Development of scientific basis for decision support by experts of the situational center under conditions of uncertainty of input information in emergency situations

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***Abstract*—Considering the uncertainty of the parameters affecting the conditions for the normal functioning of the territory of the state, it is proposed to create an effective information and analytical subsystem to manage the processes of prevention and elimination of emergencies when integrated into the existing civil protection system vertically from the object to the state levels, various functional elements of the territorial monitoring system situations and systems of situational centers. In conditions of uncertainty of the input information for experts of the system of situational centers, there is a methodology for substantiating optimal anti-crisis solutions to provide an appropriate level of life safety of the state in emergency situations of various nature.**

Keywords—information uncertainty, civil protection system, emergency monitoring system, situational centers system, decision support

I. Introduction

While providing the implementation of the state policy in the field of civil protection, the problematic issues of the implementation of the monitoring function in the civil protection system and the development of effective management solutions aimed at preventing and eliminating emergency situations, in the context of the emergence of sources of dangers of various nature, remain completely open. This indicates the necessity of resolving the issues of including the information and analytical subsystem of managing the processes of prevention and elimination of emergency situations into the civil protection system.

The creation of an effective information and analytical subsystem for managing the processes of preventing and eliminating emergency situations is proposed to be comprehensively included in the civil protection system vertically from the object to the state levels of various functional elements of the territorial subsystem for monitoring emergency situations and the components of the subsystem of situational centers, which are rigidly interconnected in informational and executive levels to make appropriate anti-crisis decisions when solving various functional tasks of monitoring, prevention and elimination of emergencies of natural, man-made, social and military nature [1–9].

One of the urgent directions of creating an information-analytical subsystem to manage the processes of prevention and elimination of emergencies in the civil protection system is the development of a justification methodology, in conditions of uncertainty of the input information for experts of the system of situational centers, optimal anti-crisis solutions to provide an appropriate level of safety of the state in emergency situations, situations of natural, technogenic, social and military nature.

II. Unresolved issues

An obligatory stage in the functioning of the system of situational centers is decision making. At the same time, not only incorrect, but also ineffective decisions lead to losses or irrational use of financial, time, labor, energy and other resources when managing the processes of prevention and elimination of emergency situations. In this regard, the problem of developing a scientifically grounded methodology to make effective decisions is one of the urgent scientific problems.

According to V.M. Hlushkov, the necessary conditions for the effectiveness of decisions are their timeliness, completeness and optimality. The listed requirements are contradictory and their satisfaction is connected with serious difficulties.

Provision the completeness (complexity) of decisions requires the fullest possible consideration of internal and external factors affecting decision-making, a deep analysis of their interrelationships, which leads to increase in the dimension of the decision-making problem, its multicriteria. In turn, this leads to increase in the uncertainty of the initial data, which is due to the incompleteness of knowledge about the relationship of factors and, as a consequence, its inaccurate description, the impossibility or inaccuracy of measuring some factors,

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random external and internal influences, etc. An additional complication is in the fact that uncertainties are heterogeneous and can be represented as random variables, fuzzy sets or simply interval values.

Thus, an increase in the efficiency of decisions made is connected with the need to solve multicriteria optimization problems in conditions of uncertainty.

The traditional, widespread approach to solving such problems, based on their heuristic simplification, determinization as a means of removing uncertainty, becomes less and less effective as the tasks become more complex and the significance of solutions increases.

In these conditions, it is extremely important to develop formal, normative methods and models for a comprehensive solution to the problem of decision-making in conditions of multi-criteria and uncertainty.

In this direction, main, fundamental results were obtained [10–31], however, the only solution to the problem is far from completion and the continuation of research in this direction is undoubtedly relevant both in theoretical and applied aspects for the development of a justification methodology, in conditions of uncertainty in the input information for experts of the system of situational centers, optimal anti-crisis solutions to provide the necessary level of life of the state in emergency situations of natural, man-made, social and military nature.

III. Main part

The purpose of this study is to develop the scientific and technical foundations for creating an information-analytical subsystem to manage the processes of preventing and localizing the consequences of emergencies of the civil protection system by developing a methodology for substantiating optimal anti-crisis solutions to provide an appropriate level of safety of the state life in emergency situations of various character, in conditions of uncertainty of input information for experts of the system of situational centers.

The situational center operating in the civil protection system shall, in accordance with the data in Fig. 1, provide: 1) analysis of the information received from the monitoring subsystem; 2) modeling the development of emergency situations on the territory of the city, region, state; 3) development and adoption of managerial decisions to prevent and eliminate emergencies, as well as to minimize their consequences.

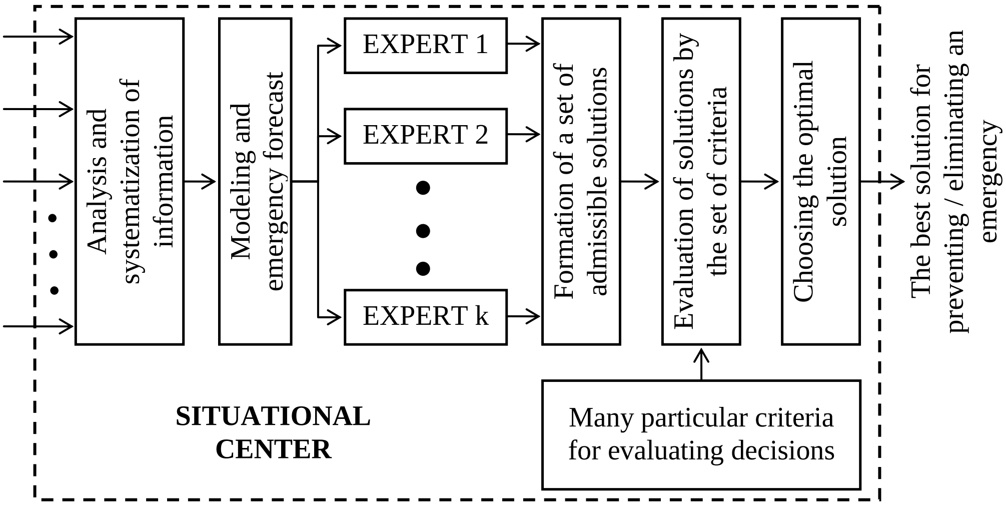

Fig. 1. Functional scheme for substantiating optimal anti-crisis solutions to ensure an appropriate level of life safety of the state in emergencies of a different nature, in conditions of uncertainty of initial information for experts of the system of situational centers of the civil protection system

The functioning of the scheme shown in Fig. 1 in the conditions of completeness of the input information and the presence of one partial criterion for assessing the set of feasible decisions does not present difficulties in substantiating optimal anti-crisis solutions. On the other hand, modern problem situations are characterized by incompleteness of knowledge (uncertainty) of the input data and multiplying particular evaluation criteria.

Thus, the traditional approach, based on the decomposition of the problem into two conditionally independent tasks – in-criterial optimization in deterministic, that is, without considering uncertainty, setting and making a decision under uncertainty for a scalar objective function in modern conditions, does not meet the requirements of practice by accuracy and efficiency.

This is due to the fact that the problem of multicriteria optimization is incorrect, since it allows one to determine the solution only up to the area of compromise solutions, and its regularization for determining a single solution, based on the calculation of a generalized multivariate scalar estimate, is based on poorly structured, subjective expert assessments, the determination of which leads to large errors.

On the other hand, methods of decision-making in conditions of uncertainty on a scalar estimate and the expected effect, without considering its multicriteria, are also inadequate. Therefore, there is a need to develop a methodology for comprehensive solutions to the problem of decision-making, considering the multi-criteria and incomplete uncertainty of the original data.

In general, the admissible set of solutions contains subsets of consistent X^S and contradictory (compromise) X^C solutions. A feature of the latter is the impossibility of improving any particular criterion $k_j(x)$, $j=\overline{1,n}$ without deteriorating the quality of at least one particular criterion. In this case, by definition, an effective solution x° necessarily belongs to the area of compromise. This means that the problem of multiobjective optimization

$$x^{\circ} = \arg\underset{x\in X}{extr} < k_j(x) >, \forall j=\overline{1,n}, \tag{1}$$

has no solution, i.e. is incorrect according to Adamar, since in the general case it does not provide the definition of the only optimal solution from the set of compromises X^C [32–34].

Thus, the problem of multiobjective optimization arises. The main idea of the methods for solving a multicriteria decision-making problem (MDMP) is to develop a certain regularizing procedure that allows choosing a single solution from the area of compromises X^C. There are two possible approaches to the implementation of such a task: heuristic, when the decision-maker (DM) makes a choice based on their experience, and formal, based on some formal rules (compromise schemes).

The main methods of regularizing the problem of multicriteria optimization are the principle of the main criterion, functional-cost analysis and the principle of sequential optimization. Each of the listed optimality principles has its own area of correct application and is used in engineering practice, but the most general and universal approach is based on the formation on a set of particular criteria $K = K_{\phi} \cup K_{з} = \{\kappa_i(x)\}$, $i=\overline{1,n}$ of a generalized scalar estimate (criterion), which is often called a utility function of the form

$$\overline{K}(x) \equiv P(x) = F[\lambda_j, K_j(x)],\ j=\overline{1,m}, \tag{2}$$

where λ_j – is the isomorphism coefficients that bring heterogeneous particular criteria $K_j(x)$ to isomorphic form.

The theoretical basis for the formation of multicriteria scalar estimates is the utility theory, which assumes the existence of a quantitative assessment of the preference of decisions. It means that

$$x_1, x_2 \in X,\ \ x_1 \succ x_2, \text{ then } P(x_1) > P(x_2), \tag{3}$$

where $P(x_1)$, $P(x_2)$ – are the utility functions.

In the general case, the converse is also true. Thus, utility is a quantitative measure of the "quality" of decisions, therefore

$$x^{\circ} = \arg\max_{x\in X} P(x). \tag{4}$$

In this regard, the problem arises of substantiating the rule (metric), according to which the utility function is formed in the space of particular criteria $k_i(x)$.

It is crucial that there is no objective metric, and the principle of ranking decisions reflects the subjective preferences of a particular decision maker.

Consider the systemological grounds for choosing the metric of the utility function.

The synthesis of any mathematical model, including the synthesis of the utility function, presupposes the need to solve two interrelated problems: structural and parametric identification. The first of them provides for: identification of significant factors that affect the output of the model; structure definition, i.e. the kind of operator that determines the connection between the input and output data of the model.

The solution to the problem of parametric identification is to determine the specific quantitative values of the model parameters.

The problem of structural identification of a model is connected with the heuristic advance and verification of a hypothesis. In the case under consideration, the form of the decision utility function x is determined by particular characteristics (criteria) $k_i(x)$.

The next step in solving the problem is to identify the type of operator F. There are most widely known two forms of the utility function: additive and multiplicative.

Additive utility function. Fishbern made a great contribution to substantiating this hypothesis. He determined the necessary and sufficient conditions for the adequacy of the additive utility function for many cases. In the case of n factors, the condition for the additivity of the utility function according to Fishbern can be formulated as follows: the factors $x_1, x_2, \ldots x_n$ are additively independent if the preference of lotteries on $x_1, x_2, \ldots x_n$ depend only on their marginal probability distributions.

Using this definition, we can formulate the main result of the theory of additive utility:

$$P(x) = \sum_{i=1}^{n} \lambda_i k_i(x). \tag{5}$$

The multiplicative form of the utility function has the following form

$$P(x) = \prod_{i=1}^{n} \lambda_i k_i(x). \tag{6}$$

The analysis showed that the multiplicative form does not allow considering the information about the weight coefficients. The disadvantage of the additive form is that it does not allow considering the nonlinearity and interconnection of particular criteria.

Therefore, in the general case, a more universal structure of the utility function is needed, which would allow considering both the additive form and nonlinear effects.

As such a universal form, the Kolmohorov-Habor polynomial can be used, which in the general case has the form:

$$P(Y) = \lambda_0 + \sum_{i=1}^{n} \lambda_i x_i + \sum_{i=1}^{n}\sum_{i\le j} \lambda_{ij} x_i x_j + \\ + \sum_{i=1}^{n}\sum_{j\le i}\sum_{k\le j} \lambda_{ijk} x_i x_j x_k + \ldots, \tag{7}$$

For the purposes of evaluating utility, it shall be modified by putting $\lambda_0 = 0$, as a result, it will take the form

$$P(Y) = \sum_{i=1}^{n} \lambda_i k_i + \sum_{i=1}^{n} \sum_{j=1}^{n} \lambda_{ij} k_i k_j + ... \qquad (8)$$

Moreover, in most practical situations, it is sufficient to consider only the members of the second order.

The Kolmohorov-Habor polynomial contains the fragments of the additive and multiplicative functions and is linear in parameters. Considering that, by expanding the space of variables by introducing additional variables such as $\sum_{i=1}^{n} \sum_{j=1}^{n} k_i k_j = z_l$, we obtain an additive function of the following form

$$P(x) = \sum_{l=1}^{L} \lambda_l z_l, \qquad (9)$$

Based on the above mentioned, we will consider the additive form in more detail, using model (5) for clarity. All particular criteria, by definition, have different dimensions, intervals and measurement scales, i.e. are not comparable to each other.

Consequently, formula (4) is valid only if λ_i considers the importance of particular criteria and, at the same time, are the isomorphism coefficients, i.e. lead heterogeneous $k_i(x)$ to a single dimension and range of change. However, in the general case, it is difficult to determine the values of such isomorphism coefficients. This circumstance can be overcome by presenting the additive utility function in the following form:

$$P(x) = \sum_{i=1}^{n} a_i k_i^{н}(x), \qquad (10)$$

where a_i – is the relative dimensionless weight coefficients for which the constraints are satisfied

$$0 \le a_i \le 1, \quad \sum_{i=1}^{n} a_i = 1, \qquad (11)$$

and $k_i^{н}(x)$ – normalized, i.e. partial criteria reduced to isomorphic form. The criteria are normalized according to the formula

$$k_i^{H}(x) = \left(\frac{k_i(x) - k_i^{HX}}{k_i^{HЛ} - k_i^{HX}} \right)^{\alpha_{ш}}, \qquad (12)$$

where $k_i(x)$ – is the value of a particular criterion; $k_i^{HЛ}$, k_i^{HX} – respectively, the best and worst value of the particular criterion, which he takes on the area of admissible solutions $x \in X$.

Depending on the type of extremum (direction of dominance)

$$k_i^{HЛ} = \begin{cases} \max_{x \in X} k_i(x), \text{ if } k_i(x) \to \max \\ \min_{x \in X} k_i(x), \text{ if } k_i(x) \to \min \end{cases} \qquad 13)$$

$$k_i^{HX} = \begin{cases} \min_{x \in X} k_i(x), \text{ if } k_i(x) \to \max \\ \max_{x \in X} k_i(x), \text{ if } k_i(x) \to \min \end{cases} \qquad (14)$$

The estimation model (10) is constructive only if the weighting coefficients a_i of particular criteria are set by point quantitative values. As it was mentioned above, decision makers are the carriers of this information, which means that some procedures for obtaining it are necessary, i.e. solving the problem of parametric identification of the model. For various reasons, to obtain accurate quantitative information about the values a_i is not always possible, therefore, in the general case, the evaluation of the usefulness of decisions has to be carried out under conditions of a greater or lesser degree of uncertainty about the mutual importance of particular criteria. In general, the general model for determining the utility of a solution $x \in X$ has a form

$$P(x) = G[J(a_i), k_i(x)], \ i = \overline{1,n}, \qquad (15)$$

where $J(a_i)$ – is the information about the values of the coefficients of relative importance.

Extreme situations are ones when:

1) the weight coefficients a_i are specified in the form of exact point quantitative values;

2) information about the preference of particular criteria is completely absent.

Typically, between these extremes, there are many situations with varying degrees of uncertainty in the assignment of weighting factors.

Based on the presented approach, the problem of synthesizing a model for calculating the interval phased value of a scalar multifactorial assessment of the effectiveness (utility) of feasible solutions is solved in this study.

It is assumed that the model for calculating the utility function in the general case is a certain fragment of the Kolmohorov-Habor polynomial, linear in parameters, but nonlinear in variables (partial criteria). This means that in the extended space of variables, the utility function model $P(x)$ can be viewed as an additive function of the form

$$\overline{P}(x) = \sum_{i=1}^{n} \overline{a}_i \overline{k_i^{H}(x)} \qquad (16)$$

where $\overline{a}_i$ – is dimensionless weight coefficients that meet the requirements $0 \le a_i \le 1, \sum_{i=1}^{n} a_i = 1$; $\overline{k_i^{H}(x)}$ are normalized, that is, reduced to dimensionless form, the same metric and dominance direction, partial criteria; the "–" sign means interval uncertainty.

An analysis of the features of the problem of multicriteria scalar estimates showed that fuzzy sets are a widespread form of representing uncertainties in model

(16). Under the accepted assumptions, the parametric identification of the model of the multicriteria optimization problem (16) consists in determining the interval values of the parameters $\overline{a_i}$ and particular criteria $\overline{k_i(x)}$, their fuzzification and calculating the interval phased value of the solution utility function $P(x)$.

Since the problem of multivariate estimation is an intellectual procedure and there are experts who are carriers of the input information, the problem of parametric identification of model parameters (16) is solved directly by the methods of expert assessment or by the method of comparative identification.

The method of comparative identification of the additive model for scalar evaluation of the utility of alternatives is as follows. The input information is the relation of a strict or non-strict order, determined by experts on a set of admissible alternatives

$$x_1 \succ x_2 \sim x_3 \sim x_4 \succ ...., \qquad (17)$$

where $\succ, \sim$ are the signs of advantage and equivalence correspond. According to the theory of utility for (17), the following relations hold:

$$P(x_1) > P(x_2) = P(x_3) > P(x_4) > .... \qquad (18)$$

Based on (18), one can compose a system of equations of the form

$$\begin{array}{l} P(x_2) - P(x_1) \le 0, \\ P(x_3) - P(x_2) = 0, \\ P(x_4) - P(x_3) \le 0. \\ .... \end{array} \qquad (19)$$

By substituting the utility function (16) into (19), we obtain a system of a_i irregularities that are linear with respect to the parameters, which determine the area of their possible values. The method of linear programming on the selected area determines the interval values $[a_i^{max}, a_i^{min}]$ of the parameters. In this case, regardless of the method, interval estimates of the parameters are determined $a_i = [a_i^{max}, a_i^{min}]; \forall i = \overline{1,n}$, and the size of the intervals depends on the scatter of the subjective individual labels of experts.

The interval uncertainty of the model variables (particular criteria) is determined by non-factors. Their analysis and accounting allows you to determine the range of possible values of each of them.

The next stage in identifying the model (16) consists in its fuzzification, that is, in the choice of the type and parameters of the membership function of the interval parameters and changes.

The weight coefficients a_i are interval fuzzy numbers, and the value of particular criteria can be specified both numerically, in the form of fuzzy numbers, and qualitatively, in the form of linguistic terms.

IV. Conclusion

1. It is shown that the basis of the civil protection system shall be a classical control loop, providing: collection, processing and analysis of information; modeling of the development of the situation at the object of management and the development of emergency situations on the territory of the city, region, state; development and two-overthrow of managerial decisions to prevent and eliminate emergencies, as well as to minimize their consequences; implementation of decisions on prevention and elimination of emergency situations, as well as minimization of their consequences.

2. It is proposed to create an effective information and analytical sub-system for managing the processes of prevention and elimination of emergencies by integrated inclusion in the existing civil protection system vertically, from the object to the state levels, of various functional elements of the territorial system for monitoring emergency situations and components of the system of situational centers, rigidly connected among themselves at the information and executive levels for making appropriate anti-crash decisions, for solving various functional tasks of monitoring, preventing and eliminating emergencies of a natural, man-made, social and military nature.

3. It has been determined that the functioning of the civil protection system, and the information and analytical subsystem for managing the processes of handling and liquidating emergencies (which consists of functional elements of the territorial system for monitoring emergencies and the system of situational centers) is visible, takes place in conditions of probabilistic dynamics of the level dangers of vital functions of the country's regions. This dynamics is due to the uncertainty of the parameters affecting the conditions of normal functioning of the territory of Ukraine. In this regard, the problem arises of making optimal anti-crisis decisions in conditions of uncertainty regarding the provision of an appropriate level of safety for the life of the state.

It is shown that the procedure for making managerial decisions is complicated by the fact that the necessary conditions for the effectiveness of decisions are their timeliness, completeness and optimality. Therefore, an increase in the efficiency of decisions made is associated with the need to solve the problem of multi-criteria optimization in conditions of uncertainty, which requires the development of formal, normative methods and models for a comprehensive solution to the problem of decision-making in conditions of multi-criteria and uncertainty when managing the processes of prevention and elimination of emergency situations to provide effective functioning protection system.

4. In order to solve the problem of multicriteria optimization in conditions of uncertainty, in this study, firstly, methods for obtaining input information about the advantages of a decision-maker are formalized, based on both the traditional heuristic procedures of expert evaluation, and on their formal methods of comparator identification. It is shown that regardless of the method of obtaining the input information and the form of its presentation, the most adequate is the interval assessment of the preferences of the decision-maker. Secondly, it is synthesized a model of a multicriteria scalar assessment of the usefulness of the assumed alternative solutions.

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