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# MULTI-CRITERIA DECISION AIDING IN PROJECT MANAGEMENT — OUTRANKING APPROACH AND VERBAL DECISION ANALYSIS

## Introduction

A project is 'a temporary endeavour undertaken to deliver a unique product or service'. Project management, then, is 'the application of knowledge, skills, tools and techniques to project activities to meet project requirements. This application of knowledge requires the effective management of appropriate processes' (*PMBOK Guide* 2008).

Each project is original and exceptional because at least one of the following parameters always changes: goals, resources and/or environment. This makes project management a complex undertaking (Vidal et al. 2011), with many stages and processes, unavoidably connected with multi-criteria decision making. Various situations and issues during the course of the project require from a project manager (or other person responsible for the particular matter) to choose the best variant from a set of available decision-making variants taking into account a number of important aspects (criteria) while comparing them. Acquiring fixed assets, selecting tender, choosing investment option are merely the examples of such issues. Exemplary criteria for these problems are presented in the table below.

Table 1

Examples of decision-making problems and evaluation criteria

| No. | Decision-making problem | Exemplary criteria |
|---|---|---|
| 1 | Acquiring fixed assets | price, production capacity, energy intensity, noise emission, availability and cost of service |
| 2 | Selecting tender | price, expected execution time, contractor's experience, resources, financial stability as well as management and technical ability |
| 3 | Choosing project concept (solution) | price, usable properties, durability and aesthetics of performance, safety of the utilization, impact on the environment, influence on the employment, in fluence on the inhabitants' health, impact on the investment attractiveness, impact on the tourist attractiveness |

Besides above mentioned decision-making problems MCDA in project management can be used in:

- project selection (which is a crucial issue for every organization),
- selection of workers,
- selection of software project management tool,
- measuring project complexity,
- controlling project performance,
- assigning priorities to activities.

Examples of suggested applications are briefly described in the table below.

Table 2

Examples of MCDA applications in project management

| No. | Application area | Citation | Description |
|---|---|---|---|
| 1 | Project selection | [Pirdashti et al., 2009] | Article is connected with Research and Development (R&D) project selection in chemical industry. It presents several different methods of MCDM for use in candidate project evaluation and prioritization. |
| 2 | Selection of workers | [Ling, 2003] | Article presents a conceptual model for the selection of architects by project managers. The model was developed from four theories: Theory of Job Performance, Theory of Contextual Performance, Network Theory of Embeddedness and Theory of the Firm. It was tested by a postal survey of project managers who work for property developers. |

| | | | |
|---|---|---|---|
| | | | The principal finding is that 34 of the 40 attributes identified are important, and these were used to construct the Architect Selection Model. It is based on MAUT and uses weighted sum method to determine overall score of the architects who are being evaluated. |
| 3 | **Selection of soft-ware tool** | [Ahmad, Laplante, 2006] | In the paper a model for selecting a software project management tool using the AHP is presented.<br><br>Several relevant factors based on the most common features offered by commercial off-the-shelf solutions (COTS) are used as the selection criteria in ranking the software tools.<br><br>The contribution of the work is to apply a well-known decision-making method in a novel way to help decision-makers better identify an appropriate software project management tool without having to go through a more extensive evaluation process.<br><br>Moreover, the work establishes a framework for comparing individual product decisions across projects, project managers, organizational groups and organizations. |
| 4 | **Measuring pro-ject complexity** | [Vidal et al., 2011] | The aim of the paper is to define a measure of project complexity in order to assist decision-making. A synthesized literature review on existing complexity measures is proposed in order to highlight their limitations. Then, a multi-criteria approach to project complexity evaluation, through the use of the AHP, is proposed.<br><br>A case study within a start-up firm in the entertainment industry (the main activity of whichis the production of stage musicals in France) is performed. |
| 5 | **Controlling pro-ject performance** | [Marques et al., 2010] | Study is focused on decision support in the context of product and service development projects. In the paper a new multi-dimensional Project Performance Measurement System to enable managers to deal with the volume of data is proposed.<br><br>The proposition integrates the unique character of each project (tasks, objectives, decision-makers personality and competences), several good practices in terms of universal project management dimensions on the one hand, and in terms of performance analysis on the other hand.<br><br>As an aggregation tool MACBETH method is used to analyze the performance measures according to project managers' own performance interests.<br><br>A case study connected with the landing gear door project illustrates the proposed system. |

| 6 | **Assigning priorities to activities** | [Mota et al., 2009] | Article presents a model for supporting project managers to focus on the main tasks of a project network using a MCDA approach. As a result, managers can increase their performance in controlling project activities, particularly in a dynamic and changing environment.<br><br>A case study on the construction of an electricity sub-station is used to demonstrate the model proposed. In the study, the ELECTRE TRI method is used in order to classify activities into a set of different managerial classes according to some norms. |

Source: Ahmad, Laplante, 2006; Ling, 2003; Marques et al. 2010; Mota et al. 2009; Pirdashti et al. 2009; Vidal et al., 2011.

## 1. Presentation of MCDA approaches

According to the results of descriptive studies (see Russo and Rosen, 1975; Montgomery and Svenson, 1989; Payne et al. 1993; Larichev 1992; Korhonen et al. 1997), the multi-criteria decision-making problems constitute a great challenge for people, and the more criteria the problems involve, the more complicated they are (Ashikhmin, Furems, 2005).

There are several approaches which may be implemented to solve this kind of problems, for instance: multi-attribute utility theory (MAUT) (see Keeney, Raiffa 1976), approach based on the outranking relation (see Roy 1990), verbal decision analysis (VDA) (see Larichev, Moshkovich 1995, 1997).

Methods based on the multi-attribute utility theory (see Keeney, Raiffa 1976) assume that there exist global utility function to represent the decision-maker's preferences and it can be built through aggregating variants' partial utilities (according to each criterion). But the reduction of a multidimensional evaluation to one-dimensional one via the formulation of global utility function is possible only when certain rigorous conditions[1] are met. Besides, it may lead to the complete compensation between criteria – the situation in which variant evaluated low against one or even more criteria is ranked highly because it has achieved high grades against remaining criteria. In this approach not very realistic assumption is accepted that decision-maker's preferences are given and fixed, i.e. they are expressed clearly and result in good ordering variants against criteria – the decision-maker is able

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[1] For instance, the necessary and sufficient condition of applying an additive form of the utility function in the situation when the evaluations are deterministic is mutual preferential independence of the criteria. If the evaluations have the form of probability distributions the above mentioned condition is not sufficient – in that case the utility independence condition must be satisfied (Trzaskalik et al. 1998).

to indicate, without any hesitation, even the smallest differences in utilities and confidently, consequently and precisely assign the scores to variants considered. In addition, determining an analytical form of the global utility function is usually very difficult and sometimes even unfeasible – it happens frequently that the decision-maker is not able to provide information essential to build this function (Trzaskalik et al. 1998).

An interesting alternative is the approach based on the outranking relation and on the fundamental partial comparability axiom (see Roy 1990), in which incomparability plays a key role (Martel 1998). The basic idea of this approach is as follows: variant $a_i$ outranks variant $a_j$ if on a great part of the criteria $a_i$ performs at least as good as $a_j$ (concordance condition), while its worse performance is still acceptable on the other criteria (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. In this kind of approach there is place for incomparability, explained e.g. by the lack of sufficient information to define preferential situation (Trzaskalik et al. 1998). The procedures exploited according to this approach – among which the ELECTRE (see Roy, Bouyssou 1993; Vincke 1992) and PROMETHEE (see Brans, Vincke 1985; Brans et al. 1986) methods stand out – are usually less demanding for their users at the informational level and result in more balanced recommendations than those belonging to the first approach of a single criterion synthesis (Martel, 1998). Since their assumptions are in accordance with the reality they can definitely be recommended for applying in project management (Górecka 2011).

Although outranking approach has many advantages, it has also one major weakness: within respective techniques based on this approach it is essential to elicit information about parameters utilized in them from decision-makers and they may encounter problems in revealing preferences and fixing them. In fact a number of psychological experiments confirm (see Korhonen et al. 1997) that people make significant errors in quantitative measurement of subjective factors (Ashikhmin, Furems 2005).

As far as VDA-based methods are considered the situation is different: preferential information in the ordinal form (for instance 'more preferable', 'less preferable' or 'equally preferable'), which is required from the decision-makers within these methods, seems to be stable and reliable according to the results of psychological experiments. Moreover, it is checked in order to ensure its consistency. Techniques based on VDA do not use quantitative information on criteria importance, but only verbal estimates and no quantitative operations are made on them. Hence, all operations are clear and understandable to decision-makers (Ashikhmin, Furems 2005).

In the framework of VDA paradigm methods belonging to the ZAPROS family (see Larichev, Moshkovich 1995, 1997; Larichev 2001b) are very well known. In these techniques preference elicitation boils down to comparisons of pairs of hypothetical variants (each with the best evaluations on all criteria but one) differing in performances of two criteria only. Results of these comparisons are transformed into the so-called Joint Ordinal Scale (JOS), which is subsequently used to compare real decision-making variants (Ashikhmin, Furems 2005).

In the method of dyad comparison of criteria estimates (see Moshkovich et al. 2002) variants with different attainments upon only two criteria are compared as well, but – contrary to 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 variants incomparable upon JOS (Ashikhmin, Furems 2005).

Both the aforementioned methods meet the first two requirements of VDA, namely: psychological reliability of information on the decision-maker's preferences and the possibility to check the consistency of this information. Both JOS and PJOS are formed without any quantitative operations, and their correctness is proven within the framework of additive value model. Nevertheless, their implementation to the comparison of real decision-making variants, however rational, does not seem to be easily explainable to the participants of the decision-making process. Furthermore, psychological limitations assumed in these methods are rather restrictive. They are based on the results of psychological experiments, according to which the pair-wise qualitative comparisons of hypothetical variants varying in estimates of not more than two criteria are relatively easy for human beings (see Larichev 1992). As a matter of fact experiments carried out within the cooperation between the Academy of Finland and the Russian Academy of Sciences have shown (see Furems et al. 2003) that people are able to make reliable pair-wise comparisons (using special graphical aids such as color differentiation of preferences) of variants that differ in estimates on three or even on four criteria (Ashikhmin, Furems 2005). Taking that into account Intellectual Decision Support System (IDSS) UniComBOS (Unit Comparison for the Best Objective Selection) have been proposed (see Furems, Ashikhmin 2004). It is based on the VDA principles but implements a new approach to multi-criteria comparison and choice trying to overcome the limitations mentioned above as well as to adjust a decision-making procedure, i.e. the complexity of questions, to the individual capabilities of decision-makers. One of its key original features is using special visualization techniques in order to gather preference information from the decision-makers and the other one is an on-line preference consistency control system allowing to reveal among other things errors in the answers of decision-makers (Furems, Ashikhmin 2004).

The article is aimed at brief description of chosen multi-criteria decision aiding methods based on the outranking relation from the ELECTRE and PROMETHEE families as well as procedure belonging to the verbal decision analysis framework, namely UniComBOS. Additionally, it will provide short comparison of these two approaches focusing on types of decision-making problems on which they are oriented. Furthermore, an illustrating example of their application connected with project management will be presented.

## 2. Description of multi-criteria methods

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

ELECTRE Iv

ELECTRE Iv procedure consists of the following steps (Figueira et al. 2005; Metody wielokryterialne na polskim rynku finansowym 2006):

1. Calculation of concordance indices $c(a_i, a_j)$:

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

where:

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

$$\sum_{k=1}^{n} w_k = 1,$$

$f_k(a_i)$ – evaluation of variant $a_i$ with respect to criterion $f_k$,

$$\varphi_k(a_i, a_j) = \begin{cases} 1, & if & f_k(a_i) \geq f_k(a_j), \\ 0 & otherwise. \end{cases}$$

2. Construction of concordance set $C_s$:

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

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

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

where:

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

4. Construction of discordance set $D_v$:

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

5. Determination of outranking relation: $S(s, v) = C_s \cap \overline{D_v}$,

   where $\overline{D_v} = (A \times A) \setminus D_v$.

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

7. Select the best variant or a subset of variants the decision-maker should focus his attention on.

PROMETHEE I and PROMETHEE II
    Both PROMETHEE methods include (Brans, Mareschal 2005):

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 preference function showing the strength of preference of variant $a_i$ over variant $a_j$ under the 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 the determination six types of generalized criteria have been proposed: usual, u-shape, v-shape, level, v-shape with indifference and Gaussian criterion.

Table 3

Types of generalized criteria

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

Source: (Brans et al. 1986).

2. Calculation for each pair of variants $(a_i, a_j)$ aggregated preference indices $\pi(a_i, a_j)$: $\pi(a_i, a_j) = \sum_{k=1}^{n} w_k P_k(a_i, a_j)$, where $\pi(a_i, a_j)$ shows with which degree $a_i$ is preferred to $a_j$ over all the criteria.

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

- the positive outranking flow: $\phi^+(a_i) = \dfrac{1}{m-1}\sum_{j=1}^{m}\pi(a_i, a_j)$,

- the negative outranking flow: $\phi^-(a_i) = \dfrac{1}{m-1}\sum_{j=1}^{m}\pi(a_j, a_i)$.

The PROMETHEE I partial ranking is obtained on the basis of the positive and the negative outranking flows. Both flows do not usually induce the same rankings. Final ranking in PROMETHEE I is their intersection:

$$
\begin{cases}
a_i P a_j, & if \quad \begin{cases}
\phi^+(a_i) > \phi^+(a_j) & and \quad \phi^-(a_i) < \phi^-(a_j) & or \\
\phi^+(a_i) = \phi^+(a_j) & and \quad \phi^-(a_i) < \phi^-(a_j) & or \\
\phi^+(a_i) > \phi^+(a_j) & and \quad \phi^-(a_i) = \phi^-(a_j);
\end{cases} \\
a_i I a_j, & if \quad \phi^+(a_i) = \phi^+(a_j) \quad and \quad \phi^-(a_i) = \phi^-(a_j); \\
a_i R a_j, & if \quad \begin{cases}
\phi^+(a_i) > \phi^+(a_j) & and \quad \phi^-(a_i) > \phi^-(a_j) & or \\
\phi^+(a_i) < \phi^+(a_j) & and \quad \phi^-(a_i) < \phi^-(a_j);
\end{cases}
\end{cases}
$$

where $P$, $I$ and $R$ represent preference, indifference and incomparability respectively.

In PROMETHEE II on the basis of the positive and the negative outranking flows the net outranking flow $\phi(a_i)$ is calculated for each variant $a_i$: $\phi(a_i) = \phi^+(a_i) - \phi^-(a_i)$. A final complete ranking is constructed according to the descending order of the net flows.

<u>IDSS UniComBOS</u>

The procedure implemented in IDSS UniComBOS consists of the following steps (Furems, Ashikhmin 2004; Ashikhmin, Furems 2005):

1. Problem structuring
   Decision-maker has to define decision-making variants, specify a list of evaluation criteria and give verbal estimates of all variants upon all criteria. Such estimates exist in original descriptions of variants, may be determined by the decision-maker or obtained from experts, catalogues, etc.

2. Procedure of unit comparison

Let us introduce a 'D-unit' as partial description of a variant upon $D \subseteq K$ criteria, where $K = \{1, 2, ..., n\}$ is the set of criteria numbers. D-unit for variant $a_i \in A$ with estimates $\left(f_1(a_i), (f_2(a_i), ..., f_n(a_i))\right)$ is as follows: $\left(f_1(\alpha_i), ..., f_k(\alpha_i)\right), \forall j \in D \ f_j(\alpha_i) = f_j(a_i), \ \forall j \in K \setminus D \ f_j(\alpha_i) = f_j(\omega_i)$ where $f_j(\omega_i)$ stands for criterion $f_j$, an estimate of which is not present in such partial description.

Let us assume that criteria from $F$ are mutually preference-independent (see Fishburn, 1979) and preferences between D-units are transitive for any $D$. Then the following rule of unit-wise dominance (U-Dominance) takes place: variant $a_i$ is preferable to variant $a_j$, if there exists such partition of the criteria'

set $K$ on subsets $D_1, D_2, ..., D_m$, $\bigcup_{i=1}^{m} D_i = K$, $\forall i, j, \ i \neq j, \ D_i \cap D_j = \varnothing$,

that $\forall i \ a_i^{D_i} \succ a_j^{D_i}$.

Preferences of the decision-maker are elicited step-by-step through pair-wise comparisons between units within the same criteria subsets. The procedure begins with pair-wise comparisons of one-criterion units to convert nominal estimate scales of criteria to ordinal ones in accordance with the preferences of a decision-maker. Hardly ever would such type of comparisons be sufficient for the best variant choice on the basis of U-Dominance rule. If there is no variant chosen as the best one, IDSS UniComBOS proceeds to pair-wise comparisons of two-criteria units[2]. After each comparison made by a decision-maker UniComBOS algorithm is applied to check preference consistency and to try to find the best variant(s). If a set of decision-maker's answers enables it to do that, the problem deems to be solved. Otherwise, IDSS UniComBOS proceeds to three-criteria units comparisons. And once again, after each comparison made by a decision-maker algorithm verifies preference consistency and attempts to select the best variant using the preference information obtained. IDSS UniComBOS determines a maximal complexity of comparisons (i.e., the number of criteria in units) to a decision-maker individually. A decision-makers' capabilities to compare multi-criteria units are represented by the frequency of their errors. If a decision-maker encounters difficulties

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[2] IDSS UniComBOS facilitates comparisons of two- and more criteria dimension units through color differentiation of preferences. For instance, when a pair of two-criteria units is displayed to the decision-maker for comparison, the better estimates of each unit are highlighted with one color (e.g. green) and the worse estimates – with another one (e.g. blue). If two units are equally preferable to the decision-maker, they are displayed with the same color (e.g. yellow). Hence, decision-maker clearly sees advantages and disadvantages of each unit in the pair (Ashikhmin, Furems 2005).

in comparing units of the current dimension, dialogue is interrupted and information obtained from comparisons of units of the previous dimension is used to compare variants. As a consequence system might not be able to find the single best variant, but in such case it will indicate the set of incomparable variants preferable for decision-maker in comparison to any variant not included in this set.

3. Analysis and corrections of inconsistency

Inconsistencies revealed are presented to decision-maker for analysis and correction. Decision-makers have opportunity to indicate and correct the errors in their previous answers as well as to disagree with the results of the conducted operations. In the latter case it means criteria preference-dependence and/or intransitivity of preferences and the considered decision-making problem may need restructuring.

4. Display of results and explanation

Results of comparisons are presented in the form of oriented graph, in which nodes correspond to variants and arcs go from better variant to the worse one. Decision-makers may prompt explanation 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.

## 3. Outranking approach versus verbal 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, transport, industrial location, water resources, waste management, investments, manpower planning, medicine, chemistry, health care, tourism, ethics and many more.

Verbal decision analysis is a new methodological approach, based on cognitive psychology, applied mathematics and computer science, which was proposed as a framework for the unstructured decision-making problems, which are the problems with mostly qualitative parameters with 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 VDA-based ZAPROS method (and its variations) has been used in R&D planning, applicants' selection, job selection and pipeline selection (Moshkovich et al. 2005).

General features for the unstructured problems are as follows (Larichev, 2001a; Moshkovich et al. 2005):

▪ they are unique in the sense that each problem is new to the decision-maker and has characteristics not previously experienced;

▪ criteria in these problems are mostly qualitative in nature, most often formulated in a natural language;

- in many cases evaluations of variants against the criteria may be obtained only from human beings (experts or the decision-makers);
- the quality grades on criteria scales are verbal definitions presenting subjective values of the decision-maker.

Both outranking methods and verbal decision analysis provide outranking relationships among multi-criteria decision-making variants. However, there are some important differences between these approaches. They are summarized in the table below.

Table 4

Differences between outranking and VDA approaches

| Outranking methods | Verbal decision analysis |
|---|---|
| *Application* | |
| Outranking methods are intended to compare a given set of decision-making variants. | VDA is designed to elicit a sound preference relationship that can be applied to future cases. |
| *Decision-making problem* | |
| Outranking methods deal mostly with cases in which number of criteria is rather large (up to twelve or thirteen) and number of variants − relatively small. | VDA is more oriented on tasks with rather large number of variants while number of criteria is usually relatively small. |
| *Methodology* | |
| Outranking methods use criteria weights as well as other parameters, which serve an operational purpose but also introduce heuristics and possible intransitivity of preferences. | VDA bases its outranking on axiomatic relationships, to include direct assessment, dominance, transitivity and preferential independence. |
| *Decision-makers* | |
| Since some of the outranking methods are quite complex and mathematically complicated intellectual abilities and training help decision-makers to understand and accept this approach. | VDA methods do not require any special knowledge in decision analysis on the part of the decision-makers. |

Source: (Moshkovich et al. 2005).

# 4. Illustrating example

Usefulness of the above-mentioned methods for decision aiding processes connected with project management will be illustrated by an example which concerns the problem of choosing the best variant of the road construction out of five that have been identified at the stage of drawing up the project concept.

Road construction is a complex project which consists of many stages and the management in this case requires deep knowledge regarding road building. A lot of work has to be done before the first layer of concrete is ever poured. Road construction requires the creation of a right-of-way, overcoming geographic obstacles and having grades low enough to allow vehicle to travel. Besides, a variety of equipment is engaged in road building, which depends strongly on the weather conditions, resulting in the random execution time of project tasks (Biruk et al. 2007).

Before any construction can begin the courses of the proposed route solutions have to be identified and evaluated taking into account functional, technical, economic, environmental and social aspects. Citizens are encouraged to participate in this process. In many instances, several alternatives are analyzed (sometimes even over a dozen or tens). Information gathered during this stage is used to determine the location and type of the road to be constructed. In many cases a certain amount of private property must be acquired.

Once the road design (defining for example the type of intersections, interchanges, bridges, culverts and other drainage features as well as specifying the type and approximate quantity of materials to be used to construct the road) is complete, bids are received for construction. The bidder who has been awarded the contract is obliged to construct the road in accordance with plan requirements and specifications upon which the bid was received. Road can be opened to traffic only after the final inspection conducted by an engineer not involved in its construction.

Example considered in this paper is connected with the analysis regarding drafting of a road route. It is not expanded as its main aim is to illustrate the application of various MCDA methods. Input data, i.e. evaluations of decision-making variants and weights of criteria, comes from (Biruk et al. 2007). In the assessment of the route solutions the following four criteria are taken into consideration: $f_1$ – cost of realization (in million PLN), $f_2$ – vehicle's average travel time (in minutes), $f_3$ – the impact on the environment (on a scale from 0 to 10), $f_4$ – the safety of the travelers (on a scale from 0 to 10).

Table 5 provides the performance matrix for five variants of road construction and four criteria used to evaluate them. It includes also type of preference function defined for each criterion as well as thresholds and weighting coefficients. Both type of preference function and thresholds were determined by the author of this article.

Table 5

Input data for the illustrating example

| Criteria | f₁ | f₂ | f₃ | f₄ |
|---|---|---|---|---|
| | Cost of realization [million PLN] | Vehicle's average travel time [minutes] | Impact on the environment [0-10] | Safety of the travelers [0-10] |
| Max/min | min | min | max | max |
| Criteria weights | 0,4 | 0,1 | 0,2 | 0,3 |
| Type of preference function | V | V | IV | IV |
| q | 10 | 4 | 1 | 1 |
| p | 50 | 8 | 3 | 3 |
| v | 100 | 15 | 5 | 5 |
| Decision variants | | | | |
| a¹ | 250 | 50 | 8 | 2 |
| a² | 300 | 40 | 7 | 6 |
| a³ | 280 | 35 | 2 | 4 |
| a⁴ | 400 | 30 | 6 | 7 |
| a⁵ | 320 | 45 | 5 | 5 |

## Application of ELECTRE I

At the beginning, the ELECTRE Iv method was used for selecting the best variant of road construction. Tables 6 and 7 present the concordance matrix and the discordance set.

Table 6

Matrix of concordance indices

| | a¹ | a² | a³ | a⁴ | a⁵ |
|---|---|---|---|---|---|
| a¹ | 1 | 1 | 1 | 1 | 1 |
| a² | 0 | 1 | 0 | 1 | 1 |
| a³ | 0 | 0 | 1 | 0 | 0 |
| a⁴ | 0 | 0 | 1 | 1 | 1 |
| a⁵ | 0 | 0 | 0 | 0 | 1 |

Table 7

Discordance set

|  | a¹ | a² | a³ | a⁴ | a⁵ |
|---|---|---|---|---|---|
| **a¹** | 0 | 0 | 0 | 1 | 0 |
| **a²** | 0 | 0 | 0 | 0 | 0 |
| **a³** | 1 | 0 | 0 | 0 | 0 |
| **a⁴** | 1 | 0 | 1 | 0 | 0 |
| **a⁵** | 0 | 0 | 0 | 0 | 0 |

An outranking relation exists if the concordance and non-discordance conditions are fulfilled simultaneously. The table below presents the outranking relation for the concordance level equal to 0,6.

Table 8

Outranking relation for concordance level s = 0,6

|  | a¹ | a² | a³ | a⁴ | a⁵ |
|---|---|---|---|---|---|
| **a¹** | 1 | 1 | 1 | 0 | 1 |
| **a²** | 0 | 1 | 0 | 1 | 1 |
| **a³** | 0 | 0 | 1 | 0 | 0 |
| **a⁴** | 0 | 0 | 0 | 1 | 1 |
| **a⁵** | 0 | 0 | 0 | 0 | 1 |
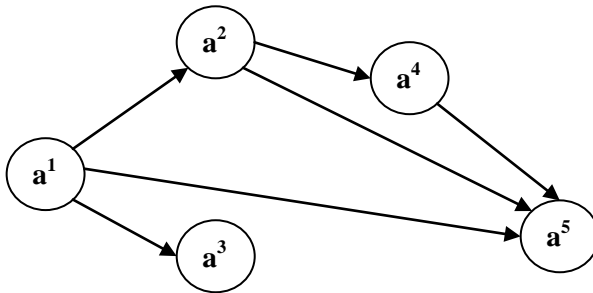


Figure 1. Outranking relation for s = 0,6 (graph constructed from the best to the worst variant)
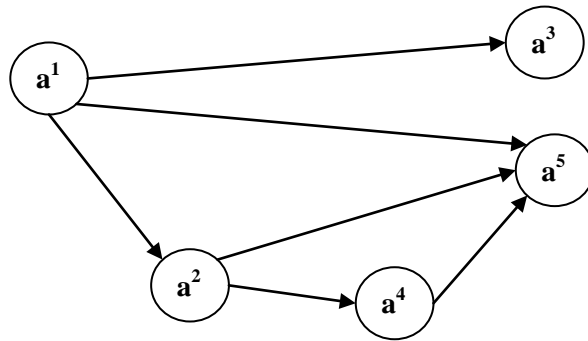
Figure 2. Outranking relation for s = 0,6 (graph constructed from the worst to the best variant)

Table 9

The results of graphs' analysis

| Level | s = 0,6 | |
|---|---|---|
| | from the best variant to the weakest one | from the weakest variant to the best one |
| 1 | $a^1$ | $a^1$ |
| 2 | $a^2, a^3$ | $a^2$ |
| 3 | $a^4$ | $a^4$ |
| 4 | $a^5$ | $a^3, a^5$ |

In both cases variant $a_1$ of road construction turned out to be the best and should be recommended for realization. On the second place variant $a_2$ was classified. In turn, on the lowest level variant $a_5$ was placed, which leads to the conclusion that this is the worst solution. Another variant that can be definitely excluded from further analysis is variant $a_3$ as it occurred on the lowest level in the case of graph constructed from the weakest to the strongest variant.

Application of PROMETHEE I and PROMETHEE II

Table 10 contains aggregated preference indices for each pair of variants as well as the positive and the negative outranking flows for each variant.

Table 10

Aggregated preference indices and outranking flows (positive and negative)

|  | $a^1$ | $a^2$ | $a^3$ | $a^4$ | $a^5$ | positive outranking flow |
|---|---|---|---|---|---|---|
| $a^1$ | 0 | 0,4 | 0,4 | 0,5 | 0,5 | **0,45** |
| $a^2$ | 0,4 | 0 | 0,35 | 0,4 | 0,225 | **0,34375** |
| $a^3$ | 0,25 | 0,125 | 0 | 0,4 | 0,4 | **0,29375** |
| $a^4$ | 0,4 | 0,1 | 0,375 | 0 | 0,25 | **0,28125** |
| $a^5$ | 0,175 | 0 | 0,1 | 0,4 | 0 | **0,16875** |
| negative outranking flow | **0,30625** | **0,15625** | **0,30625** | **0,425** | **0,34375** | |

On the basis of the positive and the negative outranking flows the partial ranking in PROMETHEE I and the complete ranking in PROMETHEE II were built.

Table 11

Relations between variants determined with the help of PROMETHEE I

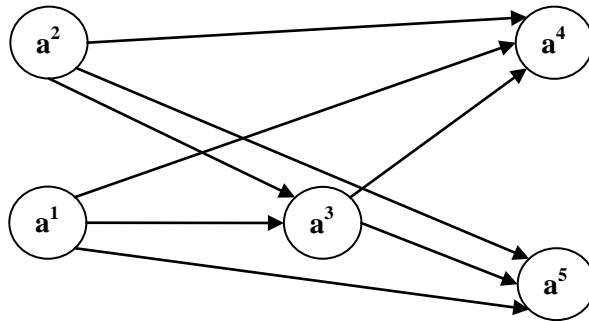|  | $a^1$ | $a^2$ | $a^3$ | $a^4$ | $a^5$ |
|---|---|---|---|---|---|
| $a^1$ | I | R | P | P | P |
| $a^2$ |  | I | P | P | P |
| $a^3$ |  |  | I | P | P |
| $a^4$ |  |  |  | I | R |
| $a^5$ |  |  |  |  | I |



Figure 3. Partial variants' ranking produced using PROMETHEE I

Table 12

Complete variants' ranking obtained with the aid of PROMETHEE II

| Place | Variant | Net outranking flow |
|:-:|:-:|:-:|
| 1 | $a^2$ | 0,1875 |
| 2 | $a^1$ | 0,14375 |
| 3 | $a^3$ | -0,0125 |
| 4 | $a^4$ | -0,14375 |
| 5 | $a^5$ | -0,175 |

It can be easily noticed that according to the results obtained with the help of methods belonging to the PROMETHEE family variants $a_1$ and $a_2$ turned out to be the best. As PROMETHEE I method is considered they are incomparable, but they are both on the highest level of the graph. In the case of PROMETHEE II they were classified on two first places with positive net outranking flows. On the opposite site we have variants $a_4$ and $a_5$ which were classified on two last places and on the lowest level of the graph according to PROMETHEE II and PROMETHEE I respectively.

Application of UniComBOS

Pair-wise comparisons of one-criterion units resulted in the graph that is placed below. The window on the figure shows how the relation between variants $a_2$ and $a_5$ was obtained.
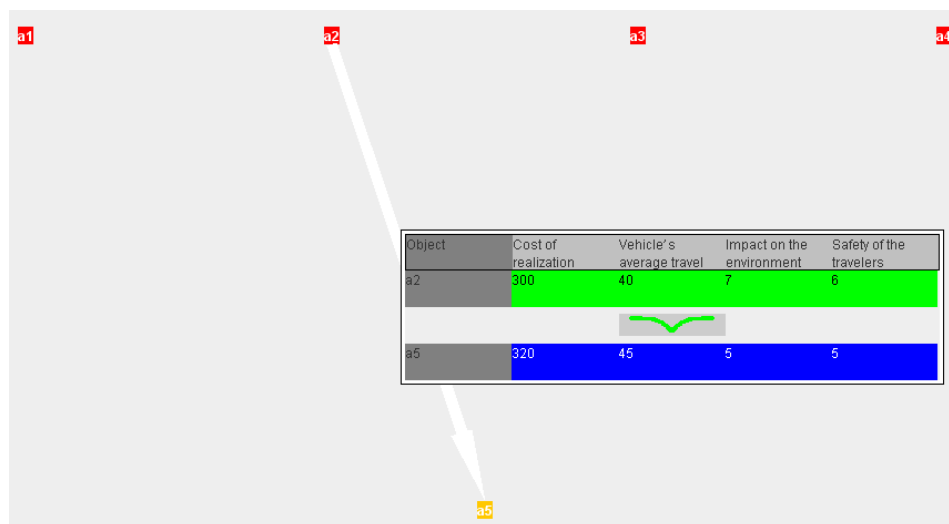


Figure 4. Result graph based on the comparisons of one-criterion units

Because comparisons of one-criterion units were not sufficient for the best variant choice, IDSS UniComBOS proceeds to pair-wise comparisons of two-criteria units. They are presented on the Figures 5-8.



**Diagrams above show that:**

1. "400" on "Cost of realization", "30" on "Vehicle's average travel time" is less preferable than "300" on "Cost of realization", "40" on "Vehicle's average travel time"
2. "7" on "Impact on the environment", "6" on "Safety of the travelers" is less preferable than "6" on "Impact on the environment", "7" on "Safety of the travelers"
3. "400" on "Cost of realization", "7" on "Safety of the travelers" is less preferable than "300" on "Cost of realization", "6" on "Safety of the travelers"
4. "400" on "Cost of realization", "7" on "Safety of the travelers" is as preferable as "250" on "Cost of realization", "2" on "Safety of the travelers"
5. "30" on "Vehicle's average travel time", "6" on "Impact on the environment" is more preferable than "50" on "Vehicle's average travel time", "8" on "Impact on the environment"

Figure 5. Comparisons of two-criteria units – part I
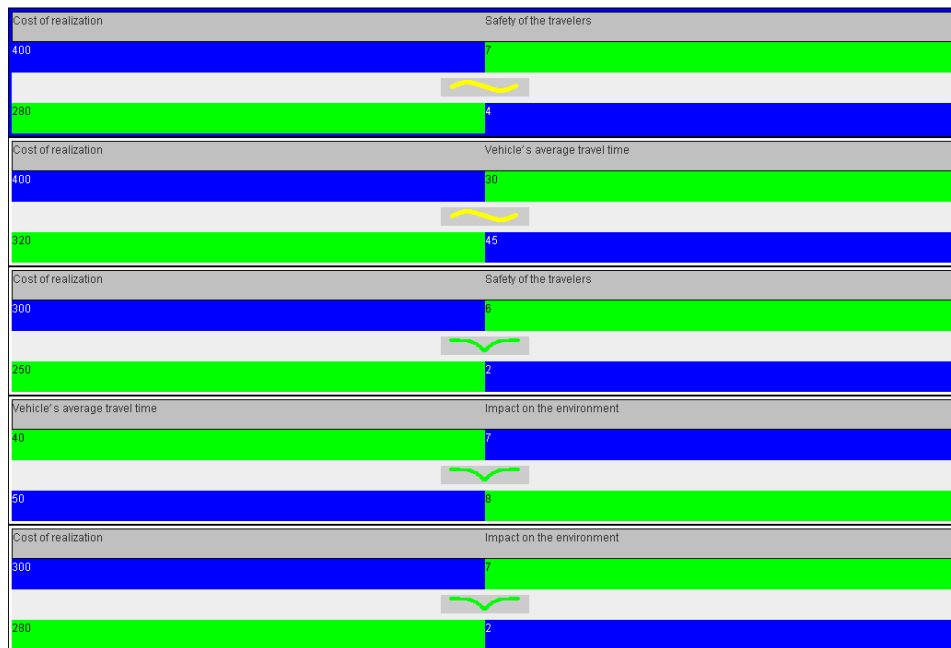
**Diagrams above show that:**

1. "400" on "Cost of realization", "7" on "Safety of the travelers" is as preferable as "280" on "Cost of realization", "4" on "Safety of the travelers"
2. "400" on "Cost of realization", "30" on "Vehicle's average travel time" is as preferable as "320" on "Cost of realization", "45" on "Vehicle's average travel time"
3. "300" on "Cost of realization", "6" on "Safety of the travelers" is more preferable than "250" on "Cost of realization", "2" on "Safety of the travelers"
4. "40" on "Vehicle's average travel time", "7" on "Impact on the environment" is more preferable than "50" on "Vehicle's average travel time", "8" on "Impact on the environment"
5. "300" on "Cost of realization", "7" on "Impact on the environment" is more preferable than "280" on "Cost of realization", "2" on "Impact on the environment"

Figure 6. Comparisons of two-criteria units – part II

**Diagrams above show that:**

1. "40" on "Vehicle's average travel time", "6" on "Safety of the travelers" is more preferable than "35" on "Vehicle's average travel time", "4" on "Safety of the travelers"
2. "250" on "Cost of realization", "2" on "Safety of the travelers" is as preferable as "280" on "Cost of realization", "4" on "Safety of the travelers"
3. "50" on "Vehicle's average travel time", "8" on "Impact on the environment" is as preferable as "35" on "Vehicle's average travel time", "2" on "Impact on the environment"
4. "280" on "Cost of realization", "2" on "Impact on the environment" is as preferable as "320" on "Cost of realization", "5" on "Impact on the environment"
5. "35" on "Vehicle's average travel time", "4" on "Safety of the travelers" is more preferable than "45" on "Vehicle's average travel time", "5" on "Safety of the travelers"

Figure 7. Comparisons of two-criteria units – part III

Figure 8. Comparisons of two-criteria units – part IV
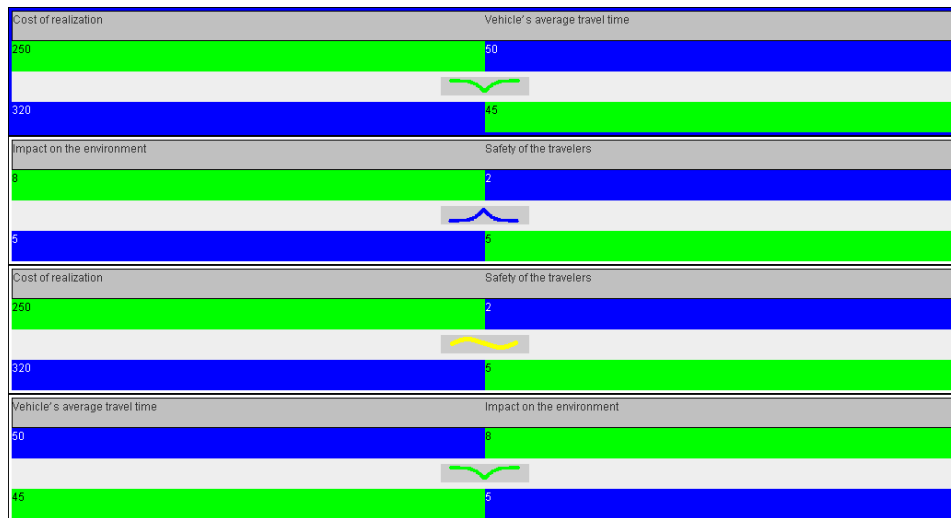
**Diagrams above show that:**

1. "250" on "Cost of realization", "50" on "Vehicle's average travel time" is more preferable than "320" on "Cost of realization", "45" on "Vehicle's average travel time"
2. "8" on "Impact on the environment", "2" on "Safety of the travelers" is less preferable than "5" on "Impact on the environment", "5" on "Safety of the travelers"
3. "250" on "Cost of realization", "2" on "Safety of the travelers" is as preferable as "320" on "Cost of realization", "5" on "Safety of the travelers"
4. "50" on "Vehicle's average travel time", "8" on "Impact on the environment" is more preferable than "45" on "Vehicle's average travel time", "5" on "Impact on the environment"

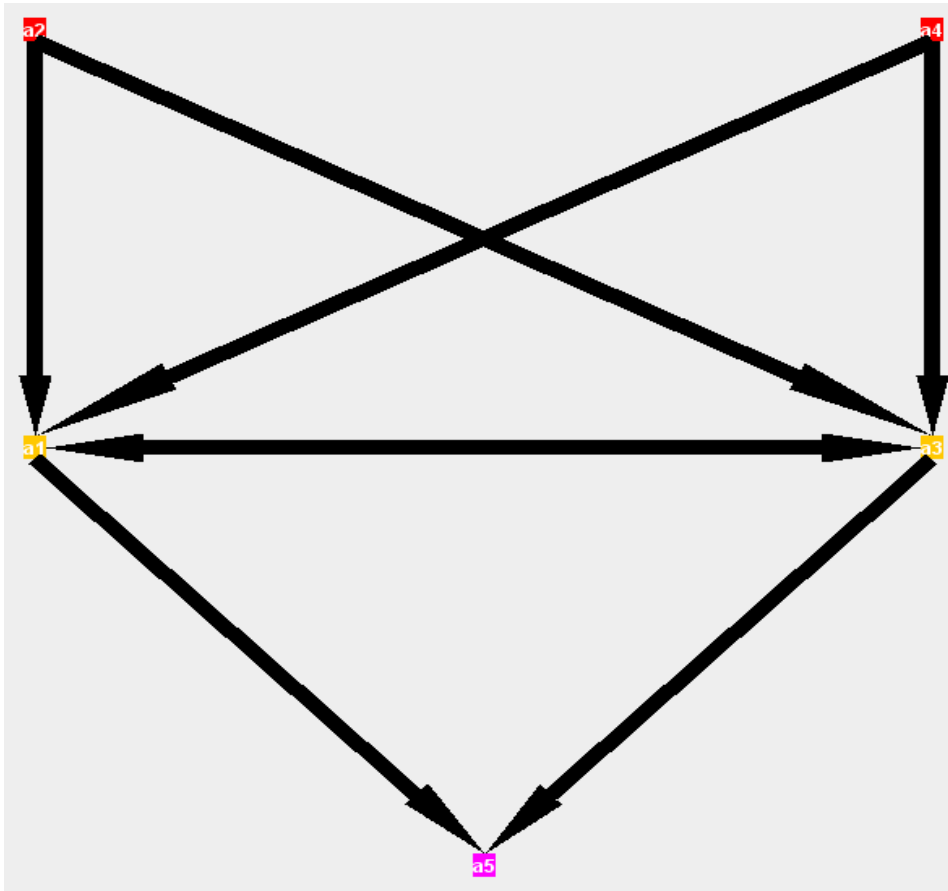On the basis of the conducted comparisons the following graph has been constructed.

Figure 9. Final graph

According to the graph the set of best variants includes variants $a_2$ and $a_4$. They are mutually incomparable but preferable to other decision-making variants. The worst solution is variant $a_5$. Additionally, it is worth mentioning that variants $a_1$ and $a_3$ turned out to be equally preferable to the decision-maker.

## Conclusions

Two different approaches were implemented to aid the process of selecting the best variant of road construction, namely approach based on the outranking relation and verbal decision analysis. Out of wide range of outranking methods three very well known were applied: ELECTRE Iv, PROMETHEE I and PROMETHEE II. In the case of VDA UniComBOS was used. The results obtained with different methods were not identical, nevertheless it was possible to identify variant worth recommendation, i.e. variant $a_2$, which was always on one of two first places in rankings, regardless of the method that was used. On the other hand, variant $a_5$ was found to be the worst solution – its weakness was confirmed by all methods.

The analysis conducted in the article proved that both described approaches can be used for solving the decision-making problems connected with project management. Although both of them have some disadvantages, as for example necessity to interact with decision-maker in order to determine values of parameters in the case of outranking methods and time-consuming as well as tiring comparisons in the case of VDA, they can improve the decision-making processes and help project managers to make more reasonable decisions. As a matter of fact, because of the differences between them, they can complement each other. Therefore it would be practical and beneficial to employ them simultaneously in all cases when it is merely possible and feasible.

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