Strategy of Effective Decision-Making in Planning and Elimination of Consequences of Emergency Situations

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Abstract. Problem of decision-making in planning and elimination of consequences of emergency situations is considered. Sources of increasing of the effectiveness of measures oriented to prevention and elimination of consequences of emergency situations are discussed. Importance of decision-making in the process of the prevention, localization and liquidation of consequences of emergency situations is underlined. Problems of determining rational resources and funds to be allocated for prevention and liquidation of emergency situations are discussed. The main goal of a system for protection from emergency situations is defined as reduction or prevention of damage to human health and life, the objects of the economy and the environment arising as a result of accidents, catastrophes and natural disasters. Strategy of effective decision-making in planning and elimination of consequences of emergency situations is proposed and discussed. A system of partial indicators that characterize the prevented damage from emergency situations is proposed. To find the optimal resource allocation corresponded to the predicted disaster, the method of ideal point is used. Some examples are given and discussed.

Keywords: Emergency · Prevention · Decision-making · Resource allocation

1 Introduction

Significant growth of anthropogenic load on the environment in the world and in Ukraine, in particular, leads to an increase in the number of emergency situations of natural and man-made disasters, as well as an increased risk of their occurrence. The effectiveness of prevention and elimination of consequences of emergency situations (ES) is largely determined by the quality of planned relevant activities, the availability of reserves of material and financial resources.

Limited financial and material resources of the state, the growing demand for them in the prevention and elimination of consequences in case of emergency situations necessitate continuous improvement of methods for solving quality problems of planning for the appropriate activities and decision making during the emergency situations.

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A lot of research papers are dedicated to different aspects of decision making when planning and elimination of consequences of emergency situations.

General questions of the development of information systems for managing the processes of prevention, localization and liquidation of the consequences of emergencies, and the basic requirements for their creation are described in [1, 2].

The paper [3] describes designing and building a comprehensive system of systems that intend to be that support for emergency decision makers. Paper [4] represents the S-HELP Strategic Disaster Management wiki which has been developed by University of Vienna, Austria (UNIVIE). The project is focused on coordination and terminology standardization of individual agencies to work together, sharing information and resources. The wiki provides main glossary terms, definitions, and standards to improve decision making. Paper [5] describes the problem of patient transport in a large-scale disaster. A new decision making method to solve the problem of patient transport is proposed.

The DiMaS Tool research project is represented in [6]. It is oriented on creating tools for sorting and mapping already existing ready-to-use solutions, by specific parameters and characteristics, through the ICT skills, in order to help choose the most adequate and effective decision on disaster risk reduction. The decision supporting instrument allows enable a broad range of relevant stakeholders to choose the most suitable sheltering solution, dwelling unit or machinery needed.

The concept of a regional information-analytical system for emergency situations is presented in [7]. The three-level architecture of the system and the functions of its main components are described. A generalized model for assessing plans for eliminating the consequences of emergencies is described. The goals and peculiarities of the structural modules for the regional information and analytical system for the prevention and elimination of emergencies are detailed; some examples of the implementation of local subsystems for Ukraine are considered.

In books [8–10] general decision-making approaches and methods oriented to social and economic applications are represented. They may be used as a formal base for developing decision-making strategy for prevention, localization and liquidation of the consequences of emergency situations.

Development of various IT tools for support activities of the executives of various levels of civil protection agencies and organizations related to the prevention, localization and liquidation of consequences of emergency situations needs creation effective strategies as a formal base of the IT tools.

The aim of the paper is to develop a decision-making strategy for planning and eliminating the consequences of emergency situations using methods of multicriteria decision-making (multifactor assessment) and optimal allocation of resources.

2 Problem Formulation

Decision-making is the main function for the executives of various levels of civil protection agencies and organizations related to the prevention, localization and liquidation of consequences of emergency situations. Since methodical decision-support apparatus for civil protection administration is developed inadequately, the program management mechanisms are imperfect.

Problems of determining rational resources and funds to be allocated for prevention and liquidation of emergency situations are classified as problems of optimal control and decision making under multicriteriality, uncertainty and risk. Taking into account importance of the problem, the objective of efficiency in protection from emergency situations may be defined as a reduction (prevention) of damage to human health and life, the objects of the economy and the environment arising as a result of accidents, catastrophes and natural disasters. The value of avoided damage may be considered as an integral indicator of the efficiency of the planning system. Efficient use of resources can be assessed from different directions a set of partial indicators that characterize the damage prevented.

3 Decision-Making Strategy in Emergency Situations Evaluation

3.1 The Main Problems of Synthesis of Decision Support Systems

The problem of synthesizing the decision support system for prevention, localization and liquidation of the consequences of emergencies, contains the following tasks: the definition of the goal; analysis of the goal and specification of the system properties necessary for goal achievement; determination of the set of alternatives having the necessary properties; the selecting of the best alternative. They completely coincide with the tasks of the generalized classical decision-making procedure [8]. Analyze each of the selected tasks from the standpoint of system analysis.

Formation of the Goal. The goal is a desirable state, the achievement of which requires the implementation of purposeful actions. The state of the system is described by the values of its properties, which are measured in a definite metric. If the actual and desired states do not coincide, a problem situation arises, the solution of which is to eliminate this inconsistency. In this case, the desired state is the goal, and the method of achieving it is the solution of the problem.

Specification of Properties. At the initial stage, the goal is most often determined by generalized verbal statements. Further constructive purposeful analysis and synthesis of the system is associated with the allocation and measurement necessary to achieve the goal of functional qualities (properties). In the general case it is impossible to highlight a single property that fully characterizes the system. Therefore, it is necessary to determine a certain set of properties, each of which characterizes the partial (local) functional quality, and together they are sufficiently fully characterizing the system as a whole. Consequently, the system is characterized by a set of properties.

Partial properties by definition have different functional content, dimensionality, intervals of possible values and are measured in different scales.

Existance of a set of properties determines belonging to a class of systems of a definite goal orientation. The specific values of these properties, which are measured on certain scales, characterize the extent to which the goal is achieved (the functional quality of the system as a whole).

The stage of selecting the necessary properties of the system is very important because the set of properties defines both the degree of compliance of the goal and the potential effectiveness of the system. The set should be limited, that is, it should contain only the most important properties, and at the same time it should be enough to fully characterize the system and its capabilities. The achievement of such a compromise in the general case, especially for complex, large-scale systems, is far from a trivial task. In real practice, the designing of the systems corresponds to the pre-project stages: feasibility study and the development of a technical task.

Determination of the Set of Alternatives. As it follows from the definition of a system, its properties can be realized only on an ordered set of elements and relations. The set of feasible solutions contains all possible variants of constructing a system that differ in quality (sets of elements and/or relations), or quantitatively, that is, the values of the parameters (characteristics) of the elements. This set defines the domain of the existence of a system with given properties. Not all the solutions in the area of existence are feasible, feasible or appropriate from technical, technological, social, economic, environmental, moral, ethical and other reasons. Set of feasible solutions is selected from the set taking into account these constraints.

3.2 Formalization of Decision-Making Tools

The goal of the decision-making problem is characterized by partial properties and the level of its achievement – by their quantitative values. Thus, comparisons of solutions can be carried out according to the achieved level of partial properties. Implementation of each decision requires, in general, the spending of various resources (financial, material, time, environmental, etc.). In conjunction, the costs determine the "price" that needs to be "paid" for achieving the goal.

As it follows from the definition, the partial criterion characterizes the partial properties of the solutions and the associated costs, reduced to a form that allows the measurement in quantitative or qualitative scales.

Formally, partial criteria are represented by scalar or vector mapping $k(x) : X \to Y$, where X is the set of feasible solutions, and Y is a criterion set containing their possible values.

A set of criteria that assess the useful functional properties of solutions is designated as $\Phi_f = \{k_1, \ldots, k_{n_f}\}$. A set of criteria that measures the level of spending on each resource is designated as $\Phi_c = \{k_1, \ldots, k_{n_c}\}$.

Note that in a particular case, sets Φ_f and Φ_c may contain single element, but in general these sets are heterogeneous in content, and, therefore, having different dimensions, measured in different scales and intervals of partial criteria. Thus, each solution is characterized by a set of heterogeneous partial criteria:

$$\Phi = \Phi_f \cup \Phi_c = \{k_1, k_2, \ldots, k_n\},\ n = n_f + n_c.$$

The choice of a system of partial criteria is an unformalized, heuristic problem. Its solving is complicated by the necessity of carrying out such, in some sense, contradictory conditions: on the one hand, a set of criteria must be sufficiently detailed to characterize the decision; on the other hand, contain minimal number of criteria. In addition, different criteria should not characterize the same qualities.

The above requirements are generally controversial and cannot be satisfied simultaneously. Therefore, when forming a set of criteria in real problems, it is necessary to find a compromise.

Thus, the mathematical model of the multicriteria decision-making problem can be represented as the following optimization problem:

$$X^0 = Arg \underset{x \in X}{extr} \{k_1(x), k_2(x), \ldots, k_n(x)\}, \tag{1}$$

where $k_i(x), i = 1, 2, \ldots, n$ are partial criteria, X is the feasible set.

It should be noted that since the problem (1) is multicriterial, then the following solutions are possible: $X^0 = \{\varnothing\}$, empty set; the single solution $X^0 = \{x^0, x^0 \in X\}$; not the single solution, $X^0 \subset X$.

3.3 System of Local Criteria for Estimation of Emergency Situations

When deciding on the assessment of emergencies, it is necessary to take into account the most important indicators that characterize the manifestation of the emergency situation, its possible predicted effects and the resources needed to eliminate it. The following parameters are among them:

- the possible zone of radioactive, chemical and bacteriological contamination;
- catastrophic flood zones, fires, explosions;
- population, economic facilities, which may be in range of damaging factors;
- the number of victims;
- possible damage to property;
- the amount of future measures to eliminate emergency situations and their consequences;
- forces, means and procedure for implementation of measures under the threat and emergency situations.

Based on these indicators, and on the requirements for decision criteria, we propose a system of criteria for assessing the emergency situation and resources for its elimination. Therefore, such the partial criteria are chosen:

- potential loss of life;
- cost of material assets, the economic objects destroyed when a disaster occurs;
- reduced material damage to the environment;
- the cost of commissioning and transportation of resources (manpower and materials);
- total present value of the resources allocated for the implementation of complex measures on prevention and liquidation of emergency situations.

3.4 Formation of a Plan of Action for the Prevention and Elimination of an Emergency Situation

Determination of rational values of resources and funds allocated to measures for the prevention and elimination of emergency situations is one of the key problems solved in the framework of the strategy. The purpose of such measures can be defined as the reduction (prevention) of damage to the health and life of people, economic objects and the environment resulting from accidents, disasters and natural disasters. The amount of damage prevented can be considered as an integral indicator of the effectiveness of the planning system.

Allocated resources are intended for two main tasks.

The first task is preventing certain emergencies specific to a given region and time period based on

- systematization of data on emergency situations and their prerequisites;
- expert assessments of the nature of the respective emergency situations.

The second one is timely response to an emergency when it occurs.

Solving problems of optimal allocation of limited resources for the formation of appropriate emergency prevention and response plans can be carried out both on the basis of expert assessments and statistical data [8], and on the basis of formal methods related to operations research [11].

3.5 Choosing Plan of Action Based on Decision-Making

The choice of the best action plan for preventing or eliminating an emergency is based on solving a multicriteria problem (1). Proceeding from the properties of the problem, we can conclude that in many cases there is no single solution of problem (1). To get a solution it is necessary to transform problem (1). One of the common approaches to solving multicriteria optimization problems is based on transformation of a multicriterial problem into one-criterion one. In this class of methods, the ideal point method was used to select the best action plan for preventing or eliminating an emergency [8].

The Method of an Ideal Point. The idea of this method is to construct and use in determining the optimal solution x^0 of the so-called ideal point $\hat{x} = (\hat{x}_1, \hat{x}_2, \ldots, \hat{x}_n)$, which is defined as follows:

$$\hat{x}_i = \arg \underset{x \in X}{extr}\, k_i(x),\ \hat{k}_i = \underset{x \in X}{extr}\, k_i(x),\ \hat{k}_i = k_i(\hat{x}_i), i \in J_n.$$

Thus, the ideal point gives extreme value to all partial criteria. It is clear that in most cases the ideal point does not belong to the set of alternatives, i.e. $\hat{x} \notin X$, and $\hat{y} = (\hat{k}_1, \hat{k}_2, \ldots, \hat{k}_n) \notin Y$, where $y = (k_1(x), k_2(x), \ldots, k_n(x))$.

The ideal point method assumes that as the optimal solution x^0, one should choose a point from the set of alternatives that is closest to the selected metric to the ideal point.

Let $\rho(y, \hat{y}) = \left\{ \sum_{i=1}^{n} | k_i(x) - \hat{k}_i |^p \right\}^{\frac{1}{p}}, p \geq 1.$

Find the optimal solution as a result of solving the optimization problem

$$\rho(y, \hat{y}) \to \min_{x \in X},\ x^0 \in Arg \min_{x \in X} \rho(y, \hat{y}),$$

Value Analysis. According to the method, the system of partial criteria $K = \{k_i(x),\ i = 1, 2, \ldots, n\}$ is divided into two subsets: $K_f = \{k_{fi}(x), i = 1, 2, \ldots, n_f\}$ and $K_z = \{k_{zj}(x), j = 1, 2, \ldots, n_z\}$, $n_f + n_z = n$.

The first subset of the criteria K_f characterizes the functional quality of the solution $x \in X$, that is, the degree of achievement of the goal. In the proposed system of criteria, these are the following partial criteria:

- prevention of potential deaths of people (number of people rescued);
- the cost of material assets, economic objects preserved during a natural disaster;
- reduced material damage to the environment.

The second subset of the criteria K_z is the costs necessary to implement the solution x, among which:

- costs of commissioning and transportation of resources (labor resources and materials);
- the total estimated cost of resources allocated for the implementation of integrated measures for the prevention and elimination of emergencies.

In each of these subsets one main criterion is specified, they are designated accordingly $k_{fi*}(x) = k_f^*(x)$ and $k_{zj*}(x) = k_z^*(x)$; the rest of the partial criteria $K \backslash \{k_f^*(x), k_z^*(x)\}$ are transformed to the system of constraints. As a result, we receive an optimization problem with two criteria $k_f^*(x)$ and $k_z^*(x)$.

In the value analysis the following approaches are used.

If both criteria $k_f^*(x)$ and $k_z^*(x)$ have the same dimension (for example, the cost of material assets, economic objects preserved during a natural disaster and costs of commissioning and transportation of resources), an optimization criterion is used

$$k(x) = k_f^*(x) - k_z^*(x) \tag{2}$$

and the optimal solution is defined as follows: $x^0 = \arg\max_{x \in X^*} k(x)$,

where

$$X^* = \left\{x \in X | k_{fi}(x) \geq k_{fi}^-, i \neq i^*, k_{zj}(x) \leq k_{zj}^-, j \neq j^*, i = 1, \ldots, n_f, j = 1, \ldots, n_z\right\}.$$

The criterion of the form (2) can be interpreted as profit.

If the criteria $k_f^*(x)$ and $k_z^*(x)$ have different dimensions (for example, the number of people rescued and the total estimated cost of resources allocated for the implementation of integrated measures for the prevention and liquidation of emergencies), then the criterion of the form is used:

$$k(x) = \frac{k_f^*(x)}{k_z^*(x)}, \tag{3}$$

and the optimal solution has this form $x^0 = \arg\max_{x \in X^*} k(x)$.

The criterion (3) is the normalized unit cost effect.

Multi-factor Estimation. The most general and universal approach to solving the multicriteria optimization problem (1) is known as the problem of multi-factor estimation. The central task of this problem is to construct a generalized assessment of solutions $x \in X$ (generalized criteria). We introduce dimensionless weighting coefficients a_i of relative importance of partial criteria for which constraints are fulfilled:

$$0 \le a_i \le 1, \quad \sum_{i=1}^{n} a_i = 1.$$

For the system of partial criteria normalization is carried out. The normalization of partial criteria means that they are transform to the same dimension and interval of possible values, and also become invariant to the type of extremum (maximum or minimum).

Requirements for the normalization of partial criteria correspond to the function of the local utility of the form $p_i(x) = \left(\frac{k_i(x) - k_i^-}{k_i^+ - k_i^-}\right)^{\alpha_i}$, where $k_i(x)$ is the value of the partial criterion; k_i^+, k_i^- are the best and worst values of the partial criterion $k_i(x)$ in the area of feasible solutions $x \in X$, respectively.

Depending on the type of extremum (the direction of domination) we have

$$k_i^+ = \begin{cases} \max_{x \in X} k_i(x), & \text{if } k_i(x) \to \max, \\ \min_{x \in X} k_i(x), & \text{if } k_i(x) \to \min; \end{cases}$$

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

The parameter α_i defines the type of dependence: $p_i(x)$ is a concave function for $0 < \alpha_i < 1$; $p_i(x)$ is a linear function for $\alpha_i = 1$; $p_i(x)$ is a convex function for $\alpha_i > 1$, respectively.

Here are the basic situations of decision-making, depending on the degree of certainty in the form of submitting information about the importance of weight coefficients $a_i, i = 1, 2, \ldots, n$.

1. Exact quantitative values of the weight coefficients a_i of partial criteria $k_i(x)$ are known, as well as their utility functions $p_i(x)$. Then the generalized criterion is presented in the form

$$P(x) = \sum_{i=1}^{n} a_i \cdot p_i(x) \tag{4}$$

and the best solution is follows:

$$x^0 = \arg\max_{x \in X} \sum_{i=1}^{n} a_i \cdot p_i(x).$$

2. Quantitative weighting factors are unknown, but Decision Maker has information that allows ranking partial criteria by their importance:

$$k_1(x) \succ k_2(x) \succ \ldots \succ k_n(x).$$

This situation is less informative in comparison with the case when there is quantitative information about the importance of weight coefficients a_i, $i = 1, 2, \ldots, n$. In this case, the defining of the domination of partial criteria $k_1(x) \succ k_2(x) \succ \ldots \succ k_n(x)$ means that $a_1 > a_2 > \ldots > a_n$, that is, qualitative information about the mutual importance of the criteria is known. This information is most fully used when choosing a compromise solution by the method of sequential optimization [8].

3. Decision Maker has neither quantitative nor qualitative information on the coefficients a_i, $i = 1, 2, \ldots, n$.
In this case we specify $a_i = \frac{1}{n}$, $i = 1, 2, \ldots, n$. Then, based on (4), the generalized criterion for the alternative $x \in X$ is

$$P(x) = \frac{1}{n} \cdot \sum_{i=1}^{n} p_i(x). \tag{5}$$

and the solution is determined in the form

$$x^0 = \arg\max_{x \in X} \frac{1}{n} \cdot \sum_{i=1}^{n} p_i(x). \tag{6}$$

The models (5), (6) are valid only if the values of the weight coefficients a_i, $i = 1, 2, \ldots, n$, are equal to each other. In the general case, real values a_i, $i = 1, 2, \ldots, n$ are unknown, and may be any values. In this case, we should use the model of a maximin:

$$x^0 = \arg\max_{x \in X} \min_{i=1,2,\ldots,n} p_i(x).$$

4 Conclusion

The proposed strategy based on formal approaches will improve the quality and speed of decision making in the planning of prevention activities and disaster management. A generalized indicator is formed as a convolution of partial characteristics, the value of which depends on the selected heterogeneous resources. To find the optimal resource allocation corresponded to the predicted disaster, the method of ideal point is used. When an emergency significantly different from the predicted one occurs, rational resource allocation may be defined based on value analysis. The strategy could serve as a basis for the creation of intellectual decision support system for officials in Civil Protection.

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