

Pairwise Comparison Methods Based on Alternatives Disaggregation for Polyaspect Decision-Making Problems

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Abstract: The article proposes a comprehensive methodology for improving pairwise comparisons for expert polyaspect evaluation of alternatives. The model of pairwise comparisons usually leads to an unsustainable policy of individual judgments, in particular due to limited knowledge and information. Therefore, the essence of our approach is primarily to use the capabilities of modern technologies to present an information picture of the subject area based on computer ontologies and visualization on graphs. This allows for the disaggregation of alternatives to individual characteristics and taking into account their advantages for evaluating problems, in particular, using the SWOT matrix and AHP. The results of modeling alternatives based on the example of finding rational solutions for determining resources for attracting aviation to ensure the elimination of forest fires confirmed the effectiveness and stability of the proposed method. Application of this method will allow the expert to take into account important factors that may be underestimated in traditional analysis. The further development of the method should be related to the intellectualization of the processes of pairwise comparisons, which can also significantly reduce the subjective influence of expert judgments.

Keywords: Decision-making; Computer ontologies; Visualization; Bipartite graph; AHP; SWOT.

1. Introduction

In contemporary conditions, decision-making processes are characterized by high dynamics of changes and are accompanied by the flow of significant information. Any problem domain typically exhibits a considerable number of aspects or properties influencing the quality of the decisions made. Researchers and experts propose various approaches to decision support in such environments. Most of these approaches rely on expert methods, which to some extent enable solving the posed tasks.

Expert assessments play a crucial role in decision-making in conditions primarily characterized by qualitative, informal processes. Experts significantly complement the lack of quantitative information about decision alternatives. Experts largely compensate for the lack of quantitative information regarding decision options, building an expert's assessment of an object or phenomenon as a logical conclusion based on personal experience and special knowledge.

1.1. Problems of Pairwise Comparisons

The majority of expert decision-making methods utilize pairwise comparison methods, based on the law of comparative judgments proposed almost a century ago by the American psychologist Louis Thurston. According to the procedure of the pairwise comparison method, all objects are compared pairwise, and each subsequent assessment is not linked to the previous one. In the process of analysis, the expert focuses attention not on all elements at once, but only on two being compared at any given moment. This simplifies the analysis and contributes to its improved quality [1]. In addition, the expert can judge the ratio of advantages between alternatives based on how certain characteristics of one alternative are compared with the characteristics of another.

All these pairwise assessments form a matrix of pairwise preferences, and through special processing, numerical parameters of the object's priority indicators are obtained. The essence of the classic method of determining relative priorities lies in experts assigning quantitative evaluations to the comparison of alternatives with each other, taking into account various factors. These quantitative assessments can then be used for further analysis [2].

An essential factor in involving an expert in choosing the best decision through pairwise comparisons is the necessity to have a certain understanding of how a person makes decisions. The modern understanding of this process is associated with the concept of a conceptual or mental model of the surrounding world used by individuals to predict the consequences of their actions. However, the complexity of this model leads to non-resilient judgment policies (preference structures). Individual judgments of decision makers (DMs) usually have shades of uncertainty due to the limitation of knowledge and information. Let's see what problems this causes when performing pairwise comparisons.

The most common application of expert pairwise comparisons was found in the well-known method of Analytic Hierarchy Process (AHP), proposed in the late 1970s by the American mathematician T. Saaty. The method involves a hierarchical decomposition of the problem into simpler components and the step-by-step establishment of priorities for the assessed components using pairwise comparisons.

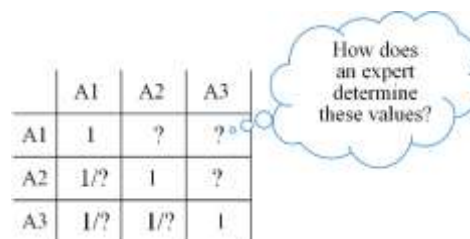
Considering that, in many cases, the preference model used by DMs is undefined and vague, and preferences differ among different DMs, leading to the distribution of ratings for the same object, assessing the level of inconsistency of pairwise comparisons when using AHP is often a crucial step in decision analysis [3, 4]. In the literature, more than ten inconsistency indices have been proposed to assess the deviation of expert judgments from a situation of complete consistency.

It is commonly believed that experts are honest and professional. However, in practice, there are cases where experts attempt to manipulate results in their favor. This necessitates the use of mechanisms that allow the detection of manipulators and minimize their influence on group consensus [5].

When enforcing the transitivity of a comparison system, an expert who makes an error in comparing a pair of objects (which is possible when there is uncertainty in the available information) is compelled, when comparing other pairs, to take into account the results of previous comparisons, including the erroneous ones. This undoubtedly leads to further errors.

To address these problems, various modifications of the process of pairwise comparisons are used, including AHP. One of the most widespread modifications involves replacing point estimates of priorities with interval values, such as computing element weights based on interval models like GPM, LUAM, and others. Another approach is associated with the introduction of fuzzy logic. It is believed that providing assessments in a fuzzy form reduces the burden on the expert. Instead of point estimates, the expert operates with more convenient linguistic assessments, for example, "approximately equal to x ," "between the values of x and y ." It is considered that such assessments better correspond to reality. There are also other methods aimed at eliminating the shortcomings of expert pairwise comparisons, such as the Best-Worst Method (BWM) [6] or the Analysis of Preferences Disaggregation Method [1].

Thus, it can be concluded that all subsequent problems of using pairwise comparisons actually have their roots in the seemingly simple stage of experts determining the numerical weights (priority) of alternatives, for example, when forming the appropriate matrix in AHP (Figure 1).



	A1	A2	A3
A1	1	?	?
A2	1/?	1	?
A3	1/?	1/?	1

Fig. 1. Cognitive roots of pairwise comparison problems in expert determination of numerical weights in AHP

1.2. Directions for Overcoming the Problems of Pairwise Comparisons

It is unrealistic to hope that humans will change for the better in the near future. Therefore, many researchers share the opinion that decision support in analytical activities, especially in multi-criteria cases, should first of all be directly related to a comprehensive representation of the information landscape in the subject area (SA). In modern conditions, to change the situation for the better regarding the cognitive

process of comparisons can already be improved through the use of information technologies [7-9]. In this regard, as a methodological basis, it is necessary, first of all: i) to make a transition to data-driven decision-making (DDDM), ii) to establish the optimal composition of information needed for effective decision-making, iii) to ensure presentation and analysis on various levels of a significant set of heterogeneous data. According to the authors [8], the first meaning is to consider the expert's mind as an attribute of the brain, and the second meaning is to consider data, knowledge and information technology as attributes of his mind.

On the other hand, to facilitate expert activities, structured formats are necessary for describing alternatives. This is a serious issue because the readability and understandability of documented information significantly impact the success and effectiveness of experts' contributions to the decision-making process. In this sense, an important capability of modern technologies is providing visualization of decision-making processes. Many studies in the field of social sciences confirm this insight [10]. Creating graphical models to assess the impacts of different types signifies their convenience, providing an effective decision support tool [11 - 13].

In summary, it can be noted that in modern conditions when making decisions, there is a shift from the influence of individual judgments to an increase in the value of available information about alternatives (Figure 2).

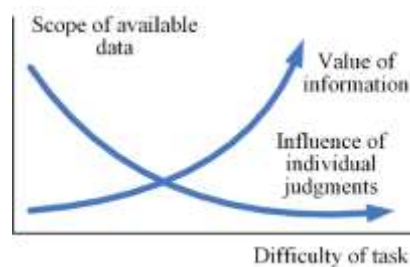


Fig. 2. Moving from the influence of individual judgments in decision-making to the importance of the value of available information

In this way, the following research goals can be formulated:

- a) to offer technological means for informational support of pairwise comparison processes;
- b) to investigate possible methods of pairwise comparisons, rely on the technological base;
- c) give an example of the use of research results in a certain subject area.

The research is aimed at obtaining theoretical results in the form of methods of disaggregating alternatives to individual characteristics when conducting pairwise comparisons with the support of information technology tools. This approach has an advantage over existing models due to the consideration of a set of additional factors for evaluating problems. The practical value of the study is related to the provision of

prompt implementation of automated iterations of problem analysis, which has potential implications for increasing the effectiveness of decision-making.

2. Methods of Alternatives Disaggregation

2.1. Technological Means for Information Support

When making comparisons, DMs can use these specific data about the elements, which typically influences their judgments regarding the relative significance and importance of these elements. In the case of complex problems, alternatives usually differ in sets of characteristics that significantly vary from each other. Therefore, experts' familiarity with the characteristics of alternatives, which forms the basis for their objective comparisons, plays a crucial role in decision-making. In this regard, an important element of modern decision support systems should be a knowledge base that represents the information model of SA. Among the existing approaches to such models, representing the SA in the form of computer ontologies [14, 15] is currently considered the most adequate. In the general case, the ontology contains informational descriptions based on an object-oriented formalization procedure, where each model O_m reflects an expressive hierarchy of interaction of concepts X , which are specified using binary relations R : $O_m = (X, R)$. Facts relating to individual instances of this world are stored either in separate databases or in Internet sources.

The simultaneous application of elements in ontological descriptions enhances the specificity of the model and provides a clearer understanding of the environmental state. As attributive characteristics of these ontologies' concepts, expert assessments of the value of objects, implementation possibilities, and characteristics of potential efficiency mechanisms, cost, complexity, etc., are defined.

The presence of a significant number of attributive characteristics of alternatives requires visualization of information, because visualized data require less cognitive effort during interpretation than text (table) descriptions. A widely used tools for visualizing information are graphs. Modern software allows you to effectively display graph diagrams and thereby help experts in clarity, speed and understanding of complex concepts.

2.2. Model Based on bipartite graph

When making decisions in various domains, pairwise comparisons of alternatives A with characteristics X can be represented as a binary scheme " A_1 " $\rightarrow$ " A_2 ," which can be expressed in the form of a bipartite graph. As known, a bipartite graph (also called a bigraph) is a graph whose set of vertices can be divided into two non-overlapping subsets, such that each edge of the graph has one vertex in the first subset and one in the second. An undirected graph $G = (V, E)$ is called bipartite if its set of vertices is partitioned into two subsets: $V = U \cup W, |U| > 0$, with the conditions that 1) no vertex in U is connected to vertices in U and 2) no vertex in W is connected to vertices in W . Figure 3 illustrates an example of a bipartite graph of

pairwise comparisons $G = (V(A1, A2), E(A1, A2))$, constructed by disaggregating the characteristics of alternatives.

In this graph, the sets of vertices in its partitions are $X_{A1} \cup X_{A2} = V(A1, A2)$, $X_{A1} = \{X11, X12, \dots, X1m\}$, $X_{A2} = \{X21, X22, \dots, X2m\}$, $A1 \cap A2 = \emptyset$, and the set of edges is $E(A1, A2)$, where an edge $(X1n, X2m) \in E(A1, A2)$ symbolizes the comparison of the corresponding characteristics $X1n$ and $X2m$. When comparing characteristics, the edges $(X1n, X2m)$ are loaded with the values of expert assessments of characteristics, respectively C_{1n} and C_{2m} . The direction of the graph's arcs indicates a preference for a particular characteristic. In cases where one alternative has more characteristics, as in the provided example in A1, a fictitious vertex (X25) is introduced in the partition of the other alternative, and its C_{25} is taken as equal to 0.

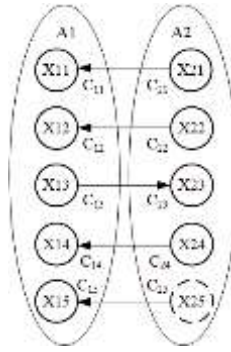


Fig. 3. Bipartite graph of pairwise comparisons

When determining expert ratings for alternative characteristics, their quantitative and qualitative indicators are represented in a quantitative (score-based) dimension according to a specific conditional scheme, for example: slight impact – 1 point, low – 3, moderate – 5, high – 7, very high – 9 points.

Now let's delve into the steps of the pairwise comparison algorithm:

1. Score ratings for alternative characteristics are determined using existing sources of information.

2. Ratings for alternatives C_{A1} and C_{A2} are calculated as the arithmetic averages of their characteristic assessments C_{1n} and C_{2m} .

3. Determining the degree of preference of one alternative over another is based on the relative rating of the smaller one compared to the larger one (for example, if $C_{A1} \succ C_{A2}$:

$$F = \frac{C_{A2}}{C_{A1}} 100. \quad (1)$$

4. If in the future it is planned to enter the results of a pairwise comparison into the AHP matrix, you can use the following rule of conversion to Saati scale (Table 1).

Table 1. The rule for conversion the degree of alternative preference to Saati scale

F	80-100	60-80	40-60	40-60	≤ 20
Saati scale	1	3	5	7	9

2.3. Model Based on SWOT analysis

The discussed approach can be applicable to relatively simple decision-making tasks. In more complex cases, such as strategic analysis, there is a need to consider a significant set of internal and external factors in pairwise comparisons, evaluating alternatives based on generalized criteria like potential benefits, existing opportunities, potential costs, and acceptable risks. One of the tools most frequently used for such consideration is SWOT analysis. Typically, SWOT is applied at the macro-level of strategic analysis. Despite its advantages and popularity, this method has faced criticism, particularly regarding the absence of a methodology for quantitatively assessing the results of compiling a SWOT matrix. The convenience of using the original SWOT is enhanced by the hybrid SWOT/AHP method, introduced back in 2000-2001. Since then, this approach has been applied in different fields such as manufacturing, agriculture, the telecommunications sector, tourism, forestry, and others [16-19].

We propose the reverse application of SWOT, namely at the micro-level, specifically in the analysis of alternative characteristics. Constructing a SWOT matrix through further disaggregation of alternatives allows the expert to consider important factors that may be underestimated in traditional analysis. The approach involves building a SWOT matrix for each alternative, with characteristic factors being considered in the quadrants of the matrix based on the influence of the characteristic on the evaluation of the alternative (Figure 4).

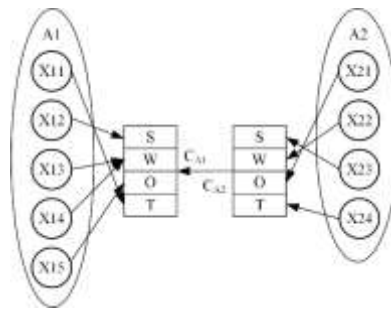


Fig. 4. Applying of SWOT in the analysis of characteristics of alternatives

Applying of this approach is based on the following algorithm:

1. Each element (characteristic) from the components of the SWOT matrix sectors is considered based on specific parameters available in the database (knowledge) and is evaluated in a quantitative (numerical) dimension. For example, according to the aforementioned conditional scheme, scores from 1 to 9 points can be assigned.

2. By summing up the expert assessments of the components of the sectors, we find for each alternative the corresponding scores CS, CW, CO, CT.

3. Next, for a comprehensive understanding, the strength of each alternative C_{A1} and C_{A2} can be determined across the four SWOT sectors:

$$C_{A1} = \frac{CS + CO}{CW + CT} \cdot \quad (2)$$

4. Determination of the degree of superiority of one alternative over another in each sector of the $F_{CS}, F_{CW}, F_{CO}, F_{CT}$ matrix is based on the relative evaluation of the smaller one from the larger one (for example, if $CS_{A1} > CS_{A2}$):

$$F_{CS} = \frac{CS_{A2}}{CS_{A1}} 100 \quad (3)$$

4. Determination of the degree of superiority of one alternative over another in general according to the SWOT matrix is found by averaging the assessments by sectors:

$$F_{SWOT} = \frac{F_{CS} + F_{CW} + F_{CO} + F_{CT}}{4} \cdot \quad (4)$$

5. Finally, if it is intended to enter the results of a pairwise comparison into AHP matrix, the rule of conversion to Saati scale according to Table 1 should be used.

3. Simulation Experiment

Let's consider the application of the proposed methods using the example of rational decision-making in determining resources for involving aviation to ensure the elimination of forest fires (FF). Success in extinguishing FF is significantly related to choosing the necessary number of resources (aircraft and/or helicopters) and selecting the "best" aviation action option during fire localization. To determine such an option, it is necessary to take into account a significant number of factors.

In the example, a model consisting of 2 alternatives is used for simplification: A1 - a composition of aviation grouping with aircraft of one type; A2 - with helicopters of one type. The following characteristics of the specified alternatives are used for the analysis: X11 (X21) - Time to localize the fire; X12 (X22) - Financial costs for providing flights; X13 (X23) - Flight safety; X14 (X24) - Number of discharges of

fire-extinguishing liquid in one flight; X15 (X25) - Duration of localization actions; X16 (X26) - Dependence on flame height; X17 (X27) - Dependence on flow turbulence; X18 (X28) - Dependence on smoke; X19 (X29) - All weather.

First, we will apply the method based on a bipartite graph to compare alternatives. On Fig. 5 shows a fragment of the interface of a software tool to support comparison based on this method with expert data for assessments alternatives.

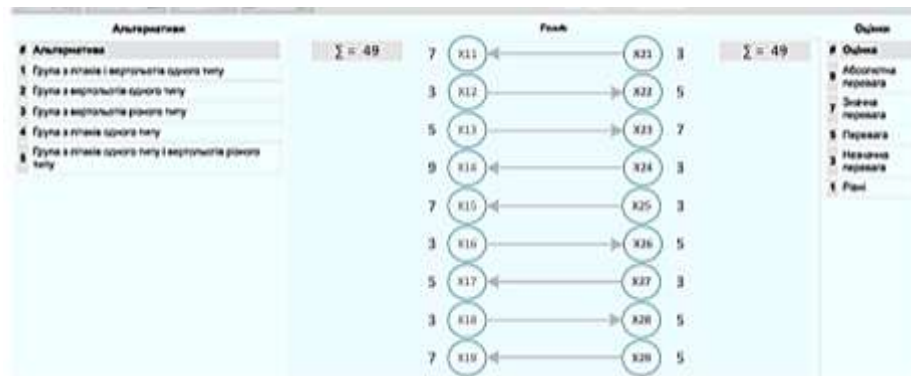


Fig. 5. Expert data on alternatives assessments using the bipartite graph comparison method

From the given data, total evaluations of the alternatives were obtained: A1=49; A2=39. Using these results, we determine the degree of preference of one alternative over another according to expression (4) and get a value of 79.6%. To transfer the results of a pairwise comparison to AHP matrix, we will use the rule according to Table 1 and get the advantage of A1 in the value of 3 according to the Saati scale.

Next, we will consider an example of the application of the micro-SWOT approach. Table 2 shows expert evaluations of performance parameters for each alternative.

Table 2. Expert assessment of the alternatives characteristics of aviation group according to the SWOT concept

A1	S	W	O	T	A2	S	W	O	T
X11	7	1	5	3	X21	3	5	3	3
X12	1	9	3	3	X22	3	7	3	1
X13	5	3	7	5	X23	7	3	3	3
X14	9	1	3	1	X24	3	7	1	3
X15	9	1	3	5	X25	3	7	1	5
X16	1	7	3	7	X26	5	3	3	5
X17	1	7	3	5	X27	5	3	3	5

X18	3	3	3	3	X28	5	3	3	7
X19	5	3	3	5	X29	5	1	3	5
Assessments	41	35	33	37	Assessments	39	24	23	37

Using the obtained estimation for the SWOT-matrix sectors, we obtain a determination of the degree of superiority of one alternative over another for each sector according to expression (4), and in general according to expression (5). The results are presented in Table 3.

Table 3. The result of the alternatives evaluation by SWOT matrix sectors

	CS	CW	CO	CT	SWOT
A1 vs A2	95,12	68,57	69,70	100	83,35

To transfer the results of a pairwise comparison to the AHP matrix, we will use the rule according to Table 1 and get the advantage of A1 in the value of 1 according to the Saati scale. Considering the closeness of the obtained score of 83.35% to the neighboring category in Table 1, it is possible to use the intermediate scores of the Saati scale and define the advantage as 2. This result indicates the clarification of the previous result obtained by the bipartite graph method, thanks to a more detailed consideration of all factors and their advantages

4. Discussion

The complexity of decision-making tasks is due to the extremely large dimension of the information space of the subject area, the weak structuring of data, which occurs due to their uniqueness, uncertainty of conditions, variability of aspects of alternatives. Automation of processes based on the use of computer ontologies and visualization on graphs provides a number of advantages for solving problems of paired comparisons in decision-making. This approach allows you to significantly expand the scope of practical application of the proposed methods in the conditions of poly-aspect analysis and multi-criteria.

The result is the discovery of an effective way to eliminate various ambiguities in the understanding of individual judgments of expert knowledge in integration with software and information support. The value of the research is to accelerate the formation of a breakthrough innovative system of human-machine collective intelligence to support decision-making, which will allow making better decisions thanks to the mitigation of human biases and the productive use of information.

5. Summary And Conclusion

The research is aimed at obtaining theoretical results in the form of methods of

disaggregating alternatives to individual characteristics when conducting pairwise comparisons with the support of information technology tools. Thus, a scheme for reducing the subjective influence of individual judgments of experts on the result of solving real-world problems is proposed. An example from the field of emergency response demonstrates the applicability of the proposed methodology in a human-machine environment.

A more objective calculation of estimates based on the disaggregation of alternatives to their individual characteristics is provided on the basis of computer ontologies, visualization of information based on graphs, as well as the application of micro-SWOT analysis and AHP. Thanks to these technologies, it becomes possible to eliminate potential sources of errors or systematic errors, increase the reliability of the data provided and the reliability of the results.

The obtained results were tested in the computer-oriented didactic-psychological provision of preliminary and pre-flight training of aircraft crews for flight-tactical training related to extinguishing fires in the ecosystem [20].

Acknowledgment

This project is supported by Key Projects by order of the Ministry of Education and Science of Ukraine.

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