Cluster analysis of the regions of Ukraine by the number of the arisen emergencies

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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

In Ukraine, to provide the implementation of the state policy in the field of civil protection, the USCPS operates, which consists of functional and territorial subsystems [1–3] and is aimed to solve the issues of provision the necessary level of life safety of the state territory only in conditions when an emergency has arisen.

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 [4–8].

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 [9–11].

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 when these hazards are arisen, which requires a comprehensive study considering the uncertainty of the initial data, both directly the conditions for the generation and development of the 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.

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 [12–44].

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.

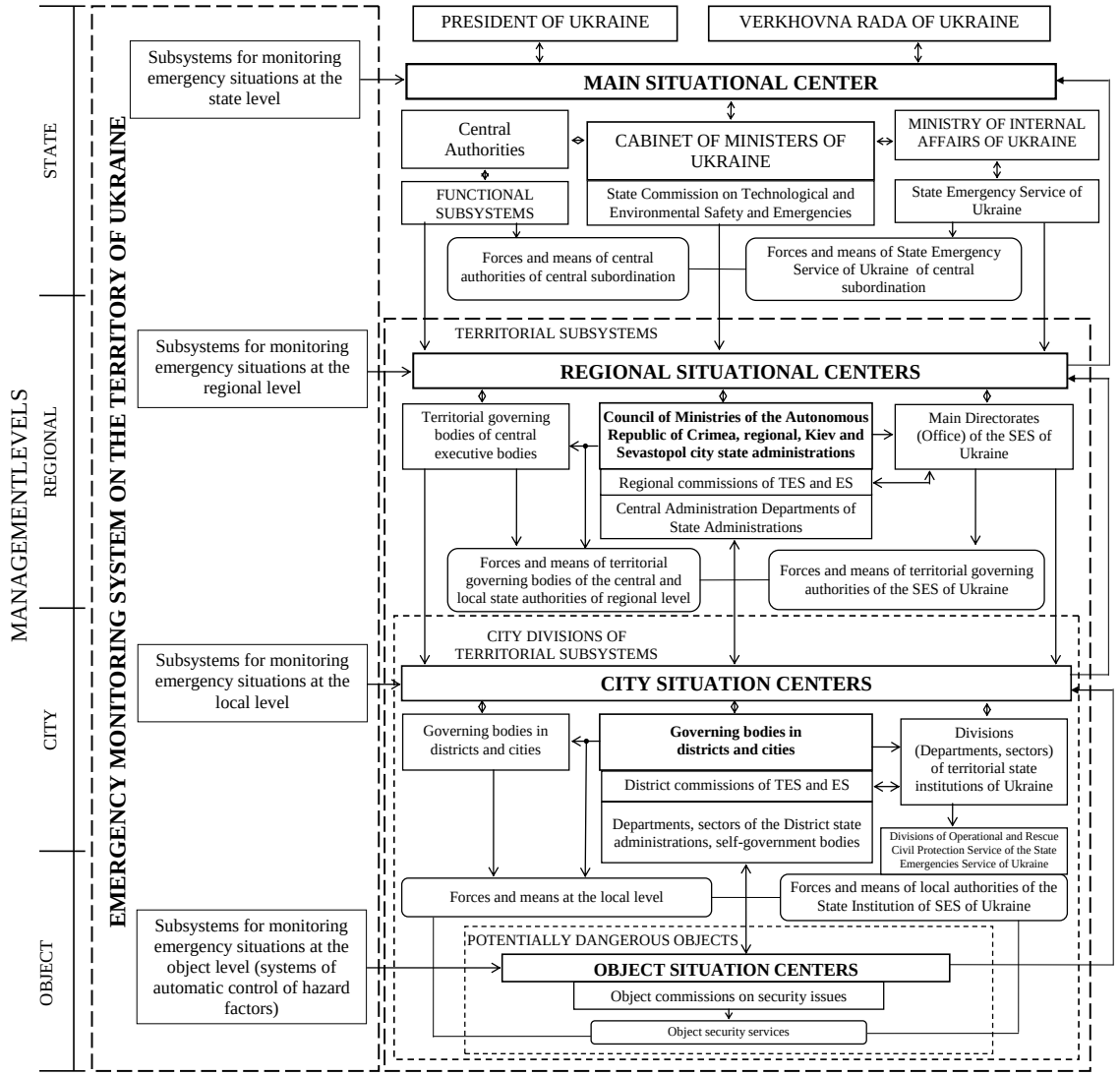

Fig. 1. Integrated functional diagram of the information-analytical subsystem to manage emergency prevention and liquidation processes in the Unified State Civil Protection System

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 territory of Ukraine by the number of natural and technogenic emergencies.

The condition of stability of the functioning of the territory of the state in the conditions of the demonstration of fires and the functioning of the USCPS – F_{USCPS} , is possible to write in the form of a system of equations based on the basic principles of catastrophe theory and synergetics [45–48]:

$$\begin{cases} R_N(P_N, W_N) = \varphi_N(G_N, F_N, F_{USCPS\ N}), \\ R_T(P_T, W_T) = \varphi_T(G_T, F_T, F_{USCPS\ T}), \\ R_S(P_S, W_S) = \varphi_S(G_S, F_S, F_{USCPS\ S}), \\ R_M(P_M, W_M) = \varphi_M(G_M, F_M, F_{USCPS\ M}), \end{cases} \quad (1)$$

where $R_N(P_N, W_N)$, $R_T(P_T, W_T)$, $R_S(P_S, W_S)$, $R_M(P_M, W_M)$ – risk indicators of emergency situations of natural, technogenic, social and military nature; P_N , P_T , P_S , P_M – indicators of the likelihood of emergencies of a natural, technogenic, social and military nature; $W_N = row(w_{N_M}, w_{N_S}, w_{N_E})$, $W_T = row(w_{T_M}, w_{T_S}, w_{T_E})$, $W_S = row(w_{S_M}, w_{S_S}, w_{S_E})$, $W_M = row(w_{M_M}, w_{M_S}, w_{M_E})$ – indicators of damage from emergency situations of natural, technogenic, social and military nature; w_M , w_S , w_E – indicators of material, social and environmental damage from emergency situations φ_N , φ_T , φ_S , φ_M – general functionals, which are determined by the properties of the territory to the demonstration of emergency situations of natural, technogenic, social and military nature; $G_N = \xi_N(g_N, g_T, g_S, g_M)$, $G_T = \xi_T(g_N, g_T, g_S, g_M)$, $G_S = \xi_S(g_N, g_T, g_S, g_M)$, $G_M = \xi_M(g_N, g_T, g_S, g_M)$ – previous factors of demonstration of the emergency

situations of natural, technogenic, social and military nature; g_N, g_T, g_S, g_M – natural, technogenic, social and military sources of emergencies; ξ_N, ξ_T, ξ_S, ξ_M – primary functionals, which are determined by the properties of the territory to the demonstration of previous factors of emergency situations of natural, technogenic, social and military nature; F_N, F_T, F_S, F_M – dangerous (destructive) factors from emergencies of natural, technogenic, social and military nature; $F_{USCPS\ N}$, $F_{USCPS\ T}$, $F_{USCPS\ S}$, $F_{USCPS\ M}$ – the functions of the USCPS system in the context of the demonstration of the previous factors of emergency situations of natural, technogenic, social and military nature, as well as the destructive effects of dangerous factors from these emergency situations.

Then in this study, to assess the effectiveness of the functioning of the USCPS, the classification of the state regions was made by the number of natural and technogenic emergencies.

The classification of the state regions by the number of natural and technogenic emergencies 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 [49, 50].

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

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

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:

$$X^*_{iz} = \frac{X_{iz} - M\left[X_i\right]}{\sigma_{X_i}}; \quad X^*_{jz} = \frac{X_{iz} - M\left[X_j\right]}{\sigma_{X_j}}, \qquad (3)$$

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.

The analysis of the sample, which determined the conditions for demonstration of emergency situations of the nature, included 150 observations over the territory of 25 regions of Ukraine for the period 2014–2019 with an observation step which is one year.

The results of a step-by-step unification of regions of Ukraine according to the results of determining measures of Euclidean distances between the values of variables that determine the conditions for the demonstration of the emergency situations of a natural nature, are presented herein Fig. 2.

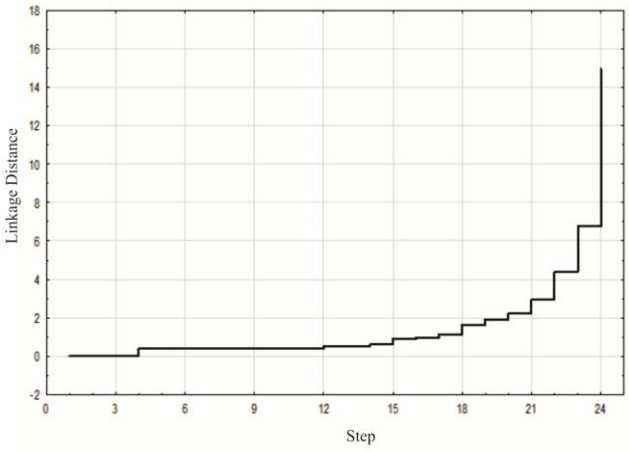

Fig. 2. The diagram of step-by-step unification of regions of Ukraine by the number of emergencies of a natural basis

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

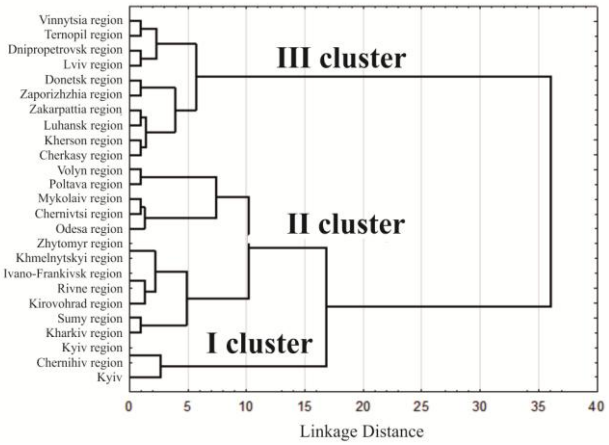

Fig. 3. The dendrogram of clustering of regions of Ukraine by the number of emergencies of a natural basis for 2014–2019

There is a division of the territory of Ukraine into regions with different numbers of natural emergencies in 2014–2019 in the Fig. 3 and 4. A comprehensive analysis of the state made it possible to divide the territory of Ukraine into three main clusters.

The first cluster, with a high level of emergencies of a natural basis, includes the Kyiv and Chernihiv regions, as well as Kyiv city. The number of natural emergencies in these areas is at the level of 7–8 events.

The second cluster, with an average level of natural emergencies, includes Volyn, Poltava, Mykolaiv, Chernivtsi, Odesa, Zhytomyr, Khmelnytskyi, Ivano-Frankivsk, Rivne, Kirovohrad, Sumy and Kharkiv regions. The number of natural emergencies in these areas is at the level of 4–6 events.

The third cluster, with a relatively low level of emergencies of a natural basis, includes other areas of the state. The number of natural emergencies in these areas is up to 3 events.

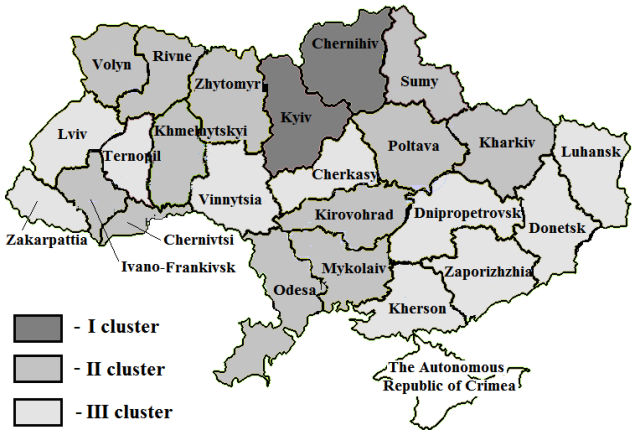

Fig. 4. The cartographic presentation of the clustering results of the regions of Ukraine by the number of emergencies of a natural basis for 2014–2019.

Then in this study on a similar algorithm a cluster analysis of the regions of Ukraine by the number of emergencies of anthropogenic nature has been performed.

The analysis of the sample, which determined the conditions for the demonstration of technological emergencies, also included 150 observations in the territory of 25 regions of Ukraine for the period 2014–2019 with an observation step in one year.

The results of a step-by-step unification of the regions of Ukraine according to the results of determining measures of Euclidean distances between the numbers of variables that determine the conditions of the demonstration of emergencies of an anthropogenic nature, are presented in the Fig. 5.

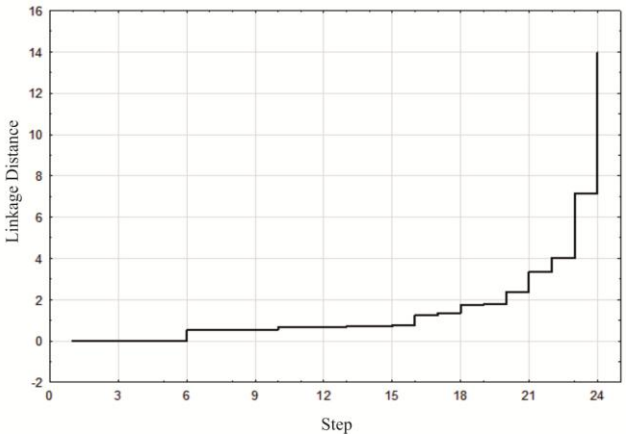

Fig. 5. The diagram of step-by-step unification of the regions of Ukraine by the number of technogenic emergencies

The results of the clustering of the territory of Ukraine by the number of emergencies of a technogenic nature are presented in the form of a dendrogram in Fig. 6 and the cartographic representation in the Fig. 7.

There is a separation of the territory of Ukraine into regions with a different number of technogenic emergencies for 2014–2019 in the Fig. 6 and 7. A comprehensive analysis of the state made it possible to divide the territory of Ukraine into three main clusters.

The first cluster, with a high level of technological emergencies, includes Kyiv, Zaporizhzhia and Mykolaiv regions, as well as Kyiv city. The number of technological emergencies in these areas is at the level of 5–6 events.

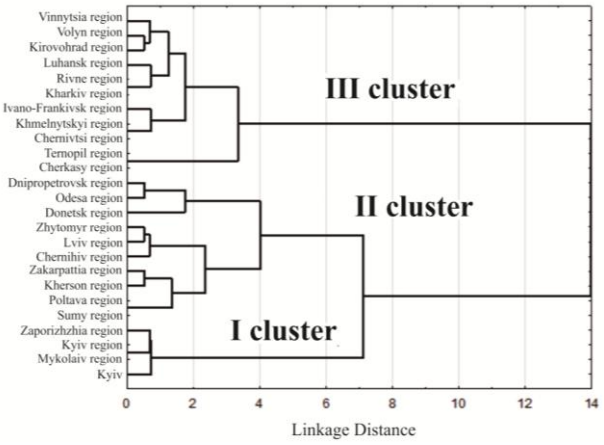

Fig. 6. The dendrogram of clustering of regions of Ukraine by the number of emergencies of the technogenic nature for 2014–2019

The second cluster, with an average level of technological emergencies, includes Dnipropetrovsk, Odesa, Donetsk, Zhytomyr, Lviv, Chernihiv, Kyiv,

Kherson, Poltava and Sumy regions. The number of technological emergencies in these areas is at the level of 3–4 events.

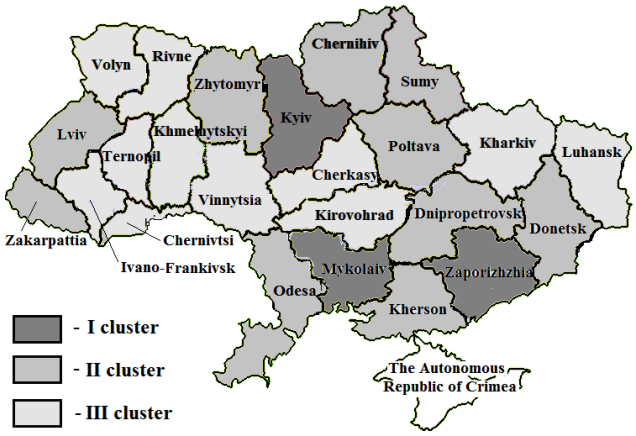

Fig. 7. The cartographic presentation of the clustering results of the regions of Ukraine by the number of technogenic emergencies for 2014–2019.

The third cluster, with a relatively low level of technological emergencies, includes other areas of the state. The number of technological emergencies in these areas is up to 2 events.

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. A cluster analysis of the territory of Ukraine has been performed according to the number of emergencies of a natural basis for the periods 2014 – 2019. According to the results of the analysis, it has been established: Kyiv and Chernihiv regions, as well as Kyiv city belong to the first cluster (with a high level of vital activity hazard); the second cluster (with an average level of vital activity hazard) is Volyn, Poltava, Mykolaiv, Chernivtsi, Odesa, Zhytomyr, Khmelnytskyi, Ivano-Frankivsk, Rivne, Kirovohrad, Sumy and Kharkiv regions; the third cluster (with a relatively low level of vital activity hazard) includes other areas of the state.

4. A cluster analysis of the territory of Ukraine has been performed according to the number of technogenic emergencies for the periods 2014 – 2019. According to the results of the analysis, it has been established: the first cluster (with a high level of vital activity hazard) includes Kyiv, Zaporizhzhia and Mykolaiv regions, as well as Kyiv city; the second cluster (with an average level of vital activity hazard) is the Dnipropetrovsk, Odesa, Donetsk, Zhytomyr, Lviv, Chernihiv, Kyiv, Kherson, Poltava and Sumy regions; the third cluster (with a relatively low level of vital activity hazard) includes other areas of the state.

5. 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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