Center and other situational centers that are the parts of the safety and defense sector; 2) the introduction of a system to manage all the types of technological safety (with the release of various types of energy) based on a risk-based approach and European standards for assessing and analyzing the risks of these types of technological safety of business entities; 3) the creation and operation of an automated system to manage telecommunications networks, a data center, an integrated subsystem of information support for decision-making and their implementation on emergencies, including an integrated information protection system.

At the same time, the problematic issues concerning the implementation in the USCPS system of the monitoring function and the development of effective management decisions aimed to prevent and eliminate the emergencies when some sources of hazards of various nature are born, remain completely open to the state [5–10].

This indicates the need for an urgent solution to the issues of including in the USCPS an information-analytical subsystem to manage the processes of emergency prevention and liquidation.

The creation of an effective information-analytical subsystem to manage emergency prevention and liquidation processes is proposed in accordance with the approach, which is graphically presented in Fig. 1. This approach implements a comprehensive inclusion in the current system of USCPS vertically from the object level to the state on of the various functional elements of the territorial subsystem of monitoring emergency situations and constituent subsystems of situational centers, tightly interconnected at the information and performing levels to make appropriate anti-crisis decisions when solving various functional tasks of monitoring, preventing and eliminating emergency situations of natural, technogenic, social and military nature [11–13].

One of the actual development directions in the USCPS information-analytical subsystem to manage emergency prevention and liquidation processes is the provision of a stable functioning of the territory of Ukraine in the conditions of demonstration of fire danger which needs complex studying, considering the uncertainty of the initial data, both directly the conditions for the generation and development of the fire danger and interconnections that will subsequently affect the cascading demonstrations of a different nature hazards, as well as the consequences of these hazards. To implement above mentioned, it is necessary to formulate objective criteria, which, firstly, shall determine the level of expediency of applying the proposed measures to increase the level of state security, and secondly, will be the basis for creating an appropriate protection system.

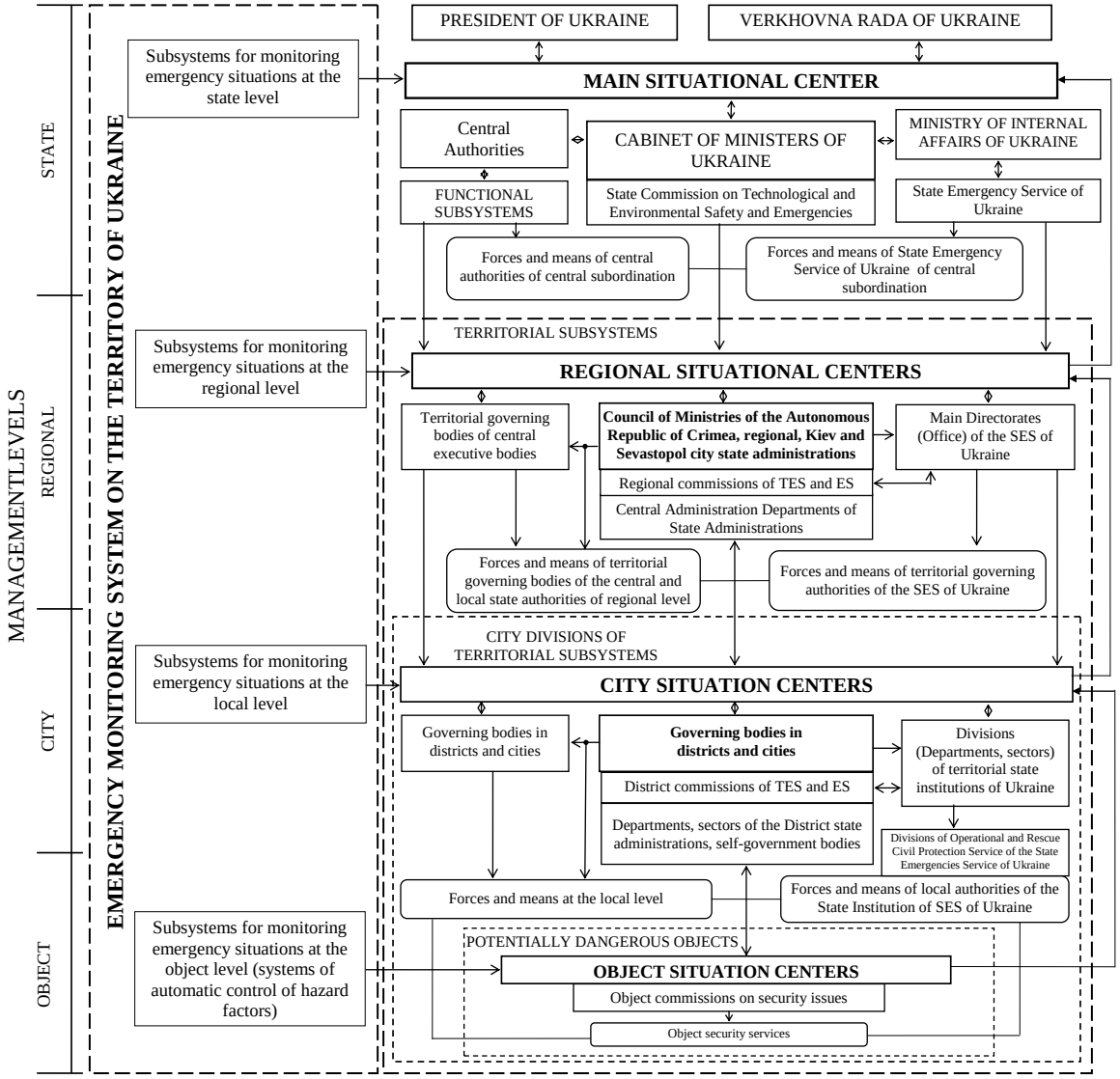

Fig. 1. Integrated functional diagram of the information-analytical subsystem to manage emergency prevention and liquidation processes in the Unified State Civil Protection System

II. Literature Review

In the conditions of irregular distribution of sources of hazards in Ukraine, each state region has its own level of natural, technogenic, social and military loads, which affect the composition of forces and the tactical and technical characteristics of security system. Knowledge of these levels is necessary to react in adequate manner to the hazards. Therefore, assessing the effectiveness of the functioning of the existing USCPS requires the development of scientific approaches to consider the characteristics of the regions for the qualitatively-quantitative level of hazard and the stability of the life of the state under the conditions of the destabilizing effect of these hazards [14–39].

When solving the problem of forming a system of comprehensive measures to prevent emergencies of various nature, there is a need to study the features of the demonstrations of non-linear connections between the components of the vital processes of Ukraine in everyday functioning and emergency situations.

Therefore, the overall goal of the study is to develop, based on the ideas of a systematic approach and through the use of artificial intelligence methods, the scientific and technical foundations for the creation in the USCPS information-analytical subsystem to support the making decision process to ensure the functioning of situational centers for the strategic management of emergency prevention and liquidation.

III. Statement Problem and Solution

The aim of this study is to develop a system of criteria for evaluating the effectiveness of functioning considering the uncertainty in the initial data of the USCPS through scientific research aimed at classifying and ranking at the regional level the management on the local territories of Ukraine by the degree of fire danger.

In order to achieve this aim and to assess the effectiveness of the functioning of the USCPS, it has been performed the classification of the state regions by the number of fires arise in this study. Based on the classification results, a comparative analysis of the dynamics of changes in the results of the classification of

regions according to the data of 2014–2019 has been performed regarding the results of the classification of regions according to the data of 2004–2013.

The classification of the state regions by the number of fires arisen has been performed using cluster analysis, which consists in finding groups of similar objects in a data sample, the so-called clusters, characterized by the following main properties: density, dispersion, size, shape and separability. Density refers to a property that allows defining a cluster as a cluster of points in a data space that is relatively dense compared to other areas of space, containing either a small number of points or it does not have any of them. Dispersion characterizes the degree of dispersion of points in space relative to the center of the cluster. Cluster size is closely related to dispersion. The shape of the cluster is determined by the position of the points in space. When depicting clusters in the form of various forms, it becomes necessary to determine the "connectedness" of points in the cluster in the form of the relative degree of distance between them. Distance measures are usually not limited from above and depend on the choice of scale of measurements. Separation characterizes the degree of overlap of clusters and how far apart they are located in space [40, 41].

When determining the distance measure, one of the most famous distances is the Euclidean distance, which is defined as follows:

$$d_{ij} = \sqrt{\sum_{z=1}^{p} \left(X_{iz} - X_{jz}\right)^2}, \qquad (1)$$

where d_{ij} – is the distance between objects *i* and *j*; X_{iz} – is the absolute value of the *z*-th variable for the *i*-th object; X_{jz} – is the absolute value of the *z*-th variable for the *j*-th object.

However, when analyzing the degree of distance, the similarity score is highly dependent on differences in data shifts; thus, variables characterized by large absolute values and standard deviations can reduce the influence of variables which are characterized by small absolute values and standard deviations. Therefore, to reduce this influence in this study, before determining the distance measure d_{ij}, a data standardization process was performed under the normalization of variables to a unit variance and a zero mean:

$$X^*_{iz} = \frac{X_{iz} - M\left[X_i\right]}{\sigma_{X_i}}; \qquad X^*_{jz} = \frac{X_{iz} - M\left[X_j\right]}{\sigma_{X_j}}, \qquad (2)$$

where X^*_{iz}, X^*_{jz} – are the standardized values of *z*-variables for the *i*-th and *j*-th objects; $M\left[X_i\right]$, $M\left[X_j\right]$ – are mathematical points characteristic of variables of the *i*-th and *j*-th objects; σ_{X_i}, σ_{X_j} – are standard deviations characteristic of variables of the *i*-th and *j*-th objects.

Known methods of the cluster analysis can be divided into two groups, namely: hierarchical and non-hierarchical methods.

The essence of hierarchical clustering consists in sequentially combining smaller clusters into large, so-called agglomerative methods or in dividing large clusters into smaller, so-called divisible methods.

The use of the Ward method, as one of the widely used agglomerative methods for hierarchical clustering of the main variables that determine the conditions for the daily functioning of the territory and the demonstration of technological hazards, as well as for the hierarchical clustering of the regions of Ukraine in accordance with the values of these variables, allowed us to obtain new results. The advantage of the Ward method is that it differs from all other agglomerative methods because it uses analysis of variance methods to estimate the distance between clusters. The method minimizes the sum of squared dispersion for clusters that can be formed at each step.

At the first step, the analysis of the sample included 250 observations over the territory of 25 regions of Ukraine for the period 2004–2013 with an observation step in one year.

A diagram of step-by-step unification of regions of Ukraine in clusters by the number of fires, considering the results of determining measures of Euclidean distances between the values of variables that determine the number of fires, is presented herein Fig. 2.

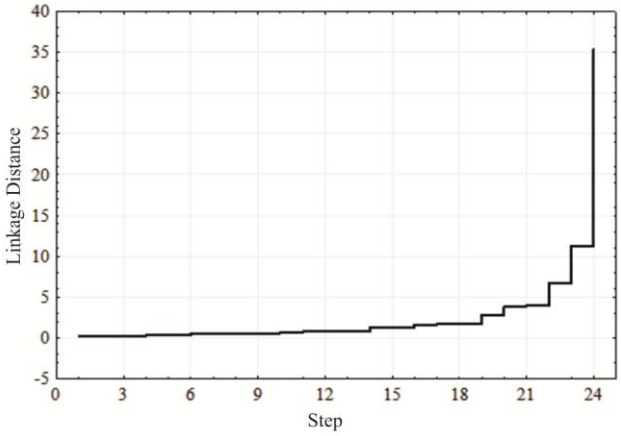

Fig. 2. The diagram of step-by-step unification of regions of Ukraine by the number of fires arisen for 2004–2013.

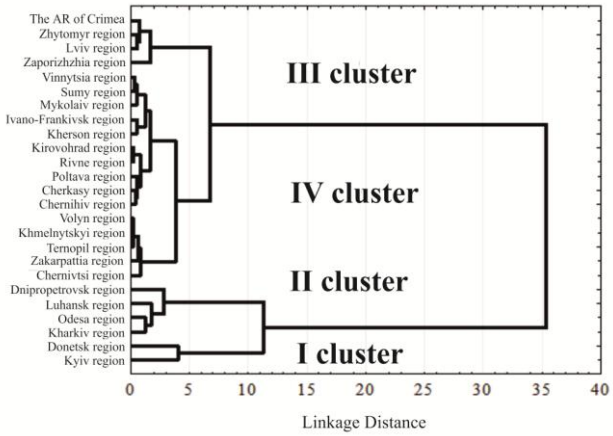

Fig. 3. The dendrogram of clustering of regions of Ukraine by the number of fires arisen for 2004–2013.

The results of clustering of the territory of Ukraine by the number of fires arisen are presented in the form of a dendrogram in Fig. 3 and the cartographic representation in Fig. 4.

Analysis of the state regions by the number of fires arisen for the period 2004–2013 has allowed at the level of 5 units the Euclidean distance to rank the territory of Ukraine into four main clusters. The first cluster, with a high level of fire danger, includes Donetsk and Kyiv regions. The second cluster, with an increased level of fire danger, includes the Dnipropetrovsk, Luhansk, Odesa and Kharkiv regions. The third cluster, with an average level of fire danger, includes the Autonomous Republic of Crimea, as well as the Vinnytsia, Zhytomyr, Zaporizhzhia and Lviv regions. The remaining regions belong to the fourth cluster, with a low fire danger.

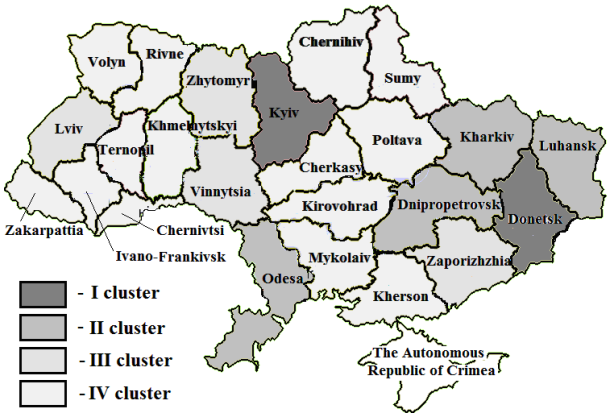

Fig. 4. The cartographic presentation of the clustering results of the regions of Ukraine by the number of fires arisen for 2004–2013.

At the second step, the analysis of the sample included 144 observations over the territory of 24 regions of Ukraine for the period 2014–2019 with an observation step in one year.

The results of the clustering of the territory of Ukraine by the number of fires arisen are presented in the form of a dendrogram in Fig. 5 and the cartographic demonstration in Fig. 6.

A comprehensive analysis of the state regions by the number of fires arisen for 2014–2019 has allowed at the level of 4 units of the Euclidean distance also ranked the territory of Ukraine into four main clusters. The first cluster, with a high level of fire danger, includes Donetsk and Dnipropetrovsk regions. The second cluster, with an increased level of fire danger, includes Kyiv, Zaporizhzhia, Odesa and Kharkiv regions. The third cluster, with an average level of fire danger, includes Volyn, Khmelnytskyi, Cherkasy, Chernivtsi, Kirovohrad, Ternopil, Zakarpattia, Sumy, Poltava, Chernihiv and Luhansk regions. The remaining regions belong to the fourth cluster, with a low fire danger.

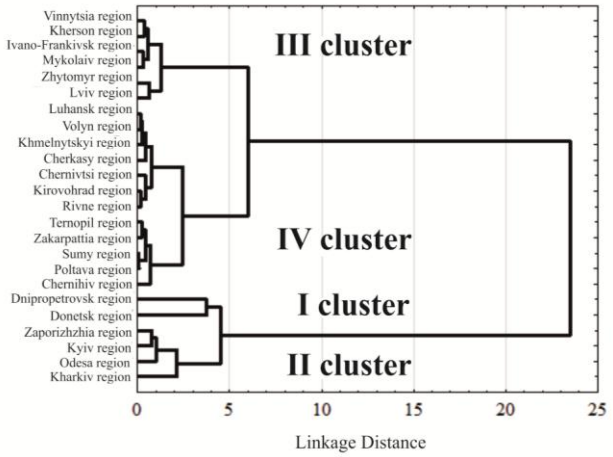

Fig. 5. The dendrogram of clustering of regions of Ukraine by the number of fires arisen for 2014–2019.

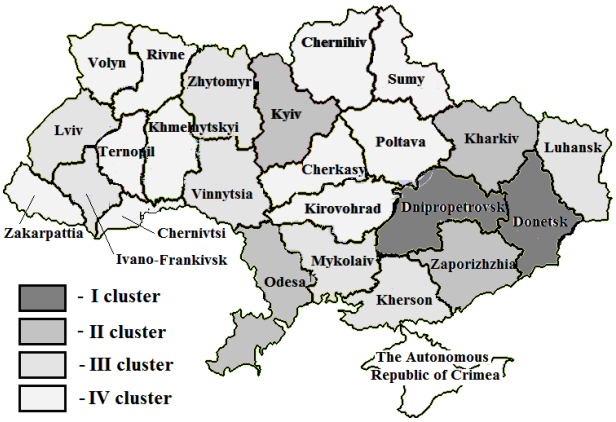

Fig. 6. The cartographic presentation of the clustering results of the regions of Ukraine by the number of fires arisen for 2014–2019.

The dynamics of clustering of the territory of Ukraine by the number of fires arisen for 2004–2013 and 2014–2019 is presented in Tab. 1, where there is a transition of Kyiv region from the first cluster to the second one, and also there is a transition of the Dnipropetrovsk region from the second cluster to the first one.

Table 1 – The dynamics of clustering of the territory of Ukraine by the number of fires arisen ($K_{Fire} = min \div max$, where min – minimum rate, max – maximum rate) for 2004–2013 and 2014–2019.

Fire danger groups	2004–2013	2014–2019
I cluster (high level of fire danger)	Donetsk region ($K_{Fire} = 5323 \div 9885$); Kyiv region ($K_{Fire} = 2338 \div 7446$)	Dnipropetrovsk region ($K_{Fire} = 7732 \div 9569$); Donetsk region ($K_{Fire} = 4454 \div 9983$)
II cluster (increased level of fire danger)	Dnipropetrovsk region ($K_{Fire} = 3265 \div 7015$); Luhansk region ($K_{Fire} = 2404 \div 5865$); Odesa region ($K_{Fire} = 2208 \div 4189$); Kharkiv region ($K_{Fire} = 2882 \div 4799$)	Zaporizhzhia region ($K_{Fire} = 3556 \div 7539$); Kyiv region ($K_{Fire} = 2764 \div 7072$); Odesa region ($K_{Fire} = 4196 \div 6694$); Kharkiv region ($K_{Fire} = 3956 \div 6918$)

III cluster (average level of fire danger)	The Autonomous Republic of Crimea ($K_{Fire} = 1470 \div 2064$); Vinnytsia region ($K_{Fire} = 1287 \div 1913$); Zhytomyr region ($K_{Fire} = 1561 \div 2179$); Zaporizhzhia region ($K_{Fire} = 1614 \div 3411$); Lviv region ($K_{Fire} = 1619 \div 2576$)	Vinnytsia region ($K_{Fire} = 2005 \div 2661$); Zhytomyr region ($K_{Fire} = 2348 \div 3476$); Ivano-Frankivsk region ($K_{Fire} = 1870 \div 3067$); Lviv region ($K_{Fire} = 2502 \div 4356$); Luhansk region ($K_{Fire} = 1383 \div 2753$); Mykolaiv region ($K_{Fire} = 2168 \div 3311$); Kherson region ($K_{Fire} = 1728 \div 2846$)
IV cluster (low level of fire danger)	Volyn region ($K_{Fire} = 763 \div 1217$); Zakarpattia region ($K_{Fire} = 717 \div 1834$); Ivano-Frankivsk region ($K_{Fire} = 958 \div 2072$); Kirovohrad region ($K_{Fire} = 900 \div 1362$); Mykolaiv region ($K_{Fire} = 1350 \div 2123$); Poltava region ($K_{Fire} = 1106 \div 1975$); Rivne region ($K_{Fire} = 994 \div 1374$); Sumy region ($K_{Fire} = 1333 \div 2197$); Ternopil region ($K_{Fire} = 809 \div 1199$); Kherson region ($K_{Fire} = 1023 \div 2509$) Khmelnytskyi region ($K_{Fire} = 813 \div 978$); Cherkasy region ($K_{Fire} = 966 \div 1444$); Chernivtsi region ($K_{Fire} = 545 \div 777$); Chernihiv region ($K_{Fire} = 1110 \div 1475$)	Volyn region ($K_{Fire} = 1072 \div 1388$); Zakarpattia region ($K_{Fire} = 1396 \div 2249$); Kirovohrad region ($K_{Fire} = 1415 \div 2000$); Poltava region ($K_{Fire} = 1556 \div 2362$); Rivne region ($K_{Fire} = 1230 \div 1672$); Sumy region ($K_{Fire} = 1442 \div 1994$); Ternopil region ($K_{Fire} = 1099 \div 1732$); Khmelnytskyi region ($K_{Fire} = 911 \div 1172$); Cherkasy region ($K_{Fire} = 1206 \div 1594$); Chernivtsi region ($K_{Fire} = 679 \div 884$); Chernihiv region ($K_{Fire} = 1664 \div 2351$)

In addition, there is also a transition of Luhansk region from the second to the third cluster, and Zaporizhzhia region, vice versa, from the third to the second cluster. Also, there is a transition of Mykolaiv region and Kherson region from the fourth to the third cluster.

IV. Conclusion

1. It is shown that the basis of the Unified State Civil Protection System of Ukraine shall be the classical model of management, which provides: collection, processing and analysis of information; modeling of the development of the situation at the object of management and development of emergency situations in the city, region, state; the development and adoption of management decisions to prevent and eliminate emergency situations, as well as minimize their consequences; implementation of decisions concerning the prevention and liquidation of emergency situations, as well as minimizing their consequences.

2. It is proposed to create an effective information-analytical subsystem for managing emergency prevention and liquidation processes by comprehensive integration into the current Unified State Civil Protection System vertically, from the object to the state levels of various functional elements of the territorial emergency monitoring system and the components of the system of situational centers that are tightly interconnected at the information and executive levels to make appropriate anti-crisis decisions, to solve various functional tasks of monitoring, prevention and elimination of emergencies of natural, technogenic, social and military nature.

3. It has been performed the analysis of the dynamics of clustering of the territory of Ukraine by the number of fires arisen for 2004–2013 and 2014–2019. According to the results of the analysis performed, it has been found some transitions, namely: Kyiv region from the first (with a high level of fire danger) to the second one (with an increased level of fire danger); Dnipropetrovsk region from the second cluster to the first one; Luhansk region from the second cluster to the third one (with an average level of fire danger); Zaporizhzhia region, on the contrary, from the third cluster to the second one; Mykolaiv region and Kherson region from the fourth cluster (with a low fire danger) to the third one.

4. Based on the analysis performed, it has been found that the functioning of the USCPS, and, accordingly, the information and analytical subsystem to manage emergency prevention and liquidation processes (which consists of the functional elements of the territorial emergency monitoring system and the system of situational centers), occurs under conditions of probabilistic dynamics of the vital activity hazard level of the state regions. Such dynamics is explained by the uncertainty of the parameters affecting the conditions for the normal functioning of the territory of Ukraine. In this regard, the problem arises of making optimal anti-crisis decisions under the uncertainty in providing an appropriate level of the state safety.

It is shown that the procedure of making managerial decisions is complicated by the fact that the necessary conditions for the effectiveness of decisions are their timeliness, completeness and optimality. Therefore, increasing of the efficiency of decisions is related to the need to solve the problem of multicriteria optimization under the uncertainty, which requires the development of formal, normative methods and models for a comprehensive solution to the problem of decision making under the multicriteria and uncertainty in managing emergency prevention and liquidation processes to provide the effective functioning of the USCPS.

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