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Theory and Methodology

Ranking multicriteria alternatives: The method ZAPROS III

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Abstract

The new version of the method for the construction of partial order on the set of multicriteria alternatives is presented. This method belongs to the family of verbal decision analysis (VDA) methods and gives a more efficient means of problem solution. The method is based on psychologically valid operations for information elicitation from a decision maker: comparisons of two distances between the evaluations on the ordinal scales of two criteria. The information received from a decision maker is used for the construction of a binary relation between a pair of alternatives which yields preference, indifference and incomparability relations. The method allows construction of a partial order on the set of given alternatives as well as on the set of all possible alternatives. The illustrative example is given. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The problems of ranking alternatives having estimations on multiple criteria are widespread in human life. There are many decision aiding methods oriented to the solution of the problems [1–4].

In this paper, we discuss the multicriteria ranking problem having the following features:

1. A decision rule is to be developed before appearance of alternatives.
2. There are a large number of alternatives.
3. Evaluations of alternatives upon criteria could be given only by human beings playing the role of measurement devices.

4. The quality grades on criteria scales are verbal definitions presenting subjective values of the decision maker.

The method ZAPROS (abbreviation of Russian words: Closed Procedures near Reference Situations) has been developed for the solution of problems having such features. This method belongs to the family of verbal decision analysis (VDA) methods [4,10].

VDA methods are oriented to the solution of problems of a special kind.

Let us stress the common features of such problems:

1. Factors in these problems are of purely qualitative, subjective nature, especially difficult for formalization and numerical measurement (prestige of an organization, attractiveness of

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a dress, attitude towards reforms, etc.); the factors are usually described in a language accepted by the decision maker.

2. The process of task analysis is also subjective by nature: rules for consideration and comparison of the main qualitative factors are mainly defined by the decision maker.

Therefore, the decision maker is the key element of the problem. This must be recognized, and attention must be paid to the capabilities and limitations of the human information processing system and to the results of investigations on human errors and heuristics [5].

The problems having such features have been called unstructured [6].

The first version of ZAPROS was published in 1978 [7]. The second version [8,9] gives the development of the original ideas. Both versions are based on the similar procedures of information elicitation from the decision maker.

The method ZAPROS-III presented in this paper uses the preference elicitation procedure proposed in first version of the method [7]. But it has quite a different structure to give more rational and strict justification to the method:

1. A simpler and more transparent procedure for the construction of a joint ordinal scale for quality variation along the scales of criteria is used.
2. New justification is given for the procedure of alternatives comparison.
3. The method gives the absolute as well as relative (as in the previous versions) ranks of alternatives.

2. Example

The practical problem is to organize a fund for investing money in R&D projects. The fund organizer is interested in developing an effective system for selection of the best projects. A decision analyst is used to carry out the job. It is decided that highly qualified experts are to be involved in the process of project estimation.

The fund organizer (we will call him the decision maker) in cooperation with the analyst develops a list of the most important criteria for

Table 1

Criteria and possible values for evaluation of R&D projects

Criteria	Possible values on their scales
A. Originality	A1. Absolutely new idea and/or approach A2. There are new elements in the proposal A3. Further development of previous ideas
B. Prospects	B1. High probability of success B2. Success is rather probable B3. Success is hardly probable
C. Qualification	C1. Qualification of the applicant is high C2. Qualification of the applicant is normal C3. Qualification of the applicant is unknown

project evaluation. The list of these criteria with possible values on their scales is shown in Table 1.

It is easy to note that criterion values are given from the most preferred to the least preferred (according to the preferences of the decision maker).

The projects to be submitted to the fund are not known in advance. It is necessary to rank-order the submitted projects according to their overall value. Each project requires some resources. Given a ranking of projects it is easy to select a group of best projects within the limit of available resources.

The question is: how to construct a rank-order for all possible combinations of the evaluations upon the criteria (in our case 27 combinations) on the basis of the decision maker preferences?

3. Formal statement of problem

The problem may be formulated as follows:

Given:

1. $K = 1, 2, \dots, N$ is a set of criteria;
2. n_q is the number of possible values on the scale of the q th criterion ($q \in K$);
3. $X_q = x_{iq}$ is a set of values for the q th criterion (the scale of the q th criterion); $|X_q| =$

n_q ($q \in K$); the values on a scale are ordered from best (first) to worst (last); the order of the values on one scale does not depend upon values on the others;

4. $Y = X_1 * X_2 * \dots * X_N$ is a set of vectors $y_i \in Y$ of the following type: $y_i = (y_{i1}, y_{i2}, \dots, y_{iN})$, where $y_{iq} \in X_q$ and $P = |Y| = \prod_{i=1}^N n_i$;
5. $A = \{a_i\} \in Y$; $i = 1, 2, \dots, t$ – the set of t vectors describing real alternatives.

Required: To rank multicriteria alternatives on the basis of a decision-maker's preferences.

4. Elicitation of DMs preferences

4.1. Joint scale of quality variation for two criteria

Let us look at the criteria list and assume that we have an “ideal” object, assigned all the best values on all criteria. We usually do not have such an alternative in real life. We will use this ideal alternative as a “reference situation”. Deviating from this ideal, we will lessen the quality of the hypothetical object on two criteria.

Let us introduce the notion of quality variation (QV). Quality variation is the result of changing one evaluation on the scale of one criteria.

The task of decision maker preference elicitation consists in pairwise comparison of all QV taken from the scales of two criteria, by supposition that they are the best evaluations on the other criteria. Evidently, QV along a criterion scale is equal to the sum of QV between the evaluations on the same scale.

The typical question posed to the decision maker is:

“What do you prefer for the transfers from better evaluations to worse ones: $x_{if} \Rightarrow x_{ik}$ or $x_{js} \Rightarrow x_{ju}(k > f; u > s)$?”

The possible decision maker answers are: “the first” or “the second” or “they are equal for me”.

Decision maker responses allow ranking of all QV from the scales of two criteria. This ranking could be called the joint scale of quality variation (JSQV) for two criteria.

Next, a different pair of criteria is taken for QV comparison by supposition that the evaluations for other are best.

There are $0.5N(N - 1)$ possible pairs of criteria. The preferences of the decision maker are elicited for each pair. So, $0.5N(N - 1)$ rankings of QV for all pairs of criteria could be constructed.

Let us illustrate the method by the example.

Let us look at the criteria list and assume that we have an “ideal” project, assigned all the best values on all criteria. We will lessen the quality of the hypothetical project against two criteria: A (“Originality”) and B (“Prospects”) criteria having the best evaluations on C. In the example, we have three QV for each criterion. Therefore, the task for the decision maker consists in pairwise comparison of six QV. Not all comparisons are needed: QV along the scales are equal to the sum of QV between the evaluations on the same scale. But, it is possible to use the transitive closure: for example, if

$$b_3 > b_2 \text{ and } b_2 > a_2 \text{ then } b_3 > a_2,$$

$$b_3 > b_2 \text{ and } b_2 > a_2 \text{ then } b_3 > a_2.$$

Eight comparisons are needed to rank QVs from the scales of A and B (four relations follow from transitivity).

Let us introduce the following notions for QVs:

$$A_1 \Rightarrow A_2 = a_1; \quad A_2 \Rightarrow A_3 = a_2; \quad A_1 \Rightarrow A_3 = a_3;$$

$$B_1 \Rightarrow B_2 = b_1; \quad B_2 \Rightarrow B_3 = b_2; \quad B_1 \Rightarrow B_3 = b_3.$$

The generic question to DM is:

Question. “What do you prefer: the transfer from a project with an absolutely new idea to one with new elements in the proposal or the transfer from a project but with high probability of success to one where the success is rather probable?”

Posing the questions in a similar way one could rank QV. Let us suppose that DM preferences define the following ranking:

$$a_1 < b_1 < a_2 < b_2 < a_3 < b_3,$$

This ranking is JSQV for the criteria A and B by pre-supposition that it is the best evaluation on criterion C.

In the same way, JSQV for the pairs (A and C) and (B and C) can be constructed.

4.2. The check of independence for two criteria

JSQV for a pair of criteria holds valuable information about DM preferences. But the possibility of its utilization depends on the independence of the decision maker comparisons with a “reference situation”.

Definition 1. Let us call two criteria independent by quality variation if JSQV constructed for those criteria do not depend on the evaluations on other criteria.

The check of independence by QV is:

Let us take a quite different “reference situation” – the worst evaluations on all criteria. It is possible to compare QV on the scale of two criteria and check the correspondence to the ranking made near first “reference situation”.

Only some part of QV comparisons could be taken with the aim of testing the independence condition. If there is no difference in QV comparisons for the same pair of criteria near different “reference situations” we could accept that the two criteria are independent by QV.

Two “reference situations” are quite contrasting alternatives. It is possible to accept that the condition of independence is true if such reference situations have no influence on the comparisons made by the decision maker.

For the example given above it is necessary to repeat some comparisons of QV by supposition about the evaluation C3 on criterion C.

Let us suppose that the results of the comparisons are:

$$b_3 > a_3 > b_2 > a_2,$$

$$b_3 > a_3 > b_2 > a_2.$$

In this case, we could accept the independence of criteria A and B.

For cases when a pair of criteria are not independent by QV, it is necessary to change the verbal

description of a problem and achieve independence (see the examples in [4]).

Let us note that the condition of independence by QV is close to the condition of preference independence [1].

4.3. Independence for the group of criteria

The dependence of a pair of criteria on the rest of the criteria is the best-understood case. It might be well to note that this kind of (in)dependence of criteria is checked in many decision methods. It was proven that, if all criteria are pairwise preference independent, any group of criteria is independent of the rest of criteria [1].

We refer to the opinion of von Winterfeldt and Fisher [11] that the group dependence of criteria “is indefinite in nature and difficult to detect” if the criteria are pairwise independent. Really, one could not find such dependence in practical cases.

Consequence. In the case when all pairs of criteria are independent by QV, it is possible to accept that all criteria are independent by QV.

The test for independence is sufficient because all pairs of criteria are considered. Therefore, one could take any pair of criteria independently from the others to analyze the differences in evaluations of alternatives.

4.4. Joint scale of quality variation for all criteria

On the basis of information elicited from the decision maker for each pair of criteria it is possible to construct JSQV for all criteria. The non-contradictory rankings of QV from all criteria scales are compared many times. It is necessary to find the place of each QV on the joint scale.

For the construction of the joint scale for all criteria it is possible to use the following algorithm.

Sequential selection of non-dominating QV. Joint Scales for the pairs of criteria could be taken as the graphs having the same root: zero quality decreasing. Let us take the node of this joint graph that is not dominated by any other and put it on

the joint scale. After excluding such nodes from all graphs, let us find the next non-dominated node, put it on the joint scale and so on. It is easy to see that such algorithm gives the rank-order of all QV.

Let us take the example given above.

Additional to the JSQV given above for criteria A and B, it is possible to construct scales of such kind for the pairs (A and C) and (B and C). Let us suppose that we have the following results:

$$c_1 < a_1 < a_2 < c_2 < a_3 < c_3$$

$$\text{and } c_1 < b_1 < b_2 < c_2 < b_3 < c_3.$$

Using the algorithm of sequential selection of non-dominated QV, it is possible to construct the joint scale of QV for all criteria:

$$c_1 < a_1 < b_1 < a_2 < b_2 < c_2 < a_3 < b_3 < c_3.$$

4.5. The check of information for contradictions

In the process of construction of the JSQV for two criteria, it is easy for the decision maker to check comparisons for possible contradictions. That is not the case for the construction of JSQV for all criteria.

Certainly, people could make errors. Therefore, we need special procedures for finding and eliminating human errors.

Fortunately, a special, “closed” procedure for finding and eliminating the decision maker contradictions has been proposed [7].

By constructing JSQV for every pair of criteria we would require additional data from the decision maker. The additional information is used to create the check for consistency. If on some step of the algorithm for sequential selection of QV it is not possible to find the next non-dominated QV, there is a contradiction in the decision maker preferences. The algorithm can discover the contradictory answer and demonstrate them to the decision maker for correction.

Let us return to the example presented above.

Let us suppose that instead of JSQV for criteria C and B given above, we have the following:

$$b_1 < c_1 < b_2 < c_2 < b_3 < c_3.$$

In this case, when combining three scales into one, there is the contradiction:

$$b_1 < c_1 < a_1 < b_1.$$

The contradiction does not allow finding a place of corresponding QV on the joint scale. Usually such a contradiction is the result of an irrational judgment. It is necessary for the decision maker to analyze the situation and find a rational compromise.

This contradiction is to be presented to the decision maker for analysis and resolution.

The construction of Joint Scale of Criteria Variations gives a check of the decision maker input for contradiction. The possibility to combine pairwise scale into a JSCV confirms the absence of contradictions in decision maker judgments.

The questions needed for JSCV construction represent the dialog between the decision maker and the computer.

4.6. Special case

For $N = 2$, the meaning of reference situations disappears. For the remaining two criteria it is possible to construct a JSQV and use it for alternative comparison (see below).

4.7. Psychological basis of the procedure

The procedure of decision maker preference elicitation proposed above is justified from a psychological point of view. All questions to the decision maker are formulated in natural language, in terms of verbal evaluations on criteria scales. The kind of questions (comparison of two quality variations) is psychologically valid [10].

The proposed procedure of DM preference elicitation was checked in experiments with a group of subjects [7]. For 5–7 criteria with 2–5 evaluations on criteria scales the number of contradictions were 1–3. When subjects were presented the contradictions, they removed them to construct a consistent decision rule.

5. Comparison of alternatives

5.1. Comparison of two alternatives

Statement 1. *The quality of every alternative can be expressed as the vector of QV corresponding to the evaluations of the alternative upon the criteria.*

Proof. Each evaluation of an alternative is connected with some QV. In the case of independence by quality variation, it is possible to represent the quality of an alternative by the set of QV, each of them corresponds to the distance along a scale of one criterion between the evaluations. Therefore, the vector QV represents the quality of an alternative.

Statement 2. *The relation between any pair of QV on JSQV is defined or determined by direct answers of DM or on the basis of expansion by transitivity.*

Proof. Let us take two arbitrary QV from JSQV. It is possible to find JSQV for the pair of criteria or for one criterion that they belong to. For both cases, those two QV are compared or assessed directly by the decision maker or by utilization of the transitivity condition.

Definition 2. Let us note as the function of alternative quality: $V(y)$.

Let us make the following supposition about the properties of this function:

- There are maximum and minimum values of $V(y)$;
- For independent criteria, the value of $V(y)$ is increasing when the evaluation on each criterion is improving.

Let us assign a rank for each QV on JSQV beginning from the best QV.

For example, for JSQV given above,

$$c_1 < a_1 < b_1 < a_2 < b_2 < c_2 < a_3 < b_3 < c_3$$

rank 1 is given to c_1 , rank 2 is given to a_1 and so on.

Let us take two alternatives: $y_i = (y_{i1}, y_{i2}, \dots, y_{iN})$ and $y_j = (y_{j1}, y_{j2}, \dots, y_{jN})$.

It is possible to find a corresponding QV for each component of vectors and rank each QV according to JSQV.

For each alternative it is possible to define the corresponding vector of component ranks:

$$V(y_i) \iff V(r_k, r_l, \dots, r_g),$$

$$V(y_j) \iff V(q_s, q_d, \dots, q_m),$$

where r_k, r_l, \dots, r_g is the ranks of components for the vector $y_i = (y_{i1}, y_{i2}, \dots, y_{iN})$, and q_s, q_d, \dots, q_m is the ranks of components for the vector $y_j = (y_{j1}, y_{j2}, \dots, y_{jN})$.

Statement 3. *If the condition of independence by QV is true for all pairs of criteria and ranks of the components for y_i are no worse than the ranks of the components for y_j and at least for one component of y_i rank is better, then an alternative y_i is more preferable for the decision maker in comparison with y_j , and $V(y_i) \succ V(y_j)$.*

Proof. If the condition of independence by QV is true, from the replacement of one component of y_i by one component of y_j , it follows:

$$V(y_i) = V(r_k, r_l, \dots, r_g) \geq V(q_s, r_l, \dots, r_g).$$

Making the replacement by one of the components of y_i by the components of y_j , we have the following inequalities:

$$V(q_s, r_l, \dots, r_g) \geq V(q_s, q_d, \dots, r_g),$$

$$V(q_s, q_d, \dots, r_g) \geq V(q_s, q_d, \dots, q_m) = V(y_j).$$

Making the sums of left- and right-hand sides of inequalities, one has:

$$V(y_i) \succ V(y_j).$$

The following two statements are evident.

Statement 4. *If the components of both vectors have the same ranks, the vectors are equivalent.*

Statement 5. *If the conditions of Statements 3 and 4 are not true, the alternatives y_i and y_j are incomparable.*

The comparison of two vectors on the basis of JSQV makes it possible to demonstrate the preference of one alternative against the other or their equivalence. If such information is not sufficient, the alternatives are incomparable.

5.2. Ranking of given alternatives

Let us suppose that the group of alternatives is given. The construction of a partial order of alternatives is completed by the following three-step algorithm.

Step 1: Formal index of quality.

A formal index of quality is introduced to minimize the number of pairwise alternative comparisons needed for partial ranking of alternatives.

For each alternative it is possible to make the sum of corresponding ranks for QV of its components. Let us nominate this sum as a formal index of quality (FIQ). It is evident that a better alternative in a pairwise comparison always has a smaller FIQ.

Let us return to the example given above. For general JSQV and for three criteria it is possible to assign the following numbers to QV:

$$c_1 < a_1 < b_1 < a_2 < b_2 < c_2 < a_3 < b_3 < c_3$$

1	2	3	4	5	6	7	8	9
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The index is calculated formally, even with the violation of properties of ordinal scales: the sum of QV between the evaluations on one criterion scale is not equal to QV along the scale. But we need this index only for finding the sequence of pairwise alternative comparisons.

Step 2: The procedure of pairwise comparisons.

The following procedure of comparison is used.

1. The alternatives are allocated according to FIQ from smaller sums to bigger ones. It is easy to notice that potentially best alternatives have smaller sums.
2. According to this order, alternatives are compared pairwise on the basis of binary relation given in Statement 4 beginning from an alternative with smallest FIQ.

3. Let us take three alternatives with increasing FIQ. If in the pairwise comparisons one could find that:

Alt $i \Rightarrow$ Alt $j \Rightarrow$ Alt k , then from definition of JSQD follows:

Alt $i \Rightarrow$ Alt k .

If Alt j and Alt k are incomparable, then Alt i is to be compared with both alternatives.

Step 3: Sequential selection of non-dominated nuclei.

Let us conduct pairwise comparison of alternatives beginning from ones with smaller FIQ on the basis of binary relation formulated in Statement 3.

Let us single out, on the basis of binary relations all non-dominated alternatives and refer to them as the first nucleus. After removing the first nucleus, let us select the second, and so on.

The rule of rank assignment to an alternative is the following. Alternatives from the first nucleus have rank 1. An alternative is ranked i if it is dominated by an alternative ranked $i - 1$ and itself dominates an alternative ranked $i + 1$.

If an alternative is dominated by an alternative ranked i but itself dominates an alternative ranked $i + j$, then its rank is fuzzy within the range from $i + 1$ to $i + j - 1$.

Relative versus absolute ranks. The ranks nominated in the way defined above could be called relative because they are related to the given group of alternatives. But using the same three-step algorithm it is possible to assign absolute rank to every alternative. The ranks can be called absolute if they are related to all possible alternatives from set Y (all possible combinations of evaluations upon the criteria). To find absolute ranks, it is necessary to apply the three-step algorithm for the set of vectors $y_i \in Y$.

Let us return to the example given above and assign to every QV on general JSQV ranks beginning from 1 for the smallest. In Table 2, the group of 9 alternatives is given with corresponding FIQ.

Let us demonstrate how FIQ is calculated. For example, for Alt 3 QV are a_3 and c_1 ; the sum is equal 8. For Alt 4 the only QV is b_3 ; the sum is equal 8.

Table 2

No. of alternative	Evaluations on criteria	FIQ
Alt 1	A1 B2 C2	4
Alt 2	A2 B2 C1	5
Alt 3	A3 B1 C2	8
Alt 4	A1 B3 C1	8
Alt 5	A2 B1 C3	11
Alt 6	A3 B2 C2	11
Alt 7	A3 B2 C1	10
Alt 8	A3 B3 C1	15
Alt 9	A2 B1 C2	3

In Fig. 1 the partial order of the alternatives is given as the result of binary comparisons. The alternatives are located from best (on the left) to worst. The alternatives in pairs: Alt 2–Alt 3, Alt 3–Alt 4, Alt 5–Alt 7, Alt 5–Alt 6, and Alt 5–Alt 8 are incomparable.

Let us demonstrate how the comparisons are made. First, the comparison of Alt 9 and Alt 1 is done. It corresponds to the comparison of a_1 and b_1 on general JSQV. According to JSQV (see above) Alt 9 is better.

Then, Alt 1 is compared with 2 and 3 in accordance with FIQ values. It is not necessary to compare Alt 9 with Alt 2 and Alt 3 because they are dominated by Alt 1. Really, c_1 is less than a_1 , and b_1 is less than a_3 on general JSQV. The next alternative involved in the process of the comparison is Alt 4 (FIQ = 8) and so on. Let us take Alt 5 and 7. In pairwise comparison one needs to compare c_3 with a_2 and b_1 . We do not have enough information on JSQV to make such a comparison.

Let us note that only 15 binary comparisons are made to obtain the partial order of the alternatives

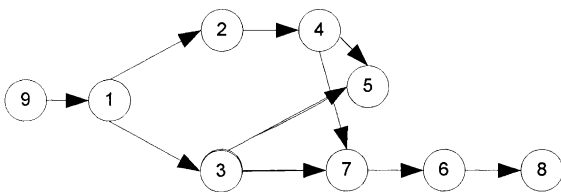


Fig. 1. The partial order of alternatives.

presented on Fig. 1 instead of 36 required by the previous version of ZAPROS.

Using the rule of rank assignment given above, the alternatives receive the ranks shown in Table 3.

The ranks in Table 3 are relative and reflect the relative values of the alternatives. Taking all vectors from the set Y it is possible to receive the absolute ranks of alternatives. For example, Alt 9, the best of the group, has in general ranking of the alternatives from the set Y , the rank 4 that gives the indication of the possible absolute value of this alternative.

Therefore, the decision maker can have relative as well as absolute ranks of alternatives. The decision maker could allocate the resources using relative ranks, but taking into account the absolute values of available alternatives to make (if necessary) the correction of resources distribution.

In the general case, the absolute ranks correspond to the general aim of ZAPROS: to prepare a decision rule before the appearance of alternatives. The three-step algorithm given above allows one to achieve this goal.

6. Conclusion

The important feature of ZAPROS methods is the utilization of psychologically justified ways of a decision maker preference elicitation. Such an approach takes into account the possibilities and limitations of human information processing system.

In a comparison with MAUT approach [1] the output of ZAPROS is very approximate. Some alternatives could be incomparable. Alternatives have only ranks (sometimes fuzzy) instead of exact quantitative evaluations of utility.

But such approximate output is much more reliable. A decision maker could use ZAPROS to gradually develop a consistent and non-contradictory policy. In experiments [12] it was

Table 3

No. of alternative	Alt 9	Alt 1	Alt 2	Alt 3	Alt 4	Alt 7	Alt 5	Alt 6	Alt 8
Rank	1	2	3	3–4	4	5	5–7	6	7

demonstrated that the methods based on MAUT are very sensitive to small human errors. Such errors are inevitable because human beings are not exact measurement devices producing exact quantitative measurements.

On the other hand, the relations between alternatives received as the output of ZAPROS are stable [12].

As the conclusion, it is possible to say:

Better to be approximately right than exactly wrong.

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