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## APPLYING MULTI-CRITERIA DECISION AIDING TECHNIQUES IN THE PROCESS OF PROJECT MANAGEMENT WITHIN THE WEDDING PLANNING BUSINESS

Numerous problems that emerge in the process of project management can be presented as multi-criteria issues and solved with the help of appropriate methods. The contracting authority, selecting one tender out of many available tenders, assesses them, taking into account various criteria, e.g. price, expected execution time and the contractor's experience. The owner of a company intending to purchase the fixed assets requisite for the realization of the project behaves similarly, i.e. the most advantageous model of the device is chosen, taking into account not only its price but also production capacity, energy intensity, noise emission, service availability, etc. From among many concepts, the investor has to choose a solution which frequently constitutes a compromise between price, functional properties, durability and aesthetics of performance, as well as safety of the utilization and impact on the environment. The choice of an investment location depends not only on the market, financial and supply factors, but also on so called soft factors such as the perceived quality of institutions and the attitude of local communities. All such situations can be described in the same way: taking into account preferences of the decision maker, the best possible choice must be made out of a finite set of alternatives evaluated according to a finite set of criteria. There are many different methods that can be used to aid a decision maker in this choice, including, but not limited to, techniques based on the outranking relation, verbal decision analysis and the MACBETH method. In this article, they will be compared and their applicability to different types of decision making problems will be considered. Furthermore, the PROMETHEE II method with a veto threshold will be presented within the text. Because the application of project management in the wedding planning business has gained wide popularity, as an illustrative example an empirical study of selecting the best venue for a wedding reception will be elaborated.

Keywords: *MCDA, outranking relation, PROMETHEE II with veto threshold, VDA, MACBETH*

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## 1. Introduction

Project management is inescapably connected with multi-criteria decision making. Various issues require a project manager (or other person responsible for a particular matter) to choose the best alternative from a set of available decision making alternatives, taking into account a number of important aspects (criteria) when comparing them. Acquiring fixed assets, selecting tender, choosing an investment option or investment location are merely examples of such issues.

According to the results of descriptive studies (see [17, 18, 24, 28, 32], multi-criteria decision making problems constitute a great challenge for people, and the more criteria the problems involve, the more complicated they are [2]. There are several approaches which may be implemented to solve this kind of problems, for instance: multi-attribute utility theory (MAUT) (see [16]), approach based on the outranking relation [30], verbal decision analysis (VDA) [21, 22] and the MACBETH method [3, 5].

Methods based on multi-attribute utility theory [16] assume that there exists a global utility function representing the decision maker's preferences and it can be built by aggregating the partial utilities of alternatives (related to each criterion). But the reduction of multidimensional evaluation to one-dimensional one via the formulation of a global utility function is possible only when certain rigorous conditions\* are met. Besides, it may lead to complete compensation between criteria – the situation in which an alternative evaluated as poor according to one or even more criteria is ranked highly because it has achieved high grades according to the remaining criteria. Using this approach, a not very realistic assumption is accepted that decision maker's preferences are given and fixed, i.e. they are expressed clearly and result in well-ordering of alternatives according to criteria – the decision maker is able to indicate, without any hesitation, even the smallest differences between utilities and reliably, systematically and precisely assign scores to the alternatives considered. In addition, determining the analytical form of the global utility function is usually very difficult and sometimes even impossible – it happens frequently that the decision maker is not able to provide the information essential to building this function [36].

An interesting alternative is the approach based on the outranking relation and on the fundamental partial comparability axiom [30], in which incomparability plays a key role [23]. The basic idea of this approach is as follows: alternative  $a_i$  outranks alternative  $a_j$  if according to a large proportion of the criteria  $a_i$  performs at least as

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\*For instance, a necessary and sufficient condition for applying an additive form of the utility function in a situation where the evaluations are deterministic is mutual preferential independence of the criteria. If the evaluations take the form of probability distributions, this condition is not sufficient – in this case, the utility independence condition must be satisfied [36]. [36]

well as  $a_j$  (the concordance condition), while its worse performance according to the other criteria is still acceptable (the non-discordance condition). Indifference thresholds and preference thresholds are introduced, in order to build outranking relations that represent decision makers' preferences and constitute partial relations of the global preferences. Using this kind of approach, there is a place for incomparability, explained e.g. by a lack of sufficient information to define preferential situation [36]. Procedures which use this approach – among which the ELECTRE [31, 37] and PROMETHEE [7, 8] methods stand out – are usually less demanding for their users at the informational level and result in more balanced recommendations than those based on a single criterion synthesis [23]. Since their assumptions are in accordance with reality, they can definitely be recommended for application in project management [14].

Although the outranking approach has many advantages, it also has one major weakness: using techniques based on this approach, it is essential to elicit information about the parameters utilized in them from decision makers and problems may be encountered in revealing preferences and fixing them. In fact, a number of psychological experiments confirm [17] that people make significant errors in the quantitative measurement of subjective factors [2].

As far as VDA-based methods are concerned, the situation is different: information on preferences in an ordinal form (for instance: more preferable, less preferable or equally preferable) which is required from decision makers within these methods, seems to be stable and reliable according to the results of psychological experiments. Moreover, this information is checked, in order to ensure its consistency. Techniques based on VDA do not use quantitative information on the importance of criteria, only verbal estimates, and no quantitative operations are made on them. Hence, all operations are clear and understandable to decision makers [22].

Within the framework of the VDA paradigm, methods belonging to the ZAPROS family [20–22] are very well known. Using these techniques, preference elicitation boils down to comparisons of pairs of hypothetical alternatives (each with the best evaluations for all the criteria but one) differing in performance according to only two criteria. The results of these comparisons are transformed into the so-called joint ordinal scale (JOS) which is subsequently used to compare real decision making alternatives [2].

Using the method of dyad comparison of criteria assessments [25], alternatives with different levels of attainment according to only two criteria are compared as well, but – contrary to the ZAPROS method – they do not necessarily include the best levels of performance. Then, in addition to JOS, a paired JOS (PJOS) is constructed in order to compare decision making alternatives which are incomparable using JOS [2].

Both of the aforementioned methods meet the first two requirements of VDA, namely: psychological reliability of information regarding the decision maker's preferences and possibility to check the consistency of this information. Both JOS and PJOS are formulated without any quantitative operations, and their correctness is

proven within the framework of the additive value model. Nevertheless, their implementation in the comparison of real decision making alternatives, however rational, does not seem to be easily explainable to participants in the decision making process. Furthermore, psychological constraints assumed in these methods are rather restrictive. They are based on the results of psychological experiments, according to which the pairwise qualitative comparisons of hypothetical alternatives varying in their assessment according to not more than two criteria are relatively easy for human beings [18]. As a matter of fact, experiments carried out within the cooperation between the Academy of Finland and the Russian Academy of Sciences have shown [12] that people are able to make reliable pairwise comparisons (using special graphical aids such as colour differentiation of preferences) of alternatives that differ in their assessment according to three or even four criteria. Taking this into account, the Intellectual Decision Support System (IDSS) UniComBOS (Unit Comparison for the Best Objective Selection) was proposed [11]. It is based on the principles of VDA but implements a new approach to multi-criteria comparison and choice by trying to overcome the limitations mentioned above, as well as adapting a decision making procedure, i.e. the complexity of the questions asked, to the individual capabilities of decision makers. One of its key original features is the use of special visualization techniques in order to gather information on preferences from decision makers and another one is an online preference consistency control system allowing IDSS UniComBOS to reveal, among other things, errors in the answers of decision makers [2].

Another interesting approach to multi-criteria decision analysis is MACBETH. It was devised as a response to the following question: how can a value scale be built on a finite set of elements, in both a qualitatively and quantitatively meaningful way, without forcing a decision maker to produce direct numerical representations of preferences and involving only two elements of the set for each judgment required from the decision maker? Hence, using the MACBETH method, a decision maker provides information about the comparison of two elements (alternatives, criteria) of the analyzed set at a time, firstly by giving an ordinal judgment as to their relative attractiveness/importance and secondly – if they are not deemed to be equally attractive/important – by expressing a qualitative judgment about the difference between their attractiveness/importance with the help of six semantic categories: very weak, weak, moderate, strong, very strong and extreme or – in the case of, for example, hesitation – a succession of them [4]. Up until that point, MACBETH is not unlike the AHP method proposed by Saaty [33]. Afterwards, numerical value scales for the considered alternatives according to each criterion, as well as a weighting scale, are built on the basis of the decision maker's semantic judgments using linear programming. Overall value scores of the alternatives that reflect their attractiveness taking into account all the criteria are calculated by additively aggregating the value scores of the alternatives according to each criterion.

The aim of this article is to briefly describe chosen multi-criteria decision aiding methods based on the outranking relation from the ELECTRE and PROMETHEE families, as well as the MACBETH method and a procedure belonging to the VDA framework, namely UniComBOS. Additionally, it provides a short comparison of these approaches. Finally, an illustrative example of their application connected with project management within the wedding planning business has been presented.

## 2. Description of multi-criteria methods

Below, some chosen multi-criteria decision-aiding procedures will be concisely presented, namely: ELECTRE I with a veto threshold (ELECTRE Iv), PROMETHEE II, PROMETHEE II with a veto threshold (PROMETHEE IIv), IDSS UniComBOS and MACBETH.

Let us assume that  $A = \{a_1, a_2, \dots, a_m\}$  is a finite set of  $m$  alternatives defined by the decision maker,  $F = \{f_1, f_2, \dots, f_n\}$  is a set of  $n$  evaluation criteria and  $f_k(a_i)$  is the assessment of alternative  $a_i$  according to criterion  $f_k$ . These assessments which exist in original descriptions of alternatives may be determined by the decision maker or obtained from experts, catalogues, etc. For the sake of simplicity, it is assumed that all criteria are maximized.

### ELECTRE Iv

The ELECTRE Iv procedure consists of the following steps [9, 35]:

1. Calculation of the concordance indices  $c(a_i, a_j)$  for each pair of alternatives  $(a_i, a_j)$ :

$$c(a_i, a_j) = \sum_{k=1}^n w_k \varphi_k(a_i, a_j) \quad (1)$$

where:

$$\sum_{k=1}^n w_k = 1 \quad (2)$$

$w_k$  – coefficient of importance for criterion  $f_k$ ,

$$\phi_k(a_i, a_j) = \begin{cases} 1, & \text{if } f_k(a_i) \geq f_k(a_j) \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

2. Construction of the concordance set  $C_s$ :

$$C_s = \{(a_i, a_j) \in A \times A : c(a_i, a_j) \geq s \wedge s \in [0, 5; 1]\}. \quad (4)$$

3. Determination of the discordance indices  $d(a_i, a_j)$ :

$$d(a_i, a_j) = \begin{cases} 1, & \text{if } \exists k : d_k(a_i, a_j) = 1 \\ 0, & \text{if } \forall k : d_k(a_i, a_j) = 0 \end{cases} \quad (5)$$

where:

$$d_k(a_i, a_j) = \begin{cases} 1, & \text{if } f_k(a_i) + v_k[f_k(a_i)] < f_k(a_j) \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

$v_k$  – veto threshold for criterion  $f_k$ .

4. Construction of the discordance set  $D_v$  :

$$D_v = \{(a_i, a_j) \in A \times A : d(a_i, a_j) = 1\} \quad (7)$$

5. Determination of the outranking relation:

$$S(s, v) = C_s \cap \bar{D}_v, \quad \bar{D}_v = A \times A / D_v \quad (8)$$

6. Defining graphs with the help of the outranking relation showing the relationships between alternatives.

7. Selecting the best alternative or a subset of alternatives that the decision maker should focus his attention on.

## PROMETHEE II

The PROMETHEE II method consists of [6]:

1. Defining a generalized criterion  $\{f_k, P_k(a_i, a_j)\}$  for each criterion  $k$ ;  $f_k$  is a criterion  $k$  and  $P_k(a_i, a_j)$  represents the preference function showing the strength

of preference for alternative  $a_i$  over alternative  $a_j$  according to criterion  $k$ :  $P_k(a_i, a_j) = F_k[d_k(a_i, a_j)] \forall a_i, a_j$ , where  $d_k(a_i, a_j) = f_k(a_i) - f_k(a_j)$  and for which  $P_k(a_i, a_j) \in [0; 1]$ . In order to facilitate this definition, six types of generalized criteria have been proposed.

Table 1. Types of generalized criteria

Generalized criterion	Preference function	Parameters
Type 1 usual criterion	$P_k(d_k) = \begin{cases} 0, & \text{if } d_k \leq 0 \\ 1, & \text{if } d_k > 0 \end{cases}$	none
Type 2 quasi-criterion (u-shape criterion)	$P_k(d_k) = \begin{cases} 0, & \text{if } d_k \leq q_k \\ 1, & \text{if } d_k > q_k \end{cases}$	indifference threshold $q_k$
Type 3 v-shape criterion	$P_k(d_k) = \begin{cases} 0, & \text{if } d_k \leq 0 \\ \frac{d_k}{p_k}, & \text{if } 0 < d_k \leq p_k \\ 1, & \text{if } d_k > p_k \end{cases}$	preference threshold $p_k$
Type 4 level criterion	$P_k(d_k) = \begin{cases} 0, & \text{if } d_k \leq q_k \\ \frac{1}{2}, & \text{if } q_k < d_k \leq p_k \\ 1, & \text{if } d_k > p_k \end{cases}$	indifference threshold $q_k$ preference threshold $p_k$
Type 5 pseudo-criterion (V-shape with indifference criterion)	$P_k(d_k) = \begin{cases} 0, & \text{if } d_k \leq q_k \\ \frac{d_k - q_k}{p_k - q_k}, & \text{if } q_k < d_k \leq p_k \\ 1, & \text{if } d_k > p_k \end{cases}$	indifference threshold $q_k$ preference threshold $p_k$
Type 6 Gaussian criterion	$P_k(d_k) = \begin{cases} 0, & \text{if } d_k \leq 0 \\ 1 - \exp\left(\frac{-d_k^2}{2s^2}\right), & \text{if } d_k > 0 \end{cases}$	$s_k$ (defines the inflection point of the preference function)

Source: [8].

2. Calculation of the aggregated preference indices  $\pi(a_i, a_j)$  for each pair of alternatives  $(a_i, a_j)$ :

$$\pi(a_i, a_j) = \sum_{k=1}^n w_k P_k(a_i, a_j) \quad (9)$$

where  $\pi(a_i, a_j)$  shows the degree to which  $a_i$  is preferred to  $a_j$  over all the criteria.

3. Defining two outranking flows for each alternative  $a_i$ :

- the positive outranking flow

$$\varphi^+(a_i) = \frac{1}{m-1} \sum_{j=1}^m \pi(a_i, a_j) \quad (10)$$

- the negative outranking flow

$$\varphi^-(a_i) = \frac{1}{m-1} \sum_{j=1}^m \pi(a_j, a_i) \quad (11)$$

4. Calculation of the net outranking flow  $\phi(a_i)$  for each alternative  $a_i$ :

$$\phi(a_i) = \varphi^+(a_i) - \varphi^-(a_i) \quad (12)$$

5. Construction of the final complete ranking of the alternatives according to the net flows  $\phi(a_i)$  in descending order.

### PROMETHEE IIv

PROMETHEE IIv [15] is a combination of the ELECTRE III and PROMETHEE II methods. The first two steps are identical to PROMETHEE II. The next steps, commencing from the third one, are as follows:

3. Calculation of the discordance indices  $d_k(a_i, a_j)$  for each pair of alternatives  $(a_i, a_j)$  and for each criterion

$$d_k(a_i, a_j) = \begin{cases} 1, & \text{if } f_k(a_j) - f_k(a_i) > v_k \\ \frac{f_k(a_j) - f_k(a_i) - L_k}{v_k - L_k}, & \text{if } L_k < f_k(a_j) - f_k(a_i) \leq v_k \\ 0, & \text{if } f_k(a_j) - f_k(a_i) \leq L_k \end{cases} \quad (13)$$

where:  $L_k$  – preference threshold  $p_k$  for criterion  $f_k$  or in the case of a quasi-criterion, where such a threshold does not exist, the indifference threshold  $q_k$ ; for the usual criterion  $L_k$  is equal to zero, whereas in the case of a Gaussian criterion  $L_k$  is infinite.



4. Calculation of the credibility indices for each pair of alternatives  $(a_i, a_j)$

$$\sigma(a_i, a_j) = \pi(a_i, a_j) \prod_{k \in D(a_i, a_j)} \frac{1 - d_k(a_i, a_j)}{1 - \pi(a_i, a_j)} \quad (14)$$

where:

$$D(a_i, a_j) = \{k : d_k(a_i, a_j) > \pi(a_i, a_j)\} \quad (15)$$

5. Calculation of the net outranking flow,  $\phi(a_i)$ , for each alternative  $a_i$

$$\phi(a_i) = \phi^+(a_i) - \phi^-(a_i) \quad (16)$$

where:

$$\phi^+(a_i) = \frac{1}{m-1} \sum_{j=1}^m \sigma(a_i, a_j) \quad (17)$$

$$\phi^-(a_i) = \frac{1}{m-1} \sum_{j=1}^m \sigma(a_j, a_i) \quad (18)$$

6. Construction of the final complete ranking of the alternatives according to the net flows  $\phi(a_i)$  in descending order.

### IDSS UniCombOS

The procedure implemented in IDSS UniCombOS consists of the following steps [11], [2]:

1. Procedure for the comparison of units: Let us introduce a  $D$ -unit as a partial description of an alternative based on the criteria in  $D \subseteq K$ , where  $K = \{1, 2, \dots, n\}$  is the set of criterion numbers. The  $D$ -unit for alternative  $a_i \in A$  with assessments  $(f_1(a_i), f_2(a_i), \dots, f_n(a_i))$  is  $(f_1(\alpha_i), \dots, f_k(\alpha_i))$ , where  $\forall j \in D f_j(\alpha_i) = f_j(a_i)$ ,  $\forall j \in K \setminus D f_j(\alpha_i) = f_j(\omega_i)$ , and  $f_j(\omega_i)$  stands for assessment of alternative  $a_i$  according to criterion  $f_j$ , which is not used in such a partial description.

Let us assume that the criteria from  $F$  are mutually preference-independent [10] and preferences between  $D$ -units are transitive for any  $D$ . Then the following rule of unit-wise dominance (U-dominance) holds: alternative  $a_i$  is preferable to alternative  $a_j$ , if there exists such a partition of the criterion set  $K$  into subsets  $D_1, D_2, \dots, D_m$ ,

$$\bigcup_{i=1}^m D_i = K, \quad \forall i, j, \quad i \neq j, \quad D_i \cap D_j = \emptyset, \quad \text{such that } \forall i \quad a_i^{D_i} \succ a_j^{D_i}.$$

The preferences of the decision maker are elicited step by step by pairwise comparisons between units based on the same subsets of criteria. The procedure begins with pairwise comparisons of single-criterion units to convert the nominal assessment scales for the criteria to ordinal ones in accordance with the preferences of a decision maker. Such a type of comparisons is hardly ever sufficient to elicit the best alternative on the basis of the U-dominance rule. If there is no alternative chosen as the best one, IDSS UniCombBOS proceeds to pairwise comparisons of two-criteria units\*. After each comparison made by a decision maker, the UniCombBOS algorithm is applied to check the consistency of preferences and to try to find the best alternative(s). If the set of decision maker's answers enables it to do that, then the problem is deemed to be solved. Otherwise, IDSS UniCombBOS proceeds to comparisons of three-criteria units. Once again, after each comparison made by the decision maker, the algorithm verifies the consistency of preferences and attempts to select the best alternative using the information on preferences obtained.

IDSS UniCombBOS determines the maximal complexity of comparisons (i.e. the maximum number of criteria used in units) for each decision maker individually. A decision makers' capability to compare multi-criteria units is represented by the frequency of their errors. If a decision maker encounters difficulties in comparing units of the current dimension, dialogue is interrupted and the information obtained from comparisons of units of the previous dimension is used to compare alternatives. As a consequence, the system might not be able to find the single best alternative, but in such a case it will indicate the set of incomparable alternatives preferable to the decision maker in comparison to any alternative not included in this set.

2. Analysis and corrections of inconsistency: The inconsistencies revealed are presented to the decision maker for analysis and correction. Decision makers have the opportunity to indicate and correct errors in their previous answers, as well as to disagree with the results of the operations conducted. In the latter case, this means criteria

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\*IDSS UniCombBOS facilitates comparisons of two- or more criteria dimension units through colour differentiation of preferences. For instance, when a pair of two-criteria units is displayed to the decision maker for comparison, the better assessments for each unit are highlighted in one colour (e.g. green) and the worse assessments – in another one (e.g. blue). If two units are equally preferable to the decision maker, they are displayed in the same colour (e.g. yellow). Hence, the decision maker clearly sees the advantages and disadvantages of each unit in the pair [2].

preference-dependence and/or intransitivity of preferences and the considered decision making problem may need restructuring.

3. Display of results and explanation. The results of comparisons are presented in the form of an oriented graph, in which nodes correspond to alternatives and arcs go from the better alternative to the worse one. Decision makers may prompt an explanatory dialogue for any arc of the graph and see how this particular relation has been obtained. Moreover, it is possible to return to the stage of unit comparisons if decision makers decide to revise their previous answers.

## MACBETH

The MACBETH procedure is as follows [4]:

1. Comparing pairwise the differences between the importance of the criteria, as well as between the attractiveness of alternatives according to each criterion using the following semantic categories: no, very weak ( $d_1$ ), weak ( $d_2$ ), moderate ( $d_3$ ), strong ( $d_4$ ), very strong ( $d_5$ ) and extreme ( $d_6$ ). The description of the difference is provided in the form:  $d_i$  to  $d_j$ ,  $i \leq j$ .

2. Solving the linear programs corresponding to all the comparisons conducted, i.e. separately for the criteria and separately for the alternatives with respect to each criterion:

- $\min v(x_1)$  subject to the following constraints  $S_{\text{mac}}$ :

$$v(x_p) - v(x_r) = 0 \quad \forall x_p, x_r \in I, \quad p < r \quad (19)$$

$$d_i + 0.5 \leq v(x_p) - v(x_r) \quad \forall i, j \in \{1, \dots, 6\}, \quad i \leq j, \quad \forall x_p, x_r \in C_{ij} \quad (20)$$

$$v(x_p) - v(x_r) \leq d_{j+1} - 0.5 \quad \forall i, j \in \{1, \dots, 6\}, \quad i \leq j, \quad \forall x_p, x_r \in C_{ij}, \quad (21)$$

$$d_1 = 0.5 \quad (22)$$

$$d_{i-1} + 1 \leq d_i \quad \forall i \in \{2, \dots, 6\} \quad (23)$$

$$v(x_i) \geq 0 \quad \forall i \in \{1, \dots, 6\} \quad (24)$$

$$d_i \geq 0 \quad \forall i \in \{1, \dots, 6\} \quad (25)$$

As a result, the optimal solution is obtained:

$$v(x_1), v(x_2), \dots, v(x_n), \quad v(x_1) = \mu(x_1), \quad v(x_n) = \mu(x_n) = 0 \quad (26)$$

3. Solving (in order to guarantee the uniqueness of the MACBETH scales) for  $i = 2$  to  $n - 1$ :

- $\max v(x_i)$  subject to:

$$S_{\max}, \quad v(x_1) = \mu(x_1), \dots, v(x_{i-1}) = \mu(x_{i-1}) \quad (27)$$

obtaining the optimal solution:

$$v(x_1), v(x_2), \dots, v(x_n), \quad \text{where } x \max = v(x_i) \quad (28)$$

- $\min v(x_i)$  subject to:

$$S_{\min}, \quad v(x_1) = \mu(x_1), \dots, v(x_{i-1}) = \mu(x_{i-1}) \quad (29)$$

obtaining the optimal solution:

$$v(x_1), v(x_2), \dots, v(x_n), \quad \text{where } x \min = v(x_i) \quad (30)$$

$$\mu(x_i) = \frac{x \min + x \max}{2} \quad (31)$$

4. Transforming the scales obtained for the alternatives and the scale constructed for the weights into 0–100 scales and assigning the scores 0 and 100 to the two end points of the scales. In the case of the criterion weights, values from the 0–100 scale should be normalized in order that their sum be equal to 1.

5. Calculating the weighted sum of the alternatives' scores with respect to each criterion.

### 3. Comparison of approaches to multi-criteria decision analysis

Outranking methods have become very popular over the last three decades. They have already been applied in various fields, such as banking, media planning, trans-

port, industrial location, water resources, waste management, investments, manpower planning, medicine, chemistry, health care, tourism, ethics and many more.

Table 2. Differences between the outranking, VDA and MACBETH approaches

Outranking methods	Verbal decision analysis	MACBETH method
Application		
Intended to compare a given set of decision making alternatives	Designed to elicit a sound preference relationship that can be applied to future cases; especially useful when a decision is made under new circumstances or in conditions of high ambiguity	Intended to compare a finite set of decision making alternatives
Decision making problem		
Deal mostly with cases in which the number of criteria is rather large (up to twelve or thirteen) and the number of alternatives – relatively small	More oriented to tasks with a rather large number of alternatives, while the number of criteria is usually relatively small in order to reduce the number of comparisons required	Due to the pairwise comparisons of elements, neither the number of criteria nor the number of alternatives should be very large
Methodology		
Use criterion weights and other parameters, which serve an operational purpose, but also introduce heuristics and possible intransitivity of preferences	Bases its outranking on axiomatic relationships, to include direct assessment, dominance, transitivity and preferential independence	Relies on a cardinal multi-criteria aggregation procedure, uses a mathematical algorithm (linear programming), employs a non-numerical interactive questioning procedure and requires only qualitative judgments about differences between attractiveness
Decision makers		
Intellectual abilities and training help decision makers to understand and accept this approach, which is quite complex and mathematically complicated	Does not require any special knowledge in decision analysis on the part of the decision makers	It is related to user friendly decision support software called M-MACBETH; in spite of this, it is desirable that decision-makers have some mathematical knowledge

Source: [3, 4, 26].

Verbal decision analysis is a relatively new methodological approach, which has lately gained popularity. It is based on cognitive psychology, applied mathematics and computer science and it was proposed as a framework for unstructured decision mak-

ing problems\*, which are problems with mostly qualitative parameters and no objective model for their aggregation. Examples of such tasks can be found in policy making and strategic planning in different fields, as well as in personal decisions. For instance the VDA-based ZAPROS method (and its variations) has been used in R & D planning [21, 22], applicant selection [27], job selection and pipeline selection [26].

The MACBETH approach was developed in the early 1990's. It has been used in many public and private applications such as: human resources evaluation and management, evaluation of suppliers' performance, strategic town planning, airport management, location of military facilities, environmental management and evaluation of flood control measures, firms' resource allocation and risk management, credit scoring, etc. [4].

Both outranking methods and verbal decision analysis provide outranking relationships between multi-criteria decision making alternatives. However, there are some important differences between these approaches. They are summarized in Table 2, which also includes information about the MACBETH method

#### 4. Illustrative example

The usefulness of the above-mentioned methods for decision aiding processes in the area of project management will be illustrated by a real-life example which concerns the project of wedding planning, namely the problem of choosing the best venue for a wedding reception.

For most people, a wedding, either personal, of a child or another family member, is a very important event. It is often one of the most significant and happiest events in one's life and because of this it should be unique, beautiful and perfect. For this reason planning the wedding reception, which is often the responsibility of the bride, usually requires a lot of time and effort. It begins with deciding on the type of reception and its location. In the context of this case study, it is assumed that the reception is a wedding ball for approximately 120 invited guests, which is going to be held in summer 2014.

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\*The general features of unstructured problems are as follows [19], [26]:

- they are unique in the sense that each problem is new to the decision maker and has characteristics not previously experienced;
- the criteria in these problems are mostly qualitative in nature, most often formulated in a natural language;
- in many cases, the evaluations of alternatives according to the criteria may be obtained only from human beings (experts or decision makers);
- the quality grades on the criterion scales are verbal definitions presenting the subjective values of the decision maker.

Eight different venues available to be booked for the wedding party in June 2014 are taken into consideration. All of them are in city X (where the wedding ceremony will take place) or nearby. In order to determine the evaluation criteria, a value tree was constructed by the decision maker who is, by tradition, a woman. She is a busy person, about 30 with a degree in economics and many different duties.

Table 3. Evaluation criteria

Criterion	Description
Cost [€]	This criterion represents the estimated cost (quoted in EUR) of the wedding menu for 120 invited guests offered by the venue, as well as the cost of accommodation (within the venue or in another location if it is not provided by the venue) for the 70 wedding guests who will need it.
Capacity [number of people]	The wedding venue has to easily accommodate the expected target audience. It should not be too small or too large for the expected number of guests. If it is too small, then the guests will feel uncomfortable. If it is too large, then attendees will have the impression that half of the guests have not shown up and they will leave with the feeling that the event was a failure. In the problem considered, the ideal capacity of a venue (determined by the decision maker) is 150 people. The criterion is represented by the distance between the ideal capacity $c_i$ and the venue's capacity $c_v$ , calculated as follows: $ c_i - c_v $ .
Glamour [0–6]	As the wedding party has to be wonderful and unforgettable, the venue should be original, stylish and elegant and it should provide charming surroundings, a serene atmosphere and romantic mood. The decision maker has scaled the attractiveness of each venue from 0 to 6.
Car park [0–4]	The wedding venue has to have its own car park. It should be big enough to accommodate the target audience's vehicles comfortably. Besides, it should be safe (monitored, guarded or at least fenced off). The decision maker has evaluated the car park of each venue using the 0–4 scale.
Distance [km]	The venue should be selected according to convenience for the target audience. It should not be very far from the church in which the wedding ceremony will take place. The distance from the church to the venue is measured in km.
Air-conditioning [0/1]	Because the wedding is going to be held in the summertime, the venue should be air-conditioned. Venues have been evaluated using a 0/1 scale: 0 represents a lack of air-conditioning and 1 means that the venue is air-conditioned.
Accommodation [0–4]	If you are planning the details of a wedding, it is important to provide hotel rooms for wedding guests. Having accommodation at the wedding venue is a great advantage, as the guests can relax and have a good time without wondering how they are going to get home, or whether they will be able to find their hotel later in the night. In the case study considered, the venue should provide a comfortable and memorable stay for 70 wedding guests. Otherwise, it will be necessary to book hotel rooms in another place and provide transport from the hotel to the venue, and then back again at the end of the party. The decision maker has scaled the assessment of the accommodation combined with the venue from 0 to 4, where 0 represents a venue without accommodation.

With the help of the value tree technique, the following seven criteria were identified:

- $f_1$  – cost of wedding menu and accommodation,
- $f_2$  – venue’s capacity (size),
- $f_3$  – venue’s glamour,
- $f_4$  – availability and quality of the car park,
- $f_5$  – proximity to the church (distance from the church to the venue),
- $f_6$  – air-conditioning facilities,
- $f_7$  – availability and quality of accommodation.

These are described in more detail in Table 3.

Table 4 provides the performance matrix for the eight wedding venues considered and the seven criteria used to evaluate them. It also includes the type of preference function defined for each criterion, as well as thresholds and weighting coefficients. The types of the preference functions, thresholds and weights of criteria were determined directly by the decision maker.

Table 4. Input data for the illustrative example

Venues	Criteria						
	Cost	Capacity	Venue’s glamour	Car park	Distance	Air conditioning	Accommodation
A	6111.11	150	4	1	7.58	0	4
B	6886.57	0	2	1	2.69	1	0
C	6932.87	100	4	3	9.22	1	4
D	5775.46	10	3	2	13.00	1	0
E	6053.24	70	2	2	0.20	1	0
F	8379.63	0	6	4	18.70	1	4
G	5750.00	10	3	1	10.10	0	2
H	5076.39	30	4	3	3.05	0	1
Weights	0.30	0.15	0.15	0.05	0.15	0.05	0.15
Max/min	min	min	max	max	min	max	max
$q$	416.67	10.00	1.00		2.00		
$p$	833.33	30.00	3.00	2.00	5.00		2.00
$v$	1944.44	120.00	5.00	4.00	30.00	2.00	4.00
Preference function	V	V	IV	III	V	I	III

### Application of ELECTRE Iv

First, the ELECTRE Iv method was used to select the best wedding reception venue. The table below presents the outranking relation established for a concordance level equal to 0.75.



Table 5. Outranking relation for concordance level  $s = 0.75$

Alternative	A	B	C	D	E	F	G	H
A	1	0	1	0	0	0	0	0
B	0	1	0	0	0	0	0	0
C	0	0	1	1	0	1	1	0
D	0	1	0	1	1	0	0	0
E	0	1	0	0	1	0	0	0
F	0	0	0	0	0	1	0	0
G	0	0	0	1	0	0	1	0
H	0	0	0	1	0	0	0	1

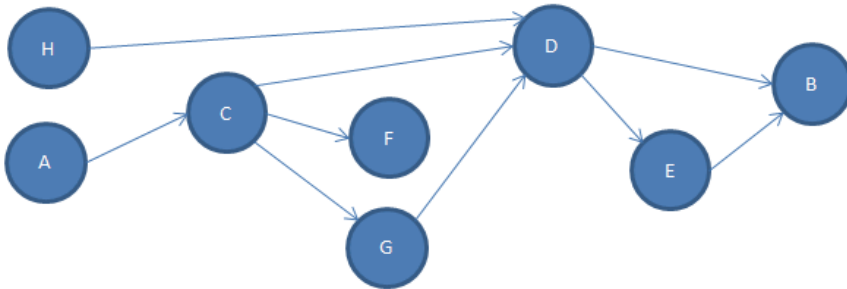


Fig. 1. Graph constructed from the best alternatives to the worst ones

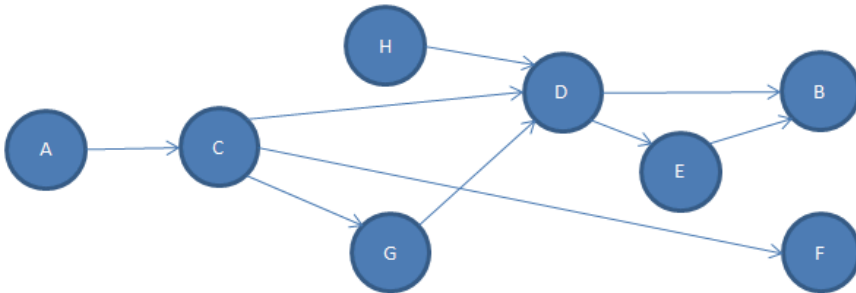


Fig. 2. Graph constructed from the worst alternatives to the best ones

Table 6. The results of the analysis of the graphs ( $s = 0.75$ )

Level	From the best alternatives to the worst ones	From the worst alternatives to the best ones
1	A, H	A
2	C	C
3	F, G	G, H
4	D	D
5	E	E
6	B	B, F

In the case of both graphs, alternative A turned out to be the best and should be recommended to the decision maker. Alternative C was classified on the second level in both graphs. Another alternative that is worth considering by the decision maker is venue H, which was placed on the first level in the graph constructed from the best alternatives to the worst ones and on the third level in the graph constructed from the worst alternatives to the best ones. In turn, alternatives D, E and B were classified on the lowest levels in both graphs, which leads to the conclusion that these are the worst solutions and can be excluded from further analysis. Venue F is a very interesting alternative as it was placed on the third level in the graph constructed from the best alternatives to the worst ones and on the last level in the graph constructed from the worst alternatives to the best ones. This is the result of its poor assessments from the point of view of the cost and distance from the church and its excellent assessments from the point of view of the other criteria.

### Application of PROMETHEE II

Table 7 contains aggregated preference indices for each pair of alternatives, as well as the positive and the negative outranking flows for each alternative.

Table 7. Aggregated preference indices and outranking flows (positive and negative)

Alternatives	A	B	C	D	E	F	G	H	Positive outranking flow
A	0.000	0.504	0.146	0.450	0.375	0.300	0.326	0.300	2.401
B	0.345	0.000	0.200	0.150	0.050	0.300	0.300	0.200	1.545
C	0.250	0.425	0.000	0.414	0.400	0.300	0.500	0.450	2.739
D	0.225	0.175	0.200	0.000	0.050	0.300	0.175	0.175	1.300
E	0.375	0.200	0.350	0.150	0.000	0.300	0.325	0.193	1.892
F	0.325	0.500	0.150	0.425	0.550	0.000	0.575	0.600	3.125
G	0.050	0.450	0.200	0.345	0.350	0.300	0.000	0.175	1.870
H	0.377	0.425	0.350	0.427	0.450	0.300	0.293	0.000	2.621
Negative outranking flow	1.946	2.679	1.596	2.361	2.225	2.100	2.494	2.093	

On the basis of the positive and negative outranking flows, a complete ranking of the alternatives was built (Table 8). It can be easily noticed that according to the results obtained with the help of the PROMETHEE II method, alternative C turned out to be the best. Alternative F was classified in second place. The two other alternatives with positive net outranking flow are H and A. In turn, alternatives D and B were

placed in seventh and eighth place, respectively. The two other alternatives with negative net outranking flow are E and G.

Table 8. Complete ranking of the alternatives obtained with the aid of PROMETHEE II

Place	Alternative	Net outranking flow
1	C	0.163
2	F	0.146
3	H	0.075
4	A	0.065
5	E	-0.048
6	G	-0.089
7	D	-0.152
8	B	-0.162

### Application of PROMETHEE IIv

Table 9 contains the credibility indices for each pair of alternatives, as well as the positive and the negative outranking flows for each alternative.

Table 9. Credibility indices and outranking flows (positive and negative)

Alternatives	A	B	C	D	E	F	G	H	Positive outranking flow
A	0.000	0.000	0.078	0.000	0.213	0.000	0.000	0.000	0.291
B	0.000	0.000	0.000	0.132	0.050	0.000	0.300	0.030	0.513
C	0.250	0.164	0.000	0.235	0.400	0.095	0.333	0.065	1.543
D	0.000	0.167	0.000	0.000	0.036	0.000	0.175	0.170	0.548
E	0.000	0.138	0.000	0.118	0.000	0.000	0.321	0.193	0.770
F	0.000	0.406	0.076	0.000	0.000	0.000	0.000	0.000	0.483
G	0.050	0.409	0.125	0.263	0.269	0.153	0.000	0.175	1.445
H	0.302	0.370	0.207	0.372	0.409	0.153	0.293	0.000	2.105
Negative outranking flow	0.602	1.655	0.486	1.121	1.378	0.401	1.422	0.633	

On the basis of the positive and the negative outranking flows, a complete ranking of the alternatives was built (Table 10). It can be easily noticed that according to the results obtained with the help of the PROMETHEE IIv method, alternative H turned out to be the best. Alternative C was classified in second place. The two other alternatives with positive net outranking flow are F and G. In turn, alternatives E and B were placed in seventh and eighth place, respectively. The two other alternatives with negative net outranking flow are A and D.

Table 10. Complete ranking of the alternatives obtained with the aid of PROMETHEE IIv

Place	Alternative	Net outranking flow
1	H	0.210
2	C	0.151
3	F	0.012
4	G	0.003
5	A	-0.044
6	D	-0.082
7	E	-0.087
8	B	-0.163

### Application of UniComBOS

Pairwise comparisons of single-criterion units did not allow the program to establish any relation between the alternatives analyzed. Subsequently, IDSS UniComBOS

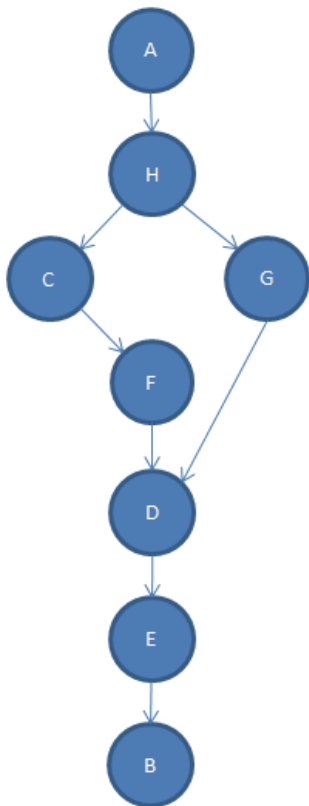


Fig. 3. Final graph

proceeds to pairwise comparisons of two- and three-criteria units. On the basis of the comparisons conducted, the graph presented in Fig. 3 was constructed. According to it, the best alternative is alternative A and the second place belongs to alternative H. The worst solution is alternative B.

### Application of MACBETH

The calculations carried out within the framework of the MACBETH method lead to the results presented in Table 11 being similar to the results obtained with the help of the PROMETHEE IIv method.

Table 11. Scores obtained using the MACBETH method

Venues	Overall	Criteria						
		Cost	Capacity	Venue's glamour	Car park	Distance	Air conditioning	Accommodation
A	49.00	58.33	0	50.00	0	60.00	0	100
B	43.00	33.33	100	0	0	86.67	100	0
C	53.29	33.33	36.36	50.00	66.67	46.67	100	100
D	50.55	75.00	90.91	25.00	33.33	26.67	100	0
E	47.35	58.33	54.55	0	33.33	100	100	0
F	55.00	0	100	100	100	0	100	100
G	54.46	75.00	90.91	25.00	0	40.00	0	57.14
H	68.03	100	72.73	50.00	66.67	80.00	0	28.57
Weights		0.30	0.15	0.15	0.05	0.15	0.05	0.15

Once again it turned out that alternative H is the most attractive one. Alternative F was classified in second place, while alternative G and alternative C were placed in third and fourth, respectively. The two last positions are occupied by alternative E and alternative B.

## 5. Analysis of the application of the methods

All five procedures that were involved in the process of selecting the best venue for the wedding reception suit the problem concerned. Nevertheless, they have different assumptions and properties and the remarkable differences in the solutions obtained with their help are apparent: while ELECTRE Iv and UniComBOS offer alter-

native A as the best one, the PROMETHEE II method suggests alternative C and the PROMETHEE IIv and MACBETH methods – alternative H.

Since the methods used to solve the problem have different virtues and drawbacks and none of them are perfect, it is recommended to use more than one method whenever possible. When they all give similar results, the analyst, as well as the decision maker, can be content. In the case where the solutions differ according to the method used, decision makers may choose among competitive top alternatives according to each technique after the analyst's description of the reasons why the solutions to a particular problem differ. Another approach to this issue might be that the decision maker, after the analyst's description of the procedures, selects the method which is most convincing for him/her and simultaneously the solution obtained with the help of this method [34].

Table 12 contains the main advantages and disadvantages of the five above-mentioned MCDA techniques in the context of selecting a wedding venue. In addition, they have been rated by the decision maker on a 0-6 subjective scale with respect to the simplicity of the algorithm, plausibility and usefulness of the solution obtained, amount of total information required, simplicity of the questions asked and interaction time required. Subsequently, compromise programming (like in the model choice algorithm of Gershon [13, 1]) was applied to rank these methods and select the one that is closest to the ideal solution determined as follows: [6, 6, 6, 6, 6]. The distance metric to be minimized was defined in the following way:

$$L_i = \sum_{k=1}^n w_k \frac{f_k^* - f_k(a_i)}{f_k^* - f_k^{\min}}$$

where  $w_k$  is the weight obtained with the help of the 'resistance to change' grid proposed by Hinkle (see [29]),  $f_k^*$  is the optimal value for the criterion  $k$ ,  $f_k^{\min}$  is the worst value attainable for criterion  $k$  and  $f_k(a_i)$  is the evaluation of technique  $a_i$  with respect to criterion  $f_k$ . The evaluation matrix and the values of the distance metric determined for each method are presented in Table 13.

Table 12. Strengths and weaknesses of the MCDA methods selected

Method	Characteristics
ELECTRE I with a veto threshold	This method requires from its users the determination of veto thresholds, as well as the weights of criteria. Thanks to the veto thresholds, this technique is partially compensatory (a really bad score according to one criterion cannot be compensated by a good score according to another), but determination of the thresholds may be difficult and time-consuming for decision makers. Moreover, differences between the assessments of alternatives are not totally taken into account – it does not matter how much one assessment is better than another with respect to a given criterion.

Method	Characteristics
	<p>Another drawback of this method is the form of the final solution – a graph that may contain direct cycles (within which the alternatives are considered to be indifferent) and isolated nodes (representing incomparable alternatives) might be inconvenient and unconvincing to decision makers.</p> <p>On one hand, this method is quite simple and because of this it can be easily and quickly understood by decision makers who often have a minimal mathematical background; on the other hand, it does not take into account the problem of imperfect knowledge.</p> <p><u>Interaction time:</u> in the case study considered, it took 25 minutes to establish the values of the veto thresholds for 7 evaluation criteria; determination of the criterion weights took 15 minutes.</p>
PROMETHEE II	<p>This method requires from its users determination of the type of preference function for each criterion, as well as the values of the parameters associated with a particular type of preference function. Despite indifference and preference thresholds, the weights of criteria have to be defined. The thresholds are easily interpretable and allow better reflection of decision maker's preferences.</p> <p>Besides, uncertainty is dealt with by them. Unfortunately, their determination is not a simple task and may be time-consuming.</p> <p>Moreover, differences between the assessments of alternatives are not fully taken into account – it does not matter by how much the preference threshold is exceeded.</p> <p>On one hand, this method is user-friendly and understandable; on the other hand, because of the lack of veto thresholds there is no possibility of decreasing the compensation between the criteria.</p> <p>The solution takes the form of a complete order, which is convenient for decision makers.</p> <p><u>Interaction time:</u> in the case study considered it took 20 minutes to define the types of preference function for 7 evaluation criteria; determination of the thresholds took 20 minutes and determination of the criterion weights – 15 minutes.</p>
PROMETHEE II with a veto threshold	<p>As this method is a combination of PROMETHEE II and ELECTRE III, it requires from its users determination of the type of preference function for each criterion, as well as the values of the parameters associated with those types of preference function. Despite indifference and preference thresholds, the weights of criteria and the values of veto thresholds have to be defined.</p> <p>Indifference and preference thresholds allow better reflection of decision maker's preferences, while veto thresholds decrease the compensation between the criteria. Unfortunately, determination of the values of all the parameters required may not only be time-consuming, but also difficult.</p> <p>On one hand, this technique is partially compensatory and takes into account the problem of imperfect knowledge; on the other hand, it is much more complex and mathematically complicated than PROMETHEE II.</p> <p>The solution takes the form of a complete order which is convenient to decision makers.</p> <p><u>Interaction time:</u> in the case study considered it took 20 minutes to define the types of preference function for 7 evaluation criteria; determination of the values of the thresholds took 45 minutes and determination of the criterion weights – 15 minutes.</p>

Method	Characteristics
UniComBOS	<p>It requires its users to make pairwise comparisons between one-, two-, and three-criteria units. They are quite simple, but may be really time-consuming and laborious, especially if the number of criteria is relatively large. After each comparison made by a decision maker, the consistency of preferences is checked. The results of comparisons are presented in the form of an oriented graph within which some alternatives can be equally preferable to a decision maker and some of them can be incomparable. The way of obtaining each relation in the graph can be explained. Unfortunately, it may happen that the system is not able to find the best alternative.</p> <p>The procedure is user-friendly and understandable.</p> <p><u>Interaction time</u>: in the case study considered, pairwise comparisons of one-, two- and three-criteria units took 130 minutes.</p>
MACBETH	<p>This method requires its users to make pairwise comparisons of the differences between the importance of the criteria, as well as between the attractiveness of the alternatives according to each criterion. This is a rather simple task, but may be very time-consuming and tiring, especially if the number of criteria and/or the number of alternatives is relatively large. As each qualitative judgement is given, the software automatically verifies the matrix's consistency and suggests modifications to the comparisons.</p> <p>The technique is complex and mathematically complicated and because of this it may be difficult to persuade people, especially those with no mathematical background, to use it.</p> <p>The final solution takes the form of a complete order which is convenient to decision makers.</p> <p><u>Interaction time</u>: in the case study considered, the pairwise comparisons of the differences between the importance of criteria, as well as the difference between alternatives according to each criterion took 120 minutes.</p>

Table 13. Evaluation of the MCDA methods chosen and distance metric determined for each of them

Criterion	Weight	ELECTRE Iv	PROMETHEE II	PROMETHEE IIv	UniComBOS	MACBETH
Simplicity of algorithm	0.1	4	4	2	5	2
Plausibility and usefulness of the solution	0.4	2	3	5	4	3
Total information required	0.1	5	4	3	1	2
Simplicity of questions	0.1	2	3	2	4	4
Interaction time	0.3	4	3	2	0	0
Distance metric		0.670	0.615	0.560	0.675	0.830



The analysis carried out in this part of the article has revealed that the most suitable method for choosing the venue for a wedding reception from the point of view of the decision maker is PROMETHEE IIv (with a distance metric of 0.56, as shown in Table 13). Therefore, using this technique (and taking into account the solution it offers) is recommended to her when it is not possible to apply several methods to solve the same problem.

## 6. Conclusions

Three different approaches were implemented to aid the process of selecting the best venue for a wedding reception: an approach based on the outranking relation, verbal decision analysis and the MACBETH method. Out of a wide range of outranking methods, two very well known ones were applied, namely ELECTRE Iv and PROMETHEE II. Additionally, PROMETHEE IIv was utilized. In the case of VDA, the UniComBOS program was used. The solution chosen by the decision maker followed the suggestion of PROMETHEE IIv (alternative H). The same alternative as the best compromise was provided by MACBETH.

The analysis conducted in the article showed that all the described approaches can be used for solving decision making problems connected with project management. Although all of them have some disadvantages, as for example the necessity to interact with a decision maker in order to determine the values of parameters in the case of outranking methods, time-consuming, as well as tiring, comparisons in the case of VDA and a lack of transparency in the decision making process for decision makers without a mathematical background as far as the MACBETH method is concerned, they can improve the decision making processes and help project managers to make more reasonable decisions.

Since the assumptions and properties of the approaches described vary (as discussed in the Introduction and shown in Table 2), they cannot be applied to all types of decision making problems. Decisions concerning the usefulness of a particular approach and method should be taken on the basis of analyzing the decision making problem and the decision making process, as well as on the basis of examining all the informational constraints and the profile of decision makers [14]. For instance, for some decision makers the use of numerical depictions of preferences may either be too complex or unacceptable, while other decision makers may find it more convenient and less time consuming to provide quantitative, rather than qualitative information about their preferences.

On one hand, solutions obtained with the help of the techniques presented in this article may differ greatly but on the other hand, these methods can complement each

other. Therefore, it may be practical and beneficial to employ them simultaneously in all cases whenever this is possible and feasible, as together they may enable the decision maker to learn more about the problem considered.

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