PROJECT PLANNING
IN MODERN ORGANIZATION

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PREFACE

People have been implementing projects since the beginning of the civilization. One could say that the projects have created the world as it is now. It is therefore somewhat surprising that research in the area of project management were initiated only 70 years ago. This delay, however, is nowadays intensively made up. Since the 1950s, project management enjoys increased interest both from the researchers, as well as the practitioners. The reason is quite simple: the projects are seen as critical to success in all three sectors: private, public and nonprofit.

While the impact of projects in modern society is immeasurable, it is evident that improper selection of projects together with their improper formulation, as well as mistakes made in the planning and implementation phases are causing evident wastage of our collective assets. Errors are the result of improper decisions. Project management is sometimes defined as a process of making series of decisions leading by the shortest route to the target. The complexity of problems that project managers must deal with, is primarily caused by the nature of the projects: their novelty and uniqueness. The lack of previous experience is a major cause of errors.

Since 1940s, projects have been extensively analyzed by operations research. Sometimes it is even said that the project management as a new field of knowledge was created as a mixture of engineering science and operations research. Initially, research activity was focused mainly on project scheduling problems. As a result techniques like CPM, PERT, MPM or GERT were proposed. Over time, the area of studies was expanded including managing project teams and project structures, quality issues, inter-organizational cooperation, etc. Still, however, "classical" problems, including project selection and project scheduling, are intensively studied. New developments in the information technology, as well as new concepts proposed by researchers working in the decision aiding field mean that the practical use of operations research achievements in project management is not reduced, on contrary – it is even getting wider.

This book includes theoretical and application papers from the field of project planning. The authors are faculty members of the University of Economics is Katowice, Department of Operations Research, and researchers from Poland and abroad, collaborating with the Department.

In the paper Multi-criteria decision aiding in project management – outranking approach and verbal decision analysis D. Górecka compares two classes of multi-criteria methods: based on outranking approach (ELECTRE, PROMETHEE) and verbal decision analysis. The author presents how these techniques can be used for selecting the best variant of road construction.

The project acceleration problem with focus on the duration/cost trade-off in a resource criticality context is considered in the paper A Way to Deal with The Project Crashing Problem by H. Kane, B. Ateme-Nguema and G. Nkubili. The heuristic based on the Tabu algorithm is used to show that the expected duration of a large project can be reduced considerably within a given budget increase by identifying the activities that provide the optimal solution.

In the paper Project portfolio scheduling as a multiple-criteria decision making problem B. Krzeszowska proposes a new methodology for solving the multi-criteria project portfolio scheduling problem. The approach proposed in the paper consists of three steps: construction of a model, identification of the Pareto set using evolutionary algorithm SPEA 2 and selection of the final solution.

In the paper Interactive decision aiding technique for a new product selection problem J. Michnik and M. Nowak consider New Product Development as a special case of the project selection problem. Authors propose a new discrete interactive decision making procedure for this problem. The technique uses trade-off information for identifying proposals for the decision maker.

The problem of risk assessment and management is analyzed in the paper Risk assessment improvement in the investment project management: Verbal Analysis Method by G. Shevchenko, L. Ustinovichius and K. Łoniewski. Authors analyse a decision-making strategy based on qualitative estimates obtained by investigating risk assessment and management methods and applying these methods to assess project risks in construction companies.

In the paper Risk and Uncertainty in Construction and Investment Projects for Infrastructure Development of the City of Wrocław in the Face of Poland's Preparations for the 2012 UEFA European Football Championship – Case Study D. Skorupka, M. Górski and D. Kuchta examine the relationship between sporting events and the development of infrastructure within the city that is hosting them. The study has been done based on the example of the preparation for UEFA European Soccer Championship 2012 in the city of Wroclaw.

In the paper The new approach for the project activities classification and its application in the Critical Chain Buffer Management Method A. Ślusarczyk and D. Kuchta propose a new typology of projects activities and use it for specifying the size of buffers in the Critical Chain method.

Project management maturity of an organization is considered in the paper Toward project management maturity. Knowledge transfer as key behaviour of mature organization by J. Świętoniowska. The author explains the importance of project knowledge transfer in building organization’s project management maturity and tries to show how project knowledge and experience are captured, shared and used by organizations at different levels of sophistication in project management practices and processes.

In the paper The use of multi-state real options in project evaluation and project management K. Targiel presents a decision support method based on Real Option Methodology. The technique can be used in multi-stage projects where there is free choice of the start of the next phases of the project.

The project portfolio scheduling problem is considered in the paper Scheduling resource constrained project portfolios with the principles of the theory of constraints by K. Targiel. The author proposes identification of strategic resource, and then solving the scheduling problem using a new heuristic.

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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 software tool**	[Ahmad, Laplante, 2006]	In the paper a model for selecting a software project management tool using the AHP is presented. 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. 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. Moreover, the work establishes a framework for comparing individual product decisions across projects, project managers, organizational groups and organizations.
4	**Measuring project 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. 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 project 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. 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. As an aggregation tool MACBETH method is used to analyze the performance measures according to project managers' own performance interests. 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. 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

[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.

<u>ELECTRE Iv</u>

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,

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

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.

<u>PROMETHEE I and PROMETHEE II</u>

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	$P_k(d_k)=\begin{cases}0, & if \quad d_k \le 0\\ 1, & if \quad d_k > 0\end{cases}$	none
Type 2: quasi-criterion (u-shape criterion)	$P_k(d_k)=\begin{cases}0, & if \quad d_k \le q_k\\ 1, & if \quad d_k > q_k\end{cases}$	indifference threshold q_k
Type 3: v-shape criterion	$P_k(d_k)=\begin{cases}0, & if \quad d_k \le 0\\ \frac{d_k}{p_k}, & if \quad 0 < d_k \le p_k\\ 1, & if \quad d_k > p_k\end{cases}$	preference threshold p_k
Type 4: level criterion	$P_k(d_k)=\begin{cases}0, & if \quad d_k \le q_k\\ \frac{1}{2}, & if \quad q_k < d_k \le p_k\\ 1, & if \quad d_k > p_k\end{cases}$	indifference threshold q_k preference threshold p_k
Type 5: pseudo-criterion (v-shape with indifference criterion)	$P_k(d_k)=\begin{cases}0, & if \quad d_k \le q_k\\ \frac{d_k - q_k}{p_k - q_k}, & if \quad q_k < d_k \le p_k\\ 1, & if \quad d_k > p_k\end{cases}$	indifference threshold q_k preference threshold p_k
Type 6: Gaussian criterion	$P_k(d_k)=\begin{cases}0, & if \quad d_k \le 0\\ 1-\exp(\frac{-d_k^2}{2s^2}), & if \quad d_k > 0\end{cases}$	s_k (it defines the inflection point of the prefer-ence 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: $\phi^+(a_i) = \frac{1}{m-1}\sum_{j=1}^{m}\pi(a_i, a_j)$,

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

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:

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

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

[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	f_1	f_2	f_3	f_4
	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				
a^1	250	50	8	2
a^2	300	40	7	6
a^3	280	35	2	4
a^4	400	30	6	7
a^5	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

	a^1	a^2	a^3	a^4	a^5
a^1	1	1	1	1	1
a^2	0	1	0	1	1
a^3	0	0	1	0	0
a^4	0	0	1	1	1
a^5	0	0	0	0	1

Table 7

Discordance set

	a^1	a^2	a^3	a^4	a^5
a^1	0	0	0	1	0
a^2	0	0	0	0	0
a^3	1	0	0	0	0
a^4	1	0	1	0	0
a^5	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

	a^1	a^2	a^3	a^4	a^5
a^1	1	1	1	0	1
a^2	0	1	0	1	1
a^3	0	0	1	0	0
a^4	0	0	0	1	1
a^5	0	0	0	0	1

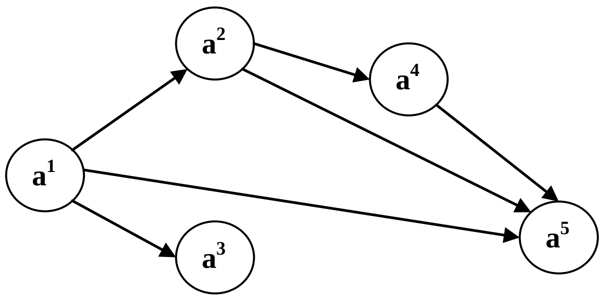


Figure 1. Outranking relation for s = 0,6 (graph constructed from the best to the worst variant)

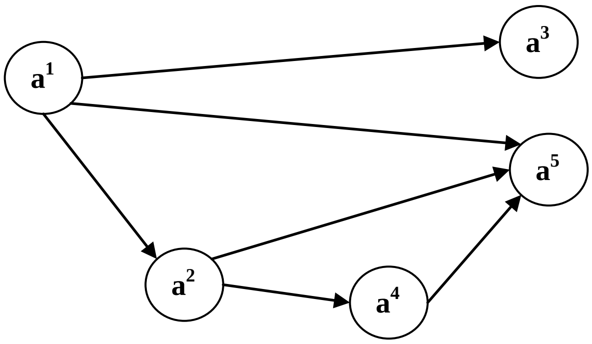


Figure 2. Outranking relation for s = 0,6 (graph constructed from the worst to the best variant)

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 outrank-ing 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

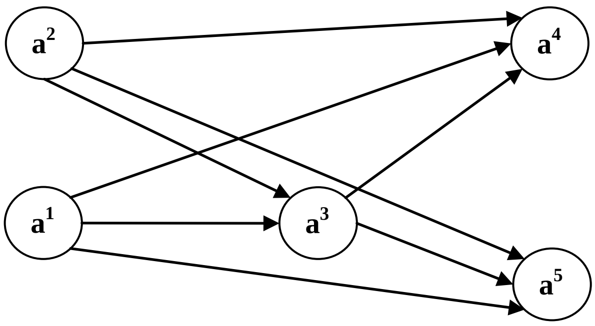


Figure 3. Partial variants' ranking produced using PROMETHEE I

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.

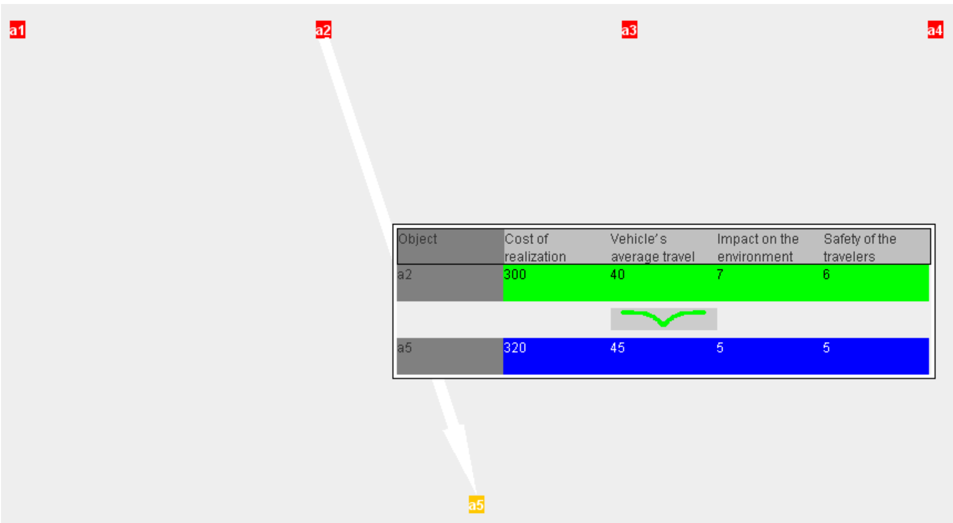


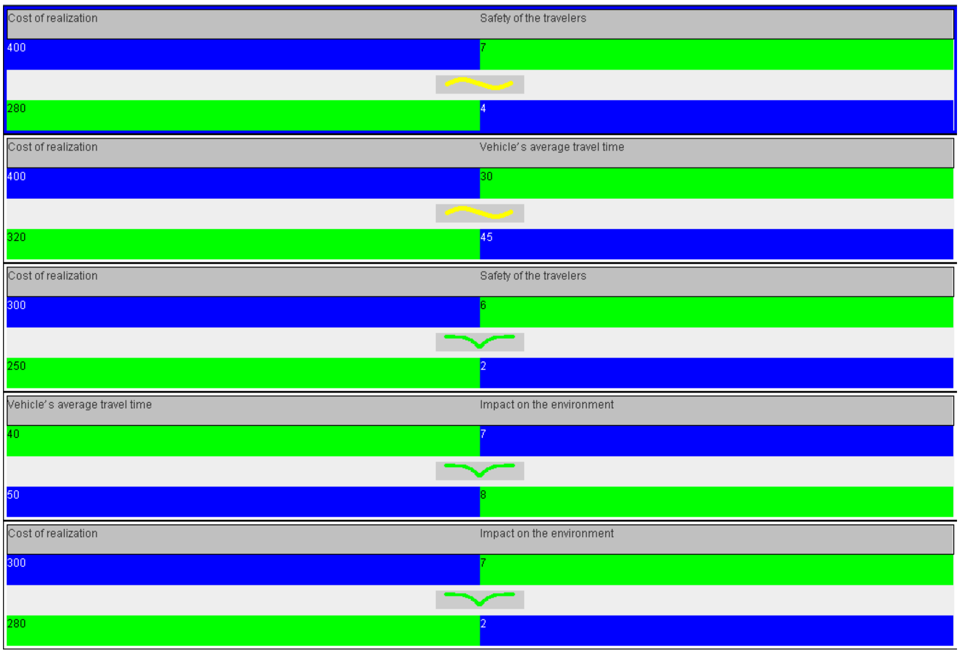
Figure 4. Result graph based on the comparisons of one-criterion units

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



<u>Diagrams above show that:</u>

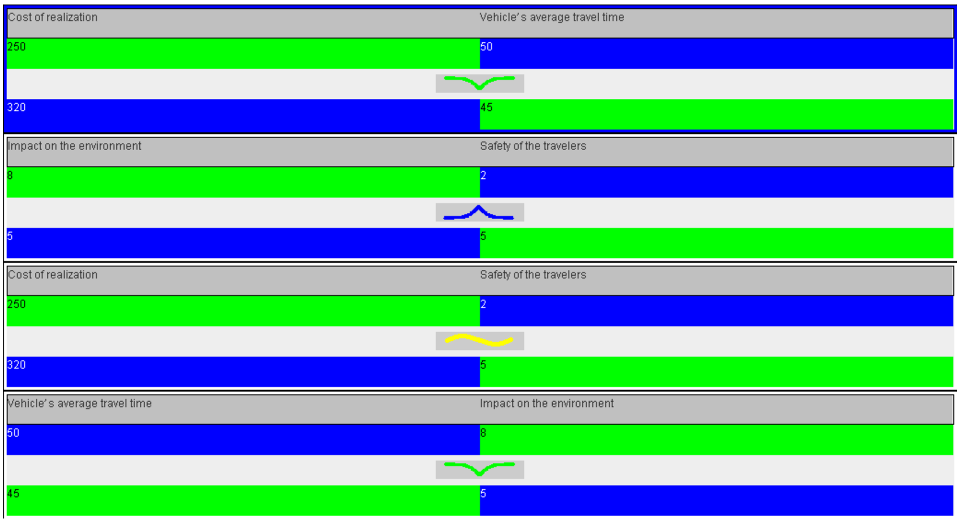
1. "400" on "Cost of realization", "7" on "Safety of the travelers" is as preferable as "280" on "Cost of realization", "4" on "Safety of the travelers"
2. "400" on "Cost of realization", "30" on "Vehicle's average travel time" is as preferable as "320" on "Cost of realization", "45" on "Vehicle's average 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

<u>Diagrams above show that:</u>

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



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"

Figure 8. Comparisons of two-criteria units – part IV

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

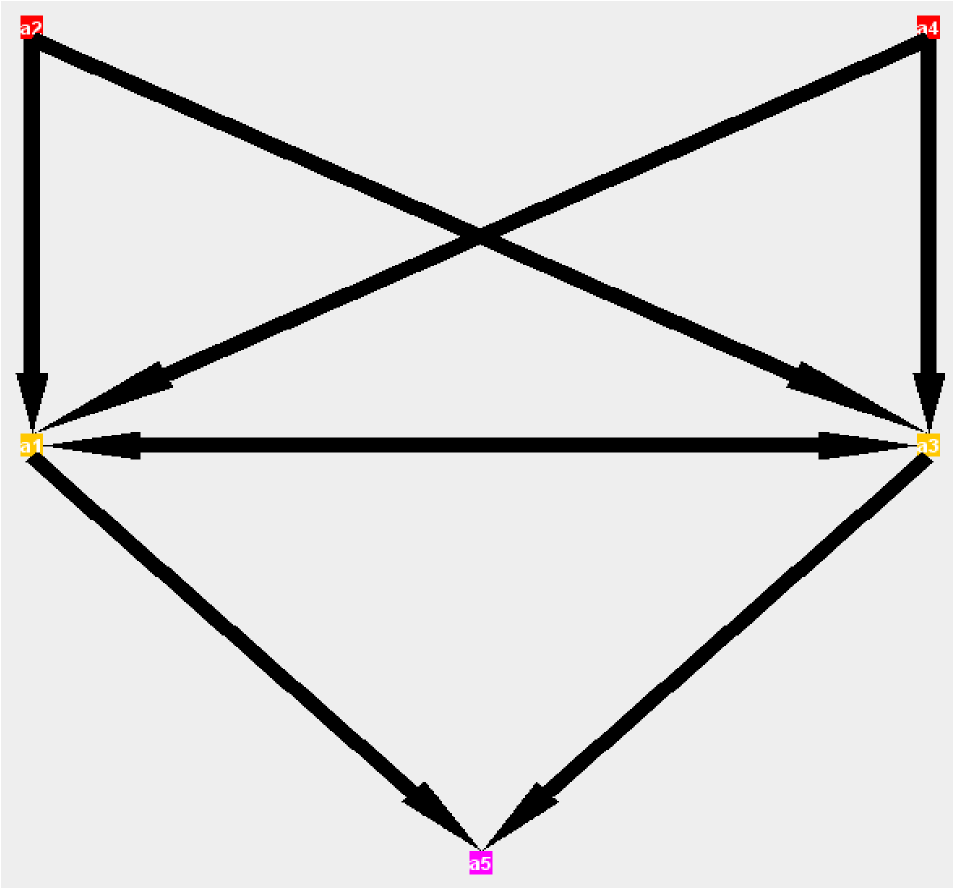


Figure 9. Final graph

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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A WAY TO DEAL WITH THE PROJECT CRASHING PROBLEM

Introduction

Completing projects as quickly as possible remains a constant preoccupation of all managers (Liberatore, Pollack-Johnson 2006). The literature is replete with affirmations that the businesses able to develop new products in the shortest time enjoy a substantial competitive edge (Swink, 2003).

Practitioners, academics and other professionals continue to search for ways, means and tools for determining a priori how much a project can be accelerated, based on inherent constraints such as budget and resources. Contemporary managerial emphasis on gaining competitive advantages obliges project managers to scope the costs of accelerating each activity of projects underway or upcoming. In the context of resource criticality, the cost of acceleration depends to a large degree on the type of resources assigned, their availability, their quantity and so on.

In this article, we propose a new approach to solving the problem of reaching an optimal compromise between duration and resources for the acceleration of projects in a context of resource criticality, in which the substitution of the resources is considered.

1. Review of the literature

In conventional project management, the mandate is carried out within pre-determined constraints such as specifications, deadlines and budget. Even though the anticipated length of a project in planning is usually longer than the critical path (Boctor 2005), projects seldom follow the classical project management scheme or meet deadlines (Gerk, Qassim 2008). In order to address this deficiency, project execution time can be accelerated to compensate for potential delays. By acceleration we mean finishing a project sooner than originally planned. In order to accelerate a project, we must have all of the information relevant to its constituent activities, including the types and quantities of the resources involved, unit costs, durations, priority relationships and so on.

The usual method of accelerating a given activity within a project is to assign to it more resources or resources with expertise and/or skills greater than those initially at the disposal of the project manager. This of course involves increased costs. However, accelerating some project activities can bring a reduction of indirect costs (Dodin, Elimam 2008; Evensmo and Karlsen, 2008) in the form of salary, amortisement of equipment and infrastructure, and so on.

Some authors have proposed accelerating projects by superimposing activities (Roemer, Ahmadi 2004). This approach is used essentially in the development of new products and services. The superimposition of activities consists of carrying out in parallel (partially or wholly) activities that were organized sequentially in the project plan. Another acceleration technique involves substituting certain activities with one and/or several other activities. There is thus the possibility of accelerating a project by applying the conventional approach, superimposing activities and substituting certain activities (Gerk, Qassim 2008).

Several approaches have been described in the literature for solving the time/cost trade-off problem. However, few of these take into consideration project particularities, that is, the peculiarities of the project resources. We may cite the cut search approach proposed by Kane, Azondekon (2008) and the linear programming model proposed by Alban (2008).

However, most of these approaches are deficient and difficult to apply to large complex projects (i.e. 100 activities or more). Calculation time in particular increases considerably. There are new methods better suited to solving the acceleration problem in the case of large projects for which more than two resources are available. These require minimal time for calculation.

We recommend a method based on application of the tabu algorithm and describe in the following section the principal steps of our approach.

2. Methodology

The logical procedure usually used to solve the duration/cost trade-off problem is the simultaneous mathematical equation approach, one equation representing time and the other representing project cost. The time taken to complete the activities as a whole depends on individual activity duration and on the priority relationships between the tasks. Cost depends on the resources assigned and of course on the allowed duration of each task. This approach generally seeks to determine exact activity completion times and total project time. These methods differ primarily in terms of the optimization techniques used to choose the activities to be accelerated and calculate by how much to accelerate them. Among these, we may cite the CPM/PERT method, the linear exact and non-linear programming techniques (Alban, 2008), the cut search approach (Kane, Azondekon 2008), and algorithmic and heuristic techniques (Bolduc, Laporte et al. 2010).

However, methods based on exact mathematical programming run into difficulty as project scale (number of activities or tasks) increases and the problem becomes of the so-called NP-hard type. The solving of this type of problem requires complex optimization techniques and the tabu search is the technique that we feel provides the best potential solution for project acceleration purposes. This algorithm technique also minimizes problem-solving time.

2.1. Mathematical model

The aim of this mathematical model is to calculated the total cost of the project. We describe below the parameters, the variables and the "objective" function of the model.

Let t_i be the time (from the beginning of the project) at which activity i is to begin according to the project plan and let x_i be the number of units of time by which activity i is accelerated.

The remaining parameters are as follows:
d_i – the normally expected duration of activity i
c_i – the unit cost of accelerating activity i
u_i – the maximum number of time units by which activity i can be accelerated
n – the number of activities (1 being the first activity and n being the last)
T – the normally expected duration of the critical path of the un-accelerated project
T_m – the calculated project duration after the m^{th} iteration, $m = 1, 2, 3, \ldots, M$

$T_m = T_a$ – the optimal duration attainable by accelerating the project
$P(j)$ – the set of activities immediately preceding activity j
C_{ki} – the normal cost per unit of time of resource k assigned to activity i
a_{ki} – the cost per time unit of obtaining via resource k a one-time-unit acceleration of activity i
K_{ki} –the total number of k resources assigned to activity i
N_a – the total number of activities that can be accelerated
$\sum_{ki=1}^{K_{ki}} c_{ki} d_i$ – the normally expected cost of completing activity i
$\sum_{ki=1}^{K_{ki}} a_{ki} x_i$ – the additional cost of accelerating activity i by x_i units of time
B – the additional budget available for accelerating the project
C_{NET} – the net cost of accelerating activity i by x_i units of time
C_n – the normally expected total cost of completing the project
$C_{\max} = C_n + B$ – the total cost not to be exceeded due to project acceleration
C_{aTOT} – the net total additional cost of accelerating the project
C_{aTOTm} – the net additional cost of the project at the m^{th} iteration

Objective function:

To minimize $C_{aTOT} = \alpha_i \sum_{i=1}^{N_a} x_i \sum_{ki}^{K_{ki}} (a_{ki} - c_{ki})$ (1)

Subject to:

$\alpha_i = 1$ if i is selected for acceleration;

0 if i is not selected for acceleration (2)

$t_j \geq t_i - x_i \qquad \forall (i, j) \in P(j)$ (3)

$t_n \leq T$ is the instant of the end of the last activity of the project (4)

$T \leq T_{m+1} \leq T_m$ avec $T_M = T_a$ (5)

$0 \leq x_i \leq u_i$ (6)

$x_i \leq u_i$ (7)

$C_{aTOT} \leq B$ (8)

With:

$t_1 = 0$ is the start of the first activity of the project

$t_i \geq 0 \quad \forall i$

$$C_{NET} = \sum_{ki=1}^{K_{ki}} c_{ki}(d_i - x_i) + \sum_{ki}^{K_{ki}} a_{ki}x_i = \sum_{ki}^{K_{ki}} c_{ki}d_i - \sum_{ki}^{K_{ki}} c_{ki}x_i + \sum_{ki}^{K_{ki}} a_{ki}x_i = \sum_{ki}^{K_{ki}} c_{ki}d_i + x_i \sum_{ki}^{K_{ki}} (a_{ki} - c_{ki}) \tag{9}$$

$$C_n = \sum_{i=1}^{N} \sum_{ki=1}^{K_{ki}} c_{ki}d_i \tag{10}$$

The problem amounts to minimizing the total project duration while remaining within the limits of additional budget B. T_m (expected project duration based on the critical path) is calculated using the CPM method. The objective function for minimizing T_m according to $T \leq T_{m+1} \leq T_m T$ consists of choosing an activity on the critical path and accelerating it by one unit of time.

Having established the method of calculating project duration and cost, our goal is to find a new approach to optimizing the solution to the problem of finding the best trade-off between project completion time and cost, with the aim of obtaining the greatest decrease in time at the lowest cost. It is at this stage that we use the tabu method to determine the project-accelerating option that costs the least. In the following section, we present the approach based on the tabu algorithm.

2.2 The tabu algorithm

The "tabu" algorithm is a local-search meta-heuristic that explores the neighbourhood beyond the optimum solution obtained (Xu et al. 2009). This search method uses an iterative process to shift from the current solution towards a neighbouring solution that achieves a superior goal. In order to avoid futile cycles, that is, exploration of solutions similar to those previously examined, the search generates a "tabu" list of shifts and solutions explored in previous iterations (Liu et al. 2010). In order to improve the efficiency of the iterative process, the tabu algorithm maintains a follow-up of the local information as well as of the search process itself (Bolduc et al. 2010). The other principles of search with tabu, namely aspiration, intensification and diversification, are treated in detail in works published by Glover (1989; 1990) and by Glover and Laguna (1997).

In each iteration, our tabu algorithm first explores the entire solutions space (the project plan as a whole) and thus defines the zone in which it will subsequently intensify the search for the activity to be accelerated. The activity configuration scheme, duration and the total cost of the project are then updated, based on acceleration of the activity thus identified.

The process is stopped when the conditions regarding project duration relative to predefined budgetary constraints are met or when it has been determined that no activity within the predefined zone of search can be accelerated to obtain a desirable result (Figure l).

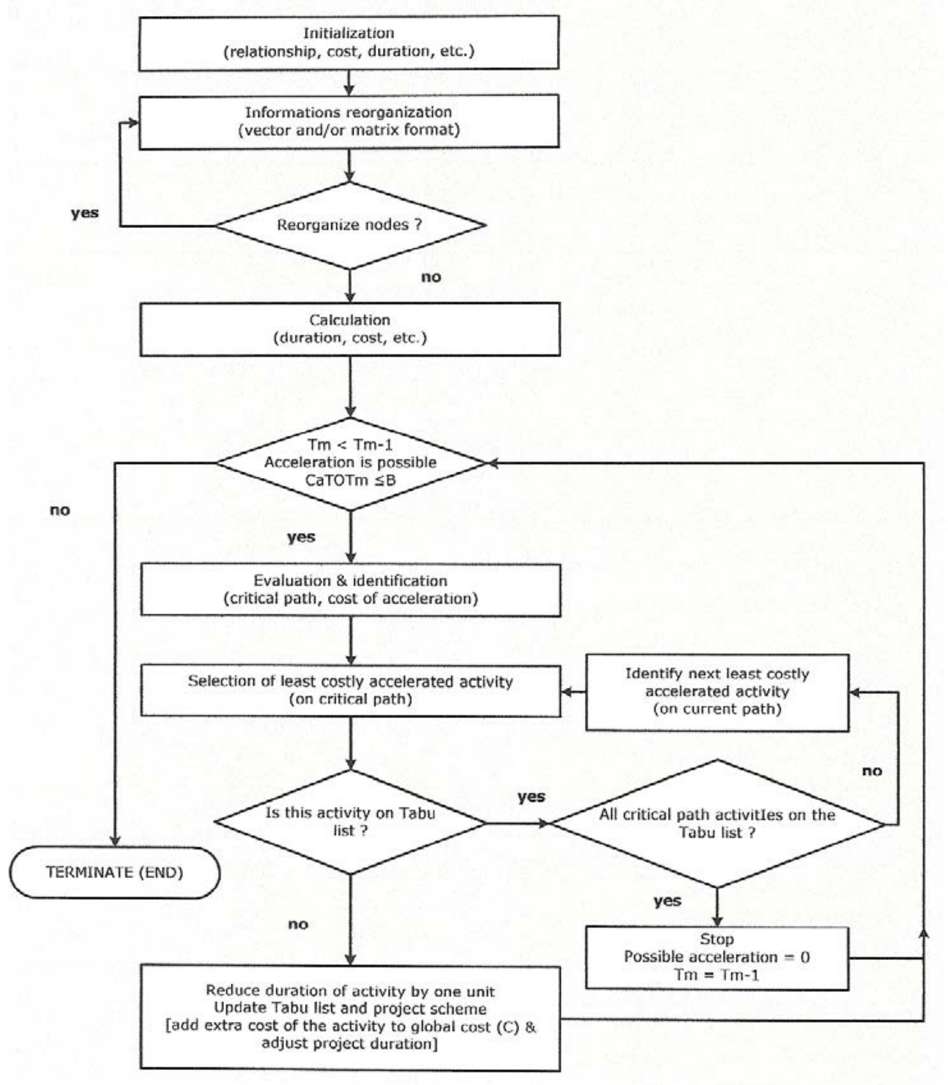

Figure 1. The project acceleration algorithm with Tabu

3. Applications

In order to validate the proposed project acceleration algorithm, we performed tests on real projects involving numerous activities (over 100). The project includes 172 activities requiring four different types of resource. Figures 2a and 2b show the project network, while Table 1 in appendix provides the time and resource-associated costs for each activity.

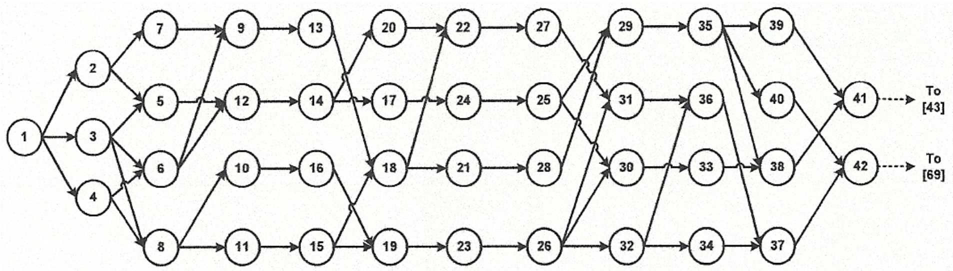

Figure 2a. The project network

Source: Doerner et al. 2008.

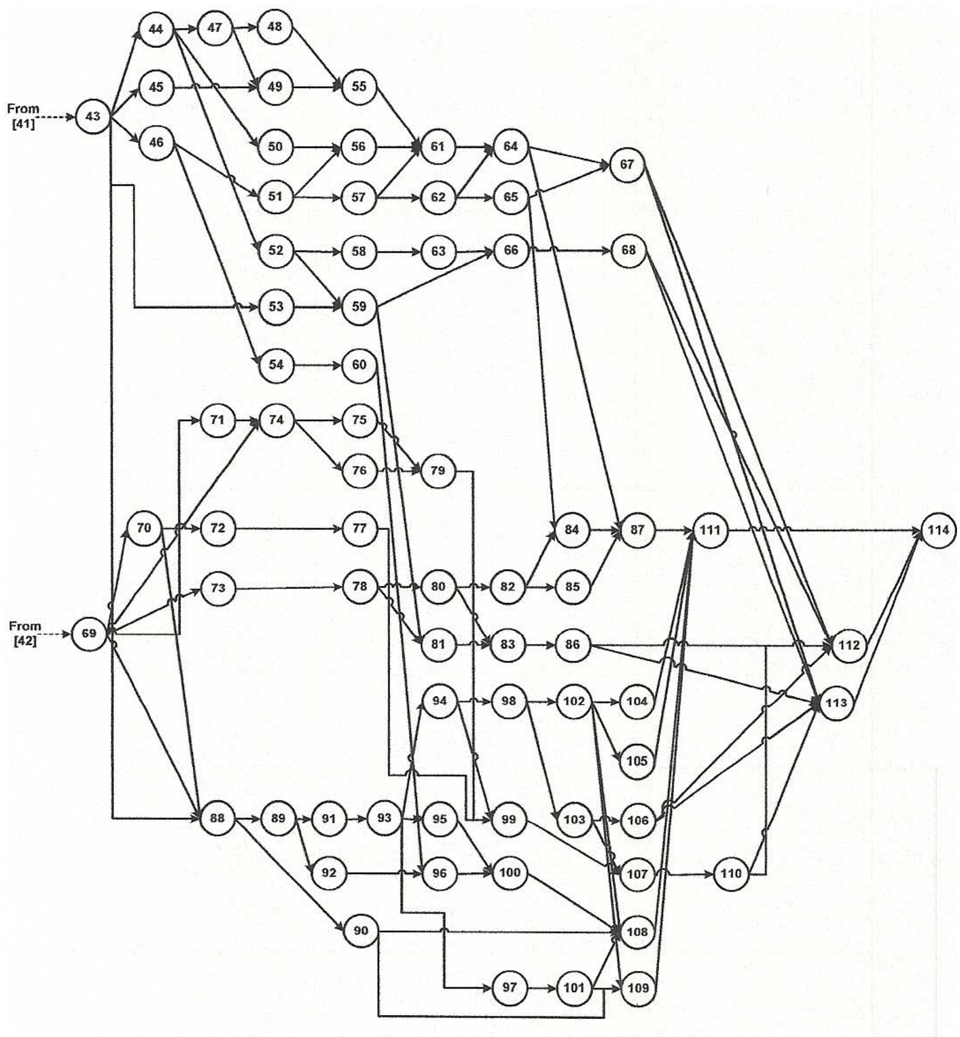

Figure 2b. The project network

Source: Doerner et al. 2008.

4. Results

We used MATLAB 6.0 to implement our algorithm. The results obtained show that the project can be accelerated with minimal increases in cost. Furthermore, the calculation time was relatively short. The expected project duration before acceleration was 83 weeks for a total cost of $1,483,600. We defined the normal unit cost of each resource arbitrarily and set the unit cost of acceleration 50% higher (see Table 1 in appendix).

If we also suppose that any activity can be accelerated without limits and that we have at our disposal a budgetary increase of up to 20% with which to accelerate the project, we can obtain a reduction in project duration from 83 to 47 weeks at an additional cost of $293,450. This is a 43.3% reduction of project time for a cost increase of 19.77%. The algorithm achieved this result by carrying out 113 iterations, which required about 3 seconds of calculation time.

These results indicate that the algorithm is effective and could be used on a daily basis by professionals to accelerate large-scale projects involving relatively large numbers of tasks.

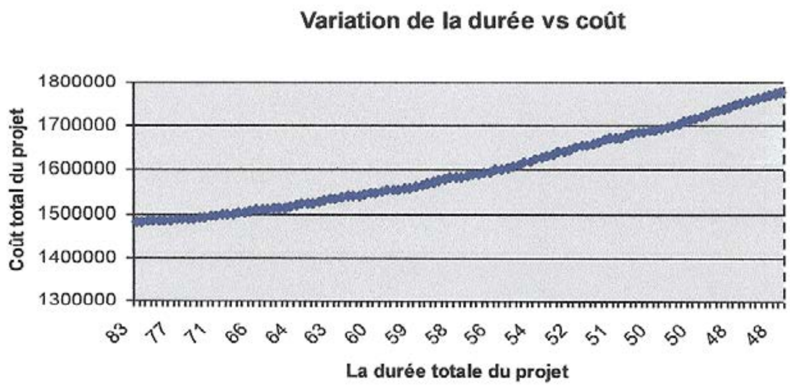

Figure 3. Cost variation VERSUS project duration

Conclusion

In this study, we have presented the results obtained using a new tool developed to solve the problem of finding the optimal trade-off between project duration and cost in the context of resource criticality. The tool we have developed applies principles of tabu search to optimize the process of identifying project activities to be accelerated.

Using our project acceleration algorithm on projects previously treated using other approaches, we demonstrated that the tool identifies the same solution or in some cases a better solution and with a shorter calculation time.

This work thus proposes a new avenue to explore with more in-depth studies for the improvement of project management.

Appendix

Table 1

Duration, acceleration and associated resource costs of activities (corresponding to arrows in the CPM/PERT diagram) for the project

Act.	Path	Pqte	d_i	u_i	C_{k1}	C_{k2}	C_{k3}	C_{k4}	a_{k1}	a_{k2}	a_{k3}	a_{k4}
1	(1,2)	---	2	1	700	700	700	700	1050	1050	1050	1050
2	(1,3)	---	3	2	900	900	900	900	1350	1350	1350	1350
3	(1,4)	---	3	2	600	600	600	600	900	900	900	900
4	(2,5)	1	2	1	600	600	600	600	900	900	900	900
5	(2,7)	1	2	1	100	100	100	100	150	150	150	150
6	(3,5)	2	2	1	700	700	700	700	1050	1050	1050	1050
7	(3,6)	2	4	3	400	400	400	400	600	600	600	600
8	(3,8)	2	5	4	100	100	100	100	150	150	150	150
9	(4,6)	3	3	2	1600	1600	1600	1600	2400	2400	2400	2400
10	(4,8)	3	2	1	3000	3000	3000	3000	4500	4500	4500	4500
11	(5,12)	4;6	6	5	700	700	700	700	1050	1050	1050	1050
12	(6,9)	7;9	3	2	900	900	900	900	1350	1350	1350	1350
13	(6,12)	7;9	2	1	600	600	600	600	900	900	900	900
14	(7,9)	5	4	3	600	600	600	600	900	900	900	900
15	(8,9)	8;10	2	1	100	100	100	100	150	150	150	150
16	(8,10)	8;10	5	4	700	700	700	700	1050	1050	1050	1050
17	(8,11)	8;10	6	5	400	400	400	400	600	600	600	600
18	(9,13)	11;14;15	4	3	100	100	100	100	150	150	150	150
19	(10,16)	16	3	2	1600	1600	1600	1600	2400	2400	2400	2400
20	(11,15)	17	4	3	3000	3000	3000	3000	4500	4500	4500	4500
21	(12,14)	11;13	2	1	700	700	700	700	1050	1050	1050	1050
22	(13,18)	18	2	1	900	900	900	900	1350	1350	1350	1350
23	(14,17)	21	3	2	600	600	600	600	900	900	900	900
24	(14,20)	21	3	2	600	600	600	600	900	900	900	900
25	(15,18)	19	2	1	100	100	100	100	150	150	150	150
26	(15,19)	20	3	2	700	700	700	700	1050	1050	1050	1050
27	(16,19)	19	2	1	400	400	400	400	600	600	600	600
28	(17,24)	23	6	5	100	100	100	100	150	150	150	150
29	(18,21)	25	5	4	1600	1600	1600	1600	2400	2400	2400	2400
30	(18,22)	22;25	2	1	3000	3000	3000	3000	4500	4500	4500	4500
31	(19,23)	26;27	3	2	700	700	700	700	1050	1050	1050	1050
32	(20,22)	24	1	0	900	900	900	900	1350	1350	1350	1350
33	(21,28)	29	3	2	600	600	600	600	900	900	900	900
34	(22,27)	30;32	3	2	600	600	600	600	900	900	900	900
35	(23,26)	31	4	3	100	100	100	100	150	150	150	150
36	(24,25)	28	3	2	700	700	700	700	1050	1050	1050	1050
37	(25,29	36	2	1	400	400	400	400	600	600	600	600
38	(25,30)	36	5	4	100	100	100	100	150	150	150	150
39	(26,30)	35	2	1	1600	1600	1600	1600	2400	2400	2400	2400
40	(26,31)	35	2	1	3000	3000	3000	3000	6000	4500	4500	4500
41	(26,32)	35	2	1	3000	3000	3000	3000	4500	4500	4500	4500
42	(27,31)	35	4	3	700	700	700	700	1050	1050	1050	1050
43	(28,29)	34	5	4	900	900	900	900	1350	1350	1350	1350
44	(29,35)	33	3	2	600	600	600	600	900	900	900	900
45	(30,33)	37;43	4	3	600	600	600	600	900	900	900	900
46	(31,36)	38;39	2	1	100	100	100	100	150	150	150	150
47	(32,34)	40;42	3	2	700	700	700	700	1050	1050	1050	1050
48	(32,36)	41	3	2	400	400	400	400	600	600	600	600
49	(33,38)	41	5	4	100	100	100	100	150	150	150	150
50	(34,37)	45	2	1	1600	1600	1600	1600	2400	2400	2400	2400

Table 1(continued)

Act.	Path	Pqte	d_i	u_i	C_{k1}	C_{k2}	C_{k3}	C_{k4}	a_{k1}	a_{k2}	a_{k3}	a_{k4}
51	(35,38)	47	4	3	3000	3000	3000	3000	4500	4500	4500	4500
52	(35,39)	44	2	1	700	700	700	700	1050	1050	1050	1050
53	(35,40)	44	2	1	200	200	200	200	300	300	300	300
54	(36,37)	44	3	2	900	900	900	900	1350	1350	1350	1350
55	(37,42)	46;48	2	1	600	600	600	600	900	900	900	900
56	(38,41)	50;54	5	4	600	600	600	600	900	900	900	900
57	(39,41)	49;51	2	1	100	100	100	100	150	150	150	150
58	(40,42)	52	3	2	700	700	700	700	1050	1050	1050	1050
59	(41,43)	53	2	1	700	700	700	700	1050	1050	1050	1050
60	(42,69)	57	2	1	400	400	400	400	600	600	600	600
61	(43,44)	55;58	4	3	200	200	200	200	300	300	300	300
62	(43,45)	59	2	1	700	700	700	700	1050	1050	1050	1050
63	(43,46)	59	3	2	900	900	900	900	1350	1350	1350	1350
64	(43,53)	59	1	0	600	600	600	600	900	900	900	900
65	(43,88)	59	3	2	600	600	600	600	900	900	900	900
66	(44,47)	59	2	1	100	100	100	100	150	150	150	150
67	(44,500	61	4	3	700	700	700	700	1050	1050	1050	1050
68	(44,52)	61	3	2	400	400	400	400	600	600	600	600
69	(45,49)	61	4	3	100	100	100	100	150	150	150	150
70	(46,51)	62	2	1	1600	1600	1600	1600	2400	2400	2400	2400
71	(46,54)	63	2	1	3000	3000	3000	3000	4500	4500	4500	4500
72	(47,48)	63	3	2	700	700	700	700	1050	1050	1050	1050
73	(47,49)	66	2	1	200	200	200	200	300	300	300	300
74	(48,55)	66	1	0	900	900	900	900	1350	1350	1350	1350
75	(49,55)	72	3	2	600	600	600	600	900	900	900	900
76	(50,56)	69;73	4	3	600	600	600	600	900	900	900	900
77	(51,56)	67	2	1	100	100	100	100	150	150	150	150
78	(51,57)	70	4	3	700	700	700	700	1050	1050	1050	1050
79	(52,58)	70	3	2	700	700	700	700	1050	1050	1050	1050
80	(52,59)	68	5	4	400	400	400	400	600	600	600	600
81	(53,59)	68	4	3	200	200	200	200	300	300	300	300
82	(54,60)	64	2	1	1600	1600	1600	1600	2400	2400	2400	2400
83	(55,61)	71	1	0	3000	3000	3000	3000	4500	4500	4500	4500
84	(56,61)	74;75	2	1	700	700	700	700	1050	1050	1050	1050
85	(57,61)	76;77	3	2	900	900	900	900	1350	1350	1350	1350
86	(57,62)	78	2	1	600	600	600	600	900	900	900	900
87	(58,63)	78	5	4	600	600	600	600	900	900	900	900
88	(59,66)	79	2	1	100	100	100	100	150	150	150	150
89	(59,81)	80;81	4	3	700	700	700	700	1050	1050	1050	1050
90	(60,96)	80;81	3	2	600	600	600	600	900	900	900	900
91	(61,64)	82	4	3	400	400	400	400	600	600	600	600
92	(62,64)	83;84;85	2	1	100	100	100	100	150	150	150	150
93	(62,65)	86	3	2	1600	1600	1600	1600	2400	2400	2400	2400
94	(63,66)	86	2	1	3000	3000	3000	3000	4500	4500	4500	4500
95	(64,67)	87	2	1	700	700	700	700	1050	1050	1050	1050
96	(64,87)	91;92	3	2	900	900	900	900	1350	1350	1350	1350
97	(65,67)	91;92	2	1	700	700	700	700	1050	1050	1050	1050
98	(65,84)	93	3	2	600	600	600	600	900	900	900	900
99	(66,68)	93	4	3	100	100	100	100	150	150	150	150
100	(67,112)	94	5	4	600	600	600	600	900	900	900	900
101	(67,113)	95;97	2	1	100	100	100	100	150	150	150	150
102	(68,112)	95;97	4	3	700	700	700	700	1050	1050	1050	1050
103	(68,113)	99	3	2	400	400	400	400	600	600	600	600
104	(69,70)	99	4	3	100	100	100	100	150	150	150	150
105	(69,71)	60	2	1	1600	1600	1600	1600	2400	2400	2400	2400
106	(69,73)	60	2	1	3000	3000	3000	3000	4500	4500	4500	4500
107	(69,74)	60	1	0	700	700	700	700	1050	1050	1050	1050
108	(69,88)	60	3	2	900	900	900	900	1350	1350	1350	1350
109	(70,72)	60	4	3	100	100	100	100	150	150	150	150

Table 1(continued)

Act.	Path	Pqte	d_i	u_i	C_{k1}	C_{k2}	C_{k3}	C_{k4}	a_{k1}	a_{k2}	a_{k3}	a_{k4}
110	(70,88)	104	2	1	600	600	600	600	900	900	900	900
111	(71,74)	104	3	2	600	600	600	600	900	900	900	900
112	(72,77)	105	2	1	100	100	100	100	150	150	150	150
113	(73,78)	109	2	1	700	700	700	700	1050	1050	1050	1050
114	(74,75)	106	4	3	400	400	400	400	600	600	600	600
115	(74,76)	107;111	2	1	100	100	100	100	150	150	150	150
116	(75,790	107;111	3	2	700	700	700	700	1050	1050	1050	1050
117	(76,79)	114	2	1	400	400	400	400	600	600	600	600
118	(77,99)	115	2	1	100	100	100	100	150	150	150	150
119	(78,80)	112	6	5	1600	1600	1600	1600	2400	2400	2400	2400
120	(78,81)	113	3	2	3000	3000	3000	3000	4500	4500	4500	4500
121	(79,99)	113	5	4	700	700	700	700	1050	1050	1050	1050
122	(80,82)	115;117	2	1	900	900	900	900	1350	1350	1350	1350
123	(80,83)	119	4	3	600	600	600	600	900	900	900	900
124	(81,83)	119	2	1	600	600	600	600	900	900	900	900
125	(82,84)	89;110	2	1	100	100	100	100	150	150	150	150
126	982,85)	122	3	2	700	700	700	700	1050	1050	1050	1050
127	(83,86)	122	2	1	400	400	400	400	600	600	600	600
128	(84,87)	123;124	4	3	100	100	100	100	I50	150	150	150
129	(85,87)	125	2	1	1600	1600	1600	1600	2400	2400	2400	2400
130	(86,112)	126	2	1	3000	3000	3000	3000	4500	4500	4500	4500
131	(86,113)	127	3	2	700	700	700	700	1050	1050	1050	1050
132	(87,111)	127	2	1	200	200	200	200	300	300	300	300
133	(88,89)	128;129	3	2	900	900	900	900	1350	1350	1350	1350
134	(88,90)	65;108;110	2	1	600	600	600	600	900	900	900	900
135	(89,91)	65;108;110	5	4	600	600	600	600	900	900	900	900
136	(89,92)	133	3	2	100	100	100	100	150	150	150	150
137	(90,108)	133	3	2	700	700	700	700	1050	1050	1050	1050
138	(90,109)	134	2	1	700	700	700	700	1050	1050	1050	1050
139	(91,93)	134	4	3	400	400	400	400	600	600	600	600
140	(92,96)	135	3	2	200	200	200	200	300	300	300	300
141	(93,94)	136	4	3	700	700	700	700	1050	1050	1050	1050
142	(93,95)	139	2	1	900	900	900	900	1350	1350	1350	1350
143	(93,97)	139	6	5	600	600	600	600	900	900	900	900
144	(94,98)	139	2	1	700	700	700	700	1050	1050	1050	1050
145	(94,99)	141	3	2	900	900	900	900	1350	1350	1350	1350
146	(95,100)	141	4	3	900	900	900	900	1350	1350	1350	1350
147	(96,100)	142	1	0	600	600	600	600	900	900	900	900
148	(97,101)	90;140	2	1	600	600	600	600	900	900	900	900
149	(98,102)	143	3	2	100	100	100	100	150	150	150	150
150	(98,103)	144	2	1	700	700	700	700	1050	1050	1050	1050
151	(99,107)	144	3	2	700	700	700	700	1050	1050	1050	1050
152	(100,108)	118;121;145	2	1	400	400	400	400	600	600	600	600
153	(101,108)	148	4	3	700	700	700	700	1050	1050	1050	1050
154	(101,109)	148	2	1	900	900	900	900	1350	1350	1350	1350
155	(102,104)	149	3	2	h00	h00	600	600	900	900	900	900
156	(102,105)	149	2	1	600	600	600	600	900	900	900	900
157	(102,108)	149	2	1	100	100	100	100	150	150	I50	150
158	(102,109)	149	5	4	700	700	700	700	1050	1050	1050	1050
159	(103,106)	150	3	2	400	400	400	400	600	600	600	600
160	(103,107)	150	5	4	100	100	100	100	150	150	150	150
161	(104,111)	155	2	1	1600	1600	1600	1600	2400	2400	2400	2400
162	(105,111)	156	4	3	3000	3000	3000	3000	4500	4500	4500	4500
163	(106,112)	159	3	2	700	700	700	700	1050	1050	1050	1050
164	(106,113)	159	4	3	200	200	200	200	300	300	300	300
165	(107,110)	151;160	2	1	900	900	900	900	1350	1350	1350	1350
166	(108,111)	137;152;153;157	2	1	600	600	600	600	900	900	900	900
167	(109,111)	138;154;158	4	3	600	600	600	600	900	900	900	900
168	(110,112)	165	3	2	100	100	100	100	150	150	150	150
169	(110,113)	165	2	1	700	700	700	700	1050	1050	1050	1050

Table 1(continued)

Act.	Path	Pqte	d_i	u_i	C_{k1}	C_{k2}	C_{k3}	C_{k4}	a_{k1}	a_{k2}	a_{k3}	a_{k4}
170	(111,114)	132;161;162;166;167	3	2	700	700	700	700	1050	1050	1050	1050
171	(112,1140)	100;102;130;163;168	4	3	400	400	400	400	600	600	600	600
172	(113,114)	101;103;131;164;169	5	4	200	200	200	200	300	300	300	300

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INTERACTIVE DECISION AIDING TECHNIQUE FOR A NEW PRODUCT SELECTION PROBLEM[1]

Introduction

The selection of new product projects is a part of continuous process and plays the crucial role in the new product development (Cooper 2004a, 2004b). Academic and industry participants which took part in the extended survey indicated "new product project selection" as belonging to the most important among top 24 technology management issues (second place after the 'strategic planning for technology products') (Scott 2000). Yet, despite the critical role of innovation management and the abundance of literature discussing the role of new product development, there are not many articles discussing the MCDA models (Michnik 2011).

We assume that the firm has definite portfolio of its products and periodically reviews some new potential products to select the new one. The new project may be added to the existed portfolio or may replace the obsolete one. Such kind of a decision is characterized by many discordant objectives. These objectives are linked to a majority of firm's activities and external environment. According to the classification published in (Michnik 2010), we propose five general categories of criteria:

- strategic criteria, designed to represent the strategic plans and long term goals,
- organizational criteria comprising organizational, marketing, logistic and other similar competencies,
- technological criteria, connected with R&D potential and technological competencies,
- financial criteria representing investment costs and potential revenues,

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- market criteria encompassing the broad range of market factors, including customers' and competitors' reaction to a new product.

The remaining part of the paper is organized as follows. The next section contains a brief review of multiple criteria models used in the NPD. In Section 2 the interactive approach to multicriteria discrete problem is presented. Using a numerical example, we illustrate in Section 3 how the procedure works. Conclusions are placed at the end of the paper.

1. Multicriteria decision methods in NPD

Englund and Graham (1999) discussed practices for upper manager teamwork and offer a complete model for selecting projects that support a strategic emphasis. AHP (Saaty 2005) was the last stage of a multi-stage process and include the following criteria:

- customer satisfaction,
- employee satisfaction,
- business value,
- the effectiveness of the process.

Each of these criteria was divided into 3 to 5 lower-level criteria. The structure of the criteria and sub-criteria was the result of the work of a team of experts. The model was successfully employed within Hewlett-Packard Company.

AHP method was also an essential part of the selection process of new products in a large division of the US company (Calantone et al. 1999). Similarly to the previous example, the team developed a set covering four criteria:

- matching the core competencies of marketing,
- matching the basic technological skills,
- profit-risk profile (in terms of money),
- the overall uncertainty of the results of the project.

The first two criteria are divided into 6 sub-criteria, and the last two into 2. The authors concluded that the presented model of AHP can be used as a standalone tool or can be integrated into a more comprehensive decision support system.

For analysis, ranking and selection of the R&D projects in the Advanced Technology Division (Bell Laboratories) the multicriteria model combined with a graphical decision support system was used (Linton et al. 2000). That model was the initial stage of the decision support system, served for the initial selection of projects that had the greatest potential. The criteria were selected by managers and project managers, and were divided into two groups:

– quantitative criteria (financial), including the amount of investment and the expected cash flows in the forthcoming years;
– qualitative criteria, including the assessment of the two stages: the product life cycle and the life cycle of the intellectual property.

Another example is the model based on multicriteria method SMART (Simple Multi-Attribute Rating Technique) developed in the 70's of the last century (Edwards 1971, 1977). This model has been applied in the international production company (Morcos, 2008). Project evaluation was based on the confrontation of resource usage and potential benefits. In order to simplify the model, resource assessment has been limited to financial resources, and the benefits have been divided into tangible and intangible ones. The short term profitability has been adopted as an tangible benefit. Intangible benefits include two items: reliability (increasing the reliability of projects) and risk (minimizing the risk of portfolio of projects). The partial aggregation of ratings has been made during the procedure, so that, finally, the model had only two criteria. That allowed a simplified analysis and a graphical presentation of the location of the variants in the two-dimensional graph.

The NPD is a special case of the project selection problem, which has been extensively analyzed for the last decades. Due to the complexity of the problem, metaheuristics are often used. Doerner et al. (2006) use ant colony with integer linear programming preprocessing to identify Pareto-optimal portfolios. The model proposed by Carazo et al. (2010) assumes strong interdependence between projects. As a result, projects have to be assessed in groups, while allowing individual projects to start at different times depending on resource availability or any other strategic or political requirements, which involves timing issues. The problem is solved using a metaheuristic procedure based on Scatter Search.

2. Interactive approach for solving multicriteria decision making problems

The problem we consider here is a discrete multi-criteria decision-making problem. We assume that the decision maker (DM) goal is to select the single alternative that maximizes his/her satisfaction, all criteria are maximized and outcomes are measured in real values (ratio scale is used for each criterion).

Let us assume the following notation:

A – the finite set of alternatives a_i, $i = 1, \dots, m$,

F – the finite set of criteria f_p, $p = 1, \dots, r$,

V – the set of evaluations of alternatives with respect to criteria v_{ip}, $i = 1, \dots, m$, $p = 1, \dots, r$.

In order to solve a multicriteria problem, single-criterion evaluations must be aggregated. Roy (1985) identified three main aggregating concepts: a concept with a single synthetic criterion, outranking concept, and dialog concept with “trial-and-error” iterations. The last idea, also known as “interactive approach”, is often used for solving real-world problems.

Interactive methods employ two main paradigms for identifying decision-maker’s preferences: direct and indirect. In the prior one, the decision maker expresses his/her preferences in relation to the values of criteria. Indirect collection of preferences means that the decision-maker is asked to analyze trade-offs among criteria at each iteration, given the current candidate solution. Methods combining these two approaches are also proposed.

Initially, interactive techniques were dedicated mainly for multi-criteria linear programming problems. Benayoun et al. (1971) used the concept of ideal solution and proposed STEM method in which a single candidate solution was presented to the decision-maker in each iteration. If the proposal was not satisfactory, the decision-maker was asked to define the amounts of relaxation for the criteria, whose values were already satisfactory and new candidate was generated. While STEM uses direct way of collecting preference information, the method proposed by Geoffrion et al. (1972) analyzes trade-offs. This approach was also adopted by Dyer (1972) for the one-sided goal programming model. In other methods the decision maker has to specify an interval for each local trade-off ratio (e.g. Salo and Hämäläinen, 1992) or comparative trade-off ratios (e.g. Kaliszewski, Michałowski, 1997).

Methods that construct and optimize a so-called achievement scalarizing function are also very popular (Wierzbicki 1980; Miettinen 1999). This function is used to minimize the distance from the reference point to the feasible region, if the reference point is unattainable, or to maximize the distance otherwise (Miettinen 1999; Ruiz et al. 2008; Luque et al. 2009; Nikulin et al. 2012).

Techniques combining various approaches are also suggested. Kaliszewski and Michalowski (1999) proposed NIDMA procedure, that allowed the decision maker to use different search principles depending on his/her perception of the achieved values of criteria and trade-offs.

Although the procedures mentioned above are dedicated mainly to continuous problems, some of them can also be adapted to the problems with a finite number of alternatives. However, some specific features of such problems make it worthwhile to try to propose techniques dedicated to them. It was observed, that the decision-maker faced with a discrete decision-making problem evaluates an alternative comparing it with other ones (Roy, 1985). Thus, a variety of methods based on pairwise comparisons were proposed, such as AHP, Electre, Promethee and others (see e.g. Figueira et al. 2005).

Most of this methods assume that the preference collection phase precedes the computation phase during which the final solution is identified. Nevertheless, interactive methods were also used, e.g. when risk is taken into account (see e.g. Nowak 2006, 2007, 2011).

2.1 Point-to-point trade-offs and global trade-offs

The term "trade-off" is widely used in economics. In the decision analysis context it is usually interpreted as a ratio that specifies the amount by which the value of one criterion increases while that of the other one decreases when a particular solution is replaced by another given solution. Following Kaliszewski and Michalowski (1999) we will use the term "point-to-point trade-off" for such ratio.

Assuming that the currently analyzed alternative a_c is to be replaced by a_i, in order to increase the value of criterion f_p at the expense of decreasing value of f_q, a point-to-point trade-off is calculated as follows:

$$t_{ic}^{pq} = \frac{v_{ip} - v_{cp}}{v_{cq} - v_{iq}} \tag{1}$$

Let us assume that the DM analyzes alternative a_c and decides that the evaluation with respect to f_p should be improved, while the evaluation with respect to f_q may be decreased. In such case we will look for alternatives a_i such that $v_{ip} > v_{cp}$ and $v_{iq} \geq v_{cq}$, and choose the one for which the increase of f_p is maximal. If it is not possible to improve f_p without decreasing f_q, the alternative that maximizes point-to-point trade-off may be a good option.

The procedures that use the trade-off information for solving multicriteria linear programming problems usually use "global trade-off" (Kaliszewski; Michalowski 1999). Let us assume that the current solution is a_c. The global trade-off is defined as follows:

$$T_c^{pq} = \max_{k \in \mathbf{Z}_c^q} \frac{v_{kp} - v_{cp}}{v_{cq} - v_{kq}} \tag{2}$$

where: $\mathbf{Z}_c^q = \left\{ k : a_k \in \mathbf{A}, v_{kq} < v_{cq}, v_{kt} \geq v_{ct}, t = 1, \ldots, r, t \neq q \right\}$.

It is also assumed that if $\mathbf{Z}_c^q = \varnothing$, then $T_c^{pq} = -\infty$

A global trade-off for given a_c is calculated as a maximum of all point-to-point trade-offs defined for pairs of solutions (a_c, a_i) such that for all but one criterion a_i has values greater or equal to those for a_c. Thus, a global trade-off specifies the least upper bound on an increase of one criterion value relative to a unit decrease of another criterion value occurring while moving from a particular solution in a direction where all the remaining criteria do not decrease. The global trade-off is used to determine the direction in which the new candidate solution should be searched.

While for continuous problems usually the set $\mathbf{Z}_c^q$ is not empty, for discrete problems it is often difficult to find alternatives for which only one criterion has a worse value than for a_c. As a result analyzing global trade-offs is not effective. In the procedure presented below we propose to use a max-min rule to analyze trade-offs for various pairs of criteria.

2.2 The procedure

The technique we propose here exploits trade-offs between criteria to identify a new candidate for the final solution. The main assumption is that the same scale is used for measuring outcomes with respect to each criterion, e.g. the one in which 0 is the worst evaluation, and 100 – the best one. The same scale keeps balance between the criteria of different nature. It is also wide enough to facilitate a differentiation between decision alternatives. Even if the original data have different scales, a simple transformation can be used to make evaluations comparable. Let $y_{i\,p}$ be the evaluation of alternative a_i with respect to criterion f_p. In such case the following formula can be used for transformation:

$$v_{i\,p} = \frac{y_{i\,p} - \underline{y}_p}{\overline{y}_p - \underline{y}_p} \times 100 \tag{3}$$

where: $\underline{y}_p = \min\limits_{i:a_i \in \mathbf{A}} \{y_{i\,p}\}$, $\overline{y}_p = \max\limits_{i:a_i \in \mathbf{A}} \{y_{i\,p}\}$.

The procedure starts with generating an initial solution. Next, the final solution is searched using the information provided by the decision-maker. For identifying the initial proposal we propose to use Euclidean metric and determine the alternative closest to the ideal solution.

Each iteration of any interactive technique consists of data presentation phase and preference collection phase. In our procedure following data are presented to the decision maker:

– evaluations of candidate alternative a_c,
– potency matrix consisting of two rows – the first one including the worst evaluation of each criterion attainable in the current set of alternatives, and the second including the best ones.

If the decision-maker is not satisfied with the proposal, he/she is asked to analyze each criterion and specify whether he/she would like to improve it, to maintain at the current level, or he/she is indifferent to changes. Next the set of alternatives satisfying decision-maker's requirements is generated and a new proposal is identified using trade-offs between criteria that should be improved and the ones that can be decreased.

Let $\mathbf{A}^{(l)}$ be the set of alternatives analyzed in iteration l. The procedure operates as follows.

Initial phase:

1. Identify initial candidate alternative a_c:
   a) for each alternative $a_i \in \mathbf{A}$ calculate:

$$d_i = \sqrt{\sum_{p=1}^{r} \left(\bar{v}_p - v_{ip}\right)^2} \tag{4}$$

where:

$$\bar{v}_p = \max_{i:a_i \in \mathbf{A}} \{v_{ip}\} \tag{5}$$

   b) identify alternative ac minimizing the distance to the ideal point:

$$a_c = \arg \min_{a_i \in \mathbf{A}} \{d_i\} \tag{6}$$

2. Assume l = 1, $\mathbf{A}^{(1)} = \mathbf{A}$.

Iteration l:

1. Construct the potency matrix:

$$\mathbf{P}^{(l)} = \begin{bmatrix} \underline{v}_1^{(l)} \cdots & \underline{v}_p^{(l)} & \cdots & \underline{v}_r^{(l)} \\ \bar{v}_1^{(l)} \cdots & \bar{v}_p^{(l)} & \cdots & \bar{v}_r^{(l)} \end{bmatrix} \tag{7}$$

where:

$$\bar{v}_p^{(l)} = \max_{i:a_i \in \mathbf{A}^{(l)}} \{v_{ip}\} \quad \underline{v}_p^{(l)} = \min_{i:a_i \in \mathbf{A}^{(l)}} \{v_{ip}\} \tag{8}$$

2. Present evaluations of the candidate alternative ac and the potency matrix to the decision maker. Ask the decision maker whether he/she is satisfied with the proposal. If the answer is YES – assume candidate alternative ac to be the final solution and finish the procedure.
3. For each criterion ask the decision maker to specify the criteria which he/she would like to improve, to maintain at the current level, and where he/she is indifferent to changes. Let $\mathbf{I}_{>}^{(l)}$ be the set of indices of criteria, that should be improved, $\mathbf{I}_{=}^{(l)}$ – the set of criteria which value should be maintained at the current level, and $\mathbf{I}_{<}^{(l)}$ – the set of criteria for which the decision-maker is indifferent to changes.
4. Identify the set of alternatives that satisfy the decision-maker's requirements:

$$\mathbf{A}^{(l+1)} = \left\{ a_i : a_i \in \mathbf{A}^{(l)}, \forall_{p \in \mathbf{I}_{>}^{(l)}} v_{ip} > v_{cp}, \forall_{p \in \mathbf{I}_{=}^{(l)}} v_{ip} \geq v_{cp} \right\} \tag{7}$$

If $\mathbf{A}^{(l+1)} = \varnothing$, inform the decision-maker, that alternatives satisfying his/her requirements do not exist, go to step (2).

5. Identify a new candidate:
   a) for each $a_i \in \mathbf{A}^{(l+1)}$ calculate:

$$T_{ic}^{(l)} = \min_{(p,q):\, p \in \mathbf{I}_{>}^{(l)},\, q \in \mathbf{I}_{<}^{(l)}} \left\{ t_{ic}^{pq} \right\} \tag{8}$$

where:

$$t_{ic}^{pq} = \begin{cases} \dfrac{v_{ip} - v_{cp}}{v_{cq} - v_{iq}} & \text{if } v_{cq} > v_{iq} \\ \propto & \text{otherwise} \end{cases} \tag{9}$$

b) identify the alternative aj maximizing the value of $T_{ic}^{(l)}$:

$$a_j = \arg \max_{a_i \in \mathbf{A}^{(l+1)}} \{T_{ic}^{(l)}\} \tag{10}$$

6. Assume c = j, l = l + 1 and go to step (1).

The initial proposal is the one that is the closest to the ideal point, which is defined by the best evaluations attainable independently within the whole set of alternatives. When the new proposal is identified, trade-offs between criteria that should be improved and the ones that can be decreased are analyzed. The move from a_c to $a_i \in \mathbf{A}^{(l+1)}$ is done to improve values of f_p for $p \in \mathbf{I}_{>}^{(l)}$. If such change does not decrease the value of criterion f_q for $p \in \mathbf{I}_{<}^{(l)}$, then the corresponding trade off is set to be equal to infinity. The max-min rule in relation to analyzed trade-offs is used to identify the new candidate for the final solution of the problem.

3. Numerical example

The following example shows the applicability of our procedure for solving the new product selection problem. As we do not like to complicate the example to much we will not consider specific criteria for each category mentioned in the Introduction. Instead, we assume that each category will be represented by a single criterion that can be regarded as a compound representative of all aspects linked to this category. The notation for criteria will be as follows: f_1 – strategic, f_2 – organizational, f_3 – technological, f_4 – financial, f_5 – market response.

In consequence, the DM will be asked the question ”To what extend the alternative a_i contribute to achieve a goal represented by the compound criterion f_p ?”.

The role of alternatives will be played by 20 different new product projects that have different profiles in regard to evaluated criteria.

Table 1 presents evaluations of the alternatives with respect to criteria.

Table 1

Evaluations of alternatives with respect to criteria

Alternative	Criterion				
	f_1	f_2	f_3	f_4	f_5
a_1	44	87	78	24	100
a_2	44	93	39	6	24
a_3	94	13	50	41	31
a_4	6	53	89	12	4
a_5	56	100	17	59	85
a_6	100	20	6	0	70
a_7	88	80	61	24	43
a_8	31	93	39	18	53
a_9	94	40	50	71	37
a_{10}	31	20	89	88	72
a_{11}	0	33	100	35	32
a_{12}	88	80	22	6	91
a_{13}	56	93	17	53	36
a_{14}	88	55	44	29	80
a_{15}	81	7	72	100	46
a_{16}	38	100	0	71	21
a_{17}	25	0	83	94	68
a_{18}	56	67	89	47	0
a_{19}	13	93	83	18	16
a_{20}	50	87	83	65	15

The procedure operates as follows:

<u>Initial phase:</u>

1. Identification of the initial candidate:
   – the ideal solution is defined by the best evaluations attainable for each criterion – the ideal vector is as follows: [100; 100; 100; 100; 100],
   – for each alternative the distance from the ideal solution is calculated (Table 2),
   – alternative a1 is chosen for the initial candidate alternative, as it's distance to the ideal point is minimal.

Table 2

Distances to the ideal point

Alternative	d_i	Alternative	d_i	Alternative	d_i	Alternative	d_i
a_1	98	a_6	162	a_{11}	153	a_{16}	145
a_2	147	a_7	105	a_{12}	125	a_{17}	130
a_3	135	a_8	132	a_{13}	123	a_{18}	126
a_4	168	a_9	105	a_{14}	104	a_{19}	147
a_5	104	a_{10}	110	a_{15}	113	a_{20}	107

2. l = 1, A(1) = A

Iteration 1:

1. Potency matrix $\mathbf{P}^{(1)}$ is generated (Table 3).

Table 3

Potency matrix $\mathbf{P}^{(1)}$

Value	Criterion				
	f_1	f_2	f_3	f_4	f_5
min	0	0	0	0	0
max	100	100	100	100	100

2. Evaluations of the candidate alternative a1 and potency matrix are presented to the decision-maker. The DM is not satisfied with the proposal. The chosen alternative is characterized by the ideal matching to the market. It means that it will very likely enjoy the positive response from potential customers. It will may have comparable long life time and the competitors will not easy develop the competitive replacement. On the other hand, it's financial score is weak because it will need a substantial investment. Also it does not work very well with the strategic goals of the firm.
3. The DM specifies, that criteria f1and f_4 should be improved, and he is indifferent to the changes of other criteria: $\mathbf{I}_{>}^{(1)} = \{1,4\}$, $\mathbf{I}_{=}^{(1)} = \varnothing$, $\mathbf{I}_{<}^{(1)} = \{2,3,5\}$.
4. The set of alternatives that satisfy the DM's requirements is identified:

$$\mathbf{A}^{(2)} = \{ a_i : a_i \in \mathbf{A}^{(1)}, v_{i1} > 44, v_{i4} > 24 \} = \{a_3, a_5, a_9, a_{13}, a_{14}, a_{15}, a_{18}, a_{20}\}$$

5. Trade-offs are calculated (Table 4).

Table 4

Trade-offs identified in iteration 1

	t_{i1}^{12}	t_{i1}^{13}	t_{i1}^{15}	t_{i1}^{42}	t_{i1}^{43}	t_{i1}^{45}	$T_{i1}^{(1)}$
a_3	0,676	1,786	0,725	0,230	0,607	0,246	0,230
a_5	∞	0,197	0,800	∞	0,574	2,333	0,197
a_9	1,064	1,786	0,794	1,000	1,679	0,746	0,746
a_{13}	∞	0,197	0,188	∞	0,475	0,453	0,188
a_{14}	1,375	1,294	2,200	0,156	0,147	0,250	0,147
a_{15}	0,463	6,167	0,685	0,950	12,667	1,407	0,463
a_{18}	0,600	∞	0,120	1,150	∞	0,230	0,120
a_{20}	∞	∞	0,071	∞	∞	0,482	0,071

6. Alternative a_9 is identified as a new candidate, $l = 2$.

Iteration 2:

1. Potency matrix $\mathbf{P}^{(2)}$ is generated.
2. Evaluations of the candidate alternative a_9 and potency matrix are presented to the decision-maker (Table 5). The DM is not satisfied with the proposal. Alternative a_9 has mach better score of financial and strategic criteria in relation to a_1. However it is gained for the price of decreasing the scores of three other criteria, especially the market response.

Table 5

The evaluations of the candidate alternative a_9 and potency matrix $\mathbf{P}^{(2)}$

Value	Criterion				
	f_1	f_2	f_3	f_4	f_5
a_9	94	40	50	71	37
min	50	7	17	29	0
max	94	100	89	100	85

3. The DM specifies, that criterion f_5 should be improved, and he is indifferent to the changes of other criteria: $\mathbf{I}_{>}^{(1)} = \{5\}$, $\mathbf{I}_{=}^{(1)} = \varnothing$, $\mathbf{I}_{<}^{(1)} = \{1,2,3,4\}$.
4. The set of alternatives that satisfy the DM's requirements is identified:

$$\mathbf{A}^{(3)} = \left\{ a_i : a_i \in \mathbf{A}^{(2)}, v_{i5} > 37 \right\} = \{a_5, a_{14}, a_{15}\}$$

5. Trade-offs are calculated (Table 6).

Table 6

Trade-offs identified in iteration 2

	t_{i9}^{51}	t_{i9}^{52}	t_{i9}^{53}	t_{i9}^{54}	$T_{i9}^{(2)}$
a_5	1,263	∞	1,455	4,000	1,263
a_{14}	7,167	∞	7,167	1,024	1,024
a_{15}	0,692	0,273	∞	∞	0,273

6. Alternative a_5 is identified as a new candidate, $l = 3$.

Iteration 3:

1. Potency matrix $\mathbf{P}^{(3)}$ is generated.
2. Evaluations of the candidate alternative a_5 and potency matrix are presented to the decision-maker (Table 7). The DM is not satisfied with the proposal. This new candidate has generally good scores of four criteria (above 50%) besides a match to technical competencies which is quite weak (score is only 17).

Table 7

The evaluations of the candidate alternative a_5 and potency matrix $\mathbf{P}^{(3)}$

Value	Criterion				
	f_1	f_2	f_3	f_4	f_5
a_5	56	100	17	59	85
min	56	7	17	29	46
max	88	100	72	100	85

3. The DM specifies, that criterion f_3 should be improved, and he is indifferent to the changes of other criteria: $\mathbf{I}_{>}^{(1)} = \{3\}$, $\mathbf{I}_{=}^{(1)} = \varnothing$, $\mathbf{I}_{<}^{(1)} = \{1,2,4,5\}$.
4. The set of alternatives that satisfy the DM's requirements is identified:

$$\mathbf{A}^{(4)} = \{ a_i : a_i \in \mathbf{A}^{(3)}, v_{i3} > 17 \} = \{a_{14}, a_{15}\}$$

5. Trade-offs are calculated (Table 8).

Table 8

Trade-offs identified in iteration 3

	t_{i5}^{31}	t_{i5}^{32}	t_{i5}^{34}	t_{i5}^{35}	$T_{i5}^{(3)}$
a_{14}	∞	0,600	0,900	5,400	0,600
a_{15}	∞	0,591	∞	1,410	0,591

6. Alternative a_{14} is identified as a new candidate, $l = 4$.

<u>*Iteration 4:*</u>

1. Potency matrix $\mathbf{P}^{(4)}$ is generated.
2. Evaluations of the candidate alternative a_{14} and potency matrix are presented to the decision-maker (Table 9). The DM is satisfied with the proposal. Alternative a_{14} has good scores for three criteria (strategic goals, organizational competencies and market response) and somewhat weaker for technical competencies and financial features. It may be considered by decision maker as a satisfactory compromise solution.

Table 9

The evaluations of the candidate alternative a_{14} and potency matrix $\mathbf{P}^{(4)}$

Value	Criterion				
	f_1	f_2	f_3	f_4	f_5
a_{14}	88	55	44	29	80
min	81	7	44	29	46
max	88	55	72	100	80

Conclusions

An important part of the innovation management is to select the best new product project from the preliminary large set of potential alternatives. This problem is broadly discussed in the extant literature. Although the qualitative approaches dominate in literature, there are few examples of more formal decision procedures based on multiple criteria analysis. This article brings an example of interactive procedure that can help decision making in the new product development. As to the authors knowledge, such approach has not been proposed so far to the problem of selecting new product.

The interactive procedure gives to the DM an opportunity to actively participate in the whole process and observe its development. During the procedure, the DM can disclose his preferences and values of trade-offs. This kind of assessment of differences in importance of criteria is assumed as more reliable then the direct assessment of weights.

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PROJECT PORTFOLIO SCHEDULING AS A MULTIPLE-CRITERIA DECISION MAKING PROBLEM

Introduction

One of the most important phase of project management is planning. During this phase tasks are identified and scheduled. Schedule consists of a list of a project`s activities with planned start and finish dates. That is why scheduling is a critical issue in project management. “Scheduling is to forecast the processing of work by assigning resources to tasks and fixing their start times. […] the different components of a scheduling problem are tasks, the potential constraints, the resources and the objectives…” (Carlier, Chretienne 1988). Scheduling concerns the allocation of limited resources to tasks over time. It is a decision-making process that has a goal – the optimization of one or more objectives (Pinedo 1995).

In project oriented companies many projects are managed at the same time. Projects are organized in portfolios. a portfolio is a collection of projects or programs grouped together to facilitate effective management to meet strategic business objectives. Those projects use resources from one set and influence the economic aspects of all portfolio.

The main project scheduling techniques are CPM and PERT. In the CPM method the longest path of planned activities to the end of the project is calculated. It delivers information about the shortest time of project realization. The Program Evaluation and Review Techniques (PERT) is a method to analyze involved tasks in completing a given project, especially the time needed to complete each task. Those methods deliver schedules with optimal project finish time. In real-life applications the schedule should optimize not only project finish time but also resource usage and cash flows.

The purpose of this paper is to present project portfolio scheduling problem as a multiple criteria decision making problem and to propose a methodology for solving this problem. An example of it project portfolio will be presented as an illustration. A schedule for portfolio of ERP deployment projects will be described. Projects have very similar structures and can be presented on the same network.

The paper begins with a rerview of literature and problem statement. Then, the methodology for project portfolio scheduling problem is described. Methodology consists of three parts: mathematical model building, non-dominated solutions identification and final solution choosing. Paper finishes with conclusions and ideas for future research.

1. Optimization in project scheduling problem – a literature review

We can assume, that there are three main factors influence project schedule. Those are: time, resources and economical factors, e.g. costs or project NPV. A time can be an optimization criterion (we aim to finish the project as fast as possible), but in many cases it is also constrained. Each activity requires some types and amount of resources. Resources are constrained in a period of time. We can also try to optimize the usage of the resources. Each project needs costs for its realization, but it is also an investment, so it should maximize the NPV.

When we take into consideration all the factors mentioned above we can build various mathematical models for project scheduling problem. Each mathematical model for project scheduling problem should include the precedence |relationship constraints and information about the extent of variables. We can also vary problems in terms of number of objectives, so there are: one objective project scheduling problems and multiple criteria project scheduling problems.

In research on project scheduling problem one objective models are the most popular. Multiple criteria optimization in this field is not frequently undertaken. Also project portfolio scheduling problem is rarely presented in the literature.

A resource constrained multiple criteria project scheduling problem was presented by Viana and de Sousa (2000). A mathematical model in which: project completion time is minimized, project delay is minimized and disorders in resource usage are minimized was proposed.
A binary variables x_{ijt} are used in the model:

$$x_{ijt} = \begin{cases} 1 & \text{when operation } j \text{ of an activity } i \text{ is finished in time} \\ 0 & t \text{ otherwise} \end{cases}$$

Lova, Maroto and Tormos (2000) presented a paper in which a multiple criteria project scheduling problem is solved in two phases. In the first phase an optimal, in terms of time criterion, schedule is prepared. In the second phase, the schedule obtained in the first phase is improved in terms of resources usage.

Leu and Yang (1999) presented multiple criteria resource constrained project scheduling problem with time, cost and resource usage optimization.

Hapke, Jaszkiewicz and Słowiński (1998) also described the multiple criteria project scheduling problem in their paper. They considered three criteria: project delay minimization, project cost minimization and resource usage optimization.

All papers presented above consider one project scheduling problem. In the case of project portfolio scheduling problem, one objective resource constrained model is considered by few authors. Goncalves, Mendes and Resende (2004) described a resource constrained project portfolio scheduling problem with time optimization. Chiu and Tai (2002) presented resource constrained project portfolio scheduling problem. They proposed a criterion function in which they join NPV and penalty for projects delays.

2. Problem statement

A company from the Silesia region deploys an ERP system. There are about 30 deployment projects managed simultaneously by 8 teams. For each project we can define some activities, which are the same for all projects in the portfolio. a single project consists of 37 activities (those activities have been described in the company`s project guide). Project contains of 11 main phases.

Company signs a contract with customer, which includes information about the main issues of the project. in this contract, a due date and penalty for project delay is defined. a payment for the project is also defined in the contract as well. Payment is split into 11 parts. At the end of each of the 11 phases customer pays 1/11 of the total amount.

There are about 10-12 employees in the project team. in case of lack of resources, project manager can hire the resources from other teams. External resources are extra paid. the availability of resources can be different in each period of time. Team manager cannot use more resources than it is available in the company. One team leads about 3-4 projects simultaneously. Projects did not started at the same time. One project can start and other one can be at the final phase.

Each project portfolio manager wants to maximize its profit. That is why project should be finished on time, external resources should not be used and the project portfolio schedule should maximize its NPV.

2.1 Current situation

Currently, projects in the portfolio are managed independently by a project portfolio manager. Scheduling is based on Gantt chart and CPM method and schedules are prepared only for one project. The schedule is prepared at the beginning of the project and is presented to the customer as a baseline to the contract regulations. Analysis of resources availability are not prepared before a contract is signed. If new project appears in the portfolio it is scheduled independently, without analyzing its influence the other projects in the portfolio. Resources availability is not controlled during the scheduling phase. Sometimes company hires external resources to meet the deadlines.

3. Methodology for project portfolio scheduling problem solving

Analysis of the current situation in the company is a base for methodology preparation. Project portfolio schedule should be prepared in each case, when some changes occurs, e.g. new project introduction, change in the resources availability, change in project scope, contract renegotiation. Each of those situations influence the project portfolio schedule. That is why a methodology and tool, which will prepare a schedule in the short period of time is necessary.

Project portfolio scheduling problem described above consists of many factors, like contract statements, resources availability and goals for project portfolio manager. to build a methodology to solve this problem some general assumptions need to be prepared.

The following assumptions were made:

- Projects in portfolio shouldn`t be delayed or the sum of penalty for project delay should be minimized. the penalty is charged for each period of time, but the total amount cannot be higher than the maximum penalty defined in the contract. a grace period is foreseen, in which the penalty is not charged.
- Project manager should use internal resources to manage the project portfolio and minimize the costs of the external resources usage. the resource usage cannot exceed the availability of resources in the company.
- The schedule should maximize the sum of NPV of all projects in portfolio.
- Only renewable resources are taken into consideration. We assume that the amount of nonrenewable resources needed for project execution is constant and is not limited for the period of time, but for the project. That is why we do not need to consider them in the model. if we will not have the relevant amount of non-renewable resources the project cannot be completed.

Single project structure was analyzed and described on AON (Activity on Node network). Activity on Node network was used (Figure 1), because various types of precedence relationships between project activities occurs. Activity on Arc network enables to use only finish-to-start precedence relationships. Milestones was identified and marked on the chart. In each milestone, company receives some amount of money for completed tasks.

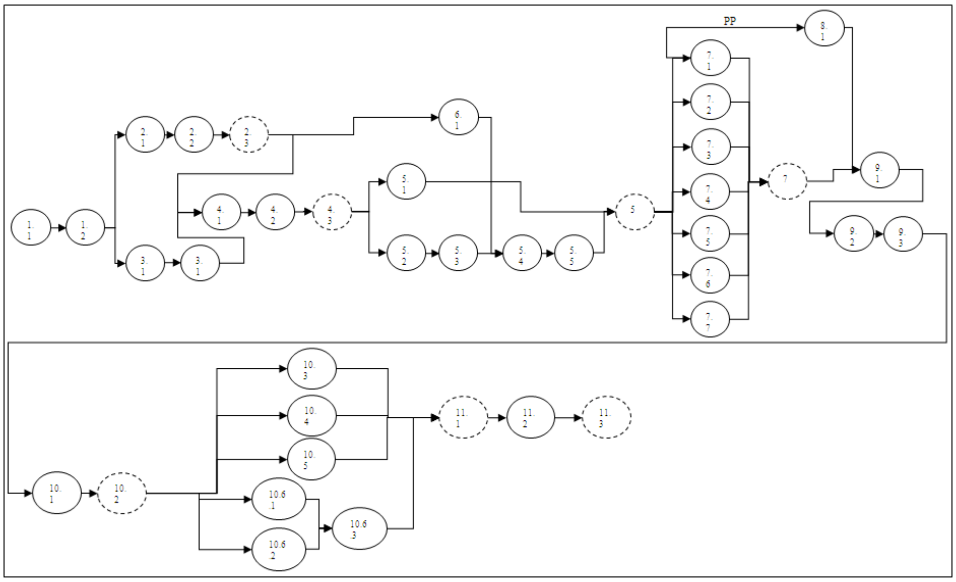

Figure 1. Activity on Node network for an ERP deployment project

Methodology for project portfolio scheduling problem proposed in this paper consists of the following steps:

1. Multiple-criteria mathematical model building.
2. Finding non-dominated solutions.
3. Choosing one solution from the Pareto set as the final solution.

At the beginning, a project portfolio scheduling problem is described as a multiple criteria decision making problem. Three main important factors are optimized: a time for project portfolio realization, resources used during each period of time and NPV for all projects in the portfolio.

In the next step an elitist evolutionary algorithm, to find non-dominated solutions, is used. The SPEA2 delivers a definite number of N non-dominated solutions.

In the last step, solutions obtained in the second step are analyzed and one schedule is chosen. The Light Beam Search (Jaszkiewicz, Słowiński 1999) procedure is used in this step.

3.1 Mathematical model

To build a mathematical model the following assumptions are made:

- there is a set of p similar projects $p=1,\ldots,P$,
- a single project consists of $j=1,\ldots, J$ activities,
- a time period is defined as $(t–1, t)$,
- project portfolio duration is constrained to T $(t=0,\ldots, T)$,
- a single project has been presented on the AON network, so precedence relationships can be: finish-to-start, finish-to-finish, start-to-start, start-to-finish type,
- there are two resources types: internal (R^w_{kt}) and external (R^z_{kt}).
- availability of the resources can be different in each period of time.
- total availability of resource k in period t is $R^w_{kt} + R^z_{kt}$
- if the usage of internal resources is exceeded, activities use external resources,
- cash flows are generated at the end of the activity duration,
- projects in the portfolio can be on the various level of progress – one project can be in the 'project definition phase' and another on the 'programming phase',
- projects can depend on other projects – if there is a precedence relationship between activities of different projects,
- schedule is prepared every time, when there is a change in project portfolio, e.g. new project introduction, change in resources availability, etc.

Notation:

- x_{jpt} – decision variable,

$$x_{jpt} = \begin{cases} 1 & \text{when an activity } j \text{ of project } p \text{ last in period } t \\ 0 & \text{otherwise} \end{cases}$$

- d_{jp} – duration of activity j of project p,
- r_{jpk} – amount of renewable resource k required by activity j of project p,
- R^w_{kt} – internal renewable resource k availability in time t,
- R^z_{kt} – external renewable resource k availability in time t,
- F_{jp} – finish time of activity j of project p,
- S_{jp} – start time of activity j of project p,
- LF_{jp} – latest finish time of activity j of project p from the CPM method,
- Y_p – grace period in project p,
- Z_p – penalty for project p delay,
- V_p – penalty for overuse of internal renewable resource k,
- α – discount rate,
- cf_{jp} – net cash flow generated by activity j of project p,
- A_{jp} – set of predecessors i $(i=1,\ldots, I)$ of activity j of project p.

Multiple criteria resource constrained project portfolio scheduling problem can be formulated as follows:

$$\sum_{p=1}^{P}[Z_p \times \max\{[[\sum_{j=1}^{J}\max\{0, F_{jp} - LF_{jp}\}] - [\sum_{i=1}^{I}\max\{0, F_{ip} - LF_{ip}\}]] - Y_p, 0] \rightarrow \min(i \in A_{jp}) \quad \text{(C1)}$$

$$\sum_{t=1}^{T}[\sum_{k=1}^{K}[\max\{\sum_{p=1}^{P}\sum_{j=1}^{J}(r_{jpk} \cdot x_{jpt}) - R_{kt}^{w}, 0\} \times V_k]] \rightarrow \min \quad \text{(C2)}$$

$$\sum_{p=1}^{P}\sum_{j=1}^{J} cf_{jp} \cdot e^{-\alpha F_{jp}} \rightarrow \max \quad \text{(C3)}$$

$$x_{jpt} = \{0,1\} \qquad (j=1,\ldots,J,\ p=1,\ldots,P,\ t=1,\ldots,T) \quad (1)$$

$$\sum_{t=1}^{T} x_{jpt} = d_{jp} \qquad (j=1,\ldots,J,\ p=1,\ldots,P) \quad (2)$$

$$F_{jp} = \max_{t=1,\ldots,T}\{(t \times x_{jpt})\} \qquad (j=1,\ldots,J,\ p=1,\ldots,P) \quad (3)$$

$$S_{jp} = \min_{\substack{t-1,\ldots,T \\ x_{jpt} \neq 0}}\{(t \times x_{jpt})\} - 1 \qquad (j=1,\ldots,J,\ p=1,\ldots,P) \quad (3')$$

$$F_{jp} = S_{jp} + d_{jp} \qquad (j=1,\ldots,J,\ p=1,\ldots,P) \quad (3'')$$

$$S_{jp} \geq F_{ip} \qquad (j=1,\ldots,J,\ p=1,\ldots,P,\ i \in A_{jp}) \quad (4')$$

$$\sum_{p=1}^{P}\sum_{j=1}^{J}(r_{jpk} \cdot x_{jpt}) \leq R_{kt}^{w} + R_{kt}^{z} \qquad (t=1,\ldots,T,\ k=1,\ldots,K) \quad (5)$$

In the (C1) criterion a penalty sum for projects in portfolio delays is minimized. A delay is a situation, when activity is finished later that latest finish time given from the CPM method (F_{jp}-LF_{jp}). A decision maker can also define latest time for activities completion. This criterion assumes that there is a grace period Y_p for project delays. During this period penalty is not charged.

The penalty cannot exceed a definite amount. A penalty function can be presented as follows (Figure 2).

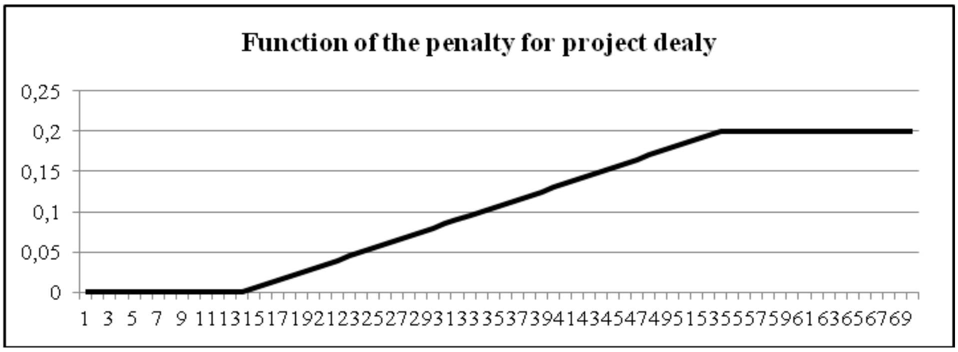

Figure 2. Penalty function

The purpose of the (C2) criterion is to minimize the cost of external resources usage. if the internal resources usage exceed the available amount, then a penalty for each unit is counted.

In the criterion (C3) NPV is maximized. This problem is used in the literature frequently. An example is presented in Icmeli and Erenguc (1996) paper. In this paper cash flows are generated in each unit of time of activity duration. This problem can be formulated as follows: $\sum_{i=1}^{J}[\sum_{t=1}^{d_j}[cf_{jt}\cdot e^{\alpha(d_j-t)}]\cdot e^{-\alpha F_j}]\rightarrow \max$.

In mathematical model presented in this paper we assumed that cash flows are generated by activities at the end of their duration and NPV is defined for project portfolio, so the criterion is formulated as follows: $\sum_{p=1}^{P}\sum_{j=1}^{J}cf_{jp}\cdot e^{-\alpha F_{jp}}\rightarrow \max$.

Binary variables are used in the considered model (1). The variable $x_{jpt}=1$ when an activity j last in time t, otherwise $x_{pjt}=0$. in the considered problem we have $J\times P\times T$ variables. Constraint (2) ensures appropriate activities duration. Finish times are used in criteria functions and in precedence relationships. Activities start times are necessary for precedence relationship constraints. That is why in equations (3) and (3') those times are determined. Constraint (3'') ensures that activity is not split. Precedence relationships are determined by constraint (4'). Constraint (5) is a resource one. Total resource usage should not exceed the sum on internal and external availability resources.

At the first phase of the methodology for project portfolio scheduling problem, mathematical model should be implemented to the problem described in this paper.

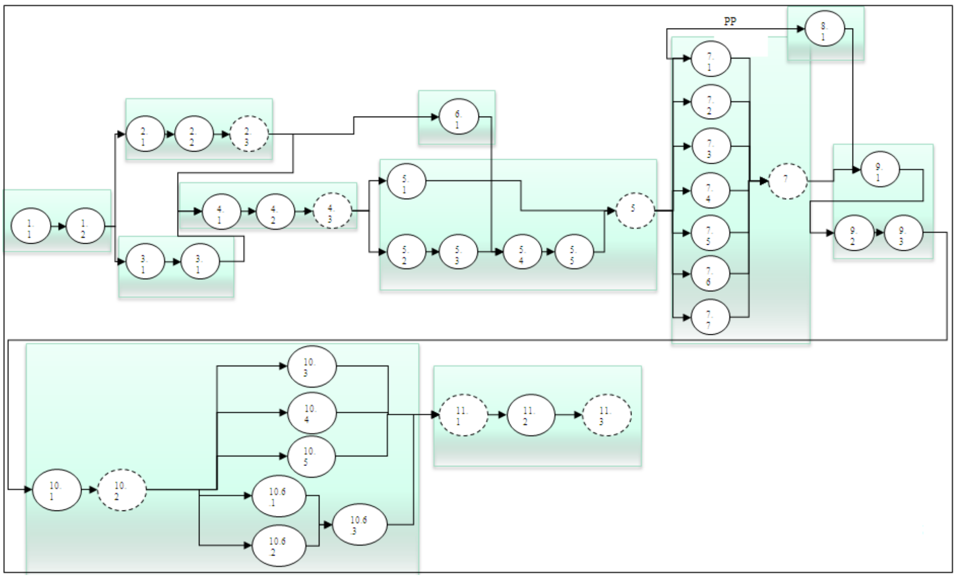

Figure 3. AON Network with activities group to aggregation

There are four projects in the project portfolio *P=4*. a single project has been described by 37 activities, *J=37*. Time planned for project portfolio realization is 252 (working days) *T=252*. Number of variables for this problem is $J{\times}P{\times}T=4{\times}37{\times}252=37296$. This number is huge, that is why activities aggregation will be used. We can reduce the number of variables three times by activities aggregation. In the given problem activities will be grouped into 11 phases (Figure 3, 4). After activities aggregation there is $J{\times}P{\times}T=4{\times}11{\times}252=11088$ activities. A schedule is a tool for project portfolio manager, for whom information about project phases is more important than information about single activity, reduced information caused by activity aggregation is not a disadvantage.

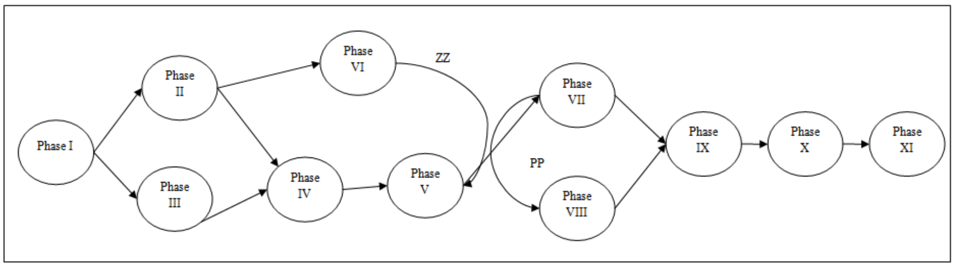

Figure 4. AON Network with aggregated activities

3.2 Finding non-dominated solutions

The second step of the methodology is to find the Pareto set. To find non-dominated solution an elastic evolutionary algorithm SPEA 2 (Zitzler, Laumanns, Thiele 2001) (Strength Pareto Evolutionary Approach) is used.

The main loop for SPEA2 algorithm can be presented as follows:

Step 1: Initialization.

Generate initial population P_0 and create the empty external set $\overline{P_0}$.

Step 2: Performance.

Fitness assignment for individuals in $P_{0\ and}$ $\overline{P_0}$.

Step 3: Selection and external set updating.

Copy All non-dominated solutions from $\overline{P_t}$ and P_t to $\overline{P_{t+1}}$.

If $\overline{P_{t+1}}$ exceeds the size of external set it should be reduced.

If the number of individuals in $\overline{P_{t+1}}$ is less the size of external set then it should be filled with dominated individuals from $\overline{P_t}$ and P_t.

Step 4: Termination.

If stop criterion is fulfilled then stop the algorithm. Individuals from external set $\overline{P_{t+1}}$ became a decision vectors.

Step 5: Mating selection.

A tournament selection with replacement on $\overline{P_{t+1}}$ to fill the mating pool.

Step 6: Variation.

Genetic operators are applied on individuals from the mating pool. the population P_{t+1} is a result of variation.

An elitist evolutionary algorithms use an external set, which is filled with the best solutions (in case of multiple criteria decision making problems there are non-dominated solution in external set). In each generation the external set is updated.

In step 1 an initial population is generated as a set of feasible solutions. At first, the projects sequences is randomized. Then activities are put to the empty schedule with appropriate sequence. an activity is schedule in the earliest possible time. Precedence relationships and resources availability is taken into account.

In step 2 values of objective functions are evaluated. There is a penalty, when an individual does not meet all constraints. Then, each individual from external set is assigned a strength value *S(i)* representing the number of individuals its dominate: $S(i) = |\{ j \mid j \in P_t + \overline{P_t} \wedge i \succ j\}|$. on the basis on this value a raw fitness of individual i is calculated $R(i) = \sum_{j \in P_t + \overline{P_t},\, j \succ i} S(j)$. to discriminate between individuals with the same raw fitness value a density information is incorporated. Density is defined by $D(i) = \frac{1}{\sigma_i^k + 2}$. An individual fitness is $F(i) = R(i) + D(i)$.

In step 3 an environmental selection is performed. if the number of individual fits exactly into the external set, then the environmental selection is completed. Otherwise, there can be two situations: the external set is too small or too large. When external set is too small, then dominated individuals in previous external set and population are copied to the new external set. When external set is too large, then it is reduced by individual removing. an individual with the smallest distance to another one is removed (Figure 5).

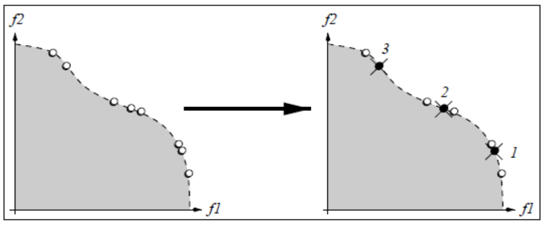

Figure 5. External set reduction in SPEA2 algorithm

Source: [11]

In the problem described in this paper binary variables are proposed. That is why an individual is a binary matrix with the projects and activities in rows and time periods in columns. the matrix size is $JP \times T$ and can be presented as follows:

$$i = \begin{bmatrix} x_{1,1,1} & x_{1,1,2} & \cdots & x_{1,1,T} \\ x_{2,1,1} & x_{2,1,2} & \cdots & x_{2,1,T} \\ \vdots & \vdots & \vdots & \vdots \\ x_{JP,1} & x_{JP,2} & \dots & x_{JPT} \end{bmatrix}$$

In step 6 genetic operators (crossover and mutation) are applied on individuals from the mating pool. a crossover is a process of exchanging a random row between two individuals. In mutation a random chosen activity is delayed.

3.3 Final solution choosing

A non-dominated set obtained in the second stage are used in the third stage of the methodology. in this stage the Light Beam Search (Jaszkiewicz, Roman 1999) with decision maker engagement is used to find the final solution.

A finite sample of non-dominated points is generated in each computation phase. This sample consists of middle point (obtained in previous iteration), and non-dominated solutions from its neighborhood.

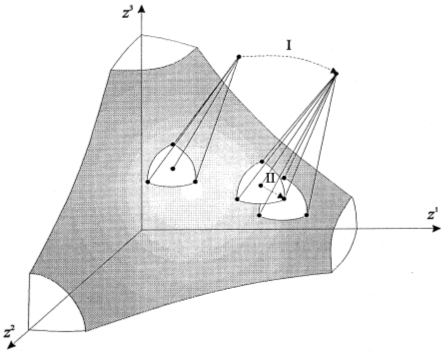

Figure 6. External set reduction

Source: Jaszkiewicz, Słowiński 1999.

A neighborhood of the middle point is a set of non-dominated points that are not worse than the middle point. In each phase of computation a sample of the solutions is presented to the decision maker. Decision maker can: make a point from the neighborhood to be a new middle point, define new aspiration and reservation points (starting aspiration and reservation points are used to define starting middle point), update preferential information, store point or decide that point found in the process is the final solution (Figure 6).

Conclusions

A new methodology for project portfolio scheduling problem has been presented in this paper. This methodology delivers information about project portfolio schedule, which is important for project portfolio managers.

The methodology consists of three steps: multiple-criteria mathematical model building, finding non-dominated solutions and choosing one solution from the Pareto set as the final solution.

In the first step a multiple-criteria mathematical model for project portfolio scheduling problem is built. Three criteria are considered in the model: the penalty for projects delays minimization, the penalty for resources overusage minimization and NPV maximization. Disadvantage of proposed mathematical model is a big amount of variables, which is $J \times T \times P$. In cases when we will have larger projects or larger planning horizon the number of variables will be huge. That is why activities aggregation was proposed. It reduces a number of variables in given model. It also delivers a general information about project portfolio schedule, which is more important for project portfolio managers.

In the second step a set of non-dominated solutions is identified by using an elitist evolutionary algorithm. As research shows using an external set with the best solutions in each generation increases an algorithm efficiency.

In the third step the LBS procedure is used to identify the final solution. The LBS procedure proposes is a way of learning-oriented interactive search for the best compromise solution for the decision maker. This procedure makes the comparison of non-dominated solution in the decision phase relatively easy. So this step will not burden the decision maker too much.

For the future work, the procedure presented in this paper will be applied to the problem described in the section two, and given results will be compared with the current situation in the company.

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RISK ASSESSMENT IMPROVEMENT IN THE INVESTMENT PROJECT MANAGEMENT: VERBAL ANALYSIS METHODS

Introduction

The investment of money in a project is becoming a significant problem due to rapid economic, technological and social development. The managers of companies should spend the majority of their time making investment decisions (Hopkin 2009). The process of making an investment decision is directly related to the assessment of many theoretical and practical problems of organization and management of economic activities (Haimes 2009). The investor, making investment decisions, is faced with business risk, the problems of complex project evaluation, the selection of the best alternative, etc.

Competition, inflation, changes in demand and supply as well as many other factors constantly alter the business environment (Chapman 2010, Apgar 2007). One can see that in the current markets (not taking into account financial institutions) risk assessment and management is still a relatively new and underdeveloped process. The above statement was made by analysing the causes of the bankruptcies and crises of Lithuanian and European companies, as well as the general reports of the state and other responsible institutions.

When analysing the causes of recent crises in companies, the financial causes are usually ignored (Ustinovichius et al. 2008a). Instead, the lack of quality management, as well as errors associated with personnel, technology, contract signing and planning, etc. can be observed more often. These problems (criteria) usually cannot be assessed quantitatively. Therefore, they are omitted from all calculations and further analysis. The considered problem (ignoring quantitatively unassessable criteria) has a very low chance of occurring and may be solved when the event has already happened. However, in most such cases, the company suffers very significant losses.

The problem of risk assessment and management has been analysed by the countries of the Western world for a very long time. Many risk identification, assessment and management models have been developed (Sadgrove 2009; Turskis 2008, Zavadskas and Turskis 2011). The main goal of these models is to predict, measure and decrease negative consequences of risks to company's performance. The analysis of these processes in Lithuania is a novelty. However, despite obvious benefits, usually, no investments are made in such analysis until a negative event takes place. Recent scientific papers are more often centred on research, describing qualitative evaluation of risk processes, emphasizing the importance of the fact that constantly changing market conditions can hardly be assessed by *discrete values*.

The importance of increasing the effectiveness of risk assessment and management in the Lithuanian construction sector is more apparent due to the reasons stated above.

Thus, the present paper analyses a decision-making strategy based on qualitative estimates obtained by investigating risk assessment and management methods and applying these methods to assess project risks in construction companies.

The choice of the topic of the paper was also influenced by the fact that uncertainty or risk in any activity area strongly affects not only the countries which are new to risk management mechanisms, but countries, which actively implement these mechanisms, as well. Moreover, the topic is also important because of high proficiency of Lithuanian scientists analysing under uncertainty conditions as demonstrated by their papers. Probability theorists are among a select few Lithuanian scientists, having achieved worldwide recognition for theoretical and practical results in their field. The efforts of the first Lithuanian probability theorists and their followers have made decision-making under risk and uncertainty conditions a popular object for theoretical and practical studies.

The provision of new information about making decisions under risk and uncertainty conditions is an evident contribution to science and practical application. Furthermore, the authors of recent publications often emphasize the advantages of novel multicriteria methods in solving various design problems (Zavadskas and Turskis 2011; Ustinovichius et al. 2010; Rutkauskas 2010; Ustinovicius at al. 2009). Therefore, it is only natural that theoretical and practical research aimed at finding multicriteria/multi-purpose solutions is actively carried out in educational institutions. This would help achieve better quality of solutions to the problems associated with project development and implementation.

1. The importance of risk assessment and management in investment projects

An ***investment project*** may be described as a planned, goal-oriented creation and modernization of physical objects and technological processes, the preparation of technical and organizational documentation, as well as a set of managerial implementation methods. The investment project serves as a basis for the investment of capital into tangible assets (land, buildings, machinery and equipment) or intangible assets (services, consulting and other things needed to complete a project) with the goal to create, purchase or increase the value of the assets.

All projects are carried out according to the following project diagram (*see Figure 1*), i.e. the plan is made, the problem is comprehended and, then, the means of putting the plan into effect are selected and, finally, all the goals are achieved.

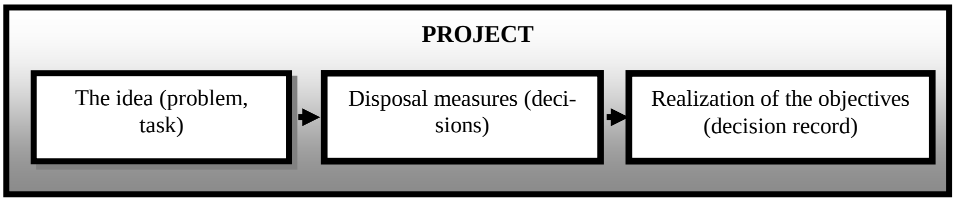

Figure 1. General diagram of a project (Petravičius and Tamošiunienė 2008)

Realization of the objectives (decision record) The stages of the project as well as their components are usually standard, though it should be noted that it is important to ensure the balance between time and quality for every process at every stage (Figure 2).

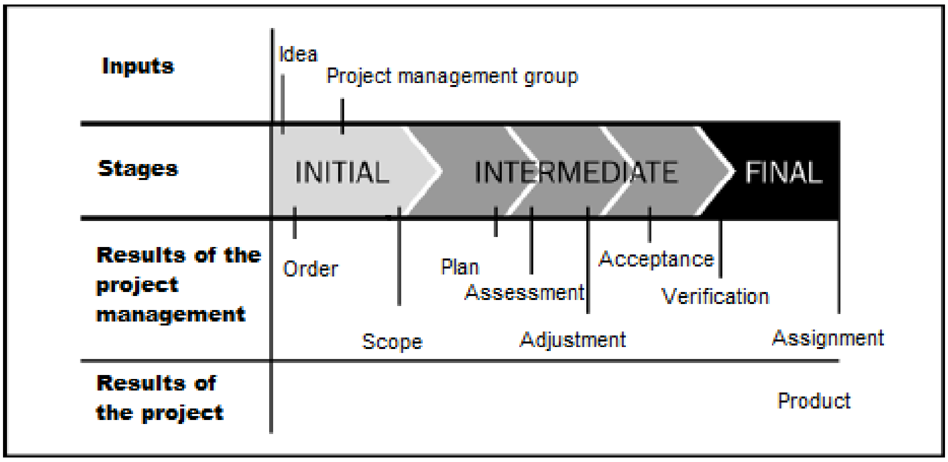

Figure 2. Typical sequence of stages in the project life cycle

Source: Petravičius and Tamošiunienė 2008; PMBOK Guide 2004.

In fact, the key features of the investment project are as follows (Shevchenko et al. 2008):

- it is assumed that the project should use the least possible amount of resources in order to maximize future profits;
- the project is planned, financed and implemented as a whole;
- the project may be the object of concrete financial agreements and have its own governing body;
- the project must have specific start and finish times, i.e. the period during which the planned goals are to be achieved (their achievement probability is comprehensively evaluated);
- the project has certain boundaries (geographical or even organizational).

All forms of capital investment are invariably associated with a certain risk (Hubbard 2009; Olson and Dash 2008). The specific features of investment activities are associated with the accumulation of all types of risk in a particular business area (Léautier, 2010). Investment projects, including a set of technical, technological, organizational, financial, personnel and other decisions, made under uncertainty conditions, is a special area of investment activities. All projects are planned for the future and are likely to be altered to a larger or smaller extent, therefore, they are inevitably bound by uncertainty and risk. After all, one cannot know if the results of the project match the expected results, despite successful completion of particular project tasks. Every project task is affected by some sort of risk, which can cause the deviation from the planned course of execution.

The investment project risk has the following distinct characteristics (Norvaišienė 2004):

1. The investment project risk is ***complex in nature***, encompassing various types of investment risk. The total risk level of the investment project can be assessed only by first assessing the constituent risks;
2. The investment project risk is ***an objective phenomenon*** in any enterprise, making capital investments, although the majority of risk parameters depend on subjective managerial decisions, made in the process of preparing the investment project;
3. ***Every stage of the investment project execution is characterized by specific types of risk***, therefore, the total project risk is assessed based on separate stages of the investment project;
4. The investment profit is usually formed after the investments have been made, i.e. in the process of company's operation, therefore, the formation of positive cash flows is directly related to the effectiveness of company's activities and activity risk. Due to this fact, ***the investment project risk is closely associated with the enterprise business risk;***
5. ***The time factor has a major influence on the project risk level.*** When executing long-term investment projects, the uncertainty of theresults is caused by the uncertainty of many external and internal environmental factors. The total risk level of the project is directly related to its duration;
6. ***The risk level of the same type of projects executed by the same company varies.*** The risk level changes because of many constantly changing objective and subjective factors. Therefore, the risk level of the investment project has to be assessed individually for the particular conditions, under which the project is executed;
7. ***The lack of sufficient information, which is needed to assess the risk level.*** The uniqueness of the parameters of every investment project does not allow a company to store sufficient information, which could be used in applying economic-statistical, analog and other project risk assessment methods;
8. ***The lack of reliable market indicators, needed to assess the risk level.*** A company making financial investments can use capital market indicators. However, the investment market segment, which is directly connected with real investments, does not have such indicators. This decreases the reliability of the assessment of market factors in risk analysis of a project;
9. ***The subjectivity of assessment.*** Although the project risk is objective, the metric by which it is measured is subjective. This subjectivity, i.e. the inadequacy of assessing a phenomenon, is caused by the use of unreliable information, the lack of qualification and inexperience of the people making the assessment, etc.

Thus, it can be concluded that many definitions of risk can be found in the literature and, usually, the *investment project risk* is understood as deviation from the expected results or a negative event, causing losses. Project risk assessment is of utmost importance. Therefore, risk is one of the most important factors, determining the results of a project and risk analysis and management are crucial for project execution.

2. Risk assessment problem at various stages of investment project realization

As mentioned above, identification of various criteria (factors or parameters) at various project realization stages is of paramount importance not only to investors but also to other interested parties during the whole period of project development, i.e. T_1T_4 (Figure 3). Project developers or initiators may attract investors at any time of this period, if required. In the period T_1T_2, project initiators, having a promising idea, may attract investors to provide the financial sources for project development.

In the period T_2T_3, when the investment project has been prepared and the stage of plan realization is reached, the real demand for investments is determined. In this period, the investor for financing the developed project may be attracted.

However, in real life, some new, unexpected problems requiring prompt solutions arise at the stage T_3T_4. These problems are usually associated with the need for getting unplanned investments. The problems of getting the additional funds from the already available sources or from the new project partners should be analysed in real time under the existing conditions by assessing all identified risk criteria (factors). It may also happen that, in this period, their value differs from that found at the time moment T_3. The question arises, if risk analysis is different at different moments T_1T_4 of project development. It is clear that risk analysis performed under different conditions and with a different uncertainty factor may yield a value different from that obtained earlier (Moskvin 2004, Apgar 2007)

In implementing any investment project, there is a certain limiting risk level, determining the possibility that the project will not be completed (Ustinovičius et al. 2009, Ustinovičius and Migilinskas 2008). In real life, the evaluation of this limiting risk level (further denoted by R_r) is a very complicated problem. The main R_r components are the investment concept and actions aimed at its realization (Moskvin 2004). The authors of the present paper believe that the investment concept determines the value of R_r, because its generation may be associated with a number of practically realized alternatives which are selected by using various decision support systems.

In Figure 3, the interrelationship between the investment risks over the period of project realization is shown. The section R_{r1} R_4 shows the possibility of limiting risk occurrence at some particular moments of time over the whole investment period. These risk values may occur due to incomplete or inaccurate information about risk factors acting at this moment, which prevent from and impede project realization. In addition, the factors causing the occurrence of these values may negatively affect the quality of other decisions, made before the final stage of project development.

Theoretically, the criteria (factors) described above can be found everywhere and at any time, until the information of a different kind can be available. Therefore, the possibility of the occurrence of the respective problems should be provided for (Shevchenko et al. 2008).

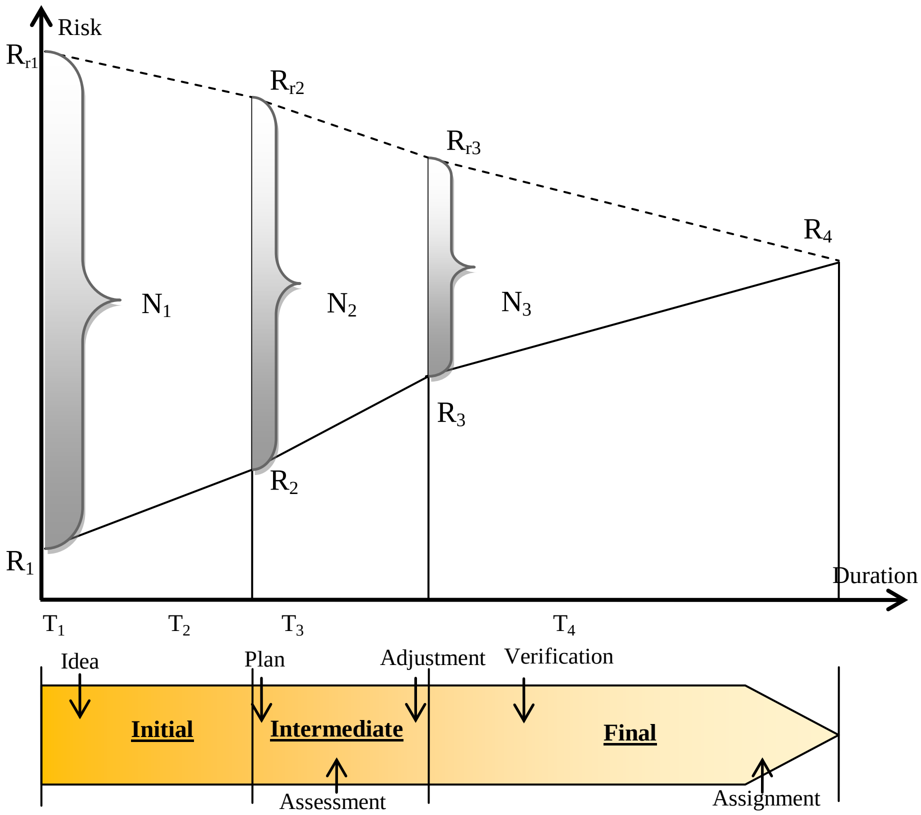

Figure 3. A graphical view of decreasing the uncertainty of risk in realizing the investment project

Source: Created by the authors based on the work of Moskvin 2004.

Where R_1 is a highly probable risk value. In Figure 3, the reduction of risk system uncertainty during the period of project implementation is shown. Here, N_1 is the uncertainty observed at the time moment T_1, while N_2 and N_3 show the uncertainty at the time moments T_2 and T_3, respectively. At points T_4 the uncertainty is reduced to zero, while the value R_4 becomes the most probable value.

Considering the most suitable time for decision-making, the optimal time was found to be at point T_3, when all possible and real risks may be provided for according to the realization of the developed business investment plan.

It is obvious that when preparing and executing investment projects the following inequality, related to uncertainties, is true: $\mathbf{N_1>N_2>N_3}$. It can also be stated that the earlier (the closest to T_1 and the farthest from T_3) the risk assessment is performed, the more criteria should be included in the assessment.

Thus, taking into account the above considerations, it may be stated that risk assessment should be performed, when the investment concept is described in detail and the realization plan of the investment project is developed. In this case, the optimal number of risk describing criteria may be determined, thereby decreasing the uncertainty typical of investment projects.

Another problem, which, according to the authors of the present work, is important for determining the optimal number of the criteria is associated with the fact that the criteria which cannot be expressed quantitatively are usually eliminated later from the list of the criteria made. This elimination is made for several reasons. The first one is associated with the lack of methods allowing for evaluation of both qualitative and quantitative criteria. This problem will be discussed below. Another reason is associated with the idea that quantitative criteria are more easily understood by investors and, therefore, risk assessment is often based on the calculation of a few criteria. The above reasons may account for poor risk assessment of an investment project and the respective ineffective decision-making, thereby considerably increasing the losses experienced in realizing the investment project.

The survey of the literature on the problem has shown that there is hardly any commonly used system of criteria for evaluating the investment projects and the risks involved in their realization (Shevchenko and Ustinovichius 2012; Ustinovichius et al. 2010; Ustinovicius and Migilinskas 2008). The suggested qualitative and quantitative risk assessment methods can actually only evaluate the numerical information, which usually present only the financial indicators (NPV, IRR, etc.). Social, economic and other problems, presenting some difficulties for evaluation because of the lack of statistical data may be assessed by expert methods, based on the scale of points. However, this method is not widely used for several reasons:

1) in some cases, the difficulties arise in finding a sufficient number of experts specializing in the same area;
2) the experts should be completely independent, which is also problematic because of the lack of experts;
3) the procedures take a long time and require considerable financial resources, while the result obtained is often subjective;
4) the method is commonly used for evaluating only large projects/enterprises because its application to the assessment of small projects/enterprises is too expensive.

The analysis of the related works also shows that application of quantitative evaluation methods is emphasized and it is even suggested to use the results obtained by these methods as a basis for decision-making. The authors of the present paper believe that this approach is not effective, particularly, with respect to risk analysis because it is the qualitative evaluation that helps to identify risk factors and to determine the types of risk, which, in turn, helps to determine risk level and to choose suitable risk management methods. In the process of qualitative evaluation of risks, it is important to identify the causes of risk development and factors stimulating their dynamics. These procedures are closely connected with the next step of qualitative analysis – a description of possible losses incurred due to risks and their evaluation. It means that quantitative risk evaluation follows the qualitative evaluation, which confirms the importance of qualitative risk analysis.

Therefore, taking into account the above considerations, the authors believe that risk assessment of the project should be based on a great number of the evaluation criteria, which could be expressed both numerically and verbally. It should also be emphasized that the problem of the investment project evaluation is a multitask problem. Therefore, the authors believe that risk assessment of the investment project should be based on the innovative multicriteria evaluation methods, allowing for using in project risk analysis the criteria, which are not expressed numerically. It may be expected that the application of these methods could facilitate decision-making in the investment area, making it understandable, comprehensive and acceptable to all interested parties of the project.

3. Verbal analysis methods in the context of using multicriteria evaluation methods

Project risk analysis based on using the financial and non-financial criteria helps to determine the present state and the prospects of enterprise performance (Shevchenko and Ustinovichius 2012). This is confirmed by close cooperation of the financing and mathematical modelling specialists and researchers. Usually, technological decisions which are made in financial analysis are based on optimization, prediction decision support systems, multicriteria analysis, artificial intelligence and stochastic models and methods.

From the perspective of performance (behaviour), one of the requirements to the results yielded by any of the available methods is the provision of explanations (Shevchenko et al. 2008). For example, a decision-maker (DM) should know why the alternative A seemed to be better than the alternative B and both of them are better than the alternative C. To satisfy this requirement, a decision-making method should be transparent and capable of finding the correspondence between the data elicited from the DM and the final estimate of the alternatives. Only in this case, it is possible to get the explanations (Larichev 2002).

In recent years, a considerable number of decision-making methods which are widely known as multicriteria decision-making methods (Multiple-Criteria Decision Making or MCDM) have been developed by the researchers all over the world. This name was given to them because their quality or effectiveness criterion is a vector, while the realization of the model yields a rational decision or a subset of decisions.

In modelling a particular situation, the real processes are often simplified to facilitate their description, however, they still should reflect the considered situation. Therefore, to perform a multicriteria analysis for solving a particular problem, the selection of the appropriate set of criteria is required.

Making decisions in the area of management, decision makers are faced with various problems. The main of these problems (Zavadskas et al. 2010; Ustinovičius et al. 2008a) may be stated as follows:

1. It is required to generalize and evaluate management criteria of various projects or organizations;
2. The evaluation should take into consideration the interests of various interested parties;
3. The available alternative decisions should be thoroughly compared.

Quite a few classifications of multicriteria decision-making methods (MCDM) may be found in the literature. However, in the present paper, we would like to suggest the most suitable (in our opinion) MCDM classification for solving risk assessment problems (see Table 1), based on the type of the available information.

Table 1

Classification of the methods based on the information available

Methods based on quantitative measurements	**Methods based on the initial quantitative measurements**	**Methods including measurements based on several criteria**	**Methods based on qualitative measurements not including the conversion to quantitative variables**
Multicriteria methods using utility function theory. Other methods	Analytic hierarchy method. Methods of fuzzy sets	Comparative preference methods	Methods of verbal analysis

Source: Made by the authors.

Multicriteria decision-making methods have been widely used in solving various problems for a long time. However, formally the multicriteria decision-making method appeared only about 30 years ago. The development of this method is closely connected with advances in computer technology. On the one hand, rapid development of computer technology in recent years helped to perform a complex analysis of multicriteria decision-making problems. On the other hand, the wide use of computer and information technology created vast amounts of information, which made multicriteria decision-making a more important and useful tool for making decisions in various fields.

As mentioned above, risk assessment is connected with high uncertainty. The lack of quantitative and qualitative information, occurring due to various reasons (complete absence of information, unwillingness to provide it, etc.) greatly influences the making of an investment decision. Therefore, verbal analysis methods, requiring only minimal quantitative information, are used for assessing risk in the present paper.

Most of the researchers considering decision-making methods are aware of and emphasize the mismatch between the available standard methods and human capabilities of accepting and processing information. One of the ways of solving this problem is the use of the verbal analysis (lexicographic) decision support method. The lexicographic methods are well scientifically grounded because they are based on the data of various disciplines and human psychology. In these methods, psychological characteristics are used as the main and most important criteria. Verbal decision support methods (Larichev and Moshkovich 1996) take into account (assess) the cognitive and behavioural aspects of a decision maker, given below in the description of the applied models. First, qualitative measurements allow for obtaining the descriptions of non-structured problems, which are similar to the real ones. Second, the use of the decision-making rules corresponding to human capabilities of processing information allows the researchers to base the method psychologically. Third, the procedures of validating the consistency of the obtained data ensure their reliability, allowing a decision-maker to gradually improve the decision-making rules. Fourth, the availability of explanations extends the scope of successful practical use of the considered method.

Practical application of verbal decision-making methods (VDM) is more advanced than the use of heuristic and axiomatic methods. Compared to a heuristic method, the verbal decision-making method has the advantage because the ways of getting information in this method are psychologically grounded, while all variations in data are mathematically explained. This analysis allows for evaluating the behaviour of the company's employees in decision-making, which is performed in steps, leading to the final decision. The verbal analysis methods are not perceived by a decision maker because he/she simply answers the questions asked by a computer in the language well understandable to him/her. Later, a decision maker checks if his/her preferences correspond to the recommended ones.

As mentioned above, most of the multicriteria methods require that the values of the criteria be defined quantitatively for determining the significances of various criteria. In using the methods of verbal analysis, the criterion values and weights (significances) are determined intuitively by a decision maker or expert and any additional calculations are not required.

At the stage of structuring, the DM should state the selection problem in a natural language in terms of the respective problem area. The alternatives available for selection should be listed, the evaluation criteria determined, and verbal scales of evaluation based on each criterion should be defined. A set of alternatives for selecting the best of them will be denoted by A.

The DM determines the characteristics of the alternatives to be used as the evaluation criteria. Let us denote a set of the criteria $C = \{C^1, ..., C^k\}, K = \{1, ...k\}$ as a set of the criteria numbers. The criteria may be both quantitative and qualitative (verbal).

The estimate of the alternative $a \in A$ based on the criterion C^j will be denoted by $C^j(a)$. The scale of evaluation $S^j = \{s_1^j, s_2^j, ..., s_{m_j}^j\}, j \in K$, associated with a particular criterion, is not specified beforehand, but is formed based on the estimates of all actual alternatives according to a particular criterion $S^j = \bigcup_{a \in A} C^j(a)$. In this approach, the preliminary arrangement of the estimates on the criterion scales is not required. Various combinations of estimates make a k-dimensional space, which is, in fact, the Cartesian product of the criterion scales $S = \prod_{j=1}^{k} S^j$. Each alternative $a \in A$ corresponds to a vector estimate (tuple) $C(a) = (C^1(a), C^2(a),...,C^k(a))$, consisting of the alternative estimates $C^j(a)$ based on the criteria $C^1,...,C^k$. Let us denote by A a set $\{C(a)|a \in A\}$ of vector estimates of the real alternatives from the set A. It is evident that $A \subseteq S$.

Thus, at this stage of problem structuring, sets of alternatives A and criteria C, as well as scales of criteria S^j and vector estimates A, are determined. The task is to elicit a subset of the best alternatives based on the DM preferences.

Table 2 given below presents a brief description of the most common verbal decision-making methods.

Table 2

A brief description of verbal methods

Name of a method	***Application of a method***
ZAPROS	Ranking the whole set of alternatives
PARK	Searching for the best alternative in a set
ŠNUR (SNOD)	Searching for the best alternative in a set (more alternatives and criteria are evaluated than by using PARK)
ORKLASS	Expert classification of all the alternatives
CIKL	Expert classification of all the alternatives (performed faster than by using ORKLASS)

Source: Compiled by the authors based on the works of (Larichev and Moshkovitch 1996, Asanov *et al. 2001,* Ustinovičius and Kochin 2008, Ustinovičius *et al.* 2008a; Zavadskas et al. 2008).

4. Classification of real alternatives

To solve the classification problems, whose formal task is described in the previous section, the method of Real Alternatives Classification, described at length in other works of the authors, has been developed. This method allows for making both complete and partial classifications of the objects with a minimum number of appeals to a decision-maker (expert). The considered method may be also used, when a not strictly linear series on the scale of criteria is found.

There is a large number of types of decision-making problems when the DM divides a particular set of alternatives into some well arranged classes. For example, people purchasing an apartment, a house or changing the real estate, subdivide the alternatives into two groups: those which require more detailed study of the consumption of the material resources and time, and those which do not require this. A merchant may sort goods based on their particular characteristics or criteria (e.g. size, colour, quantity, etc.). Similarly, people classify books, clothes, tours, etc. The same problem may arise, when decisions are made at an enterprise. For example, the crediting policy of a bank should involve the classification of its clients into the reliable and unreliable ones.

Grouping/classification of objects refers to common human activities (Ustinovičius et al. 2008b). This is accounted for by the fact that classification is an operation sufficient for solving many real problems, particularly, when the number of the objects is not very large. For example, there is no need to precisely rank several hundred objects, however, their division into some particular groups may give sufficient information about their quality. Similarly, grouping is effective in the case, when the number of the objects is not large but the type of the problem requires it. It should be mentioned that classification of objects is the result of the work of most expert systems. One of such systems or methods is ORKLASS (Ustinovičius et al. 2010).

Using this method, the whole set of objects may be divided, based on their quality, into separate classes where the objects are evaluated using a certain number of quality criteria. A complete set of objects implies that it embraces objects based on various combinations of estimates obtained by using various criteria, i.e. all available objects. Objects may be classified by presenting them one by one to the DM for evaluation. However, this will take the DM too much time. The method ORKLASS suggests a procedure of the DM questioning which allows the number of questions to be reduced, thereby increasing work efficiency. However, in some cases, it is not necessary to classify the whole set because the classification of a small number of alternatives is sufficient. Such problems arise when a small number of objects is analysed, e.g. when some old building should be demolished or reconstructed. It is also the case when some alternatives of a complete set cannot be evaluated using the available combinations of criteria. In such cases, it is not necessary to classify all the alternatives in a set, and the consideration of some real alternatives will be sufficient. The method of Real Alternatives Classification, based on the ORKLASS system, can be successfully used to solve such problems. The algorithm of this method is given in (Ustinovichius et al. 2010; Zavadskas et al. 2008; Ustinovičius et al. 2008a; Ustinovičius et al. 2008b) sources.

Getting sufficiently reliable qualitative enterprise evaluation is a complicated problem because a commonly accepted reliability criterion has not been developed yet. In fact, there are many factors (indicators) that should be taken into account, each bringing the elements of uncertainty into the evaluation of the considered objects. Moreover, the internal enterprise classification should take into account the parameters of other enterprises or developed projects. General enterprise evaluation is a complex function of its constituent parts. The settings of enterprise operation are constantly changing depending on the market changes. Therefore, the evaluation of an enterprise of any economic sector requires the consideration of its links with other enterprises or objects.

Risk classification in the case of a large number of evaluation criteria is hardly possible without the use of a special method. The problem of objects classification based on a large number of criteria is actually a decision-making problem. Such problems may be solved by using the method of Real Alternatives Classification, allowing for classifying the objects in several steps, checking the data for consistency and getting a general decision-making method. In addition, the above method helps to determine the capabilities and limitations of data processing system of humans. A formal description of the problem is presented in the survey of multicriteria decision-making methods. As shown by comparison, the idea of making a dynamic chain allows us to obtain an almost optimal algorithm for making the classification based on a minimal number of questions presented to the DM. The experience of making sequential classification systems shows that formalization of some particular area as well as introduction of the criterion structure and classes into it allows the classification (evaluation) problem to be solved by using highly effective human and computer-aided methods.

Based on the classifier developed, we can define the level of risk, but this requires a comparison of a great number of criteria. Therefore, the computer program based on the method of Real Alternatives Classification (Ustinovichius et al 2010; Zavadskas et al. 2008; Ustinovičius et al. 2008a; Ustinovičius et al. 2008b) may be used for this purpose. Practical examples using verbal analysis were implemented and given in (Ustinovichius et al. 2010; Ustinovichius et al. 2009; Zavadskas et al. 2008; Ustinovičius et al. 2008a; Ustinovičius et al. 2008b; Shevchenko et al. 2008) sources.

Conclusions

Globalization of the financial markets, the increasing competition between organizations and social and technological development encourage the application of new advanced risk assessment methods. New technological achievements help the researchers and practicians to realize the importance of using various analytical approaches in assessing enterprise performance and evaluating the criteria describing the risk of the performed operations, in particular.

Most of decision-making specialists and researchers emphasize that the standard methods used in this area do not well agree with human ability of data perception and processing. A possible solution to this problem is the application of verbal analysis decision-making methods, which are scientifically grounded and use the evaluation criteria, based on psychology.

It may be stated that risk assessment depends on a number of variables. Striving for objectivity of a decision, which should assess the risk of the considered object from various perspectives, a great number of various types of risk and the criteria describing them should be evaluated. The investment decision with a higher than planned risk level has a strong negative effect on the effectiveness of other decisions and the level of satisfaction of the interested parties. Therefore, the effect of all changes on the final estimate should be accurately evaluated and calculated. The authors of the paper suggest using the evaluation methods based on verbal analysis as the approaches, requiring the minimum amount of quantitative data.

Thus, summarizing the above considerations and the research performed, it may be said that the method of classifying the real alternatives offered in the paper and described in terms of expert classification belongs to the group of verbal analysis decision-making approaches and has the following characteristics:

- The method allows for making a complete classification of all the alternatives or their particular sets.
- A description of the objects given to an expert for evaluation is in the form suitable for analysis because it does not contain any artificially created intermediate numerical data;
- The consistency of the data elicited from experts is validated;
- The effective technique of surveying the experts is used (taking into account the number of the questions asked).

It is well-known that risks may be found in any enterprise activity or operation. Risk classification is a complicated problem because it is associated with a number of criteria, e.g. the environment where risks are found and its uncertainty. The suggested methods, based on verbal analysis, may be used for assessing risk level and yield good results in evaluating the investment projects and enterprise performance.

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RISK AND UNCERTAINTY IN CONSTRUCTION AND INVESTMENT PROJECTS FOR INFRASTRUCTURE DEVELOPMENT OF THE CITY OF WROCLAW IN THE FACE OF POLAND'S PREPARATIONS FOR THE 2012 UEFA EUROPEAN FOOTBALL CHAMPIONSHIP – CASE STUDY

Introduction

On April 18, 2007 the UEFA Executive Committee announced in Cardiff its decision which country would organize the final tournament of the 2012 UEFA European Football Championship (UEFA EURO 2012). The Committee selected Poland and Ukraine to jointly stage the event. The UEFA decision presented the Polish government and its relevant ministries, the Polish FA, the authorities of the cities hosting the matches, as well as many other national and private institutions with an enormous organizational and financial challenge. The effect of the UEFA decision was that all previous projects and plans regarding further infrastructure development would have a high degree of feasibility, as their implementation will be of importance for the successful staging and organization of the Championships. Since the very participation in the contest to host such a massive event requires potential bidders to have an adequate base, some work has already been done in Poland. Moreover, the bidders have to demonstrate either significant improvement in their preparations for the event or very realistic plans of such preparations which have a high likelihood of timely realization.. Since Poland met most of the above requirements, it was selected as the Host Association of the upcoming UEFA European Football Championship. To the final phase of the contest, apart from Poland and Ukraine, UEFA also selected jointly Hungry/Croatia as well as Italy. Its decision on the Host Association seems quite reasonable given that such event has never taken place in this part of Europe. Furthermore, the Tournament will trigger, in the host countries, an avalanche of investments in sports venues which have, so far, been very few and below required standards. However, the improvement of the existing conditions is not the only benefit gained from hosting the Football Championship. Ensuring a high standard of the entire event together with its successful organization demands that huge sports and recreational infrastructure, in addition to transport, accommodation and road infrastructure will have to be developed. Also, security systems and mechanism must be created for the smooth operation of services provided for direct participants of the event and many thousands of football fans from all over Europe.

Not only do all the above operations and actions constitute an enormous challenge for the city's authorities, local people, and especially the Polish government, there is also a great responsibility involved here. The challenge Poland is facing lies in the necessity to conduct many very complex operations on numerous organizational and technological levels within a relatively short period of time. But there also arose an opportunity to accelerate the infrastructure development including roads, motorways and motorway ring-roads designed for big urban agglomerations, which had already been planned for a long time; in addition, the infrastructure development encompasses fast train connections all over the country as well as the modernization of airports. The timely implementation of all projects ensuring adequate communication between European countries, Poland and Ukraine, and especially between the cities involved in the staging and organizing of the Tournament, including hotel and restaurant networks and other services is not only the responsibility of the Polish Government but also Poland's responsibility in front of whole Europe. The way Poland is going to deal with the organization of the Championships will not only shape the opinion of the sports world; many eyes from various industries will be fixed on Poland closely watching how the country is managing this extraordinary task the completion of which will come with the referee's blowing the whistle to begin the opening match of the 2012 UEFA European Football Championship. Yet until that moment many actions will have to be planned, organized and implemented. They will testify whether or not the preparations made and skills represented by the Polish authorities, institutions, national companies and private entrepreneurs were adequate when faced with such complicated challenges in terms of organization and investment.

For the organizational part of the Tournament UEFA selected the Polish FA. Moreover, the cities were chosen, both in Poland and Ukraine, to host the matches at various stages of the Championships. In Poland the following cities were selected: Gdańsk, Poznań, Warsaw and Wrocław; whereas in Ukraine: Dniepropetrovsk, Donetsk, Kiev and Lviv. Each of the selected cities will become an arena of sports competition as well as accommodation facilities for thousands of football fans and tourists. As a result, meeting the organizational demands will require that preparations and projects have to be carried out on local levels. However, local authorities are not responsible for the construction and financing of all venues and infrastructure needed for UEFA EURO 2012. Their main responsibility lies in the construction of facilities considered to be part of the city's investments already included in the plans and budgets of individual cities. Not unlike most of the stadiums, some of the hotels, road and public transport infrastructure of local significance will depend on the activities, skills and financing provided on the level of local governmental units. These units will have to decide independently what the priorities are and how to finance and manage the entire process, ultimately leading to the city's being ready for the Football Championship.

The goal of the paper is present the scope of the projects which have to be accomplished in Wrocław before the Championship and to analyze the risk and uncertainty linked to such projects. There are many definitions of project risk and uncertainty in the literature. We understand risk an identifiable and potentially possible event which may occur and once it does so, it may have negative consequences for attaining the project goals. Projects uncertainty, on the other hand, stands also for events that may have negative consequences for attaining the project goals, but these events are not identifiable, not known to the decision maker in the moment of project planning. Obviously, it is better to have a potentially negative event as a risk than as an uncertainty – with risks, we can do something, we can minimize their effects or at least be prepared for them to happen and foresee alternative scenarios or adequate measures. Uncertainty cannot be managed, we can just wait and see what comes.

In the moment the paper is written, the projects have been started, but not fished yet. Thus we already know which events threatening the project goals achievement have occurred. Some of these events were known at the moment of project planning, some came as a "surprise". The present case study will help the managers of similar projects to increase the set of identifiable events, of the events which can be qualified as risk. Thus, they will have less uncertainty in their projects and they will be able to increase the success probability of their projects thanks to an adequate risk management.

In the projects analyzed in the present paper several measures have been undertake to prevent risk from happening. The information about these measures will also be helpful for the managers of similar projects.

The outline of the paper is as follows. First, we discuss the problems with law and how the legal basis had to be prepared for the projects to be accomplished. Then we present projects linked to Euro 2012 and the organizational issues on the national level. Then we pass to the local issues of Wrocław. We discuss in detail the organization of the Championship in Wrocław and describe the investments that are conducted (they are a new football stadium, road construction and reconstruction, airport development, agglomeration transport investments, renovation of the main railway station). At the very end we propose some conclusions.

1. Legal basis for the investments related to UEFA EURO 2012

The organization and coordination of any investment work leading to the preparation of the Football Championship requires that a set of laws be established in order to create a platform ensuring the management of the entire enterprise. Consequently, the Polish Government devised the Act on Preparation of the Final Tournament of the 2012 UEFA European Football Championship (Journal of Laws No. 173, item 1229). In particular, the new law covers the terms and conditions under which activities in the field of planning, constructing, reconstructing and renovating of stadiums and other facilities are to be carried out on the territory of the Republic of Poland (Article 1 (1), point 2), as well as the terms and conditions for conducting other operations necessary for the organization and staging of the Tournament (Article 1 (2), point 2). In addition, the Act makes more precise the exclusions with respect to national roads and railway connections of importance to the country and to which the Act does not apply.

The enterprises described by the Act are to be understood as public purposes (Journal of Laws of 2004 No. 261, item 2603), being part of the public purpose investments to be financed by the national budget, local governments budgets and the European Union’s budget. Also, the financial assistance is to be obtained from EFTA as well as other foreign sources not subject to back payment.

The integration of supervision of all the operations is of key importance if we want to meet all the objectives involved in the preparations of UEFA EURO 2012, especially their timely realization. However, considering the huge range of operations to be performed, it seems only appropriate to transfer a number of activities on smaller entities which will finalize the preparations, this being of advantage to the Ministry of Treasury, the organizer of the Championship. In particular, this is important from the perspective of the regions where the matches will be played, as people there are the best judges of what is necessary and what is needed to ensure successful staging of sports events in terms of further development.

In a view to this, the legislation makes it possible to found companies with limited liability, the so called "special-purpose companies." Such companies can be created both by the Ministry of Treasury and the host cities, that is Gdańsk, Poznań, Warsaw and Wrocław. The Act specifies the mode of creating such entities, including the subject of their activities which is the preparation, execution, coordination and supervision of all the UEFA EURO 2012 enterprises. According to the Act, these entities may replace local governments in performing the investor's tasks and the tasks within the investor's supervision; in particular, they are authorized to obtain and prepare any documents, submit applications to obtain decision, permits, agreement and opinion, as well as to acquire property and property rights, to participate in expropriation proceedings and to conclude, supervise and execute supply contracts, including service and construction contracts.

Considering the importance of timely realization of the operations involved in the organization of UEFA EURO 2012, the Act introduced regulations simplifying judicial and administrative procedures related to the organization of the Tournament. First of all, these regulations accelerate administrative decisions issued in relation to the organization of the event, and they are subject to immediate implementation. Furthermore, the time period to appeal administrative decisions issued in relation to the organization of the Tournament was shortened from 14 to 7 days; whereas the appeal against the administrative decision issued is to be considered within 15 days instead of 30 days as was the case before. A complaint is to be considered within 30 days from the day of the receipt of the documents and the time period for considering a cassation complaint by Supreme Administrative Court in connection with conducting the operations for the Championship is 2 months from the day a complaint was filed.

The reality continues to bring new experiences, especially to the people engaged in the preparations for UEFA EURO 2012. Even the amendments to previous legal acts could not foresee all cases which encumbered the work on investment planning. There have, for example, been cases involving many property owners whose actions paralyzed important investment projects. The host cities encountered problems while acquiring property by means of signing a civil contract with the owners. The city of Wrocław was one of the host cities which experienced how the owner of a lot blocked the construction of an exit from the inner city ring road and the high-speed tram PLUS terminus (Jaraszek 2009). So an amendment was introduced to the Act on Preparation of the Final Tournament of the 2012 UEFA (Journal of Laws No. 161, item 1281) European Football Championship. The amendment makes it easier to acquire property where road investments and stadiums are to be constructed. The main value of this amendment is moreover the acceleration of investments by separating expropriation proceedings from the proceedings specifying the amount of compensation given. As a result, the above case of blocking the investment work will no longer be possible.

Furthermore, this amendment sets up some sort of bonuses for property owners who choose to transfer their property voluntarily. There is a 5 percent increase of compensation to be paid to those who vacate immediately the expropriated lots. In the case when the property is a built-up area the expropriated owner shall receive additional funds as compensation for the cost incurred as a result of having to look for new property, having to pay taxes and other fees related to moving out. The Ministry of Treasury or a local government can thus avoid judicial disputes with property owners, while at the same time shorten the time period necessary for the investment work to begin on the acquired property.

2. Planned and implemented EURO 2012 projects in Poland

While identifying organizational issues, it was very important to indicate the projects which would have to be completed before the opening of the Football Championship. Making the list of such projects opened up the opportunity to assess the costs, allocate the national and EU funding, divide responsibilities for specific operations and specify projects of key importance. There have, so far, been many reasons why the development of Poland’s infrastructure, which could be used either for the organization or support of UEFA EURO 2012, has not been running smoothly. Apart from the lack of adequate proposals regarding financing, the factors contributing to the ongoing lack of infrastructure investment, including even road investments for the use of the Polish economy alone, were protracted bidding processes, appeal and expropriation proceedings as well as other administrative proceedings. It may even seem that the government administration was unable to find any incentive to push forward the country’s infrastructure development. Fortunately, when the Executive Committee announced its decision stating that Poland and Ukraine were the Host Associations for UEFA EURO 2012, an avalanche of investments has been unleashed. The effects of the decision slowly begin to be visible not only in the cities hosting the matches but also across the whole country.

It was affirmed that Poland as a developing market could not afford being extravagant in terms of time and money. Nevertheless, it was important that the facilities which are currently under construction such as roads, stadiums, motorways, fast highways, air terminals, airports, new railways and railway stations retain high quality and functionality long after the Tournament is over.

It was thus very important that the Council of Ministers, while devising the Act on the List of EURO 2012 Projects (Journal of Laws No. 192, item 1385), specified which tasks were assumed by UEFA and for which the Council of Ministers or local governmental units were responsible and providing guarantees (Table 1). The above division allowed for a simplified use of certain procedures, especially administrative procedures during the implementation of the projects. Apart from building the stadiums, the Act provided, among others, for numerous road investments, the construction of car parks, railway stations and airports as well as rescue and support systems for police and fire brigade.

Table 1

General list of the EURO 2012 projects in Poland

GENERAL INVESTMENT PROJECTS
STADIUMS
The construction starting from the foundations up and the development of principal stadiums (Gdańsk, Poznań, Warsaw, Wrocław)
Reconstruction and development of reserve stadiums (Chorzów, Kraków)
ROADS
The reconstruction and construction from the foundations up, with the plan to increase capacity, improve traffic conditions and safety; the construction of road infrastructure around the stadiums (Gdańsk, Kraków, Poznań, Warsaw, Wrocław)
URBAN AGGLOMERATIONS RING ROADS
The construction and development of the inner city ring road and motorway ring road, including the connections to the airport and stadium (Gdańsk, Wrocław)
The construction of the inner city ring road (Warsaw)
RAILWAY TRANSPORT
Railway station renovation (Gdynia, Warsaw Central Railway Station, Wrocław Main Railway Station)
Railway stations re construction (Katowice)
Railway stations construction (Kraków Main Railway Station, Poznań Main Railway Station, Warsaw East and West Railway Stations)
The construction of the railway connection MPL „Katowice” located in Pyrzowice with the cities of Upper Silesia agglomeration (Upper Silesia Voivodship)
The construction of Metropolitan Railway (Pomorskie Voivodship)
PUBLIC TRANSPORT
The construction and reconstruction of tram transport in the city area, the construction of an integrated railway transport system and a high-speed tram (Gdańsk, Kraków, Poznań, Wrocław)
The construction of an underground (Warsaw)
Infrastructure development in the agglomeration (Upper Silesia Voivodship)
AIRPORTS
Airport development and reconstruction (Gdańsk, Modlin, Kraków, Poznań, Pyrzowice, Warsaw, Wrocław, Zielona Góra)
CAR PARK INFRASTRUCTURE
The construction of an underground and outside car park as well as a multilevel car park

GENERAL INVESTMENT PROJECTS
(Chorzów, Gdańsk, Kraków)
TRAFIC MANAGEMENT SYSTEMS
Integrated vehicular and tram traffic management systems in the cities, intelligent information systems with variable message signs (Gdańsk, Kraków, Poznań, Wrocław)
Infrastructure development of the national body for air traffic management (The whole country)
RESCUE
The construction of integrated rescue centers, crisis and emergency response centers (Gdańsk, Wrocław, Poznań)
The construction of the National Fire Brigade coordination center; the construction of fire watch towers of the National Fire Brigade (Warsaw)
POLICE
The reconstruction of the infrastructure and police headquarters (Kraków, Poznań, Warsaw, Wrocław)
The construction and reconstruction of the facilities for the Central Command of Police Squad and Information Exchange Center during EURO 2012 (Sieradz)
CITY SECURITY
The development of visual monitoring system (Poznań)
OTHER SPORTS FACILITIES
The reconstruction of sports and entertainment venues as well as sports and recreational facilities (Poznań)
COMMUNICATION
The construction of nationwide digital radio communication system for public security services and rescue teams (The whole country)
ELECTRIC POWER SUPPLY
The development of electric power supply system in the agglomeration (Lower Silesian Voivodeship, Wielkopolskie Voivodeship)
WATER AND SEWAGE INFRASTRUCTURE
Drain systems adjacent to stadiums, the construction of sewage systems, transmission lines and pumping station (Gdańsk, Warsaw)

Source: Based on the Annex to the Ordinance of the Council of Ministers of October 12, 2007 on the List of EURO 2012 Projects ("Journal of Laws" No. 192, item 1385, with subsequent amendments).

The above tasks have been included in the long-term program developed by the Council of Minister and its realization and coordination were entrusted to the Minister for Sport and Tourism. For the purpose of supervision, the Minister undertakes to deliver reports on the progress of the EURO 2012 projects both to the Council and the Seym of the Republic of Poland, respectively twice and once a year. The report describes in detail high priority projects in individual cities, indicating their objectives, current situation, percentage of work that has so far been completed, approved budget, financial assurance, risks and the means of risk reduction. Moreover, the structure of the report also reflects the tasks which were divided into major areas such as stadiums, land transport, airports, hotels and accommodation facilities, communication and promotions as well as intellectual property. Detailed analysis of the above areas provided as a report every six months allows to build a solid foundation for assessing the state of preparations for the event. The document is also a feasibility analysis procedure for the plans made, identification of time delay risk as well as a platform for decision making in critical situations.

If all the measures prove to be successful we, as the country of Poland, will have a chance to show our ability to stage and organize successfully a three-week tournament across the entire country at the cost of 25 billion EUR (Szczepaniuk 2009). The most important, however, is that we will finally manage, with the help of the Football Championship, to get rid of numerous delays in the infrastructure development of our country caused by the limitations imposed by the system and previous political eras.

By looking at the expenditures incurred in previous years as well as forecasts regarding the consumption of funds and the plans for the next years, we already get the impression that there has been a significant break through in Poland's road infrastructure sector, which has otherwise been a trouble spot for many years. It is worth mentioning that in 2009 an estimated 32.3 bln PLN (Council of Ministers, No 163/2007) (Figure 1) was spent on roads, which makes about 72% of all funds spent on road investments in the years 2002-2007.

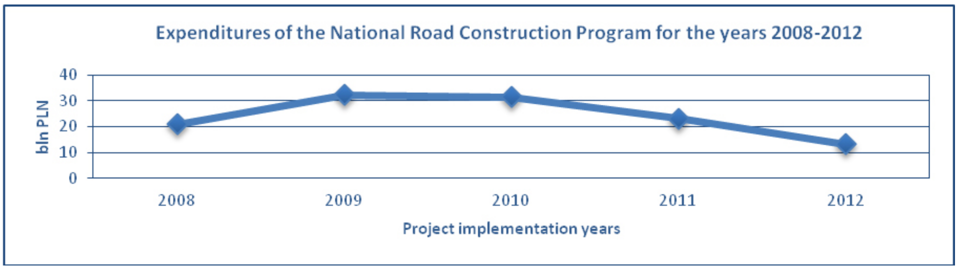

Figure 1. The expenditures planned in the National Road Construction Program for the years 2008-2012

When Poland started being considered as the candidate for the organization and staging of UEFA EURO 2012, the infrastructure expenditures began to rise. From the year 2006 to 2008 the following sums were spent each year respectively: 9.25 bln PLN; 11.7 bln PLN and 13.6 bln PLN; whereas the highest amount of the expenditures was planned for 2009 and 2010 with estimated 63.74 bln PLN (Council of Ministers 2007) total. Susequent years up to the year 2012 will be marked by a gradual process of completing the planned road investments included in the program. As a result, in 2011 the amount of the funds spent were smaller than in the previous years reaching 23.22 bln PLN and in the year 2012 it will be 13.22 bln PLN (Council of Ministers 2007) (Figure 1). Thus the total amount included in the National Road and Motorway Construction Program for the years 2008-2012 will be 121 bln PLN, of which EU funds make up 35 bln PLN (Trochymiuk 2009) (Figure 2).

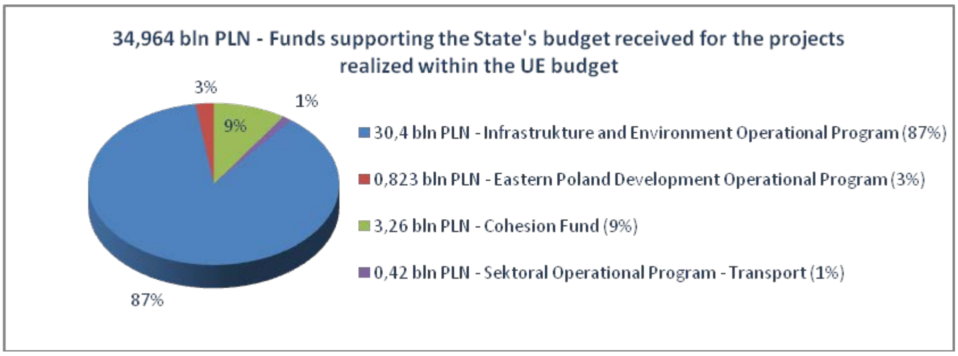

Figure 2. Funds and programs included in the EU donations

Although the above – cited data refers only to the road infrastructure, it nevertheless reflects the scale of the investments in which so many forces and measures are currently engaged within the entire country. As the result of selecting Poland and Ukraine as countries to organize and stage UEFA EURO 2012, an adequate development plan was devised for road connections between the host cities including transborder connections. The objective of these activities is to create freedom of movement across various regions and countries during the Tournament. That is why some projects, being part of the national development program, were given priority, as they were considered to be of key importance in terms of EURO 2012 preparations. We should distinguish here the projects dealing with the construction of roads connecting the cities hosting the football matches and borderland sections. Ultimately the total value of the EURO 2012 investments whose implementation have been accelerated may reach approximately 27 bln PLN (Council of Ministers, No 163/2007).

3. The organisation of the 2012 UEFA European Football Championship on the national level

By virtue of the Act on Preparation of the Final Tournament of the 2012 UEFA European Football Championship a coordinating company PL.2012 was founded. Through national coordinators, Pl.2012 supervises the projects dealing with the preparation of UEFA EURO 2012. The company's highly qualified team consists of several dozens of experts from various fields working directly with the Ministry of Sport and Tourism, UEFA, the Polish FA and pertinent representatives from Ukraine. The collaboration between these institutions serves to ensure that newly emerging problems as well as priorities are quickly identified and all the projects are implemented according to schedule. The host cities prepare investments which will be included in the network of facilities used during the Tournament. To ensure that these investments' development is carried out according to the requirements involved in the preparations for EURO 2012 across the entire country, PL.2012 is a body coordinating the activities of the institutions established by the host cities.

Apart from displaying a thorough knowledge of the UEFA guidelines imposing on Poland the scope of investments, Pl 2012 is also aware of what can be done within the state's budget, as well as knows the current state and the progress made regarding the infrastructure for UEFA EURO 2012. Also, the company conducts the following (PL.2012):

- analysis of legal acts which can impact the implementation of projects related to EURO 2012;
- periodic assessment of the state of investments, projects monitoring and specifying the areas of danger linked to the EURO 2012 organization;
- monitoring activities related to the fulfillment, by proper entities, of guarantees and obligations made while applying to become the candidate for EURO 2012;
- current reporting to UEFA on preparatory work progress;
- training and seminars for the entities responsible for the organization of the Football Championship;
- support systems to help implement security plans, including medical and rescue services for the EURO 2012;
- development and implementation of transport and communication concepts for EURO 2012;
- marketing and advertisement connected with the promotion of Poland, including providing information on the progress regarding the preparation for EURO 2012.

Since the introduction of the new regulations enabling the founding of special-purpose companies, the subsequent years have provided the companies representatives with an increased number of experiences with the result that part of the regulations had to be adjusted to the realities of the current situation. This refers mainly to the operations of PL 2012 whose powers of control over the special-purpose companies founded by the local governments were extended by the Amendment (Journal of Laws No. 68, item 575) of the Act on Preparation of the Final Tournament EURO 2012. However, this does not mean that the special-purpose companies became subordinate to PL 2012. The aim of the amendment is to specify the range of control carried out by PL 2012 over the implementation of the EURO 2012 projects, Pl 2012 being the main entity responsible for the smooth implementation of all the projects nation wide. Thus the Amendment of the Act makes it possible to require information and check in detail how the projects are carried out without inspecting a given company (Graczewska-Ivanowa 2009). Such solutions seem to be adequate to ensure instant and real monitoring of the work progress. Early detection of failure and common delays can prevent conflicts that can have impact on all the preparatory activities conducted across the country.

4. The organisation of the 2012 UEFA European Football Championship in Wrocław

Although it was already known on April 18, 2007 that Poland and Ukraine would stage the Finals of the European Football Championship, what was not known was which cities would host European footballers. Warsaw and Kiev being state capitals could feel quite secure in their position of the future host cities. However, there was still no final go-ahead for such cities as Chorzów Gdańsk, Kraków, Poznań and Wrocław. At last, as was expected in Wrocław and in line with the application filed by Poland during the early phase of bidding for EURO 2012, Gdańsk, Poznań, Warsaw and Wrocław have became official arenas of the Football Tournament as of May 13, 2009. For the people of Wrocław and its government it was obvious that their city could not be disregarded as one of the host cities, as there were many arguments speaking for Wrocław.

- The city’s location near the A4 Motorway which is the route from Western Europe to Europe’s eastern borders;
- The location at the intersection of European vehicle routes: west-east and north-south;
- The proximity of the German and Chech borders;
- Well-developed railway junction;
- International airport;

- Advanced construction work at the football stadium;
- Dynamically developing road network – inner city ring-road and motorway ring-road;
- Progressive modernization and development of the city's communication system.

Many of these projects were already in the city's development plans some years ago. However, their implementation was in many cases postponed because of financial problems. Only these projects were selected for further development which seemed to be the most needed for the city such as road renovation or maintaining the existent infrastructure. The perspective of hosting EURO 2012 by Poland triggered a serious of initiatives which turned out to be very effective and managed to influence the UEFA decision on making Wrocław one of the host cities of the Tournament. We should also consider that the state of the city's infrastructure at the moment of the decision announcement was at its minimal percentage in terms of the city's readiness to host the event. However, the projects that are currently being carried out allow us to believe that Wrocław will be ready when the time comes. Among the projects which are being conducted the most important are the following:

- The construction of the municipal stadium together with the adjacent sports and recreational infrastructure;
- The modernization of the airport by developing the passenger air terminal, the construction of aprons and taxiway;
- Investments related to land transport – the construction of the new or reconstruction of the existent transport routes in the city and in the vicinity of the city;
- Car park construction;
- The construction of an integrated railway transport system in the agglomeration;
- Accomodation facilities development;
- Integration of medical and rescue services;

A special Office dealing with EURO 2012 organization was brought into existence by Wrocław Municipal Authorities for the purpose of coordinating many projects conducted in the city. The Office belongs to the Department of Social Issues and serves as a supervision tool for the City's President who is responsible for the city's readiness to organize and stage the Wrocław part of the Tournament. Director of the Department of Social Issues has been appointed as the President's representative for EURO 2012.

The Special EURO 2012 Office is responsible for the following tasks (Report, April 2009):

- cooperation with the Union of European Football Associations (UEFA) and with the Polish Football Association for the purpose of organizing and staging the UEFA EURO 2012 in Wrocław;
- coordination of preparatory work of the city of Wrocław for UEFA EURO 2012 in such fields as infrastructure, security, medical services and volunteer work;
- cooperation with the entities involved in the organization of UEFA EURO 2012 in Poland and in Ukraine;
- compiling data related to the preparation of the city of Wrocław for UEFA EURO 2012;
- preparing and managing information connected with the preparation of the city for UEFA EURO 2012, including the cooperation with the media, investors and public administration;
- promoting Wrocław as the UEFA EURO 2012 host city and promoting UEFA EURO 2012 in Wrocław;
- preparing and implementing the budget for the project „The Construction of a Football Stadium in Wrocław;"
- the Office management, including planning and implementing the Office's budget, preparing draft resolutions of the Council and the President's regulations regarding the activities that are being conducted and, implementation of the tasks connected with public procurement.

We should add that the creation of this organizational unit, authority transfer and precise definition of the task, which is all included in the statute of the Office (Announcement, January 2009), were the items positively commented upon in the post-audit report prepared by Supreme Audit Office, after auditing the Office's work regarding Poland's preparation for the European Football Championship UEFA EURO 2012.

By virtue of the Act on Preparation of the Final Tournament of the 2012 UEFA European Football Championship, on December 3, 2007 a special-purpose company, *Wrocław 2012 Sp. z o.o.* was founded in Wrocław by Wrocław Municipality. The main task of the company is to conduct successfully the investment project of constructing of a football stadium in Maślice, Wrocław. The company plays the role of substitute investor for the investments preparing the stadium for the Tournament. Moreover, the company is responsible for selecting the General Contractor and it will participate in the proceedings selecting future Stadium Operator.

5. Investment activities preparing Wrocław for UEFA Euro 2012

Project – a new football stadium in Wrocław

At an early stage of the preparation, long before Wrocław was selected as one of the host cities for UEFA EURO 2012, the concept of a municipal stadium had been developed. Wrocław authorities organized a competition for the best venue project, including its infrastructure. The results were announced in October 2007: the so called "Stadium – Lantern" project became the winner of the competition. Out of 21 candidates a German Architects Firm, with its seat in Poland, was selected, having many years experience in the construction of large volume spaces, including sports and event facilities, airport terminals, stadiums, shopping and congress centers, high-rise buildings, office buildings, hotels and residential buildings. Among sports facilities, the Firm constructed LTU Arena in Düsseldorf, Germany. In Poland, the Firm was involved in such projects as the development of a passenger air terminal at the Warsaw airport, National Stadium in Warsaw and a new Legia Warszawa football stadium. The skills of the Architects Firm have been known in Wrocław for some time now as it was selected to devise the concept for the development of Wrocław International Airport.

At its preparatory stage, it was estimated that the construction of the stadium in Maślice would cost about 521 mln PLN and will take up to 30 months. The standard of the finish that was ultimately selected and the monitoring system were to decide about the final value of the venue. The tender to select a contractor for the construction of the stadium brought surprising results. Firstly, the most lucrative offer made by the bidders participating in the tender was still over 200 mln PLN higher than the amount the City Authorities planned to allocate for the stadium construction. Secondly, the very procedure to select a general contractor encountered great difficulties, which resulted in a significant delay to the beginning of the work. What caused the delay were the appeals against the decision by the Tender Committee submitted by the companies which were rejected from the tender process at its early stages.

At the end of January 2009 the Tender Committee assessed that the best offer, out of nine applying companies, in terms of the stadium construction was made by a Greek - Polish Consortium**.** The decision made by the Tender Committee was influenced by the fact that the Greeks had experience in stadium construction, as, among others, they had built Olimpiakos Stadium in Athens; the Consortium offered the lowest cost of the investment, which was 730 mln PLN (rejected offers included 755 mln PLN and 936 mln PLN (gross price) (Figure 3). Furthermore, the Consortium offered to complete the project within 21 months, provided a 25-year guarantee for the roof and elevation, a 10-year guarantee for the remaining parts of the facility and a 3-year guarantee for all mechanical equipment that belonged to the stadium.

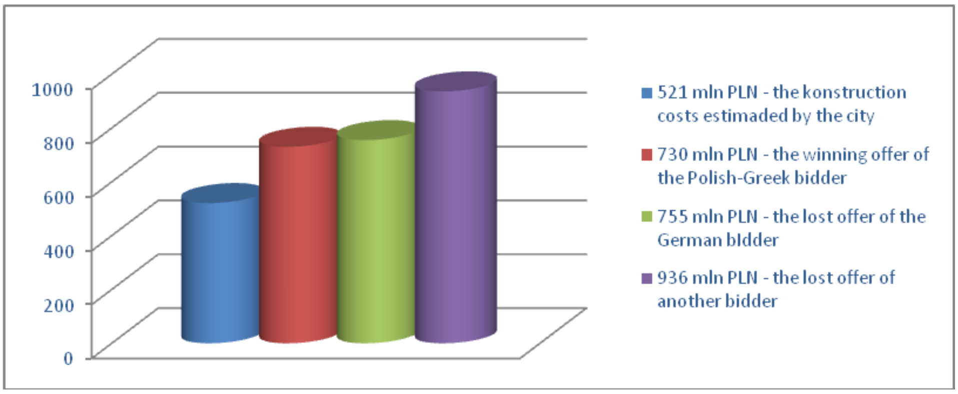

Figure 3. The stadium construction costs as proposed by the city and the bidders

However, a German Consortium lodged a protest on the grounds that the winning offer did not contain sufficient bank guarantees in the deposit document and that it was drafted according to Greek law. The Tender Committee, which for this reason assembled again, acknowledged the arguments, changing its original decision in favor of the Consortium lodging the appeal. National Appeal Chamber, however, upon the application filed by the original winner of the tender, reviewed the previous decisions made at the earlier stages of the tender, and at the turn of February and March 2009, announced its final decision, making the Greek-Polish Consortium the winner of the tender procedure. Moreover, the German company still trying to secure the contract for the construction of the stadium and not accepting the decision of the National Appeal Chamber, filed suit in District Court. Yet, this action did not bring anything new to the case.

Finally, based upon the decision made by the National Appeal Chamber on April 14, 2009 the President of the city of Wrocław signed a contract with the General Contractor – the Greek-Polish Consortium made up of several international companies, including the Polish ones. The final contract was titled, “Working Plans and Specifications for the New Stadium at ul. Drzymały, Wrocław and the Construction of the Stadium”(Mostostal, Report No. 13). The realization of the project was set to take 21 months from the date of signing the contract. The value of the contract amounts to 729.70 PLN (gross price). During the last ten days of April, preparatory works began at the construction site whose purpose was to develop the infrastructure of the entire investment. The money that was missing as a result of the difference between the city’s estimations and the actual price quoted in the winning bid was taken from the city’s budget. This was possible due to the postponement of payments for other investments currently realized in Wrocław, so that, for example, payments due in 2012 will be paid in 2013. One of the investments, to which this payment postponement applied, was the ring-road of Leśnica – a city's district as well as the reconstruction of some of the streets, the hundred apartment houses program and the construction of the line for high-speed trams. The mentioned investments are linked in varying degrees to the city's preparations for EURO 2012, hence it is assumed that their realization cannot be delayed despite the change in the manner of their financing. The assumption therefore was that part of the financial provision intended for the realization of these tasks came from own resources as in the case of Public Transport Company which is building the line for high-speed trams. To allow these decisions to come into force, the City Council had to approve and pass adequate changes in the Long-Term Investment Plan for the City of Wrocław.

Figure 4. The construction of the municipal stadium in Maślice, Wrocław

The Wrocław football stadium (Figure 4) for the European Football Championship was being built from the foundations up as an innovative venue for sports and entertainment events. It constitutes the central and most important part of a large sports and recreational facility, covering the area of 164.152 m^2, emerging in the western part of the city called Maślice. The selection of this site was not accidental; the Wrocław Motorway Ring-Road, is adjacent to the site. The Motorway Ring-Road has been considered in the city's plans for many years. It connects the A4 international motorway with national roads 5 and 8, in the future S5 and S8, in the direction of Poznań and Warsaw, serving as a transit traffic route from the west and south of Europe to Northern Poland, avoiding the central parts of Wrocław. Besides, it ensures a more smooth transport of football fans from Wrocław Airport to the stadium, close to which collision-free intersection – exits from the Motorway Ring-Road. Moreover, close to the site of the stadium there is also an important arterial road with several lanes intended for motor vehicle traffic, including a separate lane for public railway transport. Thanks to a several-meter-long lane crossing the inner city ring-road, this arterial road provides a direct connection between the stadium and the city center as well as its northern and southern districts. In addition, the system of high-speed railway transport called "Tram Plus," provides a special extension into the city center and its eastern parts.

It seems that the location of the venue for sports, entertainment and cultural events that Wrocław has been missing for so long was very well selected. The facility for over forty thousand people should be easy to access and easy to leave for fans coming from different places, not only from Wrocław, as will be the case during international events. Consequently, the entire process should occur without paralyzing the part of the city where the stadium is erected.

In terms of architectural and construction aspects, the facility surely is a big attraction both for Wrocław citizens and football fans and tourists coming from other places. The concept of the architects designing the four-storey facility is reflected in the light reinforced concrete structure of the stands with an in-built part housing conference and office rooms as well as sports infrastructure. The lightness of the structure of the facility is emphasized by open promenades, transport routes for football fans, partially glassed roof and especially by innovative elevation which will be made of a glass fiber net covered with Teflon. The net is spread on steel rings surrounding the entire venue, at the same time hiding its internal elements. Modern illumination technology designed for the external elevation is adjusted in terms of colors adequately to the character of the mass event taking place at the time.

The stadium is used mainly as the place for holding football matches. Before the opening of the European Football Championship 2012, the local league Wrocławski Klub Sportowy (WKS) Śląsk Wrocław will play here matches, and the national team as well. During the rest of the time the facility will fill the spot Wrocław has been missing for so long providing a venue for big cultural events. The stadium with the adjacent satellite facilities, including underground and ground parking will become a place for staging concerts and musical festivals, fairs, exhibitions and conferences of national and international standing. Moreover, a number of rooms will be let for fitness clubs, restaurants, casinos, discotheque and offices. The idea of using the infrastructure continually will expand the city's offer for its citizens regarding free time spending. Furthermore, the venue will contribute to the increase of income financing the facility and to economical growth of this area of the city. Basic parameters of the football stadium (Report, April 2009) are as follows: the area of the lot – 164 152 m^2, dimensions – 272 x 224 m, the height of the stadium – 39 m, the number of storeys – 6, the roof area – 38 000 m^2, the external elevation area – 23 000 m^2, the area to be let – 9 500 m^2, the number of seats (gross amount) – 41 373 m^2, parking under the crown of the stadium – 415 parking places.

Risk factors involved in the pre-construction preparatory work and during the construction of the stadium – problems with property

Despite the fact that works were conducted on the construction site of the stadium as of April 2009, the ownership problems related to the real estate where the construction works are taking place have not been fully solved. This refers especially to the property where the plans foresee car parks construction, the Wrocław Motorway Ring-Road exit and the terminus for the system of a high-speed railway transport. Also, part of the property is to be used for widening the street, thereby making the access to the stadium easier in the future.

The basic impediment to the planned work was the dispute between the current owners of the property and the local authorities wishing to acquire the property for further investments. The disagreement between the parties involved stems from the difference between the price the owners expect to obtain for their property and the price the city is willing to offer. At an early stage of the dispute, which was in the mid of 2008, the city offered 5 mln PLN to pay for the property, whereas the owners demanded 7 mln PLN. In the following months, during property market slump and based upon appraiser assessments the city offered 3.6 mln PLN while the property owners' demands remained virtually unchanged. While negotiating, the representatives of the investor tried to settle the dispute by applying various means. One way was to offer another property located in a different part of the city in exchange for the renouncement of the property in question. Moreover, independent experts were called up from Real Property Valuer Association to settle the dispute by arbitration conducting negotiations over the price that would satisfy both parties. Since all these actions did not bring any results, Lower Silesian Governor started an expropriation procedure upon the application filed by the investor, in other words the city, and in accordance with the rules and regulations of the Act, then in force, on Preparation of the Final Tournament of the 2012 UEFA European Football Championship. This, however, proved ineffective when the property owner transferred its property by Deed of Gift to another member of his/her family because by changing the property owner the expropriation procedure became formally unfounded. This situation showed that each time negotiations started, being the requirement of the first phase of property acquisition, the expropriation procedure could successfully be blocked by the property owner. A contributing factor here are Polish regulations specifying the terms for transferring property by Deed of Gift as they stipulate that members of the immediate family can transfer property to one another incurring hardly any costs, since the donation within the immediate family is tax-free. Thus mutual transferring of property within members of the immediate family appears to be a very effective tool against expropriation, thereby allowing owners to hinder public investments very effectively indeed.

The amendment to the Act on the EURO 2012 introduced at the end of 2009 was an attempt to remedy the loopholes which made it possible to block public investments by property owners, as the case in Wrocław clearly exemplified. The Amendment to the Act sets up that expropriation procedure will be conducted by the operation of law, which means that the owner will not be a party to the case. Of course, an expropriated and potentially wronged owner will ultimately be able to claim his/her rights in court, yet this will not have a limiting effect on commencing and implementing investments.

Nevertheless, the case has not been finished yet. After introducing new rules and regulations amending the Special Purpose Road Act, the city asked Lower Silesian Governor to make a new decision regarding investment localization. The new decision was to enable the application of the new rules and regulations of the amended Act. Yet, the Governor claims that such a decision was already made at the beginning of 2009 and remains in force because the city has not acquired the land since the date the decision was given. In response to that the city filed an appeal to Infrastructure Minister. In case the appeal is not accepted, another localization for the investment has been selected. The plan foreses the reduction of the number of parking places for buses and moving the transfer node of public transport to another place, which would still ensure an adequate access to the stadium.

Risk factors involved in the pre-construction preparatory work and during the construction of the stadium – problems with the contractor

On December 30, 2009 quite unexpectedly, hardly eight months after the works began, the winning Consortium was dismissed from the works on the construction site. The contract between the contractor and the investor that is, Wrocław Municipality was terminated due to the growing delay in the investment realization. According to the schedule, at the end of 2009 the so far accomplished work should reach 22 percent of the total work amount to be realized; yet, the substitute investor claimed that only 7 percent of the work was completed. The work which was performed, within the crown of the stadium, included the foundations, 500 monolithic pillars and most of the walls on the level 0 as well as a part (15%) of the roof made of prefabricated and cast elements located above the level 0. Apart from that, the works on the installation of sanitation, water/sewage and electrical systems commenced (Report, December 2009). All the works which were completed were not enough to turn the level zero into a shell, as was foreseen in the project schedule. Until the date of the contract termination the works performed at the levels 0 and +1 should have been completed while the works at the level +2 should have started. As it was not the case, finishing the construction of the stadium by the end of 2010, specified as the deadline, became simply unrealistic.

Additional danger was the ever growing delay, especially that the contractor asked the investor twice to change the commissioning date. First the contractor asked to extend the completion date by 2 months and then by 2.5 months. The special-purpose company as the substitute investor, while monitoring the increasing delays, asked the contractor on numerous occasions to implement plans to remedy the growing delays. As the contractor provided no guarantee that the existing situation would be remedied, the investor terminated the contract after having exhausted all the means to influence the contractor's actions available under the contract. The company Wrocław 2012 sp. z o.o., acting upon the authorization of the President of Wrocław terminated the contract on the following grounds: delay of over 35 days in performing the contract, delays in performing the contract making it very unlikely that the contractor would be able to complete the subject of the contract within the deadline specified under the contract and failure to perform the contract. The investor, under the provisions of the contract, called on the Consortium to pay the contractual penalty in the amount of 72.97 mln PLN (Mostostal, Report No. 1, April 2010).

At the same time it was announced that a new contractor would be selected without tender procedure, as the new tender procedure could cause further significant delay in the construction of the stadium. This was possible as Wrocław Municipality, while selecting the new contractor, used its right to apply a shorter procedure, which is a single-source procurement procedure. According to Public Procurement Law, the investor informed the President of Public Procurement Office about the procedure and presented a comprehensive argument why the Company Wrocław 2012 had decided to use the single-source procurement procedure. Of utmost importance at this stage was to fulfill all legal and formal requirements related to the contract termination and the new contractor selection. Fully aware that the entire project was on the brink of collapse as there was a chance that it would not be completed within the deadline imposed by UEFA, the city authorities had to make decisions extremely carefully in order to avoid potential claims and appeals filed by third parties.

Concerned with the slow progress of the work at the construction site and even before terminating the contract with the Polish-Greek Consortium, the investor initiated talks with the Consortium which had been dismissed in the first tender procedure. This move provided time to conduct final negotiations whose result was the signing of the contract "Continuation of the Construction of the Stadium in Wrocław, Including Working Plans and Specifications" on January 16, 2010. The contract was concluded by the German company which in the first stage of the tender made the second best offer in terms of the price.

A German based company Max Bögl has been in business for over 80 years, with its branch offices in many European countries, including Poland.

At present the company is conducting construction works in several countries. The most well-known large facilities the company has built are the stadiums in Frankfurt and Kiel as well as the sports and recreational facility “Tropical Islands” located near Berlin. One of the biggest assets of the company is its own factory manufacturing prefabricates and steel structures situated in Sengenthal, Bavaria. A significant number of elements for the stadium in Wrocław is to be produced in the factory, as for example the steel construction of the roof.

The selection of the new contractor and its presence at the construction site in January – February 2010 seemed to be the last moment before UEFA would have decided to exclude Wrocław from the group of the cities hosting the Tournament on the grounds that the City did not meet the requirement to have a sports venue ready to use for the Championship. We should remember that the stadium has to be completed early enough to ensure that many other events can be held there, confirming that the facility is technically and operationally adequate.

One positive factor in the entire situation of having to replace the contractor might be the time it happened. Although for a short period of time no technical works could be carried out at the construction site because of the above problems, fortunately this coincided with a very demanding winter season; since the beginning of January 2010 Wrocław witnessed increased snow fall and temperatures plummeting to as low as -10°C or even -20°C and remaining so for longer periods of time. Freezing temperatures kept a layer of snow 20-30 cm thick, making it very difficult to work on investments that were not a shell yet. Waiting for the weather to change provided time for intensive preparation of the construction site, which involved the removal of technical installations left by the previous contractor, stocktaking of the so far completed constructions as well as the organization and preparation of the new contractor’s temporary plant and facilities. While negotiating the terms of transferring the construction site to the new contractor, the previous contractor agreed to leave some of its equipment to be used by the new contractor in exchange for the reduction of contractual penalty for the failure to complete the work within the deadline specified. Undertaking such actions as well as avoiding disputes by both parties during the process of changing the contractor ensured that the time when the construction site stood empty was significantly shortened. Watching closely the actions taken by UEFA in the case of the stadium in Kiev, which at that time constituted a very serious threat to the Ukraine’s side organizing UEFA EURO 2012, it could have been expected that the facility would no longer be considered in the plans related to the Tournament. As far as the investment in Wrocław was concerned, it was known at that time that all the elements constituting a part of the stadium such as off site facilities may not be finished. But the stadium itself with all its functions and infrastructure necessary to stage the games is now ready to use.

6. Road infrastructure construction and reconstruction projects in Wrocław

Figure 5. The construction of the Wrocław Motorway Ring-Road A8

The Wrocław Motorway Ring-Road (AOW) (Figure 5) along with the football stadium in Maślice belong to the investments which were most awaited by the people of Wrocław and of neighbouring regions, closely watching the projects. The stadium is a facility where all important and interesting sports and cultural events will be taking place. So far, this kind of facility has never existed in Wrocław and it is expected that the venue would become a big magnet for audiences from the entire voivodeship and beyond. To access the stadium by people coming from such a big region and to meet the demands of increased traffic in Lower Silesia the usual city's road network and transport routes may notbe enough. What is needed here is a new transport solution which would enable people to avoid central district of the city which is anyway always over-crowded. The city's main arterial roads are constantly jammed with cars, giving no hope of easing the traffic consisting of different tonnage vehicles. Moreover, the traffic passes through residential districts which either have never been adjusted to this traffic or have not been reconstructed when the time was right for such an action. In spite of enjoying a very advantageous location in terms of trade with the Czech Republic and Germany, the city of Wrocław has remained a barrier hindering the increasing transit traffic as a result of its poorly developed road network, especially to the north and south. Vehicles moving from west to east or the other way round are more lucky as they do not have to face the bottleneck of Wrocław. Important for European traffic is A4, a modernized motorway which passes beyond the southern borders of the city. However, if we want to leave the "Bielany Wrocławskie" motorway intersection in order to head north towards, for example, Warsaw, Łódź or Poznań, we have to pass a 20-30 kilometer-long city road section (depending on the direction) which can take from one to three hours (depending on the time of the day). The main reason for the present situation is that the streets in Wrocław, being part of the inner the transport route, are overloaded with vehicles driven by Wrocław citizens whose number increases every year and so does the transit traffic. Moreover, this situation has led to a growing number of car accidents, pedestrian injuries, excessive road surface destruction, destruction of public transport facilities, cracking of buildings located directly at the arterial roads, increased air pollution in the city and growing dissatisfaction among its citizens. The idea of building only an inner city ring-road does not solve the traffic congestion problem because the capacity of the inner city ring-road ensures only to ease the inner traffic, and still does not function as a closed "ring."

However, the inner city ring-road has so far been the only answer to the city's transport problems. Yet the ultimate solution cannot lie in having a transit road passing through the city center, since most of the intersections there consist of just one level and can include railway transport routes too. Additional problem stems from the characteristic location of Wrocław. It is situated in a valley crossed by small rivers and where the rivers Ślęza, Bystrzyca, Oława and Widawa flow into the Oder River. Moving traffic from one river bank to another requires each time a complicated bridge infrastructure. Any road investments which were to include such infrastructure were abandoned, as the City's Authorities were daunted by their very high cost. Nevertheless, the upcoming event induced the Authorities to assume the huge financial and organizational burden of solving transport problems in the city while, at the same time, making all the adjustments necessary to host the Tournament. Taking example from Kraków with the aim of easing the traffic in the city's area, it was decided to construct a road whose features would be that of a motorway in a completely different location. Additionally, design and construction works for a number of roads, connector roads and new tram lines (Table 2) have been started, which will widen the transport infrastructure of the city, connecting it with the new motorway, the stadium and the airport.

Table 2

The projects in the land transport category, classified as the most important for the successful organization of EURO 2012 (Report, December 2009)

Name of the investment and the state of its progress	**Financing**
The reconstruction of Lotnicza street along the route of national road No. 94. The project was finished before deadline. The work ended in October 2009. In March the permit to use the road was issued.	**Co-financing –** Infrastructure and Environment Operational Program
The reconstruction of Kosmonatów street along the route of national road No. 94.	**Co-financing –** no data available
The construction of a junction between the Airport and the Football Stadium along the route of national road No 94 in Wrocław.	**Co-financing –** no data available
The construction of a junction between the inner city ring road and the Wrocław Airport – phase I.	**Co-financing –** Regional Operational Program for Lower Silesian Voivodeship for the years 2007-2013
The construction of a junction between the inner city ring road and the Wrocław Airport – phase II.	**Co-financing –** Regional Operational Program for Lower Silesian Voivodeship for the years 2007-2013
The construction of a junction between the inner city ring road and the Wrocław Airport – phase III.	**Co-financing –** no data available
The construction of the northern inner city ring road in Wrocław – phase I.	**Co-financing –** Infrastructure and Environment Operational Program
The construction of road infrastructure in the vicinity of the Football Stadium EURO 2012 in Wrocław. The investment was divided into two phases (No. I and II), encompassing the construction work along the new route and the rebuilding of the streets adjacent to the Football Stadium in order to link them with national road No. 94.	**Co-financing –** Regional Operational Program for Lower Silesian Voivodeship for the years 2007-2013

The construction of an integrated transfer node in the area of the Football Stadium EURO 2012 – Stadium EURO 2012 transfer node. The Project foresees the construction of an integrated transfer node connecting a train halt and tram stop in one place. The Project is conducted within the framework of the construction of the integrated railway transport system in the agglomeration and in Wrocław.	**Co-financing –** no data available
The construction of a car park, including land development south of national road No. 94 between the Slęza river and railway line.	**Co-financing –** no data available
The reconstruction of Lotnicza street along the national road No. 94 route – phase II. The works relate to the construction and reconstruction of the streets along the route of national road no. 94.	**Co-financing –** no data available
East land development between the area of the Stadium and the Ślęża river, including footbridges.	**Co-financing –** no data available
Integrated railway transport system in the agglomeration and in Wrocław – phase I.	**Co-financing –** EU structural funds within the framework of Infrastructure and Environment Operational Program
Intelligent Transport System in Wrocław „ITS-Wrocław”. Putting the system into operation for the first time foresees traffic control and public transport monitoring, including Tram Plus.	**Co-financing –** EU structural funds within the framework of Infrastructure and Environment Operational Program

The announced and planned A8, the Wrocław Motorway Ring-Road was built on the north-western outskirts of the city along a completely newly drawn axis. Selecting Wrocław by UEFA to be one of the organizers of EURO 2012 was with no doubt the final impulse to start the investment. Becoming the member of the European Union nations was another influencing factor, especially that some of the funds for the construction of AOW (*Wrocław Motorway Ring-Road)* will be coming from the EU. The ring-road becomes a junction between the southern sections of roads No. 5 and 8 going towards Kudowa Zdrój, Świdnica and Jelenia Góra, the A4 Motorway and the northern road network in the direction of Poznań, Łódź and Warsaw. Besides the present system of the city roads, AOW moves the transit traffic beyond the city’s borders, thus having a positive impact on the environment, among others, and improving road safety on the route and in the city itself. The motorway belongs to the technical class A, with planned speed of 120 km/h, dual-carriageways, two or three traffic lanes, the width of which ranges between 3.5 and 3.75 meters and an emergency lane. It is designed for very heavy vehicle traffic with the maximum load of 115 kN (Egis 2009).

Table 3

Tasks included in the construction of Wroclaw Motorway Ring Road

Task No.	**Task description**
I part 1	– road building from 1+603 km to 13+500 km, – the construction of the Kobierzyce junction from 0+000 km to 2+489 km,
IIA part 2a	– the construction of the bridge over the Oder river, including access trestle bridges on the section of the road, starting from 18+174 km to 19+960 km, along the route of the A-8 Wrocław Motorway Ring Road,
IIB part 2	– the construction of the road section from 13+500,00 km to 18+174,00 km, – the construction of the road section from 19+960,00 km to 28+368,75 km, – the construction of the section of the S8 expressway road from 0+000,00 km to 0+500,00 km at the Pawłowice junction, – the construction of the Długołęka junction from 0+575,00 km to 6+235,85 km,

In terms of organization, the investment was divided into three sections, whose construction was to be conducted by separate contractors selected from three different tender procedures. Six bidders offered to perform task No. II, part 2a, whereas twelve other offered their services to perform the remaining tasks. The contractors (Table No. 3) were chosen by the tender procedure, in which the most important factors were the price and the fulfillment of all terms and conditions specified in Terms of Reference. There were also appeals against the decision regarding the construction of the bridge over the Oder River. Accusations were raised against the winning bidder that he had not fulfilled all the formal requirements, made mistakes while calculating the value of the offer and lowered prices of certain materials.

Dividing the construction of AOW of only 26.765 km long into three separate sections might seem wrong. However, keeping in mind how the companies can potentially act, including lodging an appeal against decisions made during tender procedures, choosing this method at least prevented the blocking of the entire investment. Furthermore, there were three smaller facilities being constructed concurrently, which provides a much better chance of successfully completing the entire work within specified deadline. Another advantage of this way of planning the project was that if the investor was to assert claims for construction defects, the claims would regard a much smaller construction area. On the other hand, there was danger that delaying or discontinuing work on one of the tasks may impact the work performed on the other tasks. This would prevent the investor from using the road fully, forcing him to work out other costly solutions in operational and organizational terms as, for example, creating a detour around the section which is not operational.

Moreover, the complexity of the entire investment was another reason to divide the construction work among the three consortiums. The section to be constructed of 26 km long is part of a 35.5 km long road consisting of a motorway, an expressway road, two connector roads, seven junctions, forty one bridge-type structures, two animal crossings, access roads and technical infrastructure facilities.

Table 4

The scope of work performed within individual tasks related to the construction of AOW

TASK NO I, PART 1
– the construction of the A-8 motorway, approx. 12 km long, and the rebuilding of the section of the A-4 motorway in the Nowa Wieś junction area; – the construction of the Kobierzyce junction, 2,5 km-long, between national road 8 from Kudowa to Wrocław and the A-8 motorway ; – the construction of 4 motorway junctions (Kobierzyce, Nowa Wieś, Cesarzowice, Lotnisko) connecting the A-8 motorway with national and voivodeship road going to the south, the A4motorway and Wrocław Airport; – the construction of an intersection with traffic lights at the junction of national Road No. 8 and the Kobierzyce connector road ; – the construction of 20 facilities, having re-enforced concrete or prestressed structure, over water ways, roads and railway lines: – 10 flyovers along the route of the Wrocław Motorway Ring Road (AOW); – 1 motorway bridge over the Kasina river; – 4 flyovers along the route of the connector roads over roads: A4 and 347 and a railway road; – 5 flyovers over AOW along the route of the streets that are being rebuilt; – the construction of roads crossing AOW of 6,3 km total length and the construction of intersections with traffic lights;

– the construction of access and service roads of approx. 21,5 km total length ; – the construction of drainage systems for the motorway and the rest of the roads and streets; – the construction of 22 re-enforced concrete culverts with wildlife overpasses and several dozen steel pipe culverts ; – the construction of motorway lighting and foundations for the elements of the motorway communication system, lighting for the sections of the remaining roads and streets as well as reconstruction of electric, water, sewage, gas and telecommunication networks; – the reconstruction of railway facilities at the AOW crossings with railway lines; – putting up approx 8 km of noise screens, 4-7 m high, mounting road safety facilities, horizontal and vertical road signs; – removal and transfer of green areas, colliding with the construction works and planting new small and high growing greenery.
TASK No. II A PART 2a
– the construction of the bridge over the Oder River and access flyovers at the left and right river banks; – the construction of the motorway sections on the left bank and right bank of the Oder and at the right and left sides of the bridge; – the construction or reconstruction of access roads and streets to the section of A8 and the section of the bridge; – the construction of drainage system, transformer station, road lighting on the bridge, lighting of the inner corridors located in the bridge pylon and spans, including floodlighting of the bridge; – the construction of telecommunication network, cable ducting for electrical cables and emergency telephones as well as Motorway Information System and the reconstruction of overhead power lines, medium and low voltage networks that collide with construction works; – mounting special screens preventing collisions with birds;
TASK No. II B PART 2
– the construction of a 13,08 km long motorway, a 0,5 km long section of the S8 expressway road as well as a dual carriageway junction, 5,66 km long, as a connector road between the A8 motorway and national road No. 8; – the construction of 3 junctions connecting the A-8 motorway with the streets based in Wrocław, located in the route of national roads; – the construction of 3 intersections with traffic lights in the junction area; – the construction of a roundabout, street junctions and the reconstruction or construction of streets of 6.8 km total length; – the construction of 19 facilities, having re-enforced concrete or prestressed structure, over waterways, roads and railway lines: – 4 flyovers along the route of A8 over the streets, railway and tram lines as well as irrigation fields located in Wrocław; – 9 flyovers over streets, roads, junction connector roads as well as railway lines;

– 4 bridges over the rivers: Dobra, Topór and Widawa with its valley and the Sołtysowicki brook; – 2 animal crossings over and under the roads; – the construction of access roads and access service roads of 8.8 km total length; – the construction of drainage system for the motorway and the remaining roads and streets; the reconstruction of melioration facilities; – the construction of 24 ferroconcrete frame or pipe culverts as well as several dozen culverts made of PE-HD pipes; – the construction of lighting for the sections of the motorway, junctions and some of the roads and streets as well as the lighting for the technical corridors located in the box-bridge spans of the flyovers and the construction of the elements of the motorway communication system; – the construction or reconstruction of electric, water, sewage, gas and telecommunication networks; – the reconstruction of railway facilities at the AOW crossings with railway lines; – the reconstruction of tram railway (railways, traction, lighting, stop platforms); – the construction of motorway information system, including meteorological stations, traffic measurement stations, in-motion vehicle weighing systems, variable message signs, video access point system, power supply station, the mounting of supporting structures and facilities for the entire A-8 motorway, including the sections covered by the contracts that are concurrently performed; – the construction of the retaining wall of approx. 0.3 km long and putting up approx. 8 km of noise screens, 3-8 m high as well as the mounting of road safety facilities and making of vertical and horizontal road signs; – removal and transfer of green areas colliding with the construction work and planting forests on 6.5 hectares of land as environmental compensation;

The scope of the work presented in Table 4 covering the construction of AOW is truly imposing considering the number and complexity of the tasks involved. Moreover, there was relatively little hindrance to the vehicle traffic in the areas adjacent to the construction site. As mentioned above, the works were being carried out within a completely new route, causing no need to reorganize traffic flows. Only in places where the investment overlaps with the existent road facilities there were certain limitations due to safety for the contractor and traffic participants. The very localization of the ring-road was the result of public consultations of many years, whose outcome did not allow the investor to be entirely free when choosing the most advantageous scenario in terms of making the construction work as easy as possible, thus minimizing the costs of the investment. The motorway ring road passes adjacent to the western side of the stadium, which is very convenient for operating UEFA EURO 2012. However, the investor had to face the necessity to build a bridge across the Oder River in a place that required that the bridge would have to have high technical parameters in terms of the length of spans. The crossing is in the valley of the Oder River where a barrage is placed and where there are also two river channels through which the Oder flows around the island of Rędzin. The island has just been used for the erection of a 122 meter high pylon on which two independent structures, located under each of the carriageways, is suspended using 80 tension rods. Two box-bridge structures, each consisting of three chambers make the carrying structures of the bridge spans. The bridge crossing over the Oder River constructed along the AOW route becomes one of the most interesting facilities across the country in terms of its uniqueness and technological solutions, as for example the temporary technical bridge. Considering the span and the height of the pylon, the bridge will take the lead among the bridges in Poland. The full length of the bridge crossing is 1742 meters, including the main bridge of 612 meters, the left river bank flyover of 611.35 meters long and the right river bank flyover of 521.35 meters long (Bliszczuk and Onysyk 2009). The main bridge is on four spans; the left river bank flyover on eleven spans will be located over the Ślęza river and the flood areas, whereas the right river bank flyover stretching over the flood areas is on nine spans. The elements of the bridge described above as well as other bridge structure elements are monitored by a specially designed automatic supervision system. The system will make it possible to supervise the facility constantly, including the way it operates in various conditions while it is used. Force distribution, deviations, deformation and wind direction and speed are measured automatically. Thus obtained data will be then sent to the AOW management center where it is analyzed and used for responding adequately to the situations that may damage the bridge.

7. Airport development project

Currently the new airport located in Wrocławs Strachowice is already finished. The funding just from the Infrastructure and Environment Operational Program alone amounts to 128.11 mln PLN. It is worth mentioning that the airport receives additional funding of 13 mln PLN to purchase control and safety system for the new terminal. Although the number of passengers flying to and from the airport in 2008 was similar to the number of passengers in the year 2009 (respectively: 1.49 mln and 1.37 mln (Figure No. 6), the result of the global economic situation of the last two years, the airport forecasts that passenger traffic is growing since last two years. It is estimated that in 2012 this number will reach 1.9 mln and in 2014 it will increase to 2.2 mln and in 2016 it may be 2,5 mln passengers. Furthermore, we should consider that in 2012 the number of tourists will increase due to the European Football Championships UEFA EURO 2012. Previously in the article, we presented the road investments which are under construction to ease the increased passenger traffic, ensuring that travelers, tourists and football fans will be able to move easily from the airport to the city's center or to the stadium and back. The airport, in turn, is getting ready for the growing air traffic by modernizing and developing its infrastructure which, according to the plan, is to be completed in 2012.

The investment includes the construction of a new terminal with modern passenger service facilities; the cubic capacity of the terminal wll amount to 330 429.81m^3. In addition, aprons and taxiways will be constructed and modernized. Also, a high speed exit taxiway will be built along with a special surface for quick de-icing of airplanes. Besides, the plans include the construction of a bigger car park and a railway station located on the level-1 providing transport services to passengers between the newly constructed airport terminal and the main railway station situated in the city's center.

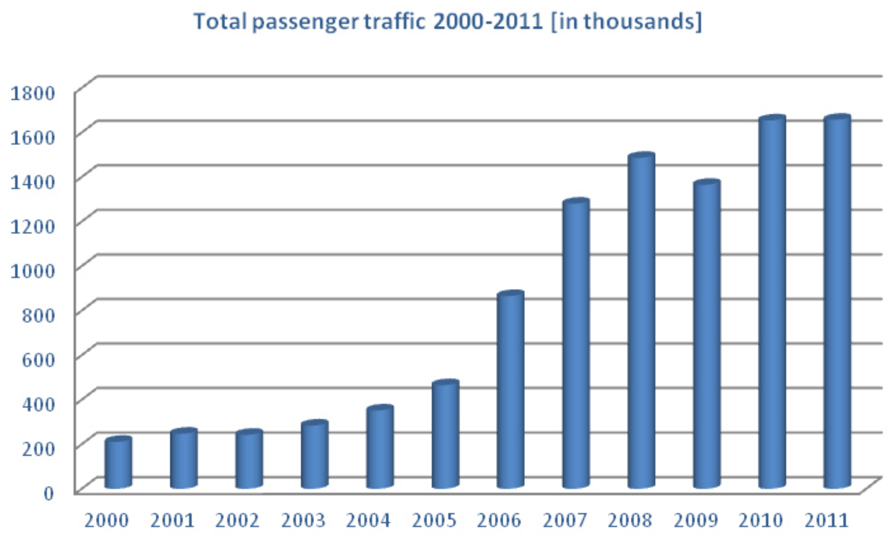

Figure 6. Passenger traffic increase at the airport in the years 2000-2011

8. Agglomeration transport development projects

Since 2006 intensive works have been carried out to integrate public transport in the city of Wrocław. The aim of the project is to integrate all the means of the present public transport into one system managed centrally. The system will include railway transport (Agglomeration Railway of the city of Wrocław – WKA, Kolej Miejska – Municipal Railway), bus transport in the agglomeration area, the subsystem of local transport to WKA, a new Tram Plus system, tram transport and municipal bus transport. There are two main guidelines according to which the goals for a series of investments are defined. The project should ensure a uniform system for public transport in the entire agglomeration and, taking example from other European countries, it is to become a viable alternative for personal transport. Consequently, actions were taken to build new tram lines and extend the existing ones; as well as to build such facilities as tunnels routing new corridors in the inner city and the construction of transfer nodes integrating all the means of public transport. In addition, adequate solutions will be introduced to give the public transport priority in the city's traffic and passengers will be able to plan easily their movement within the city thanks to dynamic passenger information.

The implementation of the system was divided into two interrelated phases (phase I – 2007-2011 and phase II 2010-2015). When the role of Wrocław in the organization and staging of EURO 2012 was unequivocally defined, some of the works from phase II were moved to phase I. This had the effect that the beginning of the construction works on the transfer node in the vicinity of the stadium was accelerated.

9. Renovation and redevelopment of the main railway station

The Main Railway Station will be the first thing some of the football fans coming to the UEFA EURO 2012 Championships will see. Built in the nineteenth century, the Station is one of the flagships of the city. It will also be rebuilt in order to operate according to European standards and so adequately serve the guests coming to watch the Tournament. Apart from improving its aesthetics, the Station will assume a bigger commercial role, which will make it more popular and no longer associated only with railway transport. Giving a new image to the Station will require its being closed to railway transport from 2010 to 2012. Its operations will be taken over by a substitute facility.

10. The state of hotels

When organizing and staging such a massive event as the European Football Championships, apart from travelling and movement comfort, the standard of accommodations during the Tournament is very important as well. It is the host city's responsibility to provide football teams, UEFA representatives as well as football fans with adequate accommodations. The UEFA guidelines are the first determinant of the required number of accommodation places, including their standard. The guidelines set up that there must be at the minimum 1220 places available in 5- star hotels for the UEFA Family; 1315 places in 4-star hotels; and 210 places in 3-star hotels (Report, April 2009). However, the UEFA Family is not the only group among football fans. Thousands of fans of individual national teams will come to Wrocław to watch the matches played by their teams. The capacity of the stadium alone, which is 41 thousand people, reflects the number of accommodation facilities that will be necessary during the Tournament.

According to the categorized list of accommodations, at present there are 41 accommodation facilities capable of providing accommodation for 6661 guests (e2012.eu), whose standard ranges from 1 to 5-star hotels. This data are changing since last two years as additional 14 facilities of higher standard are being constructed, thus increasing the number of accommodations by further 3473. Since the work is being conducted by private investors and well-known hotel brands, the city does not directly participate in the construction of the hotels. Nevertheless, it actively participates in these preparations by presenting the real-estates at fairs such as, for example, International Fair Trade for Private Property and Investment EXPO REAL in Munich and at Fair Trade MIPIN in Cannes. Moreover, in line with the plans whose purpose is to support the tourism sector and increase the number of accommodations, the City Council passed a resolution providing tax advantages for new investments within the framework of the economic support program for the region designed to support new investments in the tourism sector in the city of Wrocław. The effect of these actions was the sale of 7 real-estates in the years 2007 – 2008. Currently more land is being considered for the building of hotels in the local real-estate management plan.

Conclusions

The goal of the paper was to present a case study of the preparations for the 2012 UEFA European Football Championship in Poland, and especially in Wrocław, in order to help the managers of similar multiproject undertakings in the future to manage more effectively the risk and to reduce to uncertainty linked to such projects. In the moment the paper is written, the preparations are on their way, and we already have had some difficult, but valuable experience. Several problems occurred which were threatening the success of the projects conducted in the framework of the preparations, several problems can still be expected in the basis of the experience. The problems from the past had to be solved somehow, the problems to be expected have to be managed also – all this may constitute valuable advice for similar projects in the future.

To sum up the main problems that have been identified so far in the projects conducted in the framework of the preparations for the 2012 UEFA European Football Championship, we have to emphasize the legal problems. The law as it was formulated in the legal acts before the beginning of the preparations would have made them nearly impossible to be accomplished. Thus, several modifications had to be introduced. Also later the human nature which makes some people use the "holes" in legal acts for their personal advantage blocked the projects realization for a considerable period of time, which in case of projects which simply have to be finished in time, because otherwise we face a real disaster, is a very serious problem. The disputes concerned above all the land ownership and the bidding results. The long legal procedures of considering the appeals, the expropriation etc. were a real nuisance. Also it happened that a construction company which won the bidding did not accomplish what it was supposed to, thus we faced the necessity of changing a company, which made it necessary to deal with a an "empty" period where a new company had to be selected and the construction site had to be handed over.

We hope that the present paper will allow other project managers to learn from the lesson our country and city has been going through at the moment and that the painful learning process we have been experiencing will be of use to someone else.

Euro 2012 has not resulted in a success of the Polish representation. However, it has brought many economic effects, both positive and negative, unfortunately. Indisputably, a positive effect of the spectacular sport event consists in improving the road infrastructure, especially of the connector road of Wrocław and several sections of the motorway. This influences directly and indirectly the investment growth in the regions of newly constructed roads.

A negative effect of a too high speed of the investments and of the imperfect law of public tendering was the realization of projects which were improperly prepared. This led, paradoxically, instead to a growth of the construction enterprises, to their bankruptcy. Measurable effects of the value decrease of many big construction companies could be observed on the Warsaw Stock Exchange.

To conclude, we have to say that not always an increase in investments results in an increase of companies value. However, taking into account global pros and cons, we can observe that an improvement in the management culture, especially in project management, in a situation of an investment boom, influences the region and country economic growth in a decidedly positive way.

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THE NEW APPROACH FOR THE PROJECT ACTIVITIES CLASSIFICATION AND ITS APPLICATION IN THE CRITICAL CHAIN BUFFER MANAGEMENT METHOD[1]

Introduction

The three main project management dimensions are time, budget and scope of a project. Nowadays most of the effort, both of academics and practitioners, is paid to the first two constraints in a project scheduling. Most project managers, while planning and executing projects, try to follow two main guidelines, namely 'be on time' and 'be on budget'. Also the methodologies proposed by the academic researchers such as e.g. Critical Chain Buffer Management or Earned Value Management organize and evaluate projects from this point of view.

It does not mean of course that no attention is paid to a project scope. Nevertheless, in most of the cases, a project scope is not considered as a path leading to a final product but this final product itself. This kind of approach causes that for estimating time, but also money, needed to complete a particular project, the characteristic of the final product are taken into account instead of the content of the work which needs to be done for this project effective execution. It is not surprising then that although a wide range of the available tools for project management, also for these complex ones, plenty of projects are completed late, over budget or simply are failed. Surely one of the reasons of this situation is the fact that it is almost impossible to apply a right technique for a particular project if a content of work, which needed to be done, is unspecified.

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The outline of the paper is as follows: in section 1 the goal of this paper is defined. In section 2, the most complex section of the paper, we present the summary of existing knowledge in this matter by reviewing the literature, critical factors of project's success, contingency theory, project typology, project activities classification. Section 3 explains the applied research methodology, the process of building theory from case study. In section 4 the new approach for the project activities typology is introduced, classification of project activities from the angle of five dimensions. In section 5 the application of the proposed approach in the CC/BM is presented, incorporating five identified activities dimension in the buffer sizing procedure. Section 6 contains some conclusions.

1. The goal of the paper

The goal of this paper is presenting the typology of projects and proposes a new approach for typology of projects activities to define the impact of this factor on the size of inserted buffers in the Critical Chain Buffer Management Method (Goldratt 1997), solution applied in order to cope with inherent uncertainty associated with many projects. The presented classification was compiled from the analysis of the completed or still executed infrastructure and it projects which are performed as well by Polish public institutions, supported by European Union, and private sector.

2. Theoretical background

2.1 Critical factors of project´s success

The current achievements in the field of project management are very much inherited by the Critical Path Method, introduced in the 1950s by Morgan R. Walker of DuPont and James E. Kelley, Jr. of Remington Rand (Kelly, Walker 1959). Although many later attempts to improve this solution have been made like e.g. PERT, developed by the United States Navy in the 1950s, it needs to be said that nowadays project management requires a much complex approach than planning a sequential and interrelated set of the activities (Moder 1988). The best proof for that is the fact that a lot of projects overrun the assumed deadline and budget or are compiled not according to predefined customer requirements. However, besides ´being on time ‘and ´being on budget´ goals, which are obviously assumed to be reached by every project executor, there are some more dimensions of project success i.e.

Business results achieved by projects, impact on the customer, impact on the team or preparation for the future (Shenhar, Dvir 1996). All these factors whose performance decides about the project success of failure, brought the question what in fact are the reasons that project succeeds or fails? Many attempts to find an answer came to the same conclusion that projects performance, its success or failure, strictly depends on universal factors such as project mission, planning, communication, politics, control, top management support, etc. (Sauser, Reilly, Shenhar 2009). However, it needs to be said that although these critical factors of a project´s success are well known, their practical application in the project management environment is very low, mostly because they are defined too generally, more like philosophy than effective managerial tool. This situation causes a strong need for an effective framework of project success factors for a particular type of project.

2.2 Project management contingency theory – review of project typologies

Contingency theory was formulated in the late 1950s and applied mostly to the enduring organizations. Its main assumption is that organizational effectiveness is dependent (contingent) upon the organization´s ability to adjust or adapt to an environment, and that there is a need for cohesion between an environment and structure (Drazin, van de Ven 1985; Lawrence, Lorsch 1967; Pennings 1992).

The interest of researchers in adopting organizational contingency theory to the field of project management has been growing for the last twenty years. This approach explores a scale of fit and misfit between project characteristics and a chosen project management technique. It is rather obvious that finding potential misfits while performing an analysis of a real-life project can result not only in a better understanding of project failure reasons but also, what is even more important, can contribute to pointing a well-fitted approach for a particular type of project before it is started-up or, in case a project was already launched, give a chance to make adjustment in project tracking (Sauser, Reilly, Shenhar 2009).

Nevertheless, before the contingency theory brought a deeper insight into the nature of project management, a research about this discipline resulted already earlier in distinguishing projects according to a sector in which they are performed, like e.g. construction or research projects. In the scientific literature it can be found prior examples of project typologies. Blake (1978) claims existence normative distinction between minor change (alpha) projects and major change (beta) projects. In the matter of internal product development projects, Wheelwright and Clark (1992) proposed that projects should be divided into derivative, platform, breakthrough and R&D ones. The driver which causes this project typology is the degree of company's product portfolio changeability. The other project classifications were proposed by Cash et al. (1988), Ahituv and Neumann (1984), Pearson (1990) and Steele (1975). However, all these typologies were focused on mostly small projects, executed in a one branch of industry and, what is even more important, none of them turned into a standard, fully accepted theoretical project management framework (Shenhar, Dvir 1996; Sauser, Reilly, Shenhar 2009).

Sauser et al. (2009) make a summary of project management contingency frameworks which have been known in the scientific literature over last two decades. The most noteworthy theories which contributed to formulate a classification, categorization, or framework system for project management are described in (Sauser, Reilly, Shenhar 2009).

2.2.1 Shenhar and Dvir's project classification research

A special attention should be paid to the research of Shenhar and Shenhar and Dvir (Shenhar, Dvir 1996; Shenhar, Dvir 2007; Shenhar 2001; Sauser, Reilly, Shenhar 2009; Shenhar 1998), which offers an extension of the classical contingency theory. Among other things, their research yielded a two-dimensional model for project classification. Shenhar (1998) proposes a matrix which on one hand classifies projects into four levels of technological uncertainty at the time of a project initiation, and on the other hand into three levels of project management scope based on level of project management complexity (Figure 1).

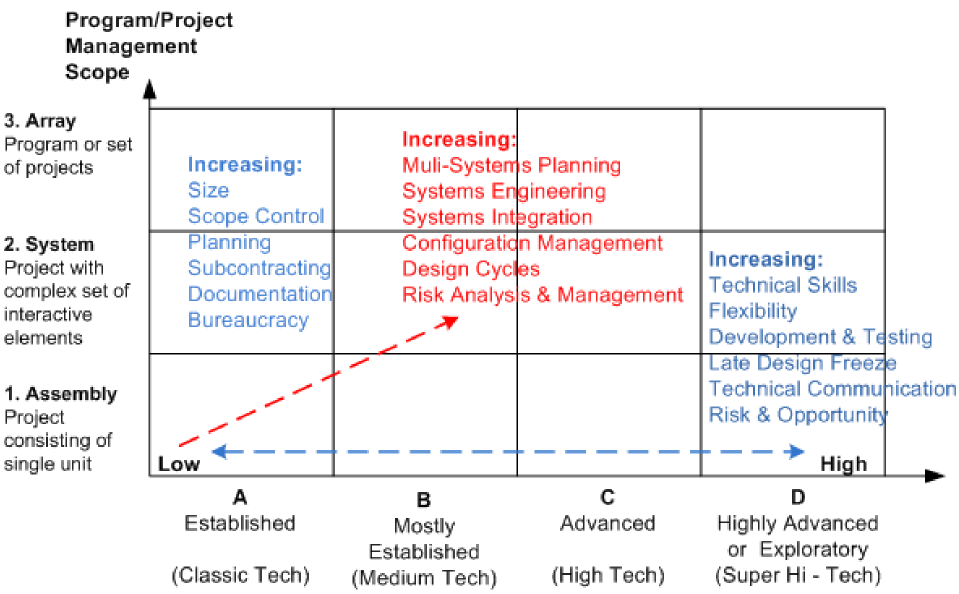

Figure 1. Project typology

Source: Shenhar, Wideman 1997.

It is rather obvious that while scheduling any project two strictly dependent processes, namely technical and managerial activities, must be taken into account. The first process comprises of gathering all technologically dependent information in order to specify the characteristics of a project final product. Shenhar specifies four level of technological uncertainty, namely type a which means low technological uncertainty (low tech), type B meaning medium technological uncertainty (medium tech), type C which means high technological uncertainty (high tech) and type D meaning superhigh technological uncertainty (superhigh tech).

The significance of involving the other process is organizing and controlling a performance of the resources, project parties communication and information flow in order to support the technical process by decision making and data management (Shenhar 1998). This dimension of project management can be classified into three levels, namely assembly, system and array.

Shenhar et al. continued their research on extending a application of contingency theory to the field of project management. In (Shenhar, Dvir 2007) the researchers introduced the 'adaptive project management approach' which states that a project is not only a sequence of dependent activities but 'a business related process that must deliver business results'. For this reason, an approach chosen for a particular project execution needs to be adapted to the specific type of project. Basically, the 'adaptive project management approach' has two features. Firstly, it assumes incorporating the project success criteria in project planning and execution. Secondly, its authors introduce a new approach to project classification, namely a diamond-shape NTCP framework, which is based on four dimensions such as novelty (N), technology (T), complexity (C) and pace (P).

This typology processes a project through its product, tasks and environment and suggests which technique is most suitable for a particular project type. The meaning of NTCP framework dimensions was precisely described by Shenhar and Dvir (2007) and it is presented in Table 1. In Figure 2, the diamond-shaped framework is depicted.

Table 1

NCTP model definitions

The NTCP model	
Novelty: the product newness to the market and the customers. It has an impact on product requirements definition and market related activities: • Derivative: Improvement in an existing product (e.g., a new color option in a MP3 player; the addition of a search feature in a software program) • Platform: a new generation on an existing product line (e.g., new automobile model; new commercial airplane) • Breakthrough: a new-to-the world product (e.g., the first Post-it Note; the first microwave oven)	Technology: the extent of new technology used. It impacts product design, development, testing and technical skills needed: • Low-tech: No new technology is used (e.g., house; city street) • Medium-tech: Some new technology (e.g., automobile; appliances) • High-tech: All or mostly new, but existing technologies (e.g., satellite; fighter jet) • Super high-tech: Necessary technologies do not exist at project initiation (e.g., stealth bomber; Apollo moon landing)
Complexity: the location of the product on a hierarchy of systems and subsystems. It impacts to coordination, organization and formality of project management: • Assembly: Subsystem, performing a single function (e.g., CD player; cordless phone); • System: Collection of subsystems, multiple functions (e.g., spacecraft; cars); • Array: Widely dispersed collection of systems with a common mission (e.g., • New York transit system; air traffic control)	Pace: Project urgency and available timeframe. It impacts time management activities and team autonomy: • Regular: Delays not critical (e.g., community center) • Fast-competitive: Time to market is important for the business (e.g., satellite radio; plasma television) • Time-critical: Completion time is crucial for success-window of opportunity (e.g., mission to Mars; Y2K) • Blitz: Crisis project- immediate solution is necessary (e.g., Apollo 13; September 11, 2001)

Source: Shenhar, Dvir 2007.

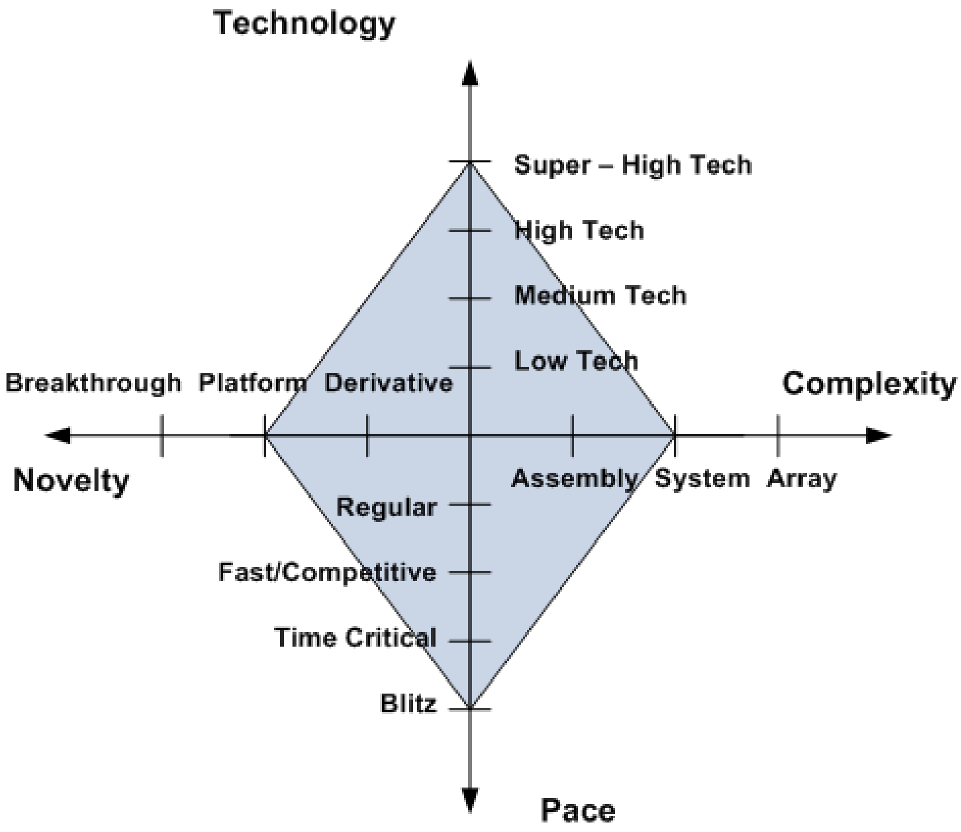

Figure 2. The Project Adaptation NTCP 'Diamond' framework

Source: Ibid.

2.3 Project activities types

The most common way of project planning is breaking down the scope of work which needs to be done into a Work-Break-Structure (WBS). Next, the project management process requires such operations as scheduling, budgeting, contracting, organizing, resource requirements specifying and evaluating project activities. An integral part of this process is also decision making, negotiation but first of all, assembling information necessary to perform the scheduled activities (Kerzner 1994). This process leads to a project schedule, a deadline and a budget, but also it should result in identifying and quantifying uncertainty linked to individual project activities and derived from these activities characteristic features.

However the scientific literature contains many attempts to find a standard, fully accepted theoretical project typology, almost no or simply no attention is paid to project activities types´ impact on a project execution. This situation may result from the fact that, as it was said before, most of the project management environment representatives do not consider project scope as a path leading to a final product but this final product itself.

2.3.1 Review of project activities typology

The researchers in the field of innovation management such as Burns and Stalker (1961) claim that organizations which perform innovative tasks should be managed in a different way than the ones which deal with standard activities, in this way pointing out the impact of tasks characteristics on the managerial process.

Shenhar and Wideman (1997) introduce a concept of the nature of the work. The authors claim that "it is necessary to look beyond a project´s nominal category or sponsoring industry and look at the fundamentally different types of work involved" (Figure 3), admitting that content of work which is needed to be done indeed does affect the project execution. However later the scholars add that "most projects encompass more than one type of work, so we must look at the major work elements (work packages) and their immediate products", what in fact means ignoring the potential impact of individual types on the project performance.

Type of Work in the Project	Type of Product from the Project: **Tangible (Value is in the entity)**	Type of Product from the Project: **Intangible (Value is in the content)**
Intellect (Requires education)	**Characteristic:** - Not done before - Subject to linear logic - Requires iterations - Resources less predictable **Result:** Development of new physical artifact **Examples:** New invention, device; All-new "mouse-trap"; New product from R&D	**Characteristic:** - non-repetitive, first of its kind - Creative effort - Minimal repetition - Resources unpredictable - Exploratory **Result:** Development of new piece of intellectual property **Examples:** New book, poem, music, movie, etc: New algorithm, theory, idea; New technology process; New software
Craft (Requires training)	**Characteristic:** - Much repetitive effort - Linear logic applies - Learning curve effects - Learn by doing - Resources predictable - Relatively high cost involved **Result:** Typical physical artifact **Examples:** Typical new physical plant, infrastructure, or product, e.g. building; utility; car; appliance	**Characteristic:** - Based on previous model - No iterations, only corrections - Learn by repetition - Physical format required only for distribution - Resources predictable - Relatively low reproduction cost **Result:** Typical piece of intellectual property **Examples:** Typical system, software upgrades, etc. Policies, procedures manual; Plan for factory shut-down

Figure 3. Basic Project or Major Project Component Classification

Source: Shenhar, Wideman 1997.

In www.projectmanagementguru.com there are presented three types of project activities, namely stable activities, which are well understood and predictable, dependent activities, whose time and effort is highly dependent upon some project attributes and characteristics and uncertain activities, which are the most difficult ones to estimate because of very little data available and many factors which need to be taken into account for a precise estimation.

Additionally the author proposes for every type of activity a suitable technique for estimating its time and effort. However, the proposed project activities classification is very much simplified; it defines uncertainty in too general terms.

In www.systemsplanning.com Toney introduces his concept of risk factors in technology projects. He defines six different aspects of risk in this kind of projects and, as a second step, he proposes several activity types. In order to quantify the impact of a particular activity, he proposes to place it into a 2x2 matrix, according to whether they are critical or noncritical for a mission, and whether they are focus or non-focus ones. By 'focus activities' the author means activities which are strongly linked to an organization mission and in which, in consequence, an organization staff are specialized. Such activities are considered as not very risky, contrary to the 'non-focus activities', which are new to the organization staff. The scale of attributed risk is from 1 till 5, where 1 means 'very low risk' and 5 means 'very high risk'. The purpose of scoring risk is identifying non-focus areas, thus the ones which do not belong to the basic mission of the particular organization. The meaning of this procedure is avoiding projects with many such activities in which the particular company has no experience. For this reason this methodology is proper only for evaluating projects with regard to the executor experience in a particular project field. The solution does not clarify how to cope with different kinds of uncertainty in projects.

2.3.2 A practical application of project activities types

One of the best proofs for an importance of a project typology, but first of all of a project activities typology for an effective project execution, is the fact that such a typology is used in practice by an it company.

In the software manual of this company it is said that activity types provide all the data that is needed to schedule and record a specific type of activity. Every activity that is scheduled in a project should be associated with an activity type which in turn should be predefined by the user or chosen from the available databases.

The activity types are one of the building blocks used by the it company in the project types which are templates on which projects plans are based. While adding a new project type, a global list of all of the organization's activity types is presented in order to select those that are appropriate for the project type in question. Projects based on this project type will have all of these pre-chosen activity types available.

A Project Type is a template that packages all the elements used to track a certain kind of project. Whiling launching a new project, it must be selected the project type on which the project will be based, and the new project is installed along with all these components (Figure 4).

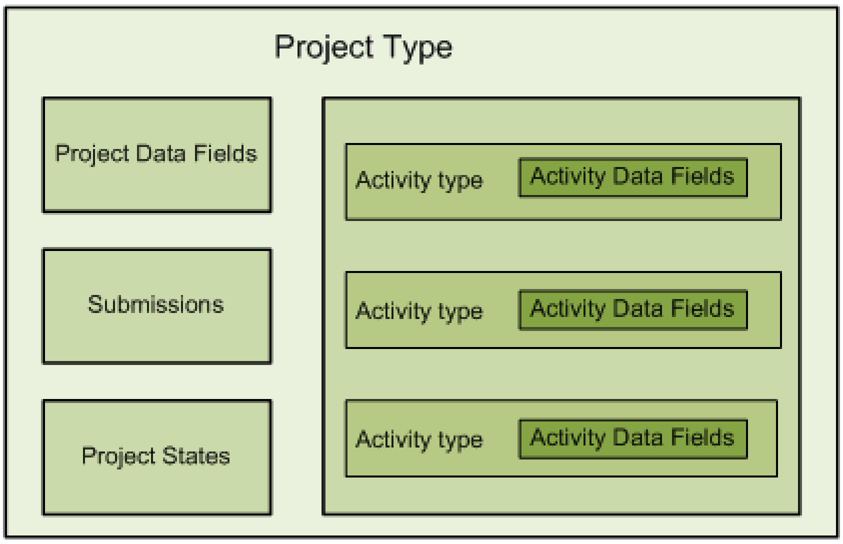

Figure 4. Project Type Components

Source: www.projectmanagementguru.com.

Unfortunately, the it company in question did not reveal details about the project and activity types used. And as mentioned above, scientific literature does not treat this subject very deeply either, although there are many facts suggesting a significant impact of project and activities types on projects performance.

In the next section we will thus propose a project activities classification and its application to the Critical Chain Buffer Management Method, more precisely to buffer sizing.

3. Research methodology

As the research methodology we chose a descriptive case study since it gives an opportunity for the characterization of real-life projects, their features such as a work content, resources requirements, activities types, relation between activities, etc. This approach to the research is recommended by Eisenhardt (1989) as a process of building theory from case study. It is a kind of prescription how to go from a theory to data and back to the theory. The object of our research is completed or still executed infrastructure and it projects which are performed by Polish public institutions and supported by European Union or performed by the private sector. The investors of the most projects are public institutions developing infrastructure dedicated to the public benefit, i.e. road construction, water supply network or the center of the science.

The scope of all these projects is complex and works which need to be done are very varied. Therefore, the fact, that a lot of different type of activities had to be performed, convinced the authors of this paper that these projects are the good objects to conduct the case study in order to identify the project activities typology.

4. Proposed project activities typology

The inherent uncertainty associated to many project activities causes that estimating time, effort, resources requirements is one of the most difficult tasks for each project planner. Sometimes a relevant estimation even seems to be impossible. Uncertainty may be caused by various factors and what is even more, uncertainty in one aspect may lead to uncertainty in another aspect: e.g. uncertainty of the activity duration causes that the total renewable resources requirements are uncertain too. All these different sources of uncertainty and links between them bring on a need of incorporate them in the formulation of project activities typology, and then further in the definition of protection absorbing negative consequences of that uncertainty.

Conducted interviews and analysis of projects being object of this research have led to the conclusion that developing a finite list of project activities types is both inefficient and ineffective. In order to classify projects activities we decided to refer to the solution proposed by Senhar and Dvir in (2007) for project typology and describe them as seen from the angle of five dimensions:

- Novelty – understood as a uncertainty of a particular project activity resulting from an imprecision of its description in a planning phase. The value of factor Novelty expresses how clearly requirements for this activity can be defined before this activity is started-up. The greater the factor, the less precise the description of the requirements.
- Complexity – understood as a managerial complexity of a particular project activity, expressed in a number of parties (e.g. resources, subcontractors, suppliers, decision makers and generally all the shareholders) involved in the activity
- Resource newness – represents the activity uncertainty derived from the degree we are acquainted with the resources used in the activity.
- Resource availability – refers to a degree to which a resource hired to a particular activity is operable and committable, including also the degree of its wearing.
- Resource reliability – refers to a degree to which a resource hired to a particular activity is reliable. This information is assembled from the historical resource performance and also during a current project execution. Thanks to this fact, the size of applied buffers can be evaluated while project tracking.

The characteristics of the presented above dimensions can be found in Table 2. The number associated with every description expresses a particular degree of the corresponding dimension which will be incorporated while computing the size of buffers in the Critical Chain Buffer Management Method. Additionally, each dimension is associated with a weight which expresses the importance of this factor which will also be used for buffer sizing purposes.

Table 2

Description of project activities dimensions

Activity dimension	Weight of activity dimension	Description of activity dimension
Novelty	1/6	• 1 – scope of work is known • 2 – scope of work is rather known • 3 – scope of work is rather unknown • 4 – scope of work is unknown
Complexity	1/6	• 1 – not complex – less than 5 parties involved • 2 – rather complex – 5 till 10 parties involved • 3 – complex – 10 till 15 parties involved • 4 – very complex – more than 15 parties involved
Resources newness	1/6	• 1 – resources used before • 2 – resources used before but with new feature • 3 – new resources used • 4 – it is not known yet what kind of resources will be used
Resource availability	2/6	• 1 – resources operable • 2 - resources rather operable • 3 – constraint resources • 4 – very constraint resources
Resource reliability	1/6	• 1 – resources reliable • 2 - resources rather reliable • 3 - resources rather unreliable • 4 – resources unreliable

5. Critical Chain Buffer Management Method vs. Project and project activity typology

5.1 Proposed approach for buffer sizing in CC/BM

A degree of an uncertainty in a project is strictly related to how innovative its scope is. It is rather obvious that the characteristics of many activities which need to be performed in a completely new venture are for the project team unknown. Lack of experience in executing the given sort of work implicates that it is impossible to identify ex-ante all possible risks of project duration and budget overrunning. Obviously, even more difficult is to attempt to quantify this kind of risks.

However, the fact, that it is almost impossible to define potential risks for this kind of work, does not mean that their existence and, what is even more significant, their possible impact, can be ignored while performing a project risk analysis. It is also important to incorporate this impact while implementing protection for absorption of time and budget overrunning risks. In this paper we want to point out that it is important to take this impact into account while applying the Critical Chain Buffer Management.

For computing size of project and feeding buffers in CC/BM the proposed approach for project activities classification will be used. The buffer lengths in the CC/BM are always a function of the characteristics of a certain sequence of activities, called chains (the buffer is supposed to protect this chain – the project buffer length is a function of the characteristics of the project critical chain, the feeding buffer length is a function of the characteristics of a feeding chain). Let LB_Z denote the length of the buffer which is meant to protect the chain Z (it may be a project chain or a feeding chain), composed of n_Z activities. We propose to calculate LB_Z according to the following formula:

$$LB_Z = \sum_{i=1}^{n_Z} d_i \frac{\sum_{k=1}^{5} W_i^k \cdot V_i^k}{5}$$

subject to:

k – activity dimension, k=1,2,3,4,5

d_i – the i-th activity duration, i=1,...n

W_i^k – weight of dimension k *of* activity i, k=1,2,3,4,5, i=1,...n

V_i^k – value of activity dimension k, k=1,2,3,4,5, i=1,...n

5.2 Buffer sizing in CC/BM

For the illustration purposes the example of the project `Development of ICT infrastructure in the region governed by the ABC district and its 7 subunits, as well as increasing availability of e-services to citizens and businesses representative from region of the district ABC and A, B, C, D, E, F and G' will be used (Kuchta at al.). The main objective of the project is to integrate and improve the functionality of the ICT infrastructure and to introduce an integrated information system supporting managing cooperating units such as the district of ABC and its 7 local subunits, as well as increasing the availability of electronic administrative services for the district of ABC citizens.

In Table 3 it can be found project activities description: d_{50} stands for the activity duration aggressive estimate, d_{95} stands for the activity duration safe estimate.

Table 3

Activities description in the CC/BM approach to project management

No	Description	d_{95}	d_{50}
1	Expansion of network connections	13	8
2	Purchase of it equipment	5	3
3	Installation of it equipment	6	4
4	Matching the user requirements with Telecommunication Platform (TP)	5	3
5	Implementing 22 four types of database	8	6
6	Implementing electronic application forms	5	3
7	Establishment of Local Certification Centre	3	2
8	Public Information Bulletin (PIB), on-line register	3	2
9	The integration of the Telecommunication Platform, PIB, web site and HR Module	5	4
10	Time recording system	3	2
11	Implementing Human Resources Module	4	3
12	Purchase of digital signature	2	1
13	Safety System related to the implementation of the e-office	4	3
14	Pilot implementation of the Telecommunication Platform	5	3
15	Configuration and starting-up of hardware and software in all locations of the project	3	2
16	Training in application using	6	4

The project network is presented in the AoN format in Figure 5. Under node *i* respectively the safe and aggressive activity duration estimations are given in weeks.

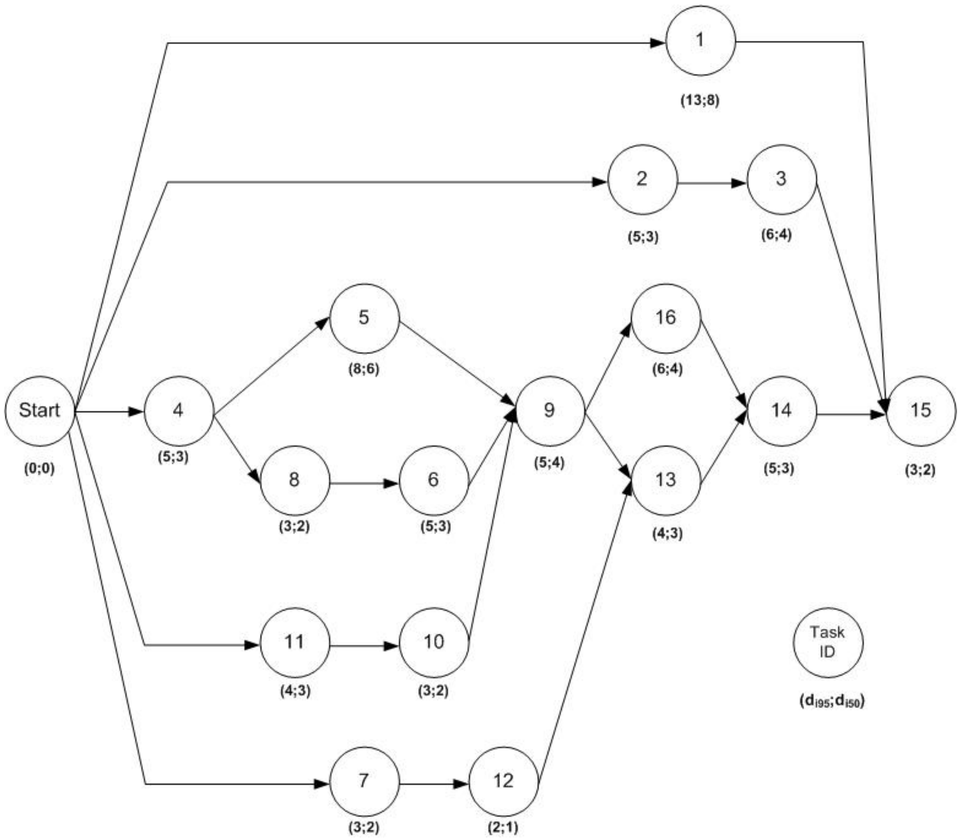

Figure 5. Project network in the Critical Chain approach in the project in question
Source: Kuchta et al.

The proposed approach to the project activities classification as well as its application in the buffer sizing procedure was introduced to the project team. The project manager had been explained the meaning and application of the new approach earlier. He found it as very efficient and wanted his team to use it during future project executions. At the beginning, the newness of the solution made the team members a little bit confused and they were not eager to give characteristics of activities for which they were responsible. Very useful and breaking-through there was a solution proposed by the project manager. He made a kind of workshop dedicated to the approach proposed by us.

He referred to the projects, so also the activities, in which his team was involved in the past. The task of the team members was defining the characteristic of the project activities which they performed before. That exercise had very positive impact on the team – not only it let them get familiar with the approach, so therefore be more encouraged to give the characteristic of the activities, but also let them practice estimating accurate values of the particular activity dimensions.

As an example, for the further analysis a feeding chain consisting out of activities 10 and 11 will be chosen. The conducted interviews with the team members responsible for these activities, and with the project manager, brought the, presented below, characteristic of these tasks (Table 4).

Table 4

Description of the activities number 10 and 11

	Activity dimension	Weight of activity dimension	Value of activity dimension
Activity 10: Time recording system	Novelty	1/6	2
	Complexity	1/6	1
	Resources newness	1/6	2
	Resource availability	2/6	3
	Resource reliability	1/6	2
Activity 11: Implanting Human Resource	Novelty	1/6	1
	Complexity	1/6	1
	Resources newness	1/6	2
	Resource availability	2/6	3
	Resource reliability	1/6	2

Both the activities, namely 'Time recording system' and 'Implanting Human Resource Module' were performed by the same team members - a software developer and an officer working in a human resource department. In the past they got an experience with this kind of work, especially if it goes about the activity number 11. It was why they gave values of dimension 'Novelty' 2 and 1 respectively to the activities 10 and 11. They classified these activities as relatively easy, that was why the 'Complexity' of both activities were described with value 1. In their opinion the only source of uncertainty lied in their availability – the factor 'Resource availability' was decided to be 3. The project manager decided that the value of the factor 'Resources newness' should be 2, of course in both activities, because even he used to cooperate with the software development before, it was the first time when his team member was the officer working in a human resource department.

After first days of work of these two team members it was rather obvious that they were competent and the cooperation between them was efficient. Taking into account this fact and the rather positive experience from the earlier cooperation with the software developer, the project manager decided to describe the factor 'Resource reliability' with value 2.

The next stage of the proposed approach was the buffer sizing procedure. The team members were introduced to the Goldratt's CC/BM already earlier and they were rather convinced to this approach while in their opinions in many aspects it reflected very accurate the project reality (Kuchta et al.).

At the beginning the buffer determined according Goldratt's method was shown to the project team (Figure 6).

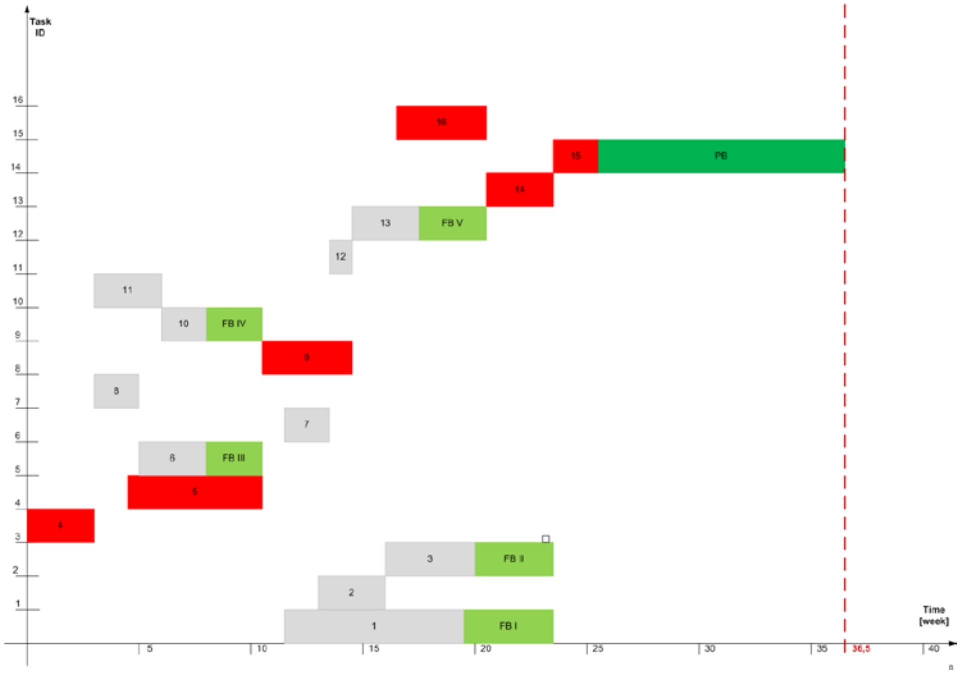

Figure 6. The schedule of the project in question. The 50% of the Chain Method

It is important to say that some of the team members raised doubts concerning the buffer sizing process. These officers were not really convinced that the deterministic 50% of the chain length was the optimal solution. They pointed out that not every chain consists out of the same type of the activities, so there should be some diversity incorporated in the buffer size determinations. The other officers, mostly the same who were not eager to estimate the activity dimension values, tried to defend Goldratt's solution.

It needs to be said that this situation appeared before the project manager brought on the idea of the workshop about the approach proposed by us. This exercise together with explanation the meaning and procedure of our solution convinced and encouraged the team to apply proposed method. When the all dimension of the activities were defined, we could pass to the determination of the buffer sizes according our approach.

As an example calculation we will use again the chain containing the activities numbers 10 and 11. We will also show the calculation for the project buffer size, the buffer protecting the critical chain.

$$LB_{10,11} = (1/6*2*2 + 1/6*1*2 + 1/6*2*2 + 2/6*3*2 + 1/6*2*2)/5 + (1/6*1*3 + 1/6*1*3 + 1/6*2*3 + 2/6*3*3 + 1/6*2*3)/5 = 2{,}1 \text{ weeks}$$

$$LB_{CC} = (1/6*1*3 + 1/6*2*3 + 1/6*2*3 + 2/6*2*3 + 1/6*3*3)/5 + (1/6*2*6 + 1/6*1*6 + 1/6*1*6 + 2/6*1*6 + 1/6*2*6)/5 + (1/6*2*4 + 1/6*4*4 + 1/6*1*4 + 2/6*3*4 + 1/6*2*4)/5 + (1/6*1*4 + 1/6*2*4 + 1/6*1*4 + 2/6*1*4 + 1/6*3*4)/5 + (1/6*3*3 + 1/6*1*3 + 1/6*2*3 + 2/6*2*3 + 1/6*1*3)/5 + (1/6*2*2 + 1/6*4*2 + 1/6*3*2 + 2/6*2*2 + 1/6*4*2)/5 = 8{,}2 \text{ weeks}$$

As the next step we depicted the project schedule derived from application of our solution in a form of Gantt chart (Figure 7).

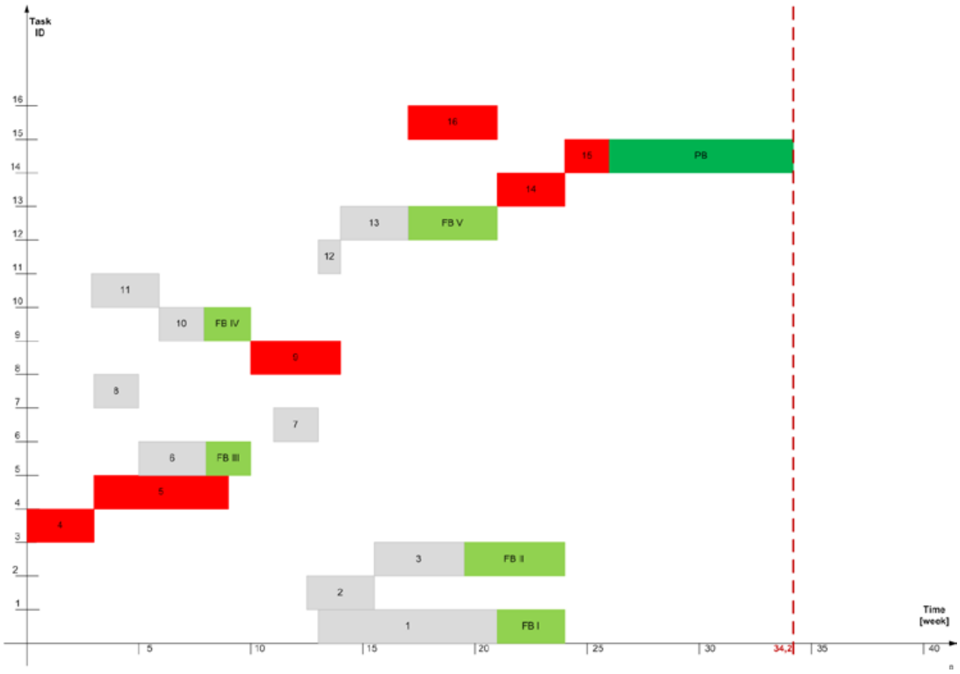

Figure 7. The schedule of the project in question. The new approach for the project activity classification

We compared the schedules obtained from both approaches – our and Goldratt's. It was pointed out that the feeding buffers placed at the end of chains 1, 8-6, 11-10 (the numbers of the activities laying on the particular chains) and the project buffer were decreased. That happened because the characteristic of activities containing these chains implicated that such a big protection was not needed. On the other hand the buffers at the end of chains 2-3 and 7-12-13 were increased while the characteristic of these activities indicated that the bigger buffer is needed. The comparison of the schedule obtained by application of our solution with the schedule derived from Goldratt´s approach finally convinced the most of the team members that the proposed approach much better reflects the reality and therefore it is more efficient for the project scheduling. The project team admitted that even according our approach they had less time to complete the project, they felt more confident with our solution since the provided protection, namely buffer sizes, was more accurate. The human aspect of the project execution, to be precise, the team motivation and fight in success is very important factor for the efficient implementation of the CC/BM method.

Conclusions

Although the last two decades have brought revolutionary solutions in project management discipline, none attention was paid to the impact of project activities on the project performance. This study proposes the approach which incorporates this important factor (project activities characteristic) in project management process. The application of presented method to the CC/BM brings the new solution for the buffer length determinations in complex infrastructure and it projects. It allows incorporating in the buffer sizing procedure such dimensions as Novelty, Complexity, Resources newness, Resource availability and Resource reliability defined from the angle of project activities. This means that this approach partly contributes to filling the gaps in Goldratt´s methodology.

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TOWARD PROJECT MANAGEMENT MATURITY. KNOWLEDGE TRANSFER AS KEY BEHAVIOUR OF MATURE ORGANIZATION

Introduction

The environment in which organizations operate nowadays changes rapidly and becomes more and more complex. The usage of project management tools and techniques becomes critical to increase competitiveness and efficiency of activities. Repetitive, standardized processes are replaced by unique and complex projects which help organizations to achieve competitiveness and growth. As Andersen & Jessens (2003) notice, project management currently pays its attention not to a single project but extends its focus on the way in which an organization deals with projects and uses them to achieve its strategic objectives.

Maturity models have become an important tool in assessing organization's abilities to deal with its projects. The models describe different levels on the maturity evolution path and allow organizations to compare their competence and processes in the area of project management. These models consist of the hierarchical collection of elements describing the characteristics of effective processes, and their use can enable organizations to reap the benefits brought by improved capability at all levels (OGC, 2006).

Many project maturity models emerged last years and have been described in project management literature (Hillson 2001; Kerzner 2001; Crawford 2006; Ibbs et al. 2003; Juchniewicz 2009). Some studies have discussed the correlation between the level of project management maturity and project performance (Ibbs & Kwak 1997; Jiang et al. 2004; Ibbs & Kwak 2000).

A lot of organizations desire to achieve excellence in project management by implementing standards for project management. Many of these standards have appeared from the observation of different practices of an organization which have led to project success or failure.

The best known standards are developed by Project Management Institute (PMI 2004), International Project Management Association (IPMA 2009) and Office of Government Commerce (2005).

However, reaching excellence in project management requires not only an implemented project management methodology but also a developed culture that facilitates distribution and re-usage of project knowledge. Most of organizations pay attention to tools and techniques implemented to improve the process of project management but take no notice of knowledge management strategy and a systematic way of capturing project knowledge. Project knowledge, especially experience-based one is a critical resource of project-oriented organizations and a fundamental factor approximating an organization to project management excellence. The steps towards project management maturity require a commitment to a continuous learning process.

The paper is organized as follows. First, the concept of project maturity is raised. Then, knowledge management in general and in project context is discussed. Afterwards, I present how maturity of project management and project knowledge management are linked and describe different levels of project management maturity in regards to transfer and re-usage of knowledge. Finally, the findings regarding the methods of capturing, sharing and using project knowledge as well as experience are submitted and analyzed. The last section gives concluding information.

1. The matter of maturity

As interest of project management maturity models has increased, the number of different definitions of this concept have been developed in literature. The Oxford Dictionary of English Dictionary (ODE 2010) defines the word mature as fully developed and having reached the most advanced stage in a process. Maturity is the quality or state of being mature. If we apply this definition to project management, it may mean that project maturity is the state in which an organization is perfectly conditioned to deal with its projects (Andersen & Jessen 2003). Project management maturity can also be described as organization's receptivity to project management (Skulmoski 2001). Some researchers underline the role of repeatability in project management. Then maturity can be viewed as the development of systems and processes that are repetitive by nature and provide a high probability that each project will be a success (Kerzner 2004). Many of the definitions pay attention to the level of abilities and techniques used in current project management practices and processes (Ibbs et al. 2003; Juchniewicz 2009) as well as on the extent to which an organization practices project management (OGC 2006). An interesting definition, from the point of view of this paper, is the concept of project maturity proposed by Anderse & Jessen (2003). According to them, maturity is best explained as the sum of action, attitude, and knowledge. The process of achieving more sophisticated levels of maturity in project management requires the implementation of structured approach – maturity models.

Maturity models have their roots in the Total Quality Management (TQM) which focuses on continuous improvement of processes and procedures within the organization to achieve higher efficiency, effectiveness and better performance. All maturity models provide a framework in the field of project management improvements and they are a point of reference for an organization to understand its current position of the overall organizational competency and to realize the aims for the future. All models illustrate the combination of steps to help an organization to improve processes and practices in the field of project management. Kania (2001) described maturity models as a repository of knowledge about what required criteria should be used for assessment and what should be done to improve processes. Maturity models can also serve as a point of reference for organization in context of project management practices.

Modern maturity models are based on capability maturity model developed by Software Engineering Institute (Paulk et al. 1993) as the feedback of experiences of the software practitioners. The main purpose of it, was to improve the quality of the software development processes to achieve outcomes through continuous improvements. The CMM is built as a five-level model where each level represents different stages of maturity from a process performed ad hoc to a mature process with high level of specialization.

Since the earliest maturity model was developed by SEI many different maturity models have been introduced to improve PM effectiveness. The current number of different project management maturity models is estimated at 30 (Pennypacker & Grant 2003). While presenting existing maturity models, the greatest attention should be paid to five maturity models. The first one is Berkeley PM Process Maturity Model – (PM)2 developed at the University of California in the late 90's (Ibbs & Kwak 1997; Ibbs & Kwak 2000; Ibbs & Kwak 2002). The model is the foundation to evaluate an organization's current PM maturity level. Each level consists of project management characteristics, factors, and processes. (PM)2 model demonstrates series of steps that help an organization to improve its effectiveness in the field of project management (Ibbs & Kwak 2002). Another PM maturity model describes maturity by utilizing the PMBOK Guide's nine PM knowledge areas and five levels of maturity in CMM model (Crawford 2006). Each organization defines its PM maturity level by examining its competency across the nine PM knowledge areas. As projects are implemented in different project environments: multiprojects, portfolios, roll-out projects etc. (Pankowska 2010) Project Management Institute has developed Organizational Project Management Maturity Model (PMI 2003) which divides project management into three elements:

project management, program management, and portfolio management. Kerzner's Project Management Maturity Model (PMMM) has been created as a result of the survey of project management practices in hundreds of organizations. In his concept maturity levels overlap each other and before moving up to the next level, the lower one must be completed. Another model, Prince 2 Maturity Model (P2MM) consists of a five-level maturity framework, seven process perspectives covering essential aspects of PM and attributes for each level of maturity within each of the process perspectives (OGC 2010).

As remarked by Jugdev and Thomas (2002), the different modifications of CMMs and other general maturity models involve five linear stages. The names of the stages differ between approaches and they are presented in table below.

Table 1

Levels in different project management maturity models

	CMM	**$(PM)^2$**	**Kerzner's PMMM**	**P2MM**
Level 1	Initial Level	Ad hoc Stage	Common Language	Awareness of Process
Level 2	Repeatable Level	Planned Stage	Common Processes	Repeatable Process
Level 3	Defined Level	Managed Stage	Singular Methodology	Defined Process
Level 4	Managed Level	Integrated Stage	Benchmarking	Managed Process
Level 5	Optimizing Level	Sustained Stage	Continuous Improvement	Optimized Process

Source: Developed for this study.

2. Essence of project knowledge

Stanislaw Gasik (2011), refering to Sankarasubramanian (2009), states that all projects have one thing in common—knowledge. Knowledge is defined by Liebeskind (1996) as the information whose validity has been established through tests of proof. It can include knowledge which is personal, know-how, skills acquired through experience as well as written documents.

As project management has become common, the need for knowledge management in projects has been widely discussed (Bellini & Canonico 2008; Boh 2007; Crawford & Pollack 2007; Disterer 2002; Levin & Rad 2007; Schindler

& Eppler 2003; Ruuska & Vartiainen 2005). Knowledge management in projects seems to be different than knowledge management in general due to their special nature. Projects are unique undertakings characterized mainly by limited time and resources, high risk, great complexity and temporary teams which require more efficiency. Gasik (2011) participates in the discussion on the definitions of knowledge management in literature. Referring to the definition of Probst, Raub & Romhard (2003), knowledge management describes a process during which knowledge is systematically and actively identified, activated, replicated, stored, and transferred. Gasik states that general definitions of knowledge management are valid and important for the management of project knowledge (Gasik 2011). Reich, Gemino and Sauer (2012) define knowledge management in the field of project as "the management activities required to source the knowledge stock, create the enabling environment, and manage the knowledge practices to result in an aligned set of project-based knowledge". Knowledge stock is the knowledge of individuals, a project team and an organization available to the project.

There are a lot of studies that deal with various aspects of project knowledge management. The important issue discussed in this field is a knowledge transfer across projects and its re-usage (Cooper et al. 2002; DeFillippi & Arthur 1998). Schindler & Eppler (2003) notice that the need to retain and re-use knowledge from projects is very important for organizations due to the knowledge loss when projects end. The main problem in temporary organizations such as projects is that project knowledge often disappears when people involved in project implementation go to other tasks or projects. The knowledge and experience are dispersed when the project is completed. It especially affects immature organizations without implemented project knowledge management standards.

Project knowledge can be consider in two dimensions (Gasik 2011): as micro-knowledge which is defined as knowledge required to perform a task or its part, and as macro-knowledge which is the total knowledge of:

- a given person in case of individual macro-knowledge or
- a given team in case of project team macro-knowledge or
- an organization in case of organizational macro-knowledge or
- a global community of project managers in case of global macro-knowledge.

Acquired knowledge should be transferred vertically between different levels e.g. from individual level to project team, organizational and global level. Knowledge needed at project level can be possessed from other levels as well (Gasik 2011).

Knowledge in the project context may occur as either tacit or explicit knowledge. Tacit knowledge is defined as knowledge which is not easily articulated. Nonaka (2000) characterizes it as knowledge which is "subjective and experimental and hard to formalized" and Polanyi (1966) summes up with the phrase "We know more than we can tell". Tacit knowledge is learned via practical experience, and it remains in the heads of the project team members. The examples of this sort of knowledge are belief, mental models, perspectives. Conversely, explicit knowledge is knowledge that can be easily articulated and disseminated to others. Explicit knowledge is described in formal language and can be transferred through documents. Explicit knowledge means 'know-what' while tacit knowledge means 'know-how' and 'know-why'.

Although explicit knowledge is important in project management which requires standardization, procedures and documentation, knowledge that matters most in the project context is tacit knowledge. Therefore in this paper more emphasis is placed on tacit knowledge.

Tools facilitating knowledge transfer

The storage, transferring and re-using of project knowledge can be supported by the appropriate system of procedures. The existing elements of this system can be such tools as lessons-learned database, project reviews or inter-project meetings.

Table 2

Exemplary tools for project experience accumulation and knowledge management

LEVEL	EXPERIENCE & KNOWLEDGE
Member of the project team	Diary Job rotation On the job training Specialization Re-use of experts Reporting systems
Project Team/project	Person-to-person communication Informal encounters Formal project reviews Ad hoc meetings Lessons learned database Project history database Project plan reviews
Organization	Project management processes Lessons learned database Organizational routines, rules Inter-project meetings

Source: Own elaboration based on Prencipe & Tell 2001.

3. Project knowledge & project management maturity

Although there have been many studies written to prove the importance and applicability of maturity models in project management, little attention has been paid to how effective project knowledge transfer can affect the ability to reach higher level of maturity in PM.

Looking for the links between project knowledge and project management maturity, attention should be paid to the definition of project management. Project management is the application of knowledge, skills, tools and techniques to project activities in order to meet or exceed stakeholder needs and expectations from a project (PMI 2008). It underlines that one of the requirements to achieve project success (measured e.g. by stakeholders' satisfaction) is the implementation of knowledge and skills which are the inseparable elements of project management. Thus, the application of knowledge is a prerequisite for building maturity in project management by an organization.

Kasvi, Vartiainen & Hailikari (2003) state that "successful project management should be based both on accumulated knowledge and individual, collective competences". Taking into consideration some definitions of maturity in project management which explain maturity as the state in which an organization is perfectly conditioned to deal with its projects (Andersen & Jessen 2003) as well as the organization's receptivity to project management (Skulmoski 2001) we can sum up that the advancement in PM maturity level is described by how successful project management in organization is. Thus, the foundation for building maturity in the project management context is the knowledge of individuals, teams and the organization involved in project implementation as well as knowledge transferred and acquired from other projects, where the latter is the most valuable one. According to Williams (2003) "learning form project is perquisite for project oriented organizations". Many trainings and guidelines have been offered on the market to rise knowledge of people involved in project management since the discipline of PM was developed. There is no difficulty in acquiring some basic knowledge how to manage project in a proper way. However, tacit knowledge especially that possessed from experience in other projects is a competitive advantage of each project team and organization and can lead to high organizational maturity in PM. Well-working project management supported by the system which allows for storing, transferring and re-using project knowledge is essential for establishing an organization pretending to achieve excellence in project management.

As Gasik (2011) suggests, the acquired knowledge should be transferred in different directions between the levels: individual level, project team level, organizational and global level. Knowledge should be acquired not only from the experience from the previous projects but also form project environment which is complex and gives great opportunities to learn from.

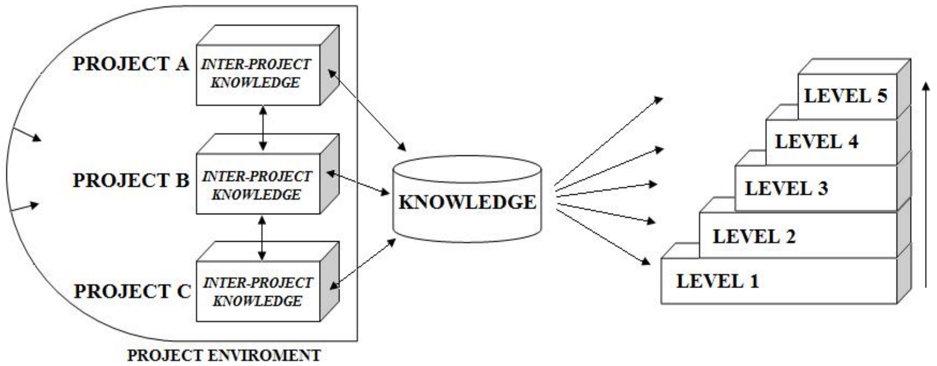

Figure 1. Impact of project knowledge flows on project management maturity level

Source: Developed for this study.

A number of project management maturity models are based on nine knowledge areas described in The Project Management Body of Knowledge (PMI 2008). The nine knowledge areas are: Project Integration Management, Project Scope Management, Project Time Management, Project Cost Management, Project Quality Management, Project Human Resource Management, Project Communications Management, Project Risk Management, and Project Procurement Management. As Spalek (2012) has noticed, knowledge management in maturity models is applied only as a part of other knowledge areas. He has underlined the need for building a new model in which knowledge management could be a separate area. As project management maturity of an organization is assessed mainly against nine knowledge areas, the additional area in the context of knowledge management would be the equivalent metric for assessment.

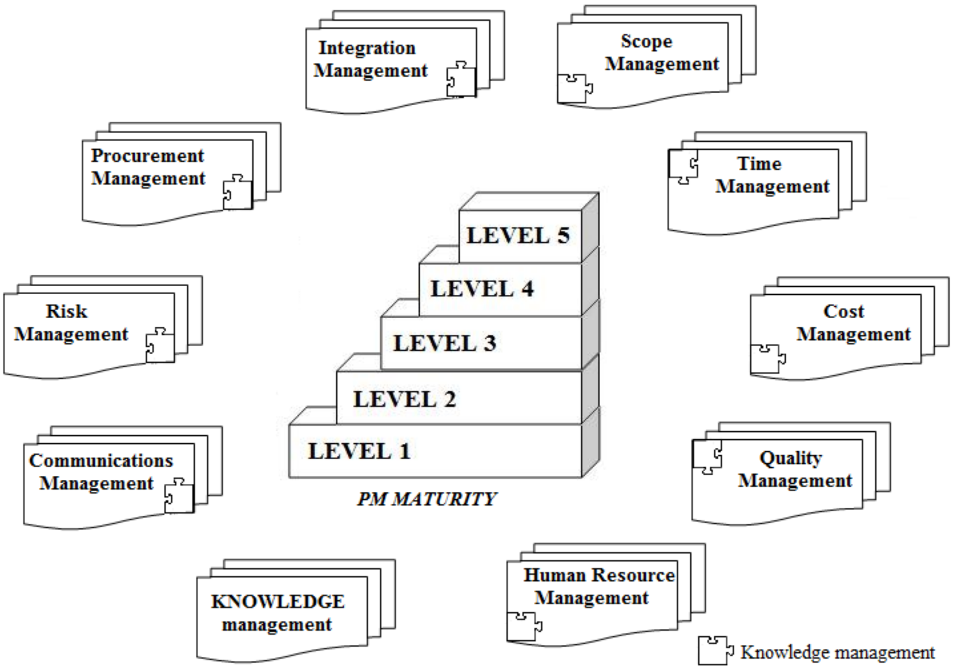

Figure 2. PM Maturity Model including Knowledge Management as a separate area

Source: Own elaboration adapted from Spalek 2012.

4. Project knowledge at maturity levels

Regarding different levels of project management maturity, the quality of created knowledge may vary as well as the extent of usage and the ability of the organization to utilize it. Below there are the descriptions of 5 levels of project management maturity in regards to transfer and re-usage of knowledge.

Level 1 is ad-hoc/initial stage, there are no project plans and procedures. Project management processes are not predictable and they are not controlled. At level 1 no knowledge management system is available and project management data and experiences are not collected. There are no formal guidelines to ensure that project management practices are continuous (Ibbs at al. 2003). Usually organizations at this level do not operate as a project-base and projects are implemented incidentally. As a result, success in project management depends on knowledge, experiences and competencies of individuals rather than organization's knowledge.

In the organization there is no wide knowledge about project management practices and processes, thus knowledge transfer and re-usage from individuals are highly important for a low mature organization to attain higher level of maturity. It is especially important in the situation where people involved in project implementation return to their line functions or leave their workplace after the project ends and take their experience with them. The finishing of the first level requires gaining fundamental knowledge on the principles of project management as well as learning from previous experiences.

At Level 2 as project management is accepted, informal procedures are used to manage project processes. Nevertheless, the process of project management still depends on a few key individuals with experience of PM who ensure the organization to repeat success continuously. As the organization introduces number of initiatives, people learn and practice by taking part in the project team which is the place where knowledge is created, learned and utilized. Informal data in the context of project management is collected. Completion of this stage requires moving from acquiring basic knowledge to standardizing PM processes. Successful applying PM principles involves the knowledge of individuals, the project team and organization as well as re-using knowledge from the previous projects.

Level 3 processes of project management are well understood and described in guidelines, procedures, standards and tools. Procedures and standards are more detailed than at level 2. The organization realizes that singular methodology could be more effective than multiple methodologies. At this level, the project standards, processes and procedures are adjusted from the organization's set of standard processes to suit a particular project. Experiences and challenges regarding project management are informally documented. The culture becomes a cooperative culture (Kerzner 2001). Project data is shared between teams members to help project management. Skills and practices are informally trained.

At level 4 project management processes are formally established, measured and documented. Data related to project management is standardized, collected and stored in a database to be re-used in current and future initiatives. The organization demonstrates the strong sense of teamwork. There is a framework to facilitate and optimize learning within or between projects. As the organization starts to manage projects at corporate level, the prototype of Project Management Office (PMO) can appear as a unit for learning and sharing knowledge in the project management. The responsibility of this unit is to centralize information so that a knowledge base is created as well as managing best practices of project management, learning from projects, and improving the maturity of project management at the organization (Desouza & Evaristo 2006).

Achieving **Level 5** means that the organization starts the phase of continuous improvement. It is the highest and the most sophisticated stage in project management maturity. At this stage processes in project management are continuously improved. Lessons-learned files after project completion are created and the learned knowledge is discussed in order to avoid mistakes in future projects. Project team members learn from both success and failures. Knowledge learned on projects is transferred to other projects and teams (Kerzner 2001).

The matter of knowledge transfer including experiences and knowledge re-use is the crucial aspect not only for organization at the highest level of maturity ladder but also for those starting in building its maturity in project management.

5. Empirical investigation

The aim of the survey was to investigate knowledge transfer and utility practices in organizations engaged in project management.

Sample

Data was collected through a paper-based questionnaire from 62 persons. The target group consisted of project managers and members of project teams. The survey was conducted in Rzeszow. The sample contained organizations of different size and different industries as well as a broad variety of different projects types and different experiences with project management.

In the sample small projects with less than five project team members account for 27%, medium sized projects: 6-10 persons account for 31%, 11-20 persons account for 19%. Large projects with 21 and more persons account for 23%.

Data collection

The survey was divided into two phases. The first phase aimed to test the suitability and comprehensibility of a designed tool. 3 project managers were asked to complete the paper-based questionnaire and provide feedback on the questions. Based on these comments, the final questionnaire was prepared. During the second phase a survey was conducted. The response rate was 74,7% corresponding to the sample size of n=83 persons.

One part of the questionnaire included questions related to activities which are used by the organization to transfer and utilize project knowledge and experience at different stages of project life cycle (initiation, planning, implementation and closer). The respondents were questioned what types of project knowledge in their organization is registered and utilized. The next part concerned those who are involved in the process of collecting and transferring project knowledge in the organization and those who are allowed to use the collected and stored knowledge. Another part of the questionnaire included different sources of project knowledge. The respondents assessed the extent of using them in a five-level scale (1 – no use, 2 – used in few projects, 3 – used in about half of the projects, 4 – used in the majority of the projects and 5 – used in all the projects).

Results

This section presents the results from the questionnaire.

Most of the interviewers (60%) mentioned that there is no particular formal system (procedures, policy, forms etc) for project knowledge management and project experiences exchange in their organization.

Among the group of organizations with implemented system for project knowledge management majority mentioned that almost all (frequently) or all (always) initiatives are implemented as projects (Figure 3). It can confirm that knowledge and lessons learned are managed and utilized to a wider extent among organizations which are more experienced in project management.

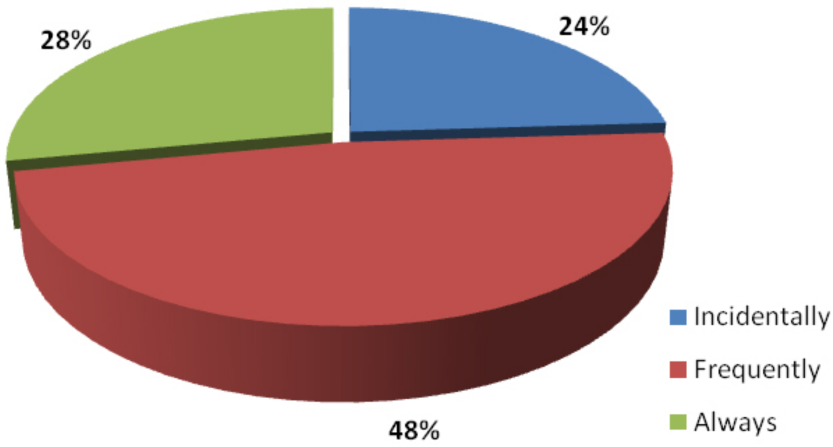

Figure 3. How often are projects implemented in your organization?

Source: Developed for this study.

Taking into account the measures of project management maturity proposed by the above-described models, some simplification has been done to analyze the results of the survey. The interviewed organizations are at the different level of maturity in project management which can be measured by:

– the number of employees who have the qualifications and skills with project management
– the extent to which projects are implemented in the organization (never, incidentally, frequently, always).

An organization at lower level of maturity in project management usually implements projects incidentally. In the organization there is no wide knowledge about project management practices and processes, people are not trained. In the survey they represent the organizations in which: 0% so nobody or 1%-25% of employees have the qualifications and skills in project management and project are implemented incidentally – 39% of the total group of the respondents.

Conversely, a more mature organization leads a number of projects, and skills and practices are formally or informally trained. These are the organizations with 26%-100% of employees who are skilled and qualified in project management and projects are the main operations in their organizations (projects are implemented frequently or always) - 6% of the total group of the respondents.

Lower level of maturity

Among the group of organizations at lower level of maturity, 79% mentioned that knowledge and experiences are not collected, stored and utilized with the support of the formal system of project knowledge management. 46% of the respondents mentioned that no one is involved in gathering and transferring of project knowledge and experiences which are kept only for themselves.

Informal and formal meetings, forums, exchange of information via e-mails were identified as the most frequent sources of project knowledge and experiences. It confirms that the sources used by immature organizations are informal and project knowledge is not collected in a systematic and comprehensive way (Figure 4). The most frequently used knowledge is the re-usage of solutions produced within the previous projects (Figure 5).

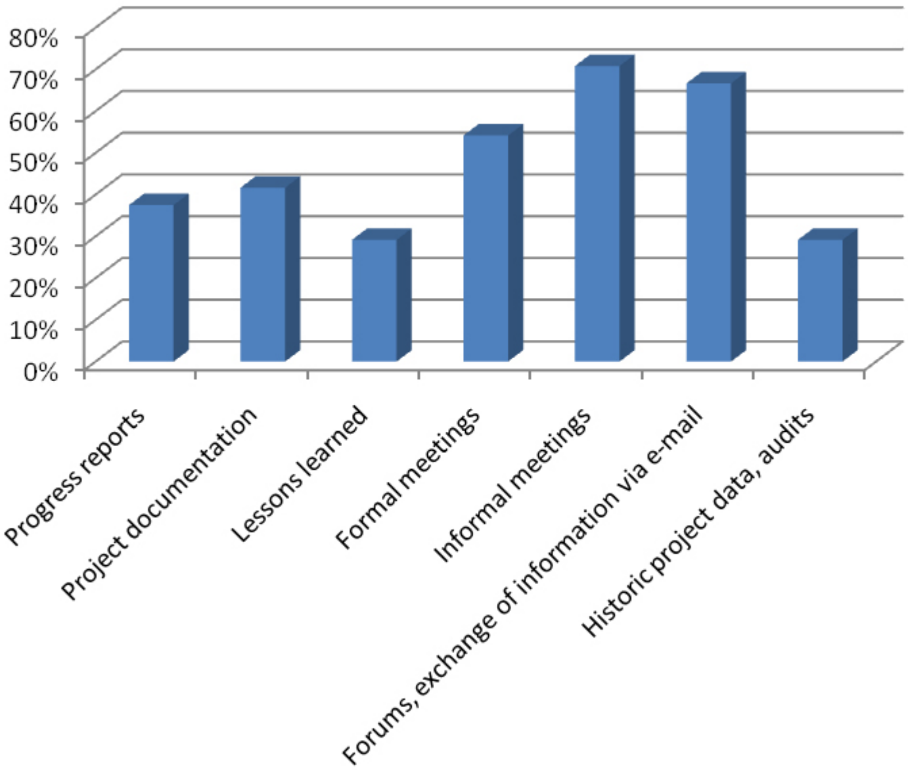

Figure 4. Sources of project knowledge (low maturity)

Source: Developed for this study.

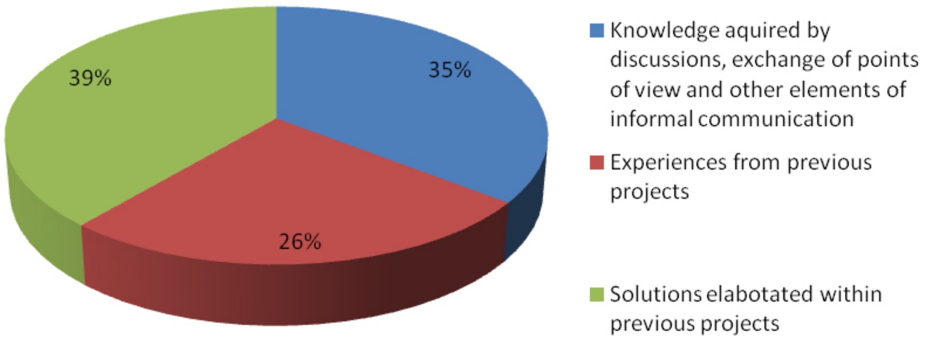

Figure 5. Types of knowledge which is the most frequently used by the organization

Source: Developed for this study.

Higher level of maturity

Only 4 of the interviewed project based organizations mentioned that more than 26% of the employed people are qualified specialists in project management, and all or almost all undertakings are implemented as projects. It can be assumed that those organizations are more professional in project management.

Only one of the respondents confirmed that the system of knowledge and experience management are implemented.

Incorporating experienced people into new project teams has been viewed as the main way to accumulate project knowledge. No respondents considered lessons learned or the exchange of knowledge via e-mails as the sources which are frequently used in their projects (Figure 6).

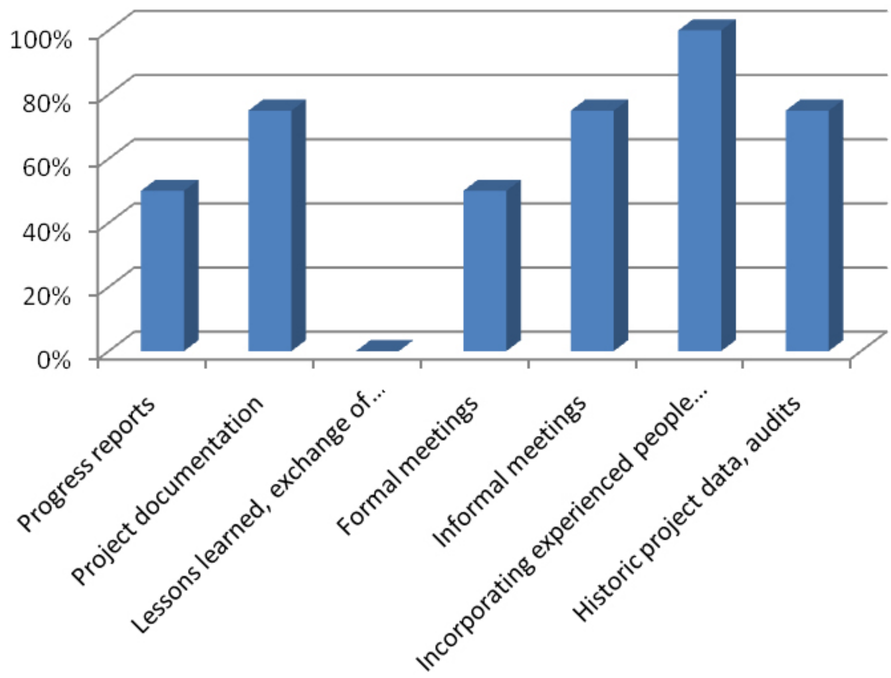

Figure 6. Sources of project knowledge (higher maturity)

Source: Developed for this study.

The role of informal sources of project knowledge and experiences for organizations with higher specialization in project management is less important than for organization with lower maturity. However, the results of the survey expose that collecting and utilizing project knowledge and experiences are important activities no matter the organization's level of maturity. The difference can be mainly in the way and the extent of tools and procedures used.

Conclusions

Knowledge transfer and utilization are prerequisites for changing position at the project management maturity evolution path. A continuous improvement of the practices in collecting and re-usage project knowledge is needed for organizations to be at higher level of proficiency in project management which develops the organization's competitive position in the market of future. Project management performance is based on the knowledge of project team members. Naftanaila (2010) states that "other individuals, either internal or external to the project at hand, can use that knowledge if and only if it is applied and transferred effectively". Efficient knowledge transfer requires not only systems and procedures but also climate for knowledge share. Knowledge transfer between projects enables development of more effective and more sophisticated practices in project management.

The results of the survey confirmed that knowledge is managed and utilized to a wider extent among organizations which are more experienced in project management. The immature organizations do not collect the project knowledge in a systematic way. However, managing project knowledge and experiences are still very important activities, no matter if organization is at the lowest or highest level of maturity.

As little attention has been paid to how effective project knowledge transfer can help in achieving higher level of maturity in project management, this paper has contributed to the description of the importance of project knowledge transfer and utilization in the manner of improving project management maturity.

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THE USE OF MULTI-STATE REAL OPTIONS IN PROJECT EVALUATION AND PROJECT MANAGEMENT[1]

Introduction

Traditional project evaluation is based on discounted cash flow method (DCF). Main measure of effectiveness is the Net Present Value (NPV). When this value is positive, the project is approved, when negative rejected. But this approach sometimes leads to the abandonment of profitable projects, as shown in many works. The reason for this is that the DCF method does not take into account the role of managerial flexibility. Real Options Valuation (ROV) method takes into account future situations in the valuation, assuming that the project is properly managed. The Project Manager shall have the right to take action as appropriate. This situation is called a real option. Using the ROV, we can provide a quantitative measurement of the situation.

The term real option was proposed by S. Myers (1974). He noted some similarities between financial options and opportunities that arise in the course of project management. The option can be defined as some right, but not the obligation, which means that the holder of that right can determine when to exercise his right, depending on the current market situation. In the case of financial options is the right to a certain amount, in the case of a real option right to a certain action. This approach was then developed by A.K. Dixit and R.S. Pindyck (1994), later covered by L. Trigeorgis (1993). The most important element in the Real Options Analysis (ROA) is the valuation (ROV –Real Option Valuation). The first were used methods known from financial market, such as the Black-Scholes Model (Black, Scholes 1973) or Cox-Ross-Rubinstein Model (CRR) (Cox, Ross, Rubinstein 1979). It is also used an approach based on Monte Carlo simulations (Boyle 1977). CRR model is based on the binomial tree.

[1] The research is supported by NCN grant no. NN 111 477740

This approach was also adopted in the Guthrie (2009) work and in this study. Despite the simplicity of the method, however, is computationally difficult method.

The methodology of real options can be used not only to the valuation of projects, but also for risk management. Kumar (2002) proposed the creation of the portfolio of real options to manage the risks of the project. At the beginning of Project Manager (PM) may be able to delay the start of the project. During his life-time PM may have the option free choice of the beginning the next phase, but also extend the scope of the project or its abandonment, depending on market conditions. After successfully completion of the project, the PM may be able to start another.

The paper presents a method for decision support in project management, an approach based on Real Option Methodology. The method can be used in multi-stage projects where there is free choice of the start of the next phases of the project, which creates a Real Option situation. The starting the next phase is chosen according to the market situation characterized by the two stochastically independent variable factors. The method will allow not only better than does the DCF to assess the value of the project, but also to calculate the best moments of the start of the next phases.

1. Problem formulation

We will consider multi-stage project, which is for a longer time than it takes to perform all of its phases. It follows from this possibility (option) free choice of the start of the next phase. This freedom has its limits, of course. This issue is discussed in the literature by Guthrie (2009, p. 168). Choosing the start of the next phase depends on market factors that affect the value of the project. Guthrie is considering one such factor. This article extends these considerations, the binding results of the project with two market factors.

Consider the simple situation where we have the right to begin the phase of the project or to wait. Decision tree for this situation is shown in Figure 1 Decision maker may start phase of the project (decision ***A***), then with probability q the project moves from the current state ***b*** to another state a and which is a desirable state of the project (the project is ready). But with probability 1-q phase of the project could fail, and therefore returns to the ***b***. Decision maker has the option to wait for positive changes (decision ***W***), but then the project will remain in state ***b***.

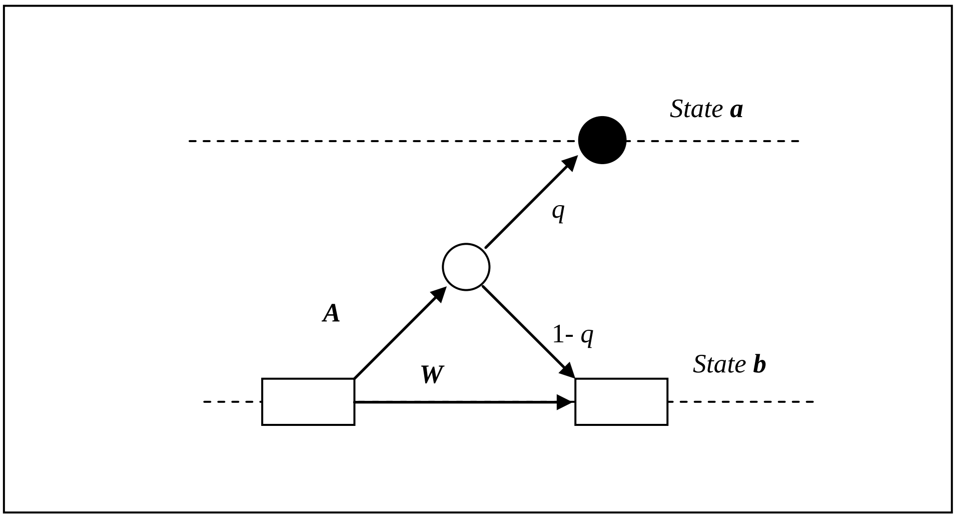

Figure 1. Possible decisions

This simple situation can occur in a real project multiple times. Consider a project consisting of two phases, each of which occupies a period of time, and the execution of the project we have available four periods. Upon successful completion of phase one, we can start the next. This situation creates options for free choice of the start of the project and the start of the second phase. The decision tree of this situation is presented in Figure 2. As previously each phase can result in a success or failed (with fixed probabilities).

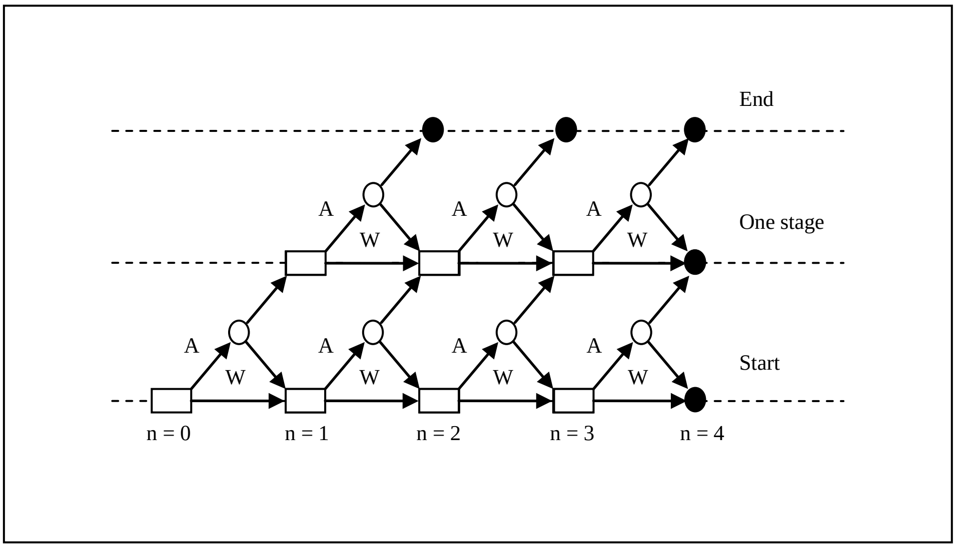

Figure 2. The decision tree

The results of the project, as its value depends on certain market factors, which may be commodity prices or exchange rates. Observing the changes, the decision maker decides on the validity take up the next phase of the project. These factors vary stochastically according to a certain random process. For these changes to take into account stochastic process is a binomial tree covered including future changes to this factor. Figure 3 shows such a tree for one variable. Each node of the tree, is related to the value of the project.

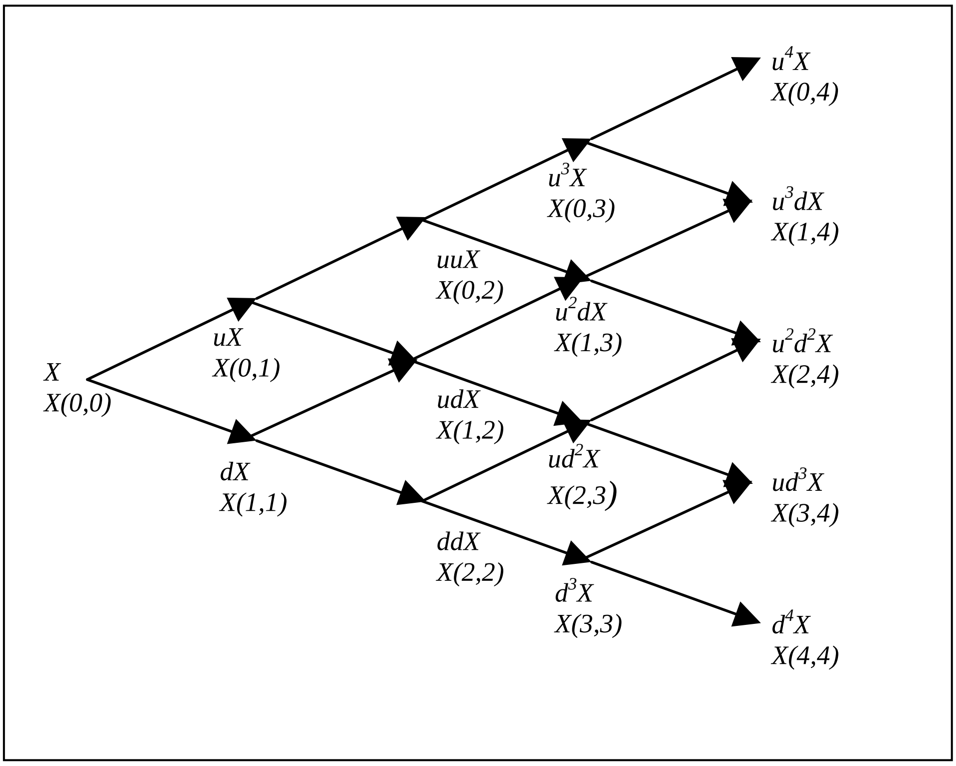

Figure 3. The binomial tree

The project depends not only on future cash flows, as is the traditional method of DCF, but also on the variable factor called state variable. The binomial tree, we assume that the variable state in one period may be increased *u*-time and fall *d*-times. This assumption leads to the tree of possible state variable values consists of nodes marked with indices (i, n) where i – means number of falls and n – means period number.

With each node is connected state variable and cash flow. We denote it as (in each node (i,n)):

- $X^k(i, n)$ – state variable in period n
- $Y_m(i, j, n)$ – cash flow in period n

We assume that we have M periods, the present value of state variable denoted by $X^k(0,0)$ and u and d are the values of growth and decline. Value of u can be obtained from historical data by the calibration procedure (Guthrie 2009, p. 263).

2. Proposed method

We will propose a procedure for the valuation of option situation that may arise in investment projects. The problem is multi-stage project. Due to the fact that until the project is more than that implementation takes time, appear in the additional options (real options), choose the appropriate time to begin the next steps. Decisions as to their start will be made based on observations of two market factors. The procedure will evaluate the validity of the start of the project under consideration and determine the best, in terms of efficiency, the moments of start of the subsequent phases. The proposed procedure for the valuation of an option position consists of the following steps:

Step 1 – Build a decision tree (D-Tree)

In this step, we recognize the possible states of the project. They may be different phases or specific stages. We recognize the possible decisions that we take in consideration the state. To take such a decision leads to a transition from one project to another state. Identify all possible transitions. The result of this step is to create a D-tree. An example of such a tree for a two-stage design problem under consideration is shown in Figure 2.

Step 2 – Build lattice of state variables (X-Tree)

In this step you need to identify quantifiable economic magnitudes, from which it may depend on the result of the project (state variables). The method the currently proposed will does not include the correlation between these variables, assuming it does not exist.

The tree starts from a known present value of state variables. Based on the history of changes of this magnitude can be determined by the values u and d is done in the calibration process (Guthrie 2009, p. 324). Formed is a tree of possible changes in state variable, as a possible scenarios of the situation.

Calibration is an appropriate choice of the number of steps and the choice of parameters, *d*, *u*, so as to best meet the future value of the variable state.

We assume the arithmetic Brownian Motion (BM) defined differential equation (Weron, Weron 1998, p. 166):

$$dX^k_t = \mu^k \cdot dt + \sigma^k \cdot dW_t \tag{1}$$

where:

k - state variable index $k = \{1, 2\}$
W_t –Wiener process
X^k_t – state variable
μ^k – drift of the process
σ^k – process volatility

Drift of the BM process, we can estimate the arithmetic average (ν^k) of historical data:

$$\hat{\mu}^k = \frac{\nu^k}{\Delta t_d} \tag{2}$$

Process volatility is assessed on the basis of the standard deviation (ϕ^k) of historical data:

$$\hat{\sigma}^k = \frac{\phi^k}{\sqrt{\Delta t_d}} \tag{3}$$

where:

Δt_d – part of the year, which corresponds to the owned historical data.

Assuming the arithmetic Brownian Motion, we can compute grid nodes binomial tree, the following formula (Guthrie 2009, p. 327):

$$X^k(i,n) = X^k_0 + (n-2i) \cdot \hat{\sigma}^k \sqrt{\Delta t} \tag{4}$$

where:

$\hat{\sigma}^k$ – volatility estimator
i – number of falls
n – period number

hence derive formulas for the parameters *u* and *d*

$$u^k = \hat{\sigma}^k \sqrt{\Delta t} \tag{5}$$

$$d^k = -\hat{\sigma}^k \sqrt{\Delta t} \tag{6}$$

The condition that $d^k = - u^k$, that yields a binomial tree.

Figure 4 shows the adjusted binomial tree (in order not to lose the legibility is shown only to the same nodes) changes in the Euro exchange rate for PLN in January 2011 (solid line). The parameters were estimated based on the Euro to PLN exchange rate changes in 2010.

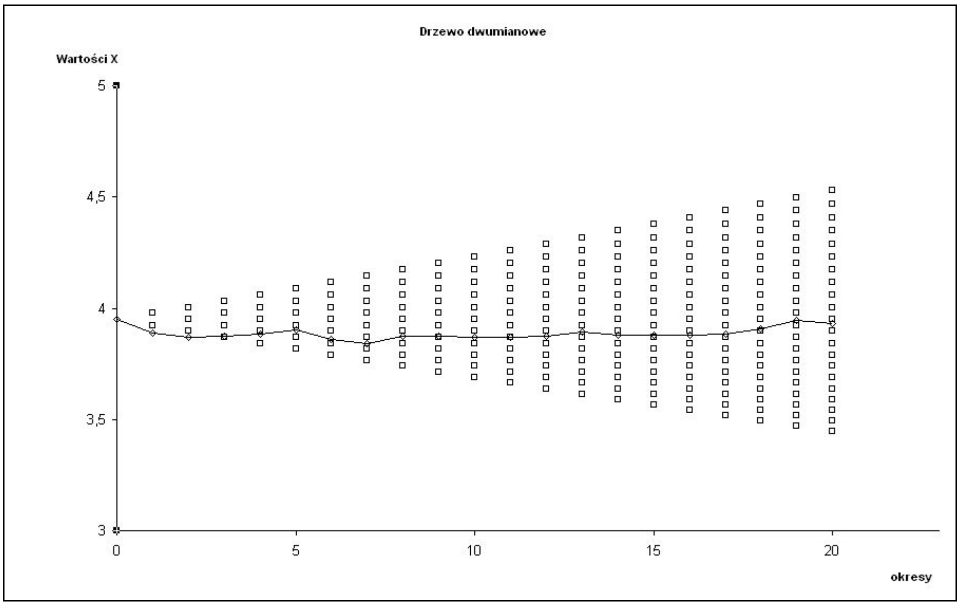

Figure 4. The adjusted binomial tree

Step 3 – Build a tree of the project values (V-Tree)

First, we denote the present value of the project, which is dependent on both state variables, as:

$V_m(i, j, n)$ – discounted present value of project in period n

where:

i – number of falls of first state variable
j – number of falls of second state variable
n – period number
m – project state index

Taking account in the consideration of two state variables, it makes the V-Tree grow in two dimensions. An example of such a tree after four periods are shown in Figure 5 For clarity, not shown on it all the links between nodes.

Calculation of the V-Tree starts from the project results in a final.We assume that the final value of the project is a function of state variables:

$$V_m(i, j, N) = F_m(X^1(i, N), X^2(j, N)) \tag{7}$$

On their basis, moving from the final set the value of the project in other previous nodes. Trees are constructed for each state project. Calculation of value is done by backward induction. Knowing the value of the project after its completion (which is usually equal to the state variable or using the right formula for this variable is calculated), we calculate the value of the project in the preceding nodes.

$$V_m(i,j,n) = max\left\{Q_m^W(i,j,n),\ Q_m^A(i,j,n)\right\} \tag{8}$$

where:

$m = a, b, c$ – project state index
$n = N-1, \ldots, 0$
$i = 0, \ldots, n$
$j = 0, \ldots, n$
$Y_m(i, j, n) = - I_m$

$$\begin{aligned} Q_m^W(i,j,n) = \Big(& \pi_u^1\pi_u^2 \cdot V_m(i,j,n+1) \\ & + \pi_u^1\pi_d^2 \cdot V_m(i,j+1,n+1) \\ & + \pi_d^1\pi_u^2 \cdot V_m(i+1,j,n+1) \\ & + \pi_d^1\pi_d^2 \cdot V_m(i+1,j+1,n+1) \Big) e^{-r\Delta t} \end{aligned}$$

– is discounted present value when we decide to Wait

$$\begin{aligned} & Q_m^A(i,j,n) = Y_m(i,j,n) \\ & + e^{-r\Delta t} \cdot \Big(\pi_u^1\pi_u^2 \cdot \big(qV_{m-1}(i,j,n+1) + (1-q)V_m(i,j,n+1)\big) \\ & \quad + \pi_u^1\pi_d^2 \cdot \big(qV_{m-1}(i,j+1,n+1) + (1-q)V_m(i,j+1,n+1)\big) \\ & \quad + \pi_d^1\pi_u^2 \cdot \big(qV_{m-1}(i+1,j,n+1) + (1-q)V_m(i+1,j,n+1)\big) \\ & \quad + \pi_d^1\pi_d^2 \cdot \big(qV_{m-1}(i+1,j+1,n+1) + (1-q)V_m(i+1,j+1,n+1)\big) \Big) \end{aligned}$$

is the discounted present value when we decide to Attempt to the next phase phase.

Subsequent values are weighted by the probability of achieving those values, which are calculated from the formulas (Seydel 2009, p. 15):

$$\pi_u^k = \frac{e^{r\Delta t} - d^k}{u^k - d^k} \tag{9}$$

for the growth of the k-th state variable,

$$\pi_d^k = \frac{u^k - e^{r\Delta t}}{u^k - d^k} \tag{10}$$

for the fall the k-th state variable.

where:

r – risk free interest rate

Because we assume that the project is properly managed, will be selected favorable decision, hence the calculations we use the maximum value.

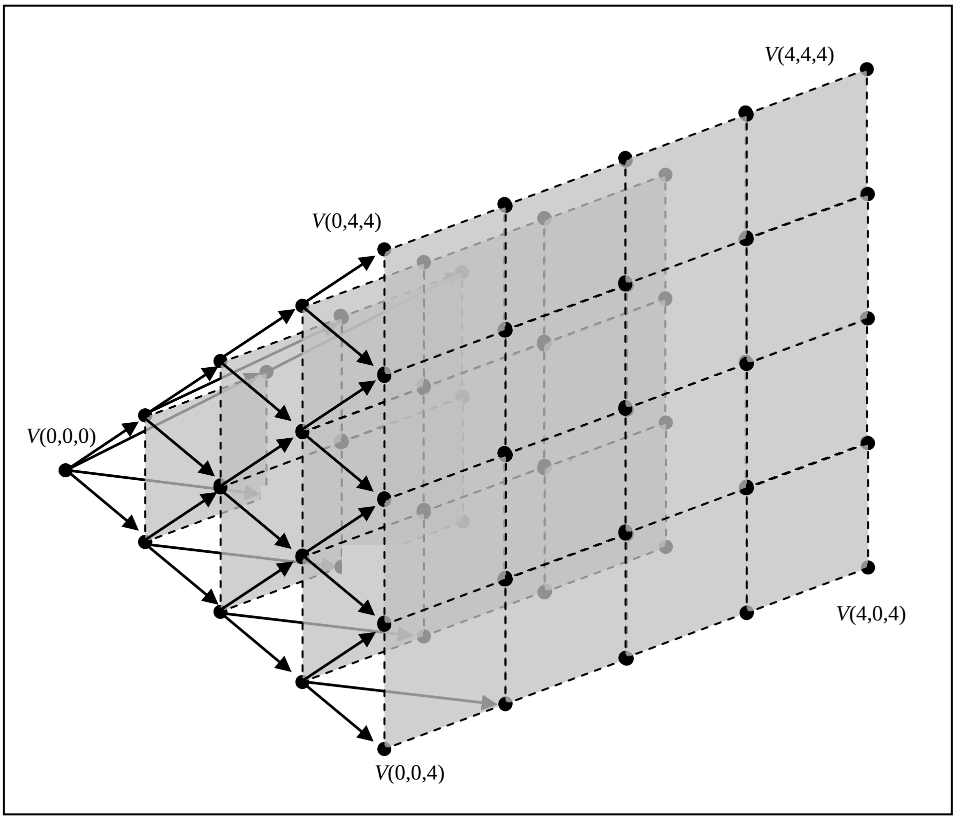

Figure 5. The V-Tree (Not all connections are shown)

When we deal with the situation of decision-making, the problem is a dynamic programming problem, because we have to choose the best decision.

Step 4 – Determine effective transitions (decisions)

Since we are considering a project in which, depending on market conditions, the decision maker may decide to move the project to another state, it is necessary to determine the moments of these transitions. In the case of one state variable, using the methods of dynamic programming is possible to determine the optimal decision. When we consider the two state variables, using multiple criteria dynamic programming methods will also be content with the efficient decisions, i,e, such for which there is no better decision.

$$\text{IF } Q_m^W(i,j,n) > Q_m^A(i,j,n) \text{ THEN } \textit{Wait} \quad \text{ELSE } \textit{Attempt} \tag{9}$$

In many cases it is sufficient to compare the value of *Q* for different decisions.

Conclusions

This paper presents the outline of the valuation method of development projects in which there are real option situations. The proposed method takes into account the dependence of the project as a result of two independent random economic factors, which are called state variables. Based on binomial trees, and uses multicriteria dynamic programming. Its use should allow not only to make the right decisions about the project, but also to support decision making during its implementation.

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SCHEDULING RESOURCE CONSTRAINED PROJECT PORTFOLIOS WITH THE PRINCIPLES OF THE THEORY OF CONSTRAINTS[1]

Introduction

Contemporary practice of project management is evolving towards accumulation of all projects in one organizational unit. This tendency manifests itself in creating a project management offices (PMO - Project Management Office). Their tasks include planning implementation and control of all projects within the organization.

As stressed in the PMBoK, one of the key properties of the PMO is to share and coordinate resources across all projects administered by the office (PMBOK 2004, p. 18). Updating the portfolio by adding new projects, they must make schedules, that all resources are best used. On the other hand, each project must have access to needed resources. This task can be reduced to the problem of scheduling with limited resources.

The problem of scheduling the project portfolio can be seen as a single project scheduling, in which there are many activities related to inconsistent graphs activities. However, they are linked to the need to use common limited resources. In this light, the problem becomes the selection of new projects in the portfolio, and thus the modification of existing schedules. The existing schedules should be forced into a new job using the available free resources.

Work attempts to formalize the principles of the Theory of Constraints for use in the project portfolio scheduling with limited resources. In particular, it will propose a identification of strategic resource, and then simplified process of scheduling by proposed heuristic.

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1. Resource Constrained Project Scheduling Problem

Resource Constrained Project Scheduling Problem (RCPSP) is widely considered in the literature. The problem is solved using metaheuristics, such as ant systems (Merkle, Middenforf, Schmeck 2002), swarms of particles (Jarboui, Damak, Siarry, Rebai 2008). They are used with the taboo search and simulated annealing (Mika, Waligora, Węglarz 2005), local search and genetic and evolutionary algorithms. It also proposes specific heuristics. Examples are the work of Neumann and Zimmermann (Neumann, Zimmermann 2000) or Tormosa and Lova (2003). They are used as optimization method. The work Ayala and Artigues (2010) used the method of linear programming. These articles are examples of recent work presenting ways to solve RCPSP. Query executed on the end of 2010 showed 458 entries for the problem.

2. Theory of Constraints

Theory of Constraints (TOC) was proposed by Eliyahu Goldratt (1997). The concept of the theory is based on two fundamental postulates:

- Each system must have at least one constraint
- The existence of constraints makes it possible to develop

Author proposed the method of applying the Theory of Constraints which consists of five iterative steps (Goldratt 1997):

1) identify constraints of the system
2) decide how to exploit the constraints
3) subordinate all others to the decisions on exploiting the constraints
4) elevate the constraints
5) by returning to Step 1, determine a new constraint

The basic element is the identification of constraints. If it is determined you can develop a method of disposal. This task should be given to all the action. Removal of this restriction allows the achievement of the organization (system) more efficient, which means that the system is based on another limitation. So the whole procedure should be repeated.

The use of the Theory of Constraints in Project Management was proposed by Goldratt (2007). The work is concerned the presentation of the Critical Chain method, streamlines the implementation of individual projects. Author also draws attention to the specificity of portfolio management, but here is restricted to introducing the concept of a strategic resource, which is a constraint in the company being considered system.

Strategic resource is a 'bottleneck' - which determines the possibility of implementation that has the company. It is constraint that dictates the rhythm of the work of other resources. Hence, the bandwidth determines the organization. For an organization to be effective resource that must be used at 100%.

To be able to use the TOC, you will need is the ability to identify strategic resource. To solve this problem was proposed as described in the next chapter heuristics.

3. Proposed method

Application of TOC philosophy in scheduling, significantly reduces the space of possible exploration. We focus only on optimal, in the sense of maximum utilization, scheduling the strategic resource. There is only a problem of defining what is a strategic resource. This paper proposes a heuristic algorithm, which allows you to define a strategic resource and then find schedule for new project.

We adapt Artigues' model (Artigues, Michelon, Reusser 2003) to the multi-project environment. We use standard notation for scheduling RCPSP problems, proposed by Brucker (Brucker et al. 1999), where:

– Q – set of projects in portfolio
– V^q – is set of activities of q-th project $q \in Q$
– q – is project index
– $q + 1$ – is new project
– $\Re^{\rho}$ – set of renewable resources
– R_k^{ρ} – availability renewable k-th resource – $k \in \Re^{\rho}$
– p_j^q – processing time of activity j *in* q-th project

RCPSP problem is to find schedule for each q-th project as vector:

$$S^q = \left(S_0^q, \ldots, S_j^q, \ldots, S_{n+1}^q\right)$$

where:

S_j^q $j = 0,1, \ldots, n, n+1$ – is the starting point of activity j in q-th project.

We add two points in time for each q-th project:
S_0^q – is moment when q-th project starts
S_{n+1}^q – is moment when q-th project is finished

To simplify the notation we introduce also the end times for each j-th activity and each project q:

$$C^q = \left(C_0^q,\dots,C_j^q,\dots,C_{n+1}^q\right)$$

where:

C_j^q $j = 0,1, \dots, n, n+1$ – is the time of completion of activity j

We will define set of activities ongoing at time t for each project q:

$$A(S^q,t) = \left\{ j \in V^q \mid S_j^q \le t \le S_j^q + p_j^q \right\}$$

and the size of the engaged k-th resource the q-th project:

$$r_k(S^q,t) = \sum_{j \in A(S^q,t)} r_{jk}$$

where

r_{jk} – is the size of the engaged k-th resource the j-th activity.

The portfolio of projects can be seen as a single project with inconsistent graph of activities. The addition of this new project portfolio can cause conflicts in the access to resources. We must do this so that these conflicts do not arise. For this purpose, we will create appropriate schedule of operations. It is a very complex task. To simplify this, we specify strategic resources from which you can start scheduling.

The method for finding strategic resources proceeds in the following steps:

Step 1: Identify a strategic resource for solving the problem of goal programming:

$$\begin{aligned}
& \min \sum_k y_{kt}^+ \\
& s.t. \\
& S_{n+1}^q \le C_{min} \quad \forall q \in Q \\
& S_j^q - S_i^q \ge p_i^q \quad \forall i \in V^q - \{n+1\}, \forall j \in V^q - \{0\}, \forall q \cup q+1 \\
& \sum_q r_k(S^q,t) - y_{kt}^+ + y_{kt}^- = R_k^\rho \quad \forall k \in \Re^\rho \ \forall t > 0 \\
& y_{kt}^+, y_{kt}^- \ge 0 \quad \forall k \in \Re^\rho
\end{aligned}$$

where :

y^{+}_{kt} – demand over the availability of resource *k* at time *t*
y^{-}_{kt} – demand below the availability of resource *k* at time *t*
C_{min} – declared time of completion of all projects

If objective function is equal 0 we have feasible schedule. Resources for which

$$\min_{k} \sum_{t} y_{kt}^{-}$$

is strategic resource.

Step 2: Add a new project activities, starting from those that use a strategic resource.
Step 3: By returning to Step 1, determine a new strategic resource.

In the first step, by solving the problem of goal programming, we are finding strategic resource. For this resource, we create a schedule by adding the activities of new project (Step 2). Adding them may cause that the new resource will become strategic, therefore in Step 3, we repeat the procedure. The proposed heuristics should significantly reduce the complexity resolved during scheduling issues.

4. Numerical example

In order to illustrate the proposed algorithm is considered a portfolio of projects considered in the literature (Hanh Quang Le 2008). We look at the portfolio as a single project activities inconsistent graph as shown in Figure 1 Summary of actions making up the designs shown in Table 1.

Table 1

Activities of the project portfolio

Activity *j*	p_j	*Pred(j)*	Resources
Project P1			
P1-1	3,33		2A, C
P1-2	4		2A, B, C
P1-3	5	*P1-1, P1-1*	A, C
Project P2			
P2-1	5		A,B,C
P2-2	4	*P2-1*	2A,
P2-3	5	*P2-1*	A,2B,C
P2-4	4	*P2-2, P2-3*	2A,C

Source: Hanh Quang Le: *Resource-Constrained Multi-Project Scheduling with Resource Moving Time for Construction Projects in Vietnam*, p. 103.

Availability of resources used (A, B, C) is shown in in Table 2.

Table 2

Availability of resources

Resource	A	B	C
Availability	4	2	2

Source: Ibid.

Graph of activities of the project portfolio is shown in Figure 1.

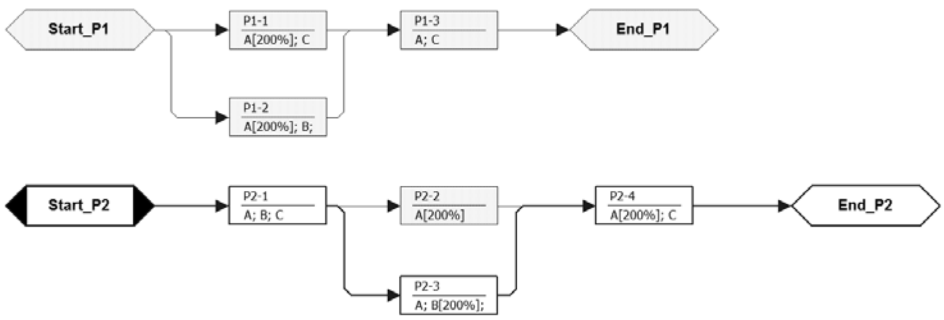

Figure 1. Graph of activities of the project portfolio

So defined problem has balanced resources to the implementation of the projects within the assumed time for schedules:

$$S^1 = (1, 1, 5)$$

$$S^2 = (5, 10, 10, 15)$$

Which are presented on Figure 2.

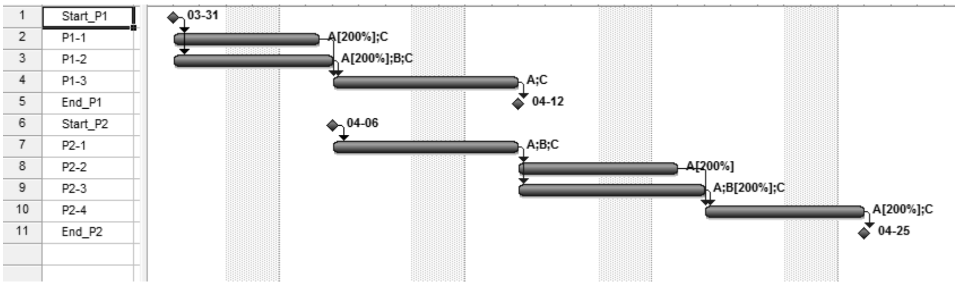

Figure 2. Project portfolio Gantt chart

Start a new project, will need to plan new activities that will be using the same resources. Considered a portfolio of projects, complemented by P3 project, which consists of the following activities: P3-1, P3-2 and P3-3 shown in Table 3. Graph of supplemented activities for this portfolio is shown in Figure 3.

Table 3

Activities of additional project

Activity *j*	p_j	*Pred(j)*	Resources
Project P3			
P3-1	5		2A, C
P3-2	4		2A, B, C
P3-3	5	*P2-1, P2-1*	A, C

If we want to add this new project to the portfolio, it is necessary to identify a strategic resource in old one.

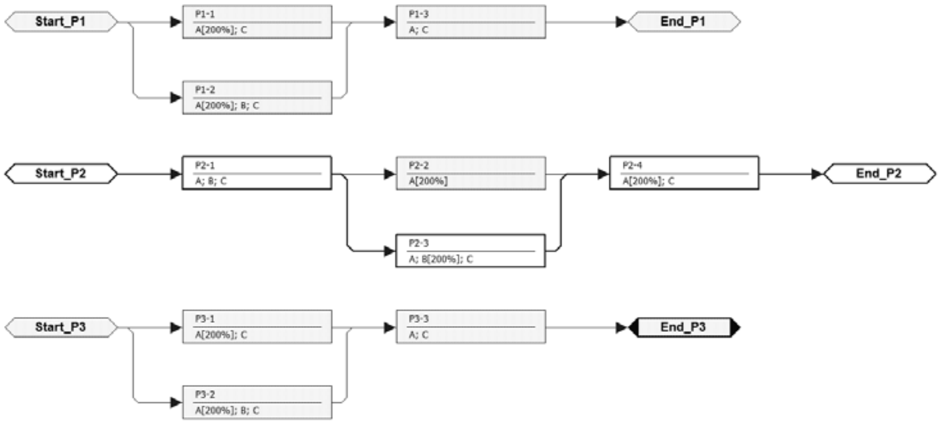

Figure 3. Supplemented project portfolio activities graph

Step 1: Implementation of the proposed method for the example shown, gives us, values of balancing variables are presented in Table 4 to 6 for all resources.

Table 4

Values of balancing variables for resource A

t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
y^+_{kt}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
y^-_{kt}	0	0	0	0	2	2	2	2	2	1	1	1	1	2	2	2	2	2	4	4

Table 5

Values of balancing variables for resource B

t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
y^+_{kt}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
y^-_{kt}	1	1	1	1	1	1	1	1	1	0	0	0	0	0	2	2	2	2	2	2

Table 6

Values of balancing variables for resource C

t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
y^+_{kt}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
y^-_{kt}	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2

It gives C as strategic resource. (Sum is equal to 11)

Step 2: We add activities of project P3 which use resource C. That is activity P3-1. First moment when we have enough is day 10, but other resources are not available (A) . We can start this activity in day 15.

Step 3: By returning to Step 1, we must determine a new strategic resource.

By continuing the procedure, we obtain a schedule for the project *P-3* as:

S^3 = (14, 19, 23)

which is presented as Gantt chart on Figure 4.

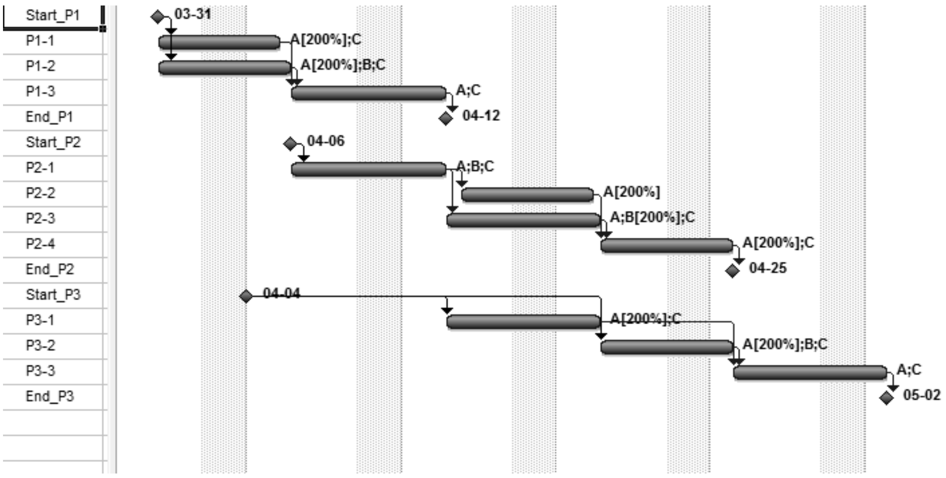

Figure 4. Gantt chart for modified portfolio

Conclusions

The paper presents a heuristic algorithm scheduling support project portfolios. It uses goal programming method, in order to identify critical resources within the meaning of E. Goldratt Theory of Constraints. Operation of heuristics is shown in a simple example. Its practical effectiveness can only be fully assessed until the computer implementation. It is planned in AIMMS environment.

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