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AN IMPROVED METHOD OF HIERARCHIC ANALYSIS FOR CHOOSING OPTIMAL INFORMATION PROTECTION SYSTEM IN COMPUTER NETWORKS

An improved hierarchic analysis method, based on the interval estimate of the preferences of criteria and alternatives, is proposed and investigated.

Key words: *decision-making, interval calculations, multicriterion problems.*

Introduction

In up-to-date computer and telecommunication networks various information protection systems and means are widely used. They must provide the required level of protection and at the same time should not be too complicated and expensive in the development and operation [1].

As a large number of conflicting criteria is a general characteristic of information protection systems (e.g., price – quality), the choice of a definite architecture for the information protection system is a complicated, multiparametric and optimization problem that, to a great extent, depends on the system of preferences of a person or persons who make the choice [2].

Currently, a large number of methods exist for solving decision-making problems with many criteria: methods of criteria reduction to a single criterion (the methods of main component, complex criterion, of a justified compromise, the method of Hermeyer, construction and analysis of Edgeworth – Pareto set) and methods for studying psychological peculiarities of a person that is making decision (DMP) (multicriterion utility theory, hierarchic analysis method, methods for ranking multicreterion alternatives) [3].

For solving the problem of choosing the optimal information protection system, methods based on the psychological study of a DMP are considered to be the most feasible ones [3]. In this group the method of hierarchic analysis is the most widely used one and the easiest for understanding. However, this method does not enable full description of DMP system of preferences. Also, it cannot be used in case of several DMP with conflicting systems of preferences. Therefore, it is feasible to improve the hierarchic analysis method.

Problem statement

Let us set the task of the development and investigation of the method for choosing the optimal information protection system in the case of several DMP or when uncertainties are present in the system of DMP preferences. For this we shall consider an improved method of hierarchic analysis.

An improved method of hierarchical analysis

The traditional analysis of hierarchies was proposed by Saati [4]. In this method a tree of criteria is used where general criteria are divided into criteria of specific character. For each group of criteria the importance coefficients are determined. The alternatives are also compared with one another according to individual criteria. Importance coefficients of the criteria and alternatives are determined by a pairwise comparison. The results of comparison are evaluated according to a definite scoring scale. On the basis of such calculations the criteria importance coefficients, estimates of the alternatives are found and general estimate is found as a weighted sum of the criteria estimates. The usage of scoring evaluation does not allow describing the uncertainty of DMP preference system or making team decisions [4].

In order to solve the stated problem we propose an improved method of hierarchic analysis, based on the usage of interval estimates for the preferences of criteria and alternatives. The improved method of hierarchic analysis includes the following stages:

1. Structuring of the task in the form of a hierarchic structure:
– objectives;
– criteria;
–alternatives.

2. By questioning of DMP or a group of DMP, using an interval scoring scale, a matrix of pairwise comparison of preferences for the criteria is filled. Relative coefficients of the criteria importance are determined by the formula:

$$\overline{w}_i = \sqrt[n]{\prod_{j=1}^{n} \overline{q}_{ij}},$$

where $\overline{w}_i$ – interval estimate for the relative coefficient of Q_i criterion importance; $\overline{q}_{ij}$ – interval scoring estimate for the preference of criterion Q_i to criterion Q_j.

3. By questioning DMP or a group of DMP, using an interval scoring scale, matrices of pairwise comparison for the alternatives for each criterion are filled. Relative coefficients of the criteria importance are determined by the formula:

$$\overline{V}_{jk} = \sqrt[n]{\prod_{j=1}^{n} \overline{a}^{k}_{ij}},$$

where $\overline{V}_{jk}$ – interval value of the relative importance coefficient for alternative a_j by criterion Q_k; $\overline{a}^{k}{ij}$ – interval score estimate for the preference of alternative a_i to alternative a_j by criterion Q_k.

4. Quantitative quality indicator for each alternative is calculated by the formula:

$$\overline{Q}^{гл}(a_j) = \sum_{i=1}^{N} \overline{w}_i \overline{V}_{ji},$$

where $\overline{Q}^{гл}(a_j)$ is interval global estimate of alternative a_j.

If a team decision is being taken, at stages 2, 3 each DMP builds matrices of pairwise comparison of criteria and alternatives. Then general matrices of pairwise comparison of criteria and alternatives are calculated by the formulas:

$$\overline{q}_{ij} = \left[q_{1ij}; q_{2ij}\right] = \left[\min_g \{q^g 1ij\}; \max_g \{q^g 2ij\}\right]$$

$$\overline{a}^{k}_{ij} = \left[a^k 1ij; a^k 2ij\right] = \left[\min_g \{q^{gk} 1ij\}; \max_g \{q^{gk} 2ij\}\right],$$

where $q^g 1ij, q^g 2ij$ are lower and upper limits of the interval scoring estimate of Q_i criterion preference to Q_j criterion of the g-th DMP; $a^{gk}1ij, q^{gk}2ij$ – interval scoring estimate of a_i alternative preference to a_j alternative by criterion Q_k of the g-th DTP.

Arithmetic operations with interval estimates are performed by the following formulas [5]:

$$a + b = c = [c_1; c_2] = [a_1 + b_1; a_2 + b_2,]$$

$$a \times b = c = [c_1; c_2] = [\min\{a_i \times b_j\}; \max\{a_i \, x \, b_j\}],$$

$$\sqrt[n]{a} = c = [c_1; c_2] = [\min\{\sqrt[n]{a_i}\}; \max\{\sqrt[n]{a_i}\}],$$

$$\frac{1}{a} = c = [c_1; c_2] = \left[\min\{\frac{1}{a_i}\}; \max\{\frac{1}{a_i}\}\right],$$

where a, b, c are interval numbers.

Experimental investigation of this method is performed by the example of solving multicriterion problem of optimal information protection system selection under various conditions. In the first case the problem is characterized by the uncertainty in the system of preferences of one DMP and in the second case – by the presence of two DMP with controversial preference systems.

Experimental investigations

Let us consider general condition of the problem of choosing the optimal information protection system.

Information protection system must be chosen so that it would meet the following requirements: maximal protection degree, reasonable price, user-friendliness.

Three alternatives are available:

a_1 – protection degree – extremely high, very expensive IPS, very complex in use;

a_2 – protection degree – high, expensive IPS, not user-friendly;

a_3 – protection degree – moderately high, inexpensive IPS, user-friendly.

In order to solve a multicriterion decision-making problem, $a_{opt} \in \{a_1, a_2, a_3\}$ must be determined.

The problem of choosing the optimal IPS is characterized by the following criteria:

Q_1 – protection degree;

Q_2 – price;

Q_3 – complexity in service.

For pairwise comparison of criteria and alternatives the following scale of relative importance will be used:

The scale of relative importance

Relative importance intensity	Definition
1	Equal importance
3	Moderate advantage
5	Essential advantage
7	Strong advantage
9	Very strong advantage
2, 4, 6, 8	Intermediate values

The first case – one DMP with uncertainties in the system of preferences.

Using interval estimates, a matrix of pairwise comparisons for the criteria was built. On the basis of this matrix relative coefficients of the criteria importance were calculated. Calculation results are presented in table 1.

Table 1

Pairwise comparison matrix for the criteria

	Q_1 (protection degree)	Q_2 (price)	Q_3 (complexity in service)	Eigenvector
Q_1 (protection degree)	1	[2; 4]	[5; 6]	[2, 16; 2, 88]
Q_2 (price)	$\frac{1}{[2;4]}$	1	[3; 4]	[0,91; 1,26]
Q_3 (complexity in service)	$\frac{1}{[5;6]}$	$\frac{1}{[3;4]}$	1	[0,35; 0,4]

The eigenvector elements are calculated as the n-th root of the product of corresponding matrix row elements. Their values are relative importance coefficients of the corresponding criteria.

By questioning DMP, matrices of pairwise comparison are built for the alternatives for each criterion, and using the proposed formulas corresponding interval estimates of the relative importance coefficients for the alternatives are calculated. The results are presented in tables 2 – 3.

Таблица 2

Pairwise comparison matrix for the alternatives connected with criteria Q1 and Q2

Q_1	a_1	a_2	a_3	Eigenvector	Q_2	a_1	a_2	a_3	Eigenvbector
a_1	1	[3; 4]	[4; 5]	[2,29; 2,7]	a_1	1	$\frac{1}{[3;4]}$	$\frac{1}{[7;8]}$	[0,31; 0,36]
a_2	$\frac{1}{[3;4]}$	1	[2; 3]	[0,79; 1]	a_2	[3; 4]	1	$\frac{1}{[4;5]}$	[0,84; 1]
a_3	$\frac{1}{[4;5]}$	$\frac{1}{[2;3]}$	1	[0,4; 0,5]	a_3	[7; 8]	[4; 5]	1	[3,04; 3,42]

Таблица 3

Pairwise comparison matrix for the alternatives connected with criterion Q3

Q_3	a_1	a_2	a_3	Eigenvector
a_1	1	$\frac{1}{[3;4]}$	$\frac{1}{[6;8]}$	[0,32; 0,38]
a_2	[3; 4]	1	$\frac{1}{[3;4]}$	[0,91; 1,1]
a_3	[6; 8]	[3; 4]	1	[2,62; 3,17]

Let us calculate the global criterion for each alternative:

$$Q^{гл}(a_1) = \sum_{i=1}^{3} w_i V_{1i} = [5{,}34;\ 8{,}36],$$

$$Q^{гл}(a_2) = \sum_{i=1}^{3} w_i V_{2i} = [2{,}78;\ 4{,}58],$$

$$Q^{гл}(a_3) = \sum_{i=1}^{3} w_i V_{3i} = [4{,}55; 7{,}01].$$

The alternative with maximal values of the upper and lower limit of $Q^{гл}$ is considered to be the best one, i.e. in our case $a_{opt} = a_1$.

The second case – two DMP with conflicting preference systems.

Table 4 presents pairwise comparison matrices for the first and the second DMP .

Таблица 4

Pairwise comparison matrix for the criteria for the first and the second DMP

The first DMP	Q_1	Q_2	Q_3	The second DMP	Q_1	Q_2	Q_3
Q_1	1	[4; 4,5]	[5; 6]	Q_1	1	[0,39; 4]	[4; 5]
Q_2	[0,25; 0,5]	1	[1,37; 1,5]	Q_2	[2; 3]	1	[2,5; 2,67]
Q_3	[0,33; 0,5]	[0,33; 0,5]	1	Q_3	[0,4; 0,66]	[0,4; 0,66]	1

Таблица 5

The matched pairwise comparison matrix for the criteria

	Q_1	Q_2	Q_3	Eigenvector
Q_1	1	[3,90; 4,50]	[4;6]	[2,5; 3,00]
Q_2	[0,25; 3]	1	[1,37;2,67]	[0,70; 2]
Q_3	[0,33; 66]	[0,33; 66]	1	[0,31; 0,48]

Pairwise comparison matrices for the alternatives for two DMP are matched and they coinside with the matrices from tables 2, 3 for the previous task. Let us calculate the global criterion for each alternative:

$$Q^{гл}(a_1) = \sum_{i=1}^{3} w_i V_{1i} = [6,0412;\ 9,0024],$$

$$Q^{гл}(a_2) = \sum_{i=1}^{3} w_i V_{2i} = [2,8451;\ 5,528],$$

$$Q^{гл}(a_3) = \sum_{i=1}^{3} w_i V_{3i} = [4,962;\ 9,8616].$$

The alternative with maximal values of the upper and lower limits $Q^{гл}$ is considered to be the best one, but in this case there is no such an alternative because the lower limit of a_3 estimate is smaller than the lower limit of a_1, and at the same time upper limit of a_3 estimate is higher than the upper limit of a_1 estimate. This means that alternatives a_1 and a_3 are incomparable. The alternative a_2 is worse than a_1 and a_3. Therefore, the two potentially optimal alternatives will be the final choice. To determine the more optimal from the two alternatives, further investigation of DMP preference systems is required, possibly, with the application of other methods or through negotiations between DMP in order to reduce contradictions between the preference systems by certain compromises.

Conclusions

An improved method of hierarchic analysis, based on the interval estimation of the preferences of criteria and alternatives, is proposed and investigated. The research has demonstrated the possibility to solve the problem of choosing optimal information protection systems when uncertainties are present in DMP preference systems and while taking team decisions. It should be noted that in the case when a single optimal alternative cannot be objectively determined on the basis of the available information, the method makes it possible to reduce the set of initial alternatives and to obtain a subset of potentially optimal alternatives and incomparable alternatives.

In further research the apparatus of the theory of fuzzy sets will be used to evaluate the preferences of criteria and alternatives.

REFERENCES

1. Домарев В. В. Безопасность информационных технологий. Методология создания систем защиты / В. В. Домарев – К.: ООО "ТИД "ДС", 2002. – 688 с.

2. Титоренко Г. А. Информационные технологии управления: учебное пособие для вузов / под ред. проф. Г. А. Титоренко. – 2-е изд., доп. – М.: ЮНИТИ-ДАНА, 2003. – 439 с.

3. Курчиков Л. Н. Неопределенность и определенность / Л. Н. Курчиков – М., 1972. – 432 с.

4. Таха Хемди Введение в исследование операций / Таха Хемди – [7-е изд.]. Пер. с англ. – М.: Вильямс, 2005. – 902 с.

5. Аленфельд Г. Введение в интервальные вычисления / Г. Аленфельд, Ю. Херцбергер – М: Мир, 1987, – 360 с.

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