THE MULTI-CRITERIA APPROACH TO PROJECT SELECTION BASED ON THE FUZZY SETS THEORY

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Abstract   This paper describes an approach to multi-criteria evaluation of project variants based on the fuzzy set theory. The multi-criteria evaluation based on the criteria proposed by experts or decision-makers in the planning phase, during which it is critical to document the tasks to be completed in a project schedule. Fuzzy sets theory transforms criterion indicators into variants fuzzy partial evaluations by means of transformation functions. The method facilitates comparison of different values by transformation to the fuzzy numbers from the range of $\langle 0, 1 \rangle$. The presented approach offers support for the decision makers in making various kinds of decisions, in all situations when we may determine an evaluation criteria set. Moreover, it takes into consideration versatility of criteria, their hierarchy and experts' uncertainty; at the same time it is efficient and quite simple to be implemented in real decision problems.

Paper type: Research Paper

1. INTRODUCTION

During the last 40 years multi-criteria approaches have become an acknowledged tool for decision aid, especially for problems on the micro- and meso-level. These include areas such as human resource management, location problems, regional and architectural planning, investment problems, logistic problems, financial decisions on the stock markets, regional environmental problems, agricultural development, natural resource management, mining, energy management, waste management, localisation, economic planning, financial management and banking, transportation, urban management, project assessment and selection, production and supply management, military planning etc. (Roy & Vanderpotten, 1996), (Martel, 1999), (Omann, 2004). However, a large part of this research is devoted to the development of algorithms and mathematical methods rather than to practical problems. This leads to a lack of transparency and flexibility in real life applications (Fandel & Spronk, 1985).

The aims of multi-criteria decision aid processes lie in creating a new entity, that helps actors engaged in the decision process to shape or transform their preferences and to make a decision that is in conformity with their objectives. It seeks to define the concepts, properties, procedures used in order to extract meaningful information from the data available and to make the behaviour of the decision maker transparent to provide her with the arguments needed to support her own preferences. It does not amount to actual decision making (Roy, 1990).

Multi-criteria evaluation can be used as general term for the evaluation process preceding each decision. It comprises the whole process of decision preparation but its aim is not actual decision. Often in research projects decisions are prepared in the form of a multi-criteria evaluation, but the decision itself remains an entirely political or social act beyond the research project. Where decision aid is not explicitly asked for or where an evaluation is seen as sufficient help in preparing for decisions, we talk about multi-criteria evaluation.

2. PROJECT PURPOSES AND CONSTRAINTS AS THE CHOICE BASIS

Projects management is based on application of knowledge, experience, tools, methods and techniques in project measures, in order to reach or exceed the employers' needs and expectations, see: (Kerzner, 2009), (Trocki, Grucza & Ogonek, 2003), (Adam & Ebert, 2009).

According to definition (Kerzner, 2004), the essence of projects, as complex ventures is their definite character. It refers to basic values which characterize project, in other words, the basic project parameters, such as: meeting the needs

and expectations of the project employer (quality), cost of execution and the execution time.

The purpose of execution of each project is to obtain all above determined parameters at an assumed level (investment plan). It is reduced to a simple rule: well (meeting the demand and the expectations – i.e. quality), cheap (i.e. cost) and fast (i.e. time).

During the project execution, all areas and processes involved in the projects management should intertwine and influence each other. Individual parameters should not be analysed separately or their best solutions should not be interpreted as optimum solutions for the execution of the project as a whole. The task of the project contractors, especially the person in charge of the surveillance of the process is to work out such parameters set as to guarantee the highest efficiency of action. It is not an easy task, especially in the execution of great long-term technical and organizational projects. Most of parameters are mutually dependant on each other. Change of one of the elements influences the remaining two.

To put it simply, project management is understood as an organization planning, and tasks and resources management process to reach a specific purpose, usually in respect of time or cost constraints.

3. PROJECT SELECTION AS A MULTI-CRITERIA DECISION PROBLEM

Project selection is a strategic decision problem which is often characterized by multiple, conflicting and incommensurate criteria (Liesiö, Mild, & Salo, 2007) while the decision maker has to decide a portfolio of the most attractive alternatives by taking into account different aspects of the projects' efficiency (Mavrotas, Diakoulaki, & Kourentzis, 2008). In other words, in the project selection problem a decision maker allocates limited resources to a set of competing projects, considering one or more corporate goals or objectives (Medaglia, Graves & Ringuest, 2007).

Project selection is a very complex decision making process since it is affected by many critical factors such as the market conditions, raw materials availability, probability of technical success and government regulations (Bard, Balachandra, & Kaufmann, 1988). In addition, there is a high level of risk for the uncertainty or incompleteness of project information which make the decision maker feel hard to analysis correctly (Wang, Xu & Li, 2009). Obviously, wrong decisions in project selection have two negative consequences: On the one hand, resources are spent on unsuitable projects and, on the other hand, the organization loses the benefits it could have gained if these resources had been spent on more suitable projects (Martino, 1995), (Shakhsi-Niaei, Torabi & Iranmanesh, 2011).

Multi-criteria approaches are able to address questions characterised by various conflicting evaluations in the form of an integrated assessment (Munda, 2003). In the case of a multi-criteria problem, the concept of the optimal solution does not hold, as there is in general no option that dominates the others with respect to all criteria considered. Solving a multi-criteria problem often does not mean searching for a single optimum, but helping the decision maker in bringing more transparency into the problem and thus in advancing towards a solution, mostly a compromise. This process depends on a multitude of different factors, such as the personality of both the decision makers and the stakeholders, but also on the prevailing circumstances, and the specific method applied (Vincke, 1992).

Contradictory optimization criteria cause, that instead of clearly defined optimum solution there is a compromise set of solutions, determined as Pareto-optimum. Decision making in such situation, is an action based on choosing particular solution in the possible or acceptable solutions space, see (Sauer, 1999).

Problems of multi criterion alternative evaluation have been analysed by many authors, see: (Vincke, 1992), (Piegat, 1999), (Belton, Stewart, 2002), (Figueira, Greco & Ehrgott, 2005). This issue in a much wider perspective described in the work (Łapuńka, 2011).

In solving this kind of problems nowadays, Saaty's approach became almost a standard (Saaty, 1990). Popularity of this solution is caused not only by its efficiency in problem analysis on various levels, including general economy problems, but also by its transparency and a wide scope of application. This method however, has got in some aspects distinct mathematic imperfections (Weck, Klocke, Schell & Rüenauver, 1997).

After a situation analysis within multi criterion alternative evaluation we may state that the problem of establishing an efficient multi criterion and hierarchy variants evaluation method is still to be solved. To solve the problem, R. Knosala (Breiing, Knosala, 1997) proposed in the 90s of 20th century linking Saaty's approach with the fuzzy sets theory mechanism. Knosala method is described in a much wider working scope (Knosala, 1989).

4. AN APPROACH TO MULTI-CRITERIA VARIANTS EVALUATION IN PROJECT SCHEDULING

4.1. General description of approach

The key of the method is division of problem search into two stages. The first stage is based on application of evolution algorithms for the preliminary selection of the plans variants. Second stage includes final evaluation by means of fuzzy sets theory method.

Diagram of multi-criteria variants evaluation in project scheduling was presented in Fig. 1.
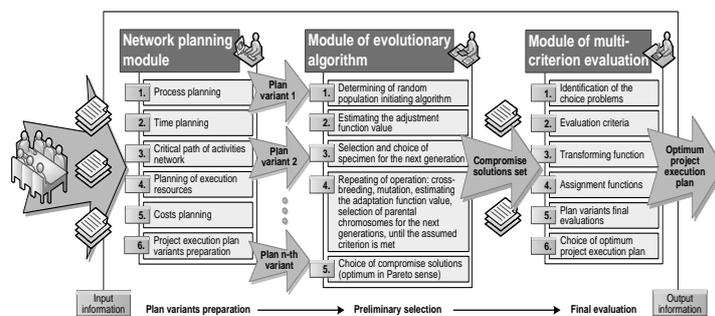
Fig. 1 Multi-criteria variants evaluation diagram

An independently designed software application was proposed for verification of the method, see (Łapuńka, 2010), based on three integrated modules:
- network planning module,
- module of evolution algorithm,
- module of multi-criterion evaluation.

Necessary parameters for the multi-criteria evaluation are chosen from databases, see (Łapuńka, 2010), which constitute input information to the network planning module in which inspection or scheduling of the process and time occurs, as well as the identification of project critical path, control or scheduling of the execution resources and cost and at the final stage preparing of project execution plan variants.

Preliminary selection is necessary in case of too many variants obtained. Set of schedule variants $\{P_1, ..., P_p\}$ after transforming into a coded unit, compatible with evolution algorithms, constitutes input to the evolution algorithm module, where the following occurs: determining a random population, initiating algorithm, estimating the value of adjustment function, selection and choice of individuals for the next generation, operation repeating: cross-breeding, mutation, estimating the adaptation function value, selection of parental chromosomes for the next generations, until the assumed criterion is met, choice of compromise solutions (optimum in Pareto sense).

The set of compromise solutions obtained in such way is under preliminary selection, finally evaluated in the module of multi-criterion evaluation. Evaluation criteria are selected in this module, transforming function and assignment functions are determined and after final evaluation of final schedule variants the optimum project execution schedule is determined. The project execution schedule evaluation is done by means of a method based on the application of fuzzy sets theory presented in a significantly wider aspect at work (Breiing, Knosala, 1997). The evaluation is of a multi-criterion character. Fuzzy sets theory transforms criterion indicators into variants fuzzy partial evaluations by means of transformation functions. The method facilitates comparison of different values by trans-

formation to the fuzzy numbers from the range of $\langle 0, 1 \rangle$. One of the basic input data to the module of multi-criterion evaluation is the number of alternative possible variants of project execution plan $a_p \in \langle 3; 10 \rangle$ – according to the method (Breiing, Knosala, 1997) assumptions.

4.2. Alternative project execution schedule variants

A test carried out for the example described in the paper (Łapuńka, 2010) gave twelve alternative project execution schedules with known: schedule number from the set $P_p = \{P_1, \ldots, P_{12}\}$; possible project execution times determined for the alternative schedules $\in P_p$ and their respective project execution cost.

Generated alternative project execution schedules at the cost curve breaking points differ as follows:

- t_n – normal activity time with its execution cost K_n being the lowest,
- t_{gr} – boundary time – shortest possible activity execution time due to technical and technological reasons at boundary cost K_{gr},
- S – average cost gradient (determines activity execution cost increase caused by shortened activity execution time by one unit).

Project execution diagrams for schedules P_1 and P_{12} have been presented in (Łapuńka, 2011).

Relations between schedules P_1 and P_{12} indicate, that there is a cost share increase for P_{12} by about 13,5% with regard to P_1, whereas there is, at the same time, a significant decrease in the project execution time (about 18%).

After the experiments, determining alternative project execution schedules at cost curve breaking points linear time (T) and cost (K) relations have been obtained. Pair of variables T and K, whose multiplication is almost a constant plus value ($\approx 128\,000$), constitutes mutually inversely proportional values, due to which time and cost are in this case certainly opposite schedule optimality criteria.

To carry out an experiment and in view of necessity to reduce the variants number, 5 sample programmes $P_p = \{P_1, P_3, P_5, P_7, P_{11}\}$ have been chosen in further evaluation of alternative project execution programmes with regard to the chosen criteria. Due to later rejection of criteria based on cost, a point of lower project execution cost was chosen out of a pair of two neighbouring points on the cost curve, which facilitated following the evaluation process for a whole spectrum of alternative time-cost scope of programmes.

4.3. Evaluation criteria, transformation and membership functions

Appropriate formulation and aggregation of criteria in multi criterion evaluation method is a problem of high significance. The criteria may be of both quantitative and qualitative character. There may be a large number of criteria and, in general,

some of them have a much higher influence on the final evaluation than the others. Moreover, in production experience at the project execution schedule construction stage, a simultaneous meeting of many, frequently opposite aims is pursued.

The multi criterion evaluation process included the following criteria (Łapuńka, 2011): K1 – maximum flow time F_{max}, K2 – maximum project execution time C_{max}, K3 – average flow time $\overline{F}$, K4 – execution deadline variation σ_{Tw}^2, K5 – average delay $\overline{L}$, K6 – maximum delay L_{max}.

Evaluation of variants (evaluation of the i-th variant in relation to the j-th criterion) may be included depending on the nature of the criterion in the form of deterministic, probabilistic or fuzzy.

List of criteria indexes for the individual production flow variants have been included in table 1. They constitute input data to the multi criterion solution evaluation. Due to the intact cost schedule (none of the generated project execution schedules has exceeded the estimated cost limit) the further cost criteria evaluation did not include.

Table 1   Criterion indexes for the obtained project execution schedule variants

No.	F_{max}	C_{max}	$\overline{F}$	σ_{Tw}^2	$\overline{L}$	L_{max}
P_1	0.9	228	0.7	0.00	-1	-1
P_3	0.9	217	0.9	4.36	-0.5	-0.5
P_5	1	211	1	6.53	-0.6	-0.8
P_7	0.8	203	0.6	11.64	0	0
P_{11}	1	202	1	13.83	0	0

Determinist variant evaluations (criteria: K1, K2, K6) have been determined in various dimensions depending on the criterion and assumed value scale. The evaluations values have been transformed by means of typical transformation functions into the interval $\langle 0,1 \rangle$.

Variant evaluations of fuzzy character are modelled by means of the so called relative evaluation. Individual variants are evaluated in pairs. The more a variant is preferred from another one, with regard to the criterion under consideration, the better its evaluation.

As a result of transformations, partial variant fuzzy evaluations are obtained as fuzzy numbers.

Qualitative criteria importance is determined by means of linguistic terms. This way of criteria importance determination requires adopting one common criterion treated as important (F_{max}) by all experts and determining common criteria sets treated as more and less important. The importance of criteria in both sets may be expressed by the experts individually and modelled using the membership function.

The decision maker no. 1 for the example assumed that given criteria are: K1 – important, K2 – very important, K3 – the least important, K4 – less important, K5 – a little more important, K6 – the most important.

4.4. Final alternative project execution schedules evaluations

Interpretation of results obtained in the aggregation process is related with the analysis of membership function values modelling the total evaluation of individual project execution schedule variants. Every set Z_i, $i=1,...,n$ is transformed for interval $\langle 0,1 \rangle$, but value $Z_i(z)$ determines the degree to which the value is in agreement with the i-th variant evaluation treated as the most preferable.

Project execution schedule variants evaluations in form of membership functions, for the example analysed in the article, have been presented in Figure 2.
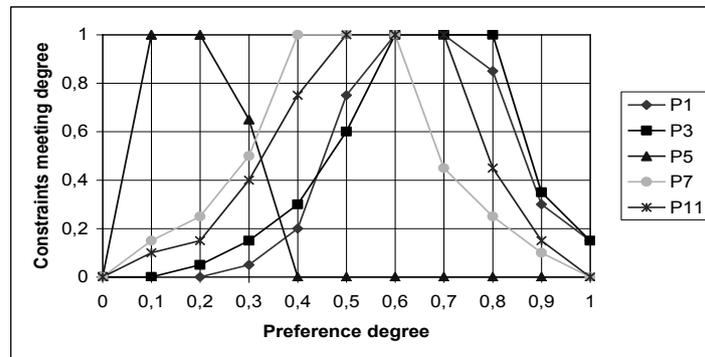
Fig. 2 Project execution schedule variants evaluations in form of membership functions

To formally determine the preference degree of individual variants it is necessary to order all fuzzy sets Z_1, Z_2,..., Z_n, where e.g. $Z_i \prec Z_j$ means, that j-th variant is preferred from i-th variant.

Si schedule variants final evaluations obtained after transformation of fuzzy values to real numbers space $g: Z_i \rightarrow R$ by means of transformation (1), have been presented in Table 2.

$$Z_i \rightarrow P_i = \frac{\int_0^1 z \cdot Z_i(z)\,dz}{\int_0^1 Z_i(z)\,dz} \tag{1}$$

where:

i-th variant is preferred with regard to the j-th if the condition $P_i > P_j$, and $P_i, P_j \in \langle 0,1 \rangle$ occurs.

Sets Z_1, Z_2,..., Z_n obtained as a result of aggregation may be characterized by an excessive, unnecessary in the aspect of interpretation fuzziness, especially for the function values $Z_i(z)$ close to zero. Constraint of the undesirable fuzziness impact, disturbing membership functions analysis results, may be obtained by adopting an appropriate precision index (in the example $a = 0.551$); the functions shall not be interpreted below the index.

Table 2   Schedule variants final evaluations obtained for the analysed example

No.	Evaluation	Normalized evaluation
P_1	0.6651	0.9731
P_3	0.6834	1.0000
P_5	0.1846	0.2702
P_7	0.5010	0.7330
P_{11}	0.5731	0.8386

The best final evaluation was given to project execution schedule variant P_3 and it was assumed as appropriate for further project execution.

5. CONCLUSION

It is easy to notice in production practice that due to economy and efficiency of company activities, both the cost and time must be somehow minimized by the project contractors. As can be seen in the example it is quite difficult and we might even call it (watching production companies) impossible. Decision maker (manager/project contractor) usually evaluates individual schedule variants in a subjective way; they possibly undergo multi criterion final evaluation due to different criteria choice.

Detailed project resources and schedule analysis gave quite an easy possibility to determine the best, as far as the criteria chosen are concerned, total project execution schedule variant within a group of solutions admitted to multi criterion final evaluation (5 alternative project execution schedules). The primary outlays schedule has been intact, and the cost schedule has been carefully adapted to the schedule, which does not make it easy for project coordinator to make decisions.

Multi-criteria approaches developed over the last 40 years as an answer to the growing complexity of decision problems. They allow one to address problems with exhibiting conflicting, incomparable, or incommensurable multiple criteria, different scales, or uncertain information. Even today, in the time of common business computerizing there is no universal approach applicable in solving all kinds of decision problems. Apart from multi criterion feature, the problem of alternative evaluation is also its multi levelling (some of the parameters may be obtained as a result of subordinate parameters aggregation).

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BIOGRAPHICAL NOTES

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