Multifunctional methodology of expert evaluation alternatives in tasks of different information complexity

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***Abstract*— The study proposes a multipurpose methodology for expert evaluation of alternatives based on applying Voting methods, Analytical Hierarchy Process (AHP) and Analytic Network Process (ANP) for decision-making problems of various classes of complexity, depending on the linear, hierarchical or network structure of their description. Simplification and optimization of pairwise comparisons of alternatives in AHP and ANP and improving consistency and compatibility of expert judgments are achieved by visualization based on oriented graphs. The methodology has been tested in the field of defense planning. But it has a universal character and can be applied in intelligent systems for various subject areas.**

***Keywords*— AHP, ANP, voting methods, evaluation of alternatives, oriented graphs, decision making**

I. Introduction

Nowadays, there is a steady increase in the number of problems and tasks that require decision-making based on alternatives in almost all spheres of life. Most of them are characterized as multicriteria. There are usually no formal algorithms to solve them, and there is a lack of appropriate analytical methods or the necessary data. Therefore, a common approach is to use procedures for expert evaluation of possible alternative solutions to such problems.

Existing expert methods often require a significant intellectual effort of experts, create an organizational and technical burden on the organizers of the expert survey and often require a lot of time to perform. To overcome these problems, it is natural to use automatization of expert procedures. However, this is not so easy to implement, as the criteria for choosing alternatives are often intangible, qualitative, informal. Also, in practice, when solving such problems, it is not always possible for experts to use specific (available) technical and economic characteristics of alternatives.

Therefore, to more effectively support decision-making through information technology, it is important to improve formalized methods of performing expert procedures and processing the results of alternatives evaluation.

II. Statement of the Problem

Expert evaluation procedures for alternatives are used in a variety of decision-making tasks. Depending on the task, experts either only evaluate alternatives or provide their suggestions for the formation of many alternatives and participate in improving the proposals of other experts.

In almost every subject area, depending on the structure of the data model that describes it, the ability to identify alternatives and criteria for their evaluation, other factors influencing the choice of alternatives, different expert groups face problems of varying complexity, to solve which have to select appropriate expert methods.

The article [1] provides a case study of evaluating the quality of services offered by airports based on several qualitative and contradictory evaluation factors. To this end, for the quantitative assessment of the relative weights of factors and the rating of airports are used methods of stepwise analysis of the coefficient of weight evaluation – new methods SWARA (Step-Wise Weight Assessment Ratio Analysis) and measuring alternatives and their ranking according to the MARCOS (Measurement of Alternatives and Ranking According to Compromise Solution). The study results show that the proposed methodology allows decision-makers to clearly express their preferences and weakens subjectivity and uncertainty in the decision-making process.

The article [2] proposes a new method that combines entropy weight and DEMATEL method (Decision Making Trial and Evaluation Laboratory) to select alternative solutions in emergencies. Considering the weights of the criteria calculated by DEMATEL, TOPSIS method (Technique for Order Preference by Similarity to Ideal Solution) is used to rank emergency alternatives. According to the authors of the article, the proposed method has advantages related to the ease of presentation and integration of linguistic assessments in conditions of uncertainty, helping decision-makers to assess the importance of criteria taking into account their direct and indirect impact.

The article [3] proposes integrating AHP (Analytical Hierarchy Process) with TOPSIS using fuzzy Pythagorean sets to choose the location of a wind farm. The approach combines the advantages of two methodologies for considering uncertainties and the lack of information in the decision-making process.

The purpose of the study [4] is to present a scheme of priority of inspections by the inspection bodies of occupational safety and health at enterprises to cover the most dangerous of them primarily. The model uses an integrated approach based on Delphi, AHP and TOPSIS (DH-TOPSIS) methods. The main decisions and sub-criteria are determined by a group of experts using the Delphi methodology. The weights of the main criteria and sub-criteria are determined by the AHP.

The article [5] proposes LGDM method (Large Group Decision Making) using a generalized multi-attribute and multiscale LINMAP method (Linear Programming Technique for Multidimensional Analysis of Preference) for a modern real estate service industry. According to the authors of the article, such a method is because traditional decision-making methods do not cope with solving such complex problems. The technique combines large-scale heterogeneous data about expert preferences and user evaluations.

The articles [6-8] are devoted to the ranking of alternatives in management, security and defense, particularly in defense planning, based on integrating AHP, ontological and graph presentation of data for forming the criteria vectors hierarchy and alternatives evaluation. The present article develops this line of research.

A brief overview of the different approaches shows their effectiveness in various areas of decision-making. At the same time, however, not significant attention is paid to the technological issues of evaluating alternatives, automatization and facilitation of expert activities, the validity of the methods used depending on the complexity of the tasks. Moreover, the methods and approaches themselves require a high enough professionalism of experts to apply them. Therefore, it is relevant and valuable to develop a multilevel methodology that has multipurpose character and the possibility of practical application in any subject area where you need to make expert decisions.

This study proposes a methodology for improving and joint application of some voting methods, AHP and ANP, depending on the class of complexity of decision-making tasks. It is assumed that the results obtained at the previous levels of methodology will be consistently used at the following levels, at that the evaluation methods will get more complicated – from reasonably simple to more complex. The proposed end-to-end formalized methodology with elements of graph visualization aims to simplify the work of experts

III. MATERIAL AND METHOD

The task of decision-making can define the following enlarged scheme (1) [9]:

$$<\{A\}, F> \rightarrow A^*, \quad (1)$$

where A is a set of alternatives (objects, solutions), that are considered as possible solutions to the problem; F – a set of rules or selection functions, which define the priorities of alternatives, A* – selected alternative (or several acceptable alternatives).

Usually, there are distinguished three possible types of decision-making tasks:

— a problem of optimal choice – if the set $\{A\}$ is clearly defined (fixed), and the principle of choice F is formalized;

— a problem of informal choice – if $\{A\}$ is defined, but F can not be formalized, and the choice depends on the preferences of experts who make decisions;

— general decision-making problem – if $\{A\}$ has no defined boundaries, it can be supplemented with or without the condition of saving the order in A^*, and F – unformalized.

The most difficult is the third type of problem when experts can choose different alternatives using informal F and change their decisions when adding new alternatives. This problem is unstructured (poorly conditioned) but can be constructively solved with the following additional requirements (restrictions):

(a) the initial set of alternatives $\{A_{(0)}\}$ exists or is defined and can be specified by experts in the decision process: $\{A_{(0)}\} \rightarrow \{A_{(1)}\} \rightarrow \ldots \rightarrow \{A\}$;

(b) any alternative may be informally evaluated by experts regarding the usefulness of including it in $\{A\}$;

(c) informal evaluations of alternatives by different experts give close results.

Further, we will consider the general decision-making problem, bearing in mind that the first two are its special cases.

In decision theory, there are two main approaches to the evaluation of alternatives to be chosen: 1) evaluation of the objects in general and the choice of alternatives based on its results; 2) detailing and evaluation of vectors of characteristics (properties) of objects and decision-making based on the results of comparison of these properties. It is believed that human thinking is better suited to evaluate preferences on a set of objects than on characteristics. But this advantage of the first approach is revealed only at an estimation of relatively simple objects. It is much easier for an expert to determine which one is better for complex alternatives, given its individual properties (characteristics). To compare the alternatives for individual properties, methods are used either (i) based on the pairwise comparison or (ii) using numerical characteristics.

A large number of multicriteria tasks can be represented by a hierarchy structure, at the lower levels of which the object is evaluated using vectors of criteria formed by the decomposition of its properties. At the upper level, the object is evaluated in general using the composition mechanism. In the hierarchy, its elements are organized by levels so that each element of a certain level may depend on some elements of the nearest lower level. More complex tasks require a network representation of its structure.

Given the above requirements the proposed methodology provides for the following sequence of actions of the expert group:

1. Determining an initial list of alternatives, the so-called "longlist" (LL), with a linear structure from which experts select a reduced list (usually no more than five alternatives), the so-called "shortlist" (SL).

2. Evaluation and selection of alternatives from SL for tasks, the description of the relationships between the

elements of which can be specified in a hierarchy structure. To compare elements that are at the same level of the hierarchy and relate to some element of a higher level, the principle of direct dominance (more significant influence, greater priority, greater probability) is used.

3. Evaluation of SL alternatives for tasks whose relationship between elements is impossible only with the use of a hierarchy and the principle of direct dominance, indirect dominance is used to compare in pairs the elements of the structure to find out which of them has more impact and how much more on the third element. The network structure can be built as a hierarchy extension by considering new data and the relationships between them.

4. Checked compatibility of judgments of different experts by calculating the Compatibility Index (SI) after evaluating alternatives. In case the *SI* exceeds the corresponding value of the limit compatibility index, the procedure of correcting by experts their judgments is proposed.

The general scheme of application of the methodology is shown in Fig. 1.

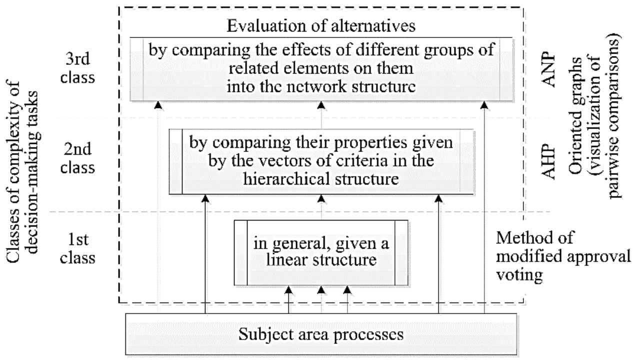

Figure 1: The general scheme of application of the methodology

Next, these actions of the expert group will be considered in more detail.

To make a collective decision in the expert group on the evaluation of alternatives two voting methods are used in the proposed methodology. Although the literature describes many dozens of voting procedures that differ significantly from each other, in practice, only a few standard techniques are used. As a result of the analysis of standard voting methods – the relative majority method, the approval voting method, the Borda method, the Condorcet method [10] and others – to determine SL alternatives from LL, the approval voting method was chosen as the primary method. According to this method, each expert must indicate which alternative he does not object to, and the number of such alternatives for each expert is not limited. Within the proposed methodology, this method is modified so that the expert can also vote for an exception some alternatives from the general list of LL, like those that, in his opinion, do not match the search solution. Let's call this method the modified approval voting method (MAVM).

Let $\{E_m\}$ are the experts of group, m = 1, ..., M; LL = $\{A_i\}$ – formed longlist of possible alternatives. In accordance with MAVM each expert evaluates of alternatives A_i by the following rule (2):

$$E_m(A_i)=\begin{cases}1, \text{ if the expert does not object to the inclusion of alternative } A_i \text{ in } SL;\\ -1, \text{ if the expert objects to the inclusion of alternative } A_i \text{ in } SL;\\ 0, \text{ if the expert is indifferent to this alternative (does not express any relation)}.\end{cases} \quad (2)$$

$E_m(A_i)$ = 1 – if the expert does not object to the inclusion of alternative Ai in SL;

$E_m(A_i)$ = -1 -- if the expert objects to the inclusion of alternative Ai in SL;

$E_m(A_i)$ = 0 -- if the expert ls different to this alternative (does not express any relation);

According to the voting results, each alternative receives $B(A_i)$ points (3):.

$$B(A_i)=\sum_{m=1}^{M}E_m(A_i). \quad (3)$$

If B(Ai) ≤ 0, alternative Ai is deleted even from LL and cannot be included in SL.

SL includes n alternatives , (usually n ≤ 5), such that (4):

$$A_{i_1}=A_i \mid B(A_{i_1})=\max_i B(A_i), A_{i_k}=A_i \mid B(A_{i_k})=\max_{i\neq(i_1,\dots,i_{k-1})} B(A_i), k=2,\dots,n. \quad (4)$$

If $\exists A_r \mid B(A_r)=B(A_{i_n}), r\neq(i_1,\dots,i_n)$, and such A_r can be two or more, then at the discretion of the responsible expert, all alternatives that scored $B(A_{i_n})$ points are included or not included in the SL, or the relative majority method is used for additional voting to determine exactly *n* alternatives for inclusion in SL. If there is still an ambiguous situation, the decision is made by the responsible expert in a consultation, if necessary, with other members of the expert group.

For the second stage of complexity is proposed to use the integrated method of expert evaluation [6], which is based on the joint use of ontological description of data about the subject area (dictionaries, glossaries, catalogs, classifiers, frames, etc.), AHP and graph representation of pairwise comparisons of alternatives. The base of the integration method is AHP [11].

The use of AHP after the formation of SL is carried out in the standard way, only the truncated scale of T. Saati is used (without inverse values: 1/3, 1/5, 1/7, 1/9) with filling in comparison tables by quantitative values that correspond to qualitative. The use of scalar (linear) convolution allows you to get total scores for each alternative and thus rank them to select the "best" alternative according to these criteria.

To more objectively build a hierarchy and improve the formation of criterion vectors, the subject area data model can be represented as a computer ontology [12-13]. At the same time, it is expedient to present attributive descriptions (properties) of criteria in the ontological database in the form of frames, the slots of which contain the corresponding numerical (quantitative natural or artificial characteristics) or linguistic data. Then, experts can use this data to support their decisions when evaluating alternatives.

The hierarchy is built in the form of an oriented tree, starting from the upper level (goals of the decision-making task) through intermediate levels (criteria/subcriteria) to their lowest level (Fig. 2). The criteria and sub-criteria of the next lower level, on which they depend, form the bushes of this tree.

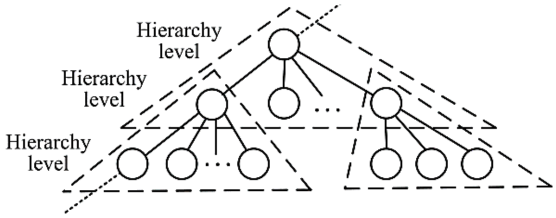

Figure 2: A graphic view of the tree bushes of hierarchy (highlighted by dotted triangles)

According to the principles of AHP, after building a hierarchy, a unified set of tables is usually formed for experts to record the results of a pairwise comparison of alternatives for each end criterion.

As a result of the processing of tables, the normalized values of estimations by all experts of all alternatives in comparison with others on these criteria are obtaining. Further, for each bush of the lower level, a linear convolution (5) is calculated:

$$C_{q+1,s}(A_i) = \sum_{m=1}^{M} \left(\sum_{k=1}^{Lq.s} C_{q,s}(i,k,m) P_{q,s}(k) \right) R(E_m), \quad (5)$$

where $C_{q+1,s}(A_i)$ – generalized for all experts comparative estimation of the alternative $A_i \subset$ SL by the criterion, which is located at the top of the bush, located at the levels q and $q+1$, in the position s of the level $q+1$;
$C_{q,s}(i,k,m)$ – a comparative estimation of the alternative A_i by the m-th expert for k-th sub-criterion of this bush;
$L_{q,s}$ – the number of sub-criteria in this bush;
$P_{q,s}(k)$ – the relative weights of the sub-criteria of the bush, $k = 1, ..., L_{q,s}$;
$R(E_m)$ – the relative weight of the m-th expert.

After performing the decomposition and evaluation of alternatives according to individual criteria/subcriteria, it is necessary to return to the evaluation and comparison of alternatives in general – i.e., to perform the composition of criteria. The method of nested scalar convolutions is used for this purpose. The composition is performed ac-cording to the following principle: the resulting values of scalar convolutions for alter-natives based on the criteria of lower-level bushes serve as input values for calculating scalar convolutions of alternatives according to the criteria of the next higher level. Wherein the requirement that the sum of the coefficients of weights in the normalized form of all sub-criteria of the bush is equal to the weight of the criterion at the top of this bush must be observed.

Scalar convolutions obtained at the highest level give generalized quantitative values of alternatives, allowing them to be ranked and determine the most preferred to solve the problem.

Pairwise comparisons of alternatives by a particular criterion consist of three steps for the expert: 1) the choice of a pair of alternatives; 2) deciding which of them has a general dominance ($\succ$) over the other; 3) determining the qualitative degree of this dominance. Step 2, in any case, precedes step 3 (sometimes, perhaps, at the subconscious level). An essential task of the methodology is to maximize the automation of steps 1 and 2, and sometimes 3, by helping experts maintain their judgments' transitivity by visualizing comparisons on an oriented graph. The vertices of this graph correspond to the alternatives. The arcs indicate the dominance of some alternatives over others. An expert selects a pair of vertices that correspond to the alternatives and the degree of dominance of one over the other on a qualitative scale. These vertices are connecting by an arc starting at the vertex (alternative) that has dominance. Wherein for any three alternatives A, B, C, if the expert has already determined that $A \succ B$ and $B \succ C$, then automatically the arc (AC) displays, i.e., the transitive closure [14] of △ ABC is performing, and the expert is asked to set the degree of dominance of A over C (Fig. 3a). The graph vertices, which correspond to the alternatives that, in the expert opinion, do not dominate each other by a particular criterion, are merged into one. The comparison tables of alternatives are filling automatically simultaneously with graph building. After all comparisons with considering merging of vertices, the resulting complete acyclic graph will be constructed (Fig. 3b), which in graph theory is also called a transitive tournament [15].

A hierarchy structure is no longer enough to solve problems with more complex connections between elements of its data model. Therefore, as a primary method for solving such problems, it is proposed to use ANP (Analytical Network Process) [16], a development of AHP.

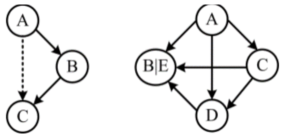

Figure 3 Visualization of pairwise comparisons of alternatives (a – the transitive closure of three vertices, b – the resulting graph of comparisons of 5 alternatives by one of the experts by a specific criterion (alternatives *B* and *E* are merged as not dominating each other))

Network structures and supermatrices are used in ANP to build models of such subject areas. For representation such structures the Berge graphs are used, i.e., direct graphs without multiple loops and multiple arcs of one direction. The vertices of a graph can be either simple elements (individual parameters) or groups of simple elements that form components, and arcs are connections between them. An example of such a graph of 4 components with the relationships between its vertices is shown in Fig. 4. A loop at the vertice indicates that elements inside the component influence each other, and arcs between the components indicate the impact between them in general.

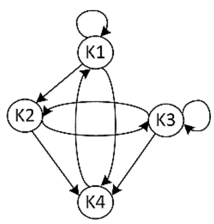

Figure 4: An example of a network structure in ANP

The supermatrix (block matrix) of influences between simple elements and components is constructed based on the graph. For the graph from the given an example, it has the following form:

$$\begin{Vmatrix} M_{11} & M_{12} & 0 & M_{14} \\ 0 & 0 & M_{23} & M_{24} \\ 0 & M_{32} & M_{33} & M_{34} \\ M_{41} & 0 & 0 & 0 \end{Vmatrix}$$

In supermatrix each block is a pairwise comparison matrix M_{ij}, which determines the influence of the elements of the i-th component on the elements of the j-th component. After forming all the necessary matrices (supermatrix blocks) and executing appropriate matrix transformations, an algorithm for calculating the supermatrix is applied. As a result, the generalized numerical values for alternatives are obtained, based on which the ranking of alternatives and selection of the "best" solution are performed.

Calculating a supermatrix in the general case is a laborious process. To identify the propagation of influences on all possible routes of the network structure (in particular, due to cycles), it is necessary to normalize (to bring to the interval [0, 1]) the values of the columns and to calculate the limit (6) of supermatrix degree sequence [16]:

$$\lim_{k\to\infty} W^k, k = 1,2,3,... \tag{6}$$

In practice, this is equivalent to raising the supermatrix to a sufficiently high degree and sometimes requires calculating the Cesaro sum if this sequence will not converge. It is recommended to build a network model by gradually increasing the complexity of the hierarchy model by adding new links between elements/components that are at the same level or at different (not necessarily adjacent) levels of the hierarchy.

According to the requirements of AHP and ANP after evaluation of alternatives using pairwise comparisons, it is necessary to check the cardinal consistency of expert judgments (which is almost impossible to achieve, even if all real numbers are used in the scale), that is, the proximity of an inversely-symmetric matrix (n x n), which corresponds to the comparison table, to a fully consistent matrix, in which there is the relationship between its elements. To do this, the main (maximum) eigenvalue λ_{max} of this matrix is found, and the consistency index CI = (λ_{max} - n)/(n-1) is calculated. The value of the consistency ratio (CR) of the expert's judgments is then calculated as dividing CI by the random matrix index of the same order as the mathematical expectation of the random consistency index calculated on a large sample of randomly generated inversely-symmetric matrices.

According to the methodology under consideration, if this ratio is unsatisfactory (CR > 10%), the arcs of the resulting comparison graph are loaded with expert estimates in quantitative terms, and the expert is recommended to review his judgments. In particular, possible options for improving the cardinal consistency of his judgments are proposed. So if the three vertices subgraph of the resulting graph after the transitive closure will look as shown in Fig. 5a, the expert will be asked to adjust his opinion, for example, as shown in Fig. 5b.

To check the compatibility of the judgments of two experts, it is necessary to calculate the SI index for matrices that correspond to the comparison tables of both experts when evaluating the same alternatives in general or according to a particular criterion by the formula (7) [16]:

$$SI = (1/n^2)e^T U \circ V^T e, \tag{7}$$

where n is the order of the matrices;
U – matrix corresponding to the comparison table of one of the experts;
V^T – transposed matrix corresponding to the comparison table of another expert;
$U \circ V^T$ – the Hadamard product of the matrices U and V^T;
e – a unit vector-column of dimension n;
e^T – a unit vector-string of dimension n.

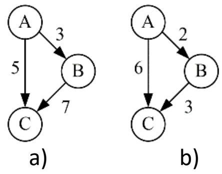

Figure 5: An example of an option improving cardinal consistency (a – visualization of quantitative values of the alternatives dominance degrees, b – the correction option of these values)

Then the SI is compared with the corresponding limit compatibility index. For example, for n = 3, 4, 5 SI should not exceed 1.10.

According to the proposed methodology, after all experts have performed a pairwise comparison of alternatives according to a particular criterion, the SI is automatically calculated for each pair of experts. Then, in cases where the index is unsatisfactory, the corresponding pairs of resulting graphs are visualized, on which "contradictory" arcs that have different orientations between two same vertices in both graphs are marked. This corresponded to when one expert preferred one alternative over another and the other expert on the contrary (Figs. 6a, 6b). The different merged vertices are also marked if any. Using such visualization, experts are invited to jointly find consensus and correct their judgments to improve compatibility, in particular by possibly merging some vertices. For this example, such a solution would be to merge vertices (alternatives) A and D (Fig. 6c), and each of the experts could adjust, if necessary, the degree of dominance of alternatives B, C and E over A and D.

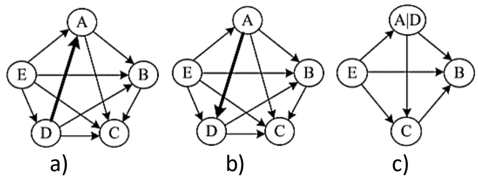

Figure 6: An example of visualization on graphs for improving the compatibility of judgments (a – the resulting graph of comparisons of the 1st expert, b – similarly for the 2nd expert, c – the resulting graph of comparisons for both experts after adjustment; the degrees of dominance by both experts may differ)

The proposed methodology is tested on the developed prototype of the software web tool. The process of expert evaluation and selection of resources in defense planning based on capabilities to determine the most acceptable means for reconnaissance in the interests of ground artillery was taken as an example [6, 17]. The test covered all levels of the methodology.

First, by the MAVM, five means (alternatives) were selected from 7, and also ten criteria for their evaluation (efficiency, probability of exposure, reliability, etc.) were selected from 15. Next, a hierarchy of these criteria was constructed using an ontological approach, and alternatives were ranked using AHP and oriented graphs. The evaluation of alternatives at this stage was compared with the previously obtained results of the assessment of this example by the Delphi method that gave their coincidence for the first two the "best" means (alternatives). Then the hierarchy has been expanded to the network structure by adding a new component, "Terrain conditions", with a question for experts: "The effectiveness of which means is more dependent on the terrain?". As a result of the application of ANP and oriented graphs, this led to adjustments in the ranking of alternatives, that confirmed the importance of considering additional factors to obtain the best solution.

The results, described in this article, were obtained and tested within the framework of the research works «Development of an integration method and software tools for solving multicriteria tasks of assessing the capabilities of the defense forces» (state registration 0120U102457) and «Development of decision-making support models in defense planning and emergency response tasks and their implementation in software tools» (state registration 0121U109802), which are financed by The Ministry of Education and Science of Ukraine

IV. Conclusion

The proposed methodology significantly simplifies the process of expert evaluation of alternatives and reduces the time of its implementation. This is achieved through the joint use, on the one hand, the natural ability of man to compare with the indication of the qualitative degree of superiority of one object over another (that used in AHP), and, on the other hand, by visualization a comparison process on graphs to use the visual apparatus of the person through whom it is perceived the greatest amount of information. Together it gives a synergistic effect. The analysis showed that due to the automation of the transitive closure operation on graphs, the number of steps of a decision-making expert in pairwise comparison of alternatives is reduced by an average of 1.5-2 times.

Dialogue recommendations for the expert during pair comparisons on the graph provided by the methodology and implemented in the prototype of the software tool bring elements of intellectual information processing into the methodology.

The methodology is multipurpose and can be applied in intelligent systems for various any subject areas where it is necessary to make expert decisions.

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