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MULTI-CRITERIA ASSESSMENT OF THE CORRECTNESS OF DECISION-MAKING IN INFORMATION SECURITY TASKS

Theoretical optimization models assume the presence of a single criterion. Therefore, the solution of the problem by the method of vector (multi-criteria) optimization is of particular interest in the problems of cybersecurity and information security. Especially when it is necessary to evaluate the correctness of the made decisions (CMD). In the paper this problem is solved so that it can be asserted that the decision was made correctly in this particular case when solving a problem while ensuring the information security of a particular object. The problems of developing and using means of protection against "weapons of mass destruction" - information weapons, which are widely used in modern conditions, are becoming relevant. Understanding and analyzing the negative consequences associated with the vulnerability of computer equipment and various information technologies, the problem arises of the need to carry out work to ensure information and cyber security. It is necessary to conduct research and work in many areas - from the development of the theoretical foundations of the information content of computer systems to the development of domestic programs and hardware for technical protection. The solution of these problems may have specific features for individual computer equipment, for automated systems, for local and distributed computing networks, and especially for the Internet. The implementation of models is possible only in the form of a complex of software and hardware based on computer technology with the obligatory use of digital maps of the area. It is necessary to take into account the usefulness of the decisions made. The decision-making problem often encounters a situation, and in our case it is very often when there are several criteria for evaluating a decision. This is due to the multipurpose nature of the situation.

Keywords: correctness of decision-making, multi-criteria assessment, information security.

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БАГАТОКРИТЕРІАЛЬНА ОЦІНКА ПРАВИЛЬНОСТІ ПРИЙНЯТИХ РІШЕНЬ У ЗАДАЧАХ ІНФОРМАЦІЙНОЇ БЕЗПЕКИ

Теоретичні моделі оптимізації припускають наявність єдиного критерію. Тому розв'язання задачі методом векторної (багатокритеріальної) оптимізації становить особливий інтерес у задачах кібербезпеки та інформаційної безпеки. Особливо, коли необхідно оцінити правильність прийнятих рішень (ППР). У роботі дана задача розв'язана таким чином, що можна стверджувати, що в даному конкретному випадку було прийнято правильне рішення при розв'язанні задачі при забезпеченні інформаційної безпеки конкретного об'єкта. Актуальними стають проблеми розробки та використання засобів захисту від «зброї масового ураження» – інформаційної зброї, яка широко використовується в сучасних умовах. Розуміючи та аналізуючи негативні наслідки, пов'язані з уразливістю комп'ютерної техніки та різних інформаційних технологій, постає проблема необхідності проведення робіт із забезпечення інформаційної та кібернетичної безпеки. Необхідно проводити дослідження і працювати за багатьма напрямками - від розробки теоретичних основ інформаційного наповнення комп'ютерних систем до розробки вітчизняних програмно-апаратних засобів технічного захисту. Рішення цих завдань може мати особливості для індивідуального комп'ютерного обладнання, для автоматизованих систем, для локальних і розподілених обчислювальних мереж і особливо для Інтернету. Реалізація моделей можлива лише у вигляді комплексу програмно-технічних засобів на базі комп'ютерної техніки з обов'язковим використанням цифрових карт місцевості. Необхідно враховувати корисність прийнятих рішень. Проблема прийняття рішення часто стикається з ситуацією, а в нашому випадку дуже часто, коли є кілька критеріїв оцінки рішення. Це пов'язано з багатоцільовим характером ситуації.

Ключові слова: правильність прийняття рішень, багатокритеріальна оцінка, інформаційна безпека.

Introduction

Information has become an important strategic resource that is necessary for the successful operation of the state, society and man. At the same time, the information society implies not only the development of the technological component, but also the appropriate level of knowledge development, the highest level of education, the rapid pace of development of science and high technologies.

Now the problems of developing and using means of protection against "weapons of mass destruction" - information weapons, which are widely used in modern conditions, are becoming relevant.

Already now, understanding and analyzing the negative consequences associated with the vulnerability of computer equipment and various information technologies, the problem arises of the need to carry out work to ensure information and cyber security. In general, these problems are multifaceted. It is necessary to conduct research and work in many areas - from the development of the theoretical foundations of the information content of computer systems to the development of domestic programs and hardware for technical protection.

It should be noted that the solution of these problems may have specific features for individual computer equipment, for automated systems, for local and distributed computing networks, and especially for the Internet.

Therefore, a rather important problem that needs to be solved is to determine the list of necessary measures for cybersecurity and technical protection of information in each specific case, determining the list of threats. Such a definition is possible based on the analysis of threat models and protection tools.

A modern approach to solving these problems requires that these models to be modern and combined. The main difference between these models is that they must be dynamic in nature, i.e. so that, along with static information of a general nature, they would allow situational modeling of defense processes using specific means, taking into account existing means of reconnaissance and attack, with reference to a specific object of protection. In this case, it becomes possible to obtain a specific threat model for each specific object in which information needs to be protected, based on the use of technical threat models and object protection. Of course, the implementation of models is possible only in the form of a complex of software and hardware based on computer technology with the obligatory use of digital maps of the area. And at the same time, it is necessary to take into account the usefulness of the decisions made. It should also be taken into account that when developing models, the decision-making problem often encounters a situation, and in our case it is very often when there are several criteria for evaluating a decision. This is due to the multipurpose nature of the situation. At the same time, theoretical optimization models assume the presence of a single criterion. Therefore, the solution of the problem by the method of vector (multi-criteria) optimization is of particular interest in the problems of cybersecurity and information security, especially when it is necessary to evaluate the correctness of the made decisions (CMD).

Related works

The whole set of vector optimization methods, despite their diversity, can be classified as follows:

1) methods of multi-criteria CMD functions, characterized by the synthesis of a single generalized criterion based on a given set of local criteria [1,2];
2) algorithmic methods that regulate a certain sequence of solving specially formulated optimization problems [3,4].

The advantage of methods belonging to the first class is the numerical evaluation of the optimal solution, as well as its numerical comparison with other solutions of interest and with the "ideal" (if it is known).

The theoretical basis for constructing the SPR function was laid down in [5], where a system of rational behavior axioms was formulated, on the basis of which the existence and uniqueness of an individual (local) CMD function was proved. These axioms have the following meaning.

Axiom 1. Comparability of objects of evaluation and transitivity of preferences.

For each pair ω_1, ω_2 only one of the relations is satisfied $\omega_1 \leftarrow \omega_2$, $\omega_1 \rightarrow \omega_2$, $\omega_1 \sim \omega_2$. Moreover, from $\omega_1 \leftarrow \omega_2$, $\omega_2 \leftarrow \omega_3$, it follows $\omega_1 \leftarrow \omega_3$.

Axiom 2. If $\omega_1 \leftarrow \omega_2 \leftarrow \omega_3$, then there is such a parameter $r \epsilon [0,1]$, that $\omega_2 \sim [r\,\omega_1 + (1-r)\,\omega_3]$.

Axiom 3. Validity of commutative and distributive laws:

$[r\omega_1 + (1-r)] \sim [(1-r)\omega_2 + r\omega_1]$;

$\{r[q\omega_1 + (1-q)\omega_2\} + (1-r)\omega_2\} \sim [p\omega_1 + (1-p)\omega_2]$, $(p = rq)$.

When axioms 1-3 are satisfied, there is a CMD function that maps the set of evaluation objects to real numbers. For it $u(\omega_1) < u(\omega_2)$ if $\omega_1 \leftarrow \omega_2$;

$$u(\omega_1) = u(\omega_2) \text{ if } \omega_1 \sim \omega_2. \quad (1)$$

This expression transforms into the next form:

$$u(\omega) = u[r(\omega_1) + (1-r)\omega_2] = [ru(\omega_1) + (1-r)u(\omega_2)]. \quad (2)$$

The CMD expression u is unique up to a positive linear transformation, i.e. for any other expression u satisfying these axioms,

$$u(\omega) = \alpha u(\omega) + \beta, \alpha > 0. \quad (3)$$

In [6] and other works, the parameter r in (2) was interpreted as the value of the probability in a lottery with two outcomes (ω_1, ω_2). However, the theory of fuzzy sets [7] allows to propose a different interpretation: if $\omega_1 \rightarrow \omega \rightarrow \omega_2$, then the parameter $r \in [0,1]$ is the degree of belonging of the object ω_1 to the fuzzy set of CMD, for which the highest degree of membership belongs to the object ω_1, the lowest - object ω_2. Then $r(\omega)$ is a membership function of ω in the same fuzzy set.

Let there be a set of local evaluation criteria *N=(1,2,3,…,n)*. Then the vector estimation problem includes two stages:

1) the stage of assessing the object ω for each i-th local criterion $x_i = u_i(\omega)$, $x_i \in X_i$;
2) the stage of assessing the object $x_N = (x_1, x_2, x_3, \dots, x_n) \in X_N$, where X_N - Cartesian product of measuring scales of local criteria $X_N = X_1 * X_2 * X_3 * \dots * X_n$.

Let introduce the assumption that axioms 1-3 are valid not only for objects ω, but also for vectors of estimates $x_N \in X_N$, which means that there is a mapping

$$U: X_N \to R^1. \quad (4)$$

This is a very strong assumption, and the most likely objections to it are: X_N objects are non-transitive. The answer to the first objection is that X_N objects are a reflection of various ways to achieve the goal, each of which is characterized by its degree of achievement. Therefore, they are just from the point of view of this purpose. Therefore, objects that are not related to this goal will be incomparable from this point of view. The case of incomparability is the absence of a goal, but here there is no need to determine the CMD in relation to objects. It is difficult to give a categorical answer to the second objection. However, experiments show that the made decisions are usually transitive [8][9].

Main part

To obtain the form of the multicriteria CMD function, we formulate two additional axioms.

Axiom 4. Symmetry. Changing the designations of local criteria does not change the nature of preferences:

$$(x_1, x_2, \dots, x_i, \dots, x_j, \dots, x_n) \sim (x_1, x_2, \dots, x_j, \dots, x_i, \dots, x_n).$$

This axiom is somewhat analogous to the commutative law from Axiom 3, which implies that no restriction is imposed on the method of numbering local criteria. In what follows, based on Axiom 4, we will use the following notation: x_N- is the vector of ratings by all local criteria, x_P- is the vector of ratings by local criteria from the non-empty set $P \subset N$, $x_{\frac{N}{P}}$- is the vector of ratings by local criteria from set that is the difference N\P. Then $x_N = (x_P x_{N\setminus i})$, if *P*- is a one-element set, $x_N = (x_i x_{N\setminus i})$.

Axiom 5. Monotony of group preferences. Any improvement in the rating vector for one or more local criteria, with the level of ratings for the rest unchanged, leads to the fact that the new rating vector will be at least no worse than the original one, i.e., from $x'_p \leftarrow x''_p$ it follows $(x_P x_{N\setminus P}) \precsim (x''_p x_{N\setminus P})$.

Suppose, for the values of each i-th local criterion, a range is given

$$x'_i \precsim x_i \precsim x''_i. \quad (5)$$

Then, based on Axioms 2 and 5, for any value of $x_{N\setminus i}$ we have

$$(x_i x_{N\setminus i}) \sim [\lambda_i (x''_i x_{N\setminus i}) + (1-\lambda_i)(x'_i x_{N\setminus i})], (i \in N). \quad (6)$$

In accordance with (2), the CMD function of the i-th local criterion, taking into account the influence of $x_{N\setminus i}$ on x_i, has the form

$$U(x_i x_{N\setminus i}) = \lambda_i (x_i | x_{N\setminus i}) U(x''_i x_{N\setminus i}) + [1 - \lambda_i (x_i | x_{N\setminus i})] U(x'_i x_{N\setminus i}), \quad (7)$$

where $\lambda_i (x_i | x_{N\setminus i}) \in [0,1]$ – conditional membership function of the vector $(x_i | x_{N\setminus i})$ to the fuzzy set of CMD defined by the boundaries $(x''_i x_{N\setminus i})$ and $(x'_i x_{N\setminus i})$. The term "conditional" here is understood in the same way as in probability theory in relation to distribution functions. If the i-th criterion does not depend on the others in terms of correctness, then expression (7) is simplified:

$$U(x_i x_{N\setminus i}) = \lambda_i (x_i) U(x''_i x_{N\setminus i}) + [1 - \lambda_i (x_i)] U\left(x'_i x_{\frac{N}{i}}\right).$$

Function (7) is indeed a function of the CMD of a local criterion, despite the use of the designation of the multi-criteria correctness function U. This is obvious if, using property (3), we denote $U(x''_i x_{N\setminus i}) = 1$, $U(x'_i x_{N\setminus i}) = 0$, whence it follows $U(x_i x_{N\setminus i}) = \lambda_i (x_i x_{N\setminus i})$.

Proceeding from these provisions, we will prove the main property of the function of multi-criteria decision-making correctness.

<u>Theorem</u>. There is an analytical expression for the multi-criteria CMD function from the set of CMD functions of local criteria.

<u>Proof</u>. First consider the two-dimensional case $x_N = (x_1 x_2)$, and then extend the result to any N.

Let us write expression (7) for the correctness function of the second criterion, provided that the evaluation of the first x_1

$$U(x_1 x_2) = \lambda_2(x_2|x_1)U(x_1 x_2'') + [1 - \lambda_2(x_2|x_1)]U(x_1 x_2). \quad (8)$$

Similarly, we write expressions for the CMD function of the first criterion for x_2'', x_2':

$$U(x_1 x_2'') = \lambda_1'(x_1|x_2'')U(x_1'' x_2'') + [1 - \lambda_1(x_1|x_2'')]U(x_1' x_2''); \quad (9)$$
$$U(x_1 x_2') = \lambda_1(x_1|x_2')U(x_1'' x_2') + [1 - \lambda_1(x_1|x_2')]U(x_1' x_2'). \quad (10)$$

Using Axiom 3, substituting (9) and (10) into (8). Thus, we supplement the preference characteristic according to the second criterion (8) with the corresponding characteristics according to the first criterion (9) and (10). As a result, we obtain the CMD function of the object $(x_1 x_2)$ according to two local criteria:

$$\begin{aligned} U(x_1 x_2) = {} & \lambda_1(x_1|x_2'')\lambda_2(x_2|x_1)U(x_1'', x_2'') + \\ & +[1 - \lambda_1(x_1|x_2'')]\lambda_2(x_2|x_1)U(x_1' x_2'') + \\ & +\lambda_1(x_1|x_2')[1 - \lambda_2(x_2|x_1)]U(x_1'', x_2') + \\ & +[1 - \lambda_1(x_1|x_2')][1 - \lambda_2(x_2|x_1)]U(x_1' x_2'). \end{aligned} \quad (11)$$

Based on Axioms 2 and 5, we express $U(x_1' x_2'')$ and $U(x_1'', x_2')$ in terms of boundary values:

$$U(x_1' x_2'') = \lambda_{(12)}(x_1' x_2'')U(x_1'' x_2'') + \left[1 - \lambda_{(12)}(x_1' x_2'')\right]U(x_1' x_2'); \quad (12)$$

$$U(x_1'' x_2') = \lambda_{(12)}(x_1'' x_2')U(x_1'' x_2'') + \left[1 - \lambda_{(12)}(x_1'' x_2')\right]U(x_1' x_2'). \quad (13)$$

Using Axiom 3, we substitute (12) and (13) into (4). As a result, we get

$$U(x_1 x_2) = \lambda_{(12)}(x_1 x_2)U(x_1'' x_2'') + \left[1 - \lambda_{(12)}(x_1 x_2)\right]U(x_1' x_2'). \quad (14)$$

where $\lambda_{(12)}(x_1 x_2) = \{1 - [1 - \lambda_1(x_1|x_2'')][1 - \lambda_{12}(x_1'|x_2'')]\}\lambda_2(x_2|x_1) + +\lambda_1(x_1|x_2')\lambda_{(12)}(x_1'' x_2')[1 - \lambda_2(x_2|x_1)]$, $\lambda_{(12)}(x_1 x_2) \in [0,1]$. (15)

Therefore, the resulting function (14) implements U: $(X_1 X_2) \to R^1$. This means that the set of the first and second local criteria can be replaced by a new scalar criterion $x_{(12)}$, for which $x_{(12)}' \precsim x_{(12)} \precsim x_{(12)}''$. Then similar reasoning for criteria $x_{(12)}$, x_3 will lead to the CMD function of three criteria $x_{(123)}$. After performing this procedure *(n-1)* times, we obtain the correctness function for N local criteria:

$$U(x_N) = \lambda_N(x_N)U(x_N'') + [1 - \lambda_N(x_N)]U(x_N'), \quad (16)$$

where $x_N'' = (x_1'' x_2'' x_3'' \dots x_n'')$, $x_1' x_2' = (x_1' x_2' \dots x_n')$.

When implementing the mapping p: $\lambda_{I|i}(x_{I|i}) \to \lambda_{I|i}(x_{I|i}|x_i)$; the value $\lambda_N(x_N)$ is determined similarly to (15) by the recursive formula

$$\begin{aligned} \lambda_I(x_I) = {} & \{1 - [1 - \lambda_{I|i}(x_{I|i}|x_i'')][1 - \lambda_I(x_{I|i}' x_i'')]\}\lambda_i(x_i|x_{I|i}) + \\ & +\lambda_{I|i}(x_{I|i}|x_i')\lambda_I(x_{I|i}'' x_i')[1 - \lambda_i(x_i|x_{I|i})],\ \lambda_I(x_I) \in [0,1). \end{aligned} \quad (17)$$

In this formula $I = (1,2,3, \dots, i)$, $I|i = (1,2,3, \dots, i-1)$.

The CMD function (16) is the only one up to a positive linear transformation (3), which is obvious from $U(x_N) = \lambda_N(x_N)[U(x_N'') - U(x_N')] + U(x_N')$. This means that the choice of the beginning and end of the scale of the correctness of decision-making is not fundamental, only the function $\lambda_N(x_N)$, which is determined by the set of N CMD functions of local criteria according to the rule (17). The theorem has been proven.

Using a similar technique, it is easy to show that for $(x_i x_{N|i}) = \alpha_i U(x_i x_{N|i}) + \beta_i$, $\alpha_i > 0$ there is $V(x_N) = \alpha_N U(x_N) + \beta_N$, where α_N, β_N are determined by recursive formulas

$$\alpha_I = \alpha_{I|i}\alpha_i, \beta_I = \beta_{I|i}\alpha_i + \beta_i.$$

The proved theorem fundamentally solves the question of the uniqueness of the multicriteria CMD function. However, the resulting expression (17) is inconvenient for analysis in real problems. In [10], it is shown that the fulfillment of Axiom 5 generates three goal-forming principles in multicriteria problems. For each of the principles, its own multi-criteria correctness function is synthesized, which is a special case of (17), which is constructive.

Conclusions

It should be noted that, in contrast to [9], the term “correctness independence” of the i-th criterion means that the utility function of the SPR is unchanged for any value of the evaluation vector $x_{N|i}$, i.e. the condition (18) is met

$$\lambda_i(x_i|x_{N|i}) = \lambda_i(x_i). \quad (18)$$

This is a less stringent condition than the equivalence of various combinations of vector objects [11]. Therefore, in this setting, independence does not mean the additivity of local estimates.

To check the possibility of fulfilling condition (18), we write the CMD function of i-th local criterion (7) in the form:

$$\lambda_i(x_i|x_{N|i}) = \frac{U(x_i x_{N|i}) - U(x_i' x_{N|i})}{U(x_i'' x_{N|i}) - U(x_i' x_{N|i})}. \quad (19)$$

Differentiating (19) in the direction determined by the vector $x_{N|i}$, and equating the numerator to zero, we obtain the required condition

$$\frac{\partial U(x_i x_{N|i})}{\partial x_{N|i}}[U(x_i'' x_{N|i}) - U(x_i' x_{N|i})] - -\frac{\partial U(x_i'' x_{N|i})}{\partial x_{N|i}}[U(x_i x_{N|i}) - U(x_i' x_{N|i})] - -\frac{\partial U(x' x_{N|i})}{\partial x_{N|i}}[U(x'' x_{N|i}) - U(x_i x_{N|i})] = 0. \quad (20)$$

For each goal-forming principle [10], condition (20) is satisfied if the change in the correctness of the vector x_N with a change in only one i-th component can be described by a function only from this component $U(x_i x_{N|i}) = \alpha_i(x_i x_i')U(x_i x_{N|i}) + \beta_i(x_i x_i')$. That is, the correctness of decision-making allows us to assert that the decision was made correctly in this particular case when solving a problem while ensuring the information security of a particular object.

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