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INTERACTIVE APPROACH TO PROJECT PORTFOLIO SELECTION

Introduction

Projects have a great impact on modern society. They are the basic tool of the strategy implementation in commercial, public, and "non-profit" organizations. Although the recognition of the project management role is higher and higher, it is evident that the wastage of resources resulting from improper selection of projects and their improper formulation is immense. Together, these two factors limit the growth potential of the organization and undermine its competitive position.

Trying to reach this challenge, it is worth to look to the solutions provided under the project portfolio management (PPM). Although it is sometimes viewed as another project management technique, in fact, it is not that. PPM goes beyond the project management, as it spans the path from the organization's vision, through project management, to the realization of the benefits (Levine, 2005). The selection of the right projects at the right time is crucial for successive PPM.

It is commonly assumed that for each project a single objective should be defined. This overall goal should be specified as clearly as possible, since the shortcomings in project definition are among the main reasons of project's fiasco. The clarity and unambiguity in defining the goal, which is an advantage for a single project, becomes a burden when the entire portfolio of projects is analyzed. Both researchers and practitioners agree that multiple goals should be considered when portfolio is constructed. This follows from the fact that the organization's strategy cannot be reduced to the single precisely defined objective.

The multidimensional nature of the project portfolio selection problem is noticed both by researchers focusing on project management, as well as those who deal with decision support methods. In most of project management textbooks simple scoring techniques for project prioritization are presented. On the other hand, operational research provide complex models requiring sophisticated algorithms. Such approaches are viewed by managers as difficult for practical implementation. One of the reason is that usually a large amount of information, in particular concerning the decision-maker preferences, is needed. The collection of such information is time-consuming and inconvenient if it is done once at the beginning of the procedure. However, preference information can also be gathered in a stepwise manner. This methodology is referred to as interactive approach.

The aim of this paper is to present the way in which interactive approach can be used for solving project portfolio selection problem in a real-world application. The procedure combines computer simulation, analysis of experts' assessments and interactive multiple criteria procedure INSDECM. Although our procedure can be applied to any type of project, it is particularly useful for engineering ones, such as those analyzed in the paper.

The numerical example presented in the paper comes from an engineering company providing solutions for the railway industry. The organization under consideration applies so-called *Project Management Style of Business Management*. Most of its business activity is focused on executing projects with clearly defined goals and precisely specified deadlines.

The paper is structured as follows. In next section the a brief review of related works is provided. Then the problem is defined and general idea of the procedure is discussed. Finally a practical application of the proposed technique is presented. The last section is a conclusion.

1. Related work

Project portfolio management is more and more popular both within researchers, and practitioners. The turbulent environment in which managers have to work today encourages them to look for new techniques, that help navigate in uncertain conditions. Analyzing the literature, we can identify two main approaches to the project portfolio construction problem. In popular textbooks on project management, and other publications addressed to project managers simple techniques based on financial models and multiple criteria scoring are proposed (Gray and Larson, 2008; Levine, 2005; Nicholas and Steyn, 2008). The approach that is used most often assumes that the portfolio is constructed in two steps: first projects are prioritized according to the set of criteria, next the portfolio is constructed taking into account additional requirements on its structure.

On the other hand, a large number of works proposing complex models requiring sophisticated algorithms is published. For example, Doerner et al. (2006) propose to use ant colony meta-heuristic for identifying Pareto-optimal portfolios. In Liesiö et al. (2007; 2008) robust portfolio modeling is used to support project portfolio selection in the presence of multiple evaluation criteria and incomplete information.

A technique that is used very often for prioritizing projects is Analytical Hierarchy Process. This approach is used for example by Lootsma et al. (1990), Kearns (2004) and Dey (2006), Ahari et al. (2011). Techniques based on the utility function constitute another group of multi-criteria techniques employed in project selection problems. They are based on the assumption that each decision maker attempts to maximize some utility function aggregating evaluation criteria. In this case, the main problem is to estimate the utility function. Multi-attribute utility analysis is used, for example, by Moselhi and Deb (1993), who treat uncertainty in a similar way to that used in the PERT technique. Wong et al. (2000) incorporate fuzzy analysis into multi-attribute utility theory.

Fuzzy set theory is often applied to model uncertainties that managers are faced with. Models for the project portfolio selection using this approach are proposed for example by Lin and Hsieh (2004) and Wei and Chang (2011).

The solution of a multiple criteria decision making problem is possible if the decision maker is able to provide information about his/her preferences with respect to the set of objectives under consideration. An efficient way to collect this information is to use interactive techniques. They assume that the decision maker is able to provide preference information with respect to a given solution or a given set of solutions (local preference information). Numerous interactive techniques have been proposed in recent years. Most of them are applicable in circumstances of certainty, although techniques devised for the case of risk are also proposed. The INSDECM (Nowak, 2006; 2008), combines interactive approach and risk analysis based on stochastic dominance and mean-risk analysis.

2. The problem and the methodology

Projects are the major tool for implementing and achieving the strategic goals of the organization (Gray, Larson, 2008). The company that selects right projects and implements them efficiently is able to achieve a competitive advantage. The question is: what does it mean "right projects"? First, projects should contribute to stakeholder value creation. Thus, financial analysis is crucial for project evaluation. However, financial return, while important, does not always reflect strategic importance. Often companies have to choose between potentially profitable projects that are outside the zone of their core mission and the ones that do not have high profit margins, but are important from strategic point of view. The reasons for selecting less profitable proposals include:

- to capture larger market share,
- to make it difficult for competitors to enter the market,
- to develop a product, which by its introduction will increase sales in more profitable products,
- to develop technology that will be used in next-generation products, etc. (Gray, Larson, 2008).

As no single criterion can reflect strategic importance, portfolio management needs multiple criteria models. It should be noticed that usually it is not easy to evaluate how much a project contributes in supporting the achievement strategic goals, since criteria are often intangible. As a result internal or external experts are asked to evaluate projects.

In this paper project portfolio selection is defined as a discrete decision making problem, for which we define:

1. A finite set of decision alternatives:
   $\mathbf{A} = \{a_1, a_2, \dots , a_m\}$
2. A finite set of criteria:
   $\mathbf{F} = \{f_1, f_2, \dots , f_n\}$
3. A set of evaluations of alternatives with respect to criteria:

$$\mathbf{E} = \begin{bmatrix} f_1(a_1) & \cdots & f_k(a_1) & \cdots & f_n(a_1) \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ f_1(a_i) & \cdots & f_k(a_i) & \cdots & f_n(a_i) \\ \vdots & \cdots & \vdots & \cdots & \vdots \\ f_1(a_m) & \cdots & f_k(a_m) & \cdots & f_n(a_m) \end{bmatrix}$$

In our problem the set of alternatives consists of the portfolios satisfying constraints defined by the decision maker (or decision makers). Such constraints may arise from the available resources, requirements for the portfolio structure (percentage of resources invested in particular types of projects), or the need for "must-do" projects.

Both financial and non-financial criteria are taken into account. Net present value (NPV), internal rate of return (IRR), profitability index (PI), payback period (PP) are the financial criteria that are used most often. They require prediction of future cash-flows. In the real world, however, none predictions are known with certainty. Our procedure uses computer simulation to estimate the financial efficiency of each project and to assess the variability of outcomes. Simulation results are then used for generating probability distributions describing profitability of each project.

Project analysis cannot ignore its duration. Faster implementation allows to release resources that can be involved in other projects. Just as in the financial analysis it is necessary to consider uncertainty, especially when an innovative project is planned. Here we assume, that simulation model is also used to estimate duration of each project.

Non-financial criteria are in general of qualitative nature. In order to evaluate them we need a rating scale. Such scale can be defined, for example, as a 5-point one, with 1 assigned to the least desirable and 5 to the most desirable output. However, sometimes it is convenient to use a multidimensional scale. Such approach is used for example in risk analysis. In *Failure Mode and Effects Analysis* (FMEA) three dimensions are taken into account for identifying the risk level: impact, probability, and detection. Each of the three dimensions is rated according to a five-point scale. The weighting of the risk is then based on the overall score which is the product of these three ratings. Although the analysis of this type is mainly used for risk assessment, it can also be applied to study other characteristics, such as the possibility to reach additional benefits from project (new contracts, service contracts, etc.).

In many companies people employed in various positions are asked to evaluate projects. As a result, a series of evaluations is obtained for each project. Commonly, a mean of such estimations is calculated. However, in such case part of information is lost, as we do not know whether people evaluating the project agree with each other or not. Instead, we can assume equal probability for each assessment and use them for constructing probability distributions.

Taking into account the above assumptions we obtain a problem in which the evaluation of each alternative with respect to each criterion is represented by a probability distribution. The problem solving procedure consists of three steps. First, the set of criteria is defined. Next, evaluations of projects with respect to the criteria are generated. Finally, interactive technique is employed for selection of the most desirable project. The steps required to perform the analysis are described below.

Step 1: Identification of criteria

The selection of the criteria is of crucial importance. According to Roy (1985), the set of criteria should meet three requirements: it should be complete, consistent, and non-redundant. The first requirements means that all important aspects of the problem are covered. The set of criteria is consistent if local relations between alternatives (with respect to each criterion individually) are consistent with global relations (with respect to the general objective). Finally, non-redundancy means that removal of any criterion causes the violation of at least one or previous requirements. It’s obvious that for any decision problem multiple sets of criteria satisfying the above conditions can be proposed. The final choice is greatly affected by the accessibility of the data.

Step 2: Generation of portfolio evaluations

As mentioned above, we propose to use simulation to analyze the financial efficiency of the project. This technique allows consideration of various risks. For example, when a construction or manufacturing project is analyzed, uncertainties related to availability of resources, market prices, or demand can be considered. On the other hand, in projects with R&D elements activity durations are much more sensitive to incorrect evaluation. In such cases simulation may provide the dates of the milestones of the project, which determine the set of cash-flows during the life cycle of the project. One of the most important elements of simulation modeling is identifying appropriate probability distributions for input data. Usually, this requires analyzing empirical or historical data and fitting these data to distributions. Sometimes, however, such data are not available and an appropriate distribution has to be selected according to the decision maker's judgment. Once the simulation model is built, verified, and validated, it can be used for generating probability distributions of output variables.

As to qualitative criteria, we assume that experts from within or outside the parent organization are asked to evaluate proposals. In the case study presented below, specialists form various departments evaluated projects taking into account various risk factors, as well as the possibility to achieve additional benefits from projects. These leads to a series of evaluations which is transferred to probability distribution, in which each evaluation obtains the same probability.

Step 3: Identifying the final solution using interactive technique

The procedure that we propose for identifying the final solution is INSDECM (Nowak, 2006). This is an iterative technique. In each step a so-called "potency matrix" is presented to the decision maker (or decision makers). Such matrix consists of two rows that group the best (optimistic) and the worst (pessimistic) values of characteristics that reflect how good are the alternatives analyzed in the current step of the procedure. As the evaluations of alternatives are not crisp values but are expressed by probability distribution, we need to find a way in which this information should be presented to the decision maker. INSDECM assumes that various distribution characteristics can be used including mean, standard deviation, semideviations and probability that the satisfactory value would be obtained. As managers are usually not familiar with sophisticated statistical analysis, simplest characteristics are used most often (mean, probability of reaching satisfactory value). The scope of information that should be presented is defined by the decision maker.

After reviewing the results, the decision maker is asked whether pessimistic values are satisfactory. If the answer is "yes", current set of alternatives is presented to him (or her) to make the final choice. Otherwise, the decision maker is asked to specify the criterion that should be improved and to define the constraint on the value of the distribution characteristic analyzed for this criterion. Next, the set of alternatives satisfying this constraint is identified and the procedure goes on.

In INSDECM additional analysis for identifying potential inconsistencies of the constraints defined by the decision maker with theoretical assumptions is conducted. However, we will not discussed it here. The details for INSDECM technique can be found in Nowak (2006; 2008).

3. A case study*

The procedure briefly discussed in previous section was used for analyzing the project portfolio selection in a company providing solutions for the railway industry. The company can be characterized as an organization that applies project management style of business. Most of it's revenues comes from executing projects. The company is famous for the exceptional care it takes with regard to the safety of equipment and the range of services offered. Due to the specialised nature of its business, the execution of each project requires particular attention to detail and care both in preparation and implementation phase.

All activities of the company are based on the project management methodology. This approach makes it possible to compare new proposals with previously completed projects and to prevent the reproduction of the same mistakes in the future. The company tries to construct a balanced project portfolio taking into account not only the profitability, but also various types of risks and criteria referred to as "political". These include factors affecting the future ability to generate additional revenue which are currently difficult to quantify.

The practice of the company is that multiple project portfolios are constructed covering different areas of its business. The problem considered here was to construct a portfolio of projects involving the installation of a particular type of equipment on railway lines located in Poland. The company assumed that it would be responsible for completing all projects, but some of them would be subcontracted. Company was interested in identifying the projects that should be realized using its own resources.

The set of potential projects consisted of 9 proposals. Based on the information about available resources 14 potential portfolios were identified (Table 1).

Table 1

The set of analyze portfolios

Portfolio	Projects					
Portfolio 1	4	8				
Portfolio 2	1	2	5	6		
Portfolio 3	1	2	3	5		
Portfolio 4	1	3	4	5	7	9
Portfolio 5	1	4	5	6	7	9
Portfolio 6	5	8				
Portfolio 7	2	9				

* The results presented in his section are partly based on the results presented in Twardoch (2011).

contd. table 1

Portfolio 8	1	2	5	7		
Portfolio 9	3	4	5	6	7	9
Portfolio 10	2	3	5	7		
Portfolio 11	2	4	5	6		
Portfolio 12	2	3	4	7		
Portfolio 13	2	3	4	6		
Portfolio 14	1	3	4	5	6	9

The general objective was to identify the portfolio maximizing the profit, minimizing the workload (measured in hours), was the least risky and guaranteed the highest potential for future benefits. Thus, following criteria were considered: the total profit of all projects, the total time required for completing all projects, risk associated with the co-operator, risk of customer, internal risk, benefits – project's impact on business operations. It was also assumed, that projects would be executed in a series – one after another. As the projects were small (the duration of each project was never more than one month), it was not necessary to take into account discounting rate. The set of criteria is presented in Table 2.

Table 2

The set of criteria

Criterion	Description	Type
f_1	total profit	quantitative
f_2	total completion time	quantitative
f_3	risk associated with co-operator	qualitative
f_4	risk of customer	qualitative
f_5	internal risk	qualitative
f_6	total impact on business operations	qualitative

In order to analyze profitability of each project following cost items were taken into account: materials, installation, training, system adaptations, project engineer, construction management, planning, project management, safety, and others. For each item three estimations were obtained: minimum, maximum, and the most probable cost. A triangle distribution was accepted to describe the variability of cost items. The same assumption was made regarding the completion time of each activity. The simulation results are presented in Table 3.

Table 3

Simulation results (means of probability distributions)

Portfolio	Total profit (thousands of PLN)	Duration (hours)
Portfolio 1	483.9	333.6
Portfolio 2	472.3	414.3
Portfolio 3	485.3	428.1
Portfolio 4	495.0	515.6
Portfolio 5	482.0	501.8
Portfolio 6	488.8	345.4
Portfolio 7	473.8	297.2
Portfolio 8	483.7	419.5
Portfolio 9	490.3	510.5
Portfolio 10	491.9	428.2
Portfolio 11	435.3	406.2
Portfolio 12	487.1	416.7
Portfolio 13	475.8	411.5
Portfolio 14	483.7	510.3

Table 4

Risk Severity Matrix

Impact										
(large) 5										
4										
3										
2										
(small) 1										
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
	Probability									

The company uses a risk severity matrix to for risk assessment (Table 4). This tool was used in our procedure. Three experts were asked to fill the risk severity matrix for each project and for each risk factor. In order to calculate risk value the impact factor was multiplied by 2 and the probability was multiplied by 10. Thus, both dimensions were measured in scale from 1 to 10. For example expert no. 1 assessed the first project with respect to criterion f_3 (risk associated with co-operator) in the following way: impact = 3, probability = 0.5. As a result, the risk value was calculated in the following way:

$$\text{Risk value} = (3 \times 2) \times (0.5 \times 10) = 30$$

The same technique was used to evaluate projects with respect to criterion f_6. However, in this case the impact was assumed to be positive. The results are presented in Table 5.

Table 5

Evaluations of projects by experts

Expert	Project								
	1	2	3	4	5	6	7	8	9
f_3 – risk associated with co-operator									
1	30	8	4	72	8	16	64	12	4
2	16	12	8	8	18	2	18	30	18
3	36	36	80	30	30	30	12	6	80
f_4 – risk of customer									
1	16	12	4	64	4	100	64	24	12
2	4	8	30	4	12	30	8	10	4
3	12	12	12	70	70	30	8	8	80
f_5 – internal risk									
1	48	12	12	64	12	36	42	24	12
2	8	12	12	12	4	12	30	20	12
3	8	8	8	18	8	8	8	8	18
f_6 – total impact on business operations									
1	72	36	24	8	42	24	8	24	30
2	30	48	56	28	64	48	42	24	64
3	60	60	72	70	42	56	32	16	100

Evaluation of the portfolio with respect to qualitative criterion was calculated as the average of evaluations of projects included. For example, for the first expert evaluations of portfolio no. 1 (projects 4 and 8) are: for criterion f_3 – 42 (average of 72 and 12), for criterion f_4 – 44 (average of 64 and 24), for criterion f_5 – 44 (average of 64 and 24), and for criterion f_6 – 16 (average of 8 and 24). For each portfolio and for each qualitative criterion we obtained three evaluations.

Final solution of the problem was identified using interactive procedure INSDECM. The dialog was conducted with the manager responsible for the selection of the projects. First, he was asked what information should be presented. His answer was as follows:

– criterion f_1: mean and probability of reaching value 485 thousands PLN,
– criterion f_2: mean,
– criterion f_3: the highest risk evaluation (from assessments provided by three experts),

- criterion f_4: the highest risk evaluation (from assessments provided by three experts),
- criterion f_5: the highest risk evaluation (from assessments provided by three experts),
- criterion f_6: the lowest benefit evaluation (from assessments provided by three experts).

The data presented that were presented to the manager are listed in Table 6. Criteria f_1 and f_6 are maximized, while others are minimized. Thus, optimistic values for criteria f_1 and f_6 are the highest values attainable within the whole set of feasible solutions, and pessimistic are the lowest ones. For other criteria the situation is opposite: optimistic value is the lowest, and pessimistic is the highest.

Table 6

Information presented to the decision maker in iteration no. 1

criterion	f_1		f_2	f_3	f_4	f_5	f_6
characteristic	mean	$P\{f_1(a_i) \geq 485\}$	mean	max	max	max	min
pessimistic value	435.4	0.00	515.6	58.0	46.0	80.0	16.0
optimistic value	495.0	0.87	297.2	24.0	25.5	43.0	43.5

After reviewing the information, the manager said that the pessimistic values were not satisfactory. He decided to consider only those portfolios for which the probability of reaching the profit not less than 485 thousands was at least 0.5:

$$P\{f_1(a_i) \geq 485\} \geq 0.5$$

The numbers of portfolios satisfying this constraint are as follows: 1, 3, 4, 5, 6, 8, 9, 10, 12, 14. Thus, portfolios no. 2, 7, 11, and 13 were no longer considered.

In the next iteration the manager focused on criterion f_2. He was interested in the probability that the value of this criterion (the number of hours used for completing projects) would not exceed 430. New potency matrix was constructed and presented to the manager (Table 7).

Table 7

Information presented to the decision maker in iteration no. 2

criterion	f_1	f_2		f_3	f_4	f_5	f_6
characteristic	mean	mean	$P\{f_2(a_i) \leq 430\}$	max	max	max	min
pessimistic value	482.0	515.6	0.00	47.7	45.7	66.7	16.0
optimistic value	495.0	333.6	1.00	24.0	25.5	43.0	43.5

It is not difficult to state that only for criterion f_2 optimistic value was worsened. For other criteria optimistic values were the same as in iteration 1. On the other hand, pessimistic values were improved for all criteria except f_2 and f_6. The manager was again asked whether pessimistic values were satisfactory, and the answer once more was "no". The next constrained defined by him was to consider only such portfolios for which the probability that the value of the second criterion would not exceed 430 was not less than 0.5:

$$P\{f_2(a_i) \leq 430\} \geq 0.5$$

His constraint was not satisfied for portfolios no. 4, 5, 9, and 14. Thus, the following portfolios were still under consideration: 1, 3, 6, 8, 10, and 12.

Next, the manager decided to analyze criterion f_3. The potency matrix presented in iteration 3 is listed in Table 8.

Table 8

Information presented to the decision maker in iteration no. 3

criterion	f_1	f_2	f_3	f_4	f_5	f_6
characteristic	mean	mean	max	max	max	min
pessimistic value	483.7	428.2	45.5	44.0	58.5	16.0
optimistic value	491.9	333.6	24.0	25.5	43.0	43.5

The constraint that was defined by the manager in this phase was: for criterion f_3 the risk value should not exceed 40. As a result two portfolios were excluded: 1 and 3. After two other iterations two alternate portfolios were presented to the decision maker (Table 9). The manager decided to choose portfolio 6. Two projects (no. 5 and 8) were chosen to be executed using the company's own resources. Other were subcontracted.

Table 9

Portfolios proposed to the decision maker at the end of the procedure

criterion	f_1	f_2	f_3	f_4	f_5	f_6
characteristic	mean	mean	max	max	max	min
Portfolio_6	488.8	345.4	24.0	39.0	44.0	29.0
Portfolio_8	483.7	419.5	28.5	25.5	48.5	39.5

Conclusions

The procedure presented here was implemented in a real-world environment. Although, it was not easy to explain the idea of our approach to the manager, finally he was content with the technique. He was especially satisfied with the possibility to analyze how the choices he made, affect the results. He stated also, that by using this procedure, his conviction of making the right choice significantly increased.

Another result of this experiment was the formulation of additional requirements for the procedure. First, the manager pointed out, that the project portfolio selection cannot be treated as a static problem. In fact, the company in which he is employed constructs its project portfolio continuously. According to him, the procedure should therefore take into account the potential of new, more attractive projects that are currently not available. What's more, the area for which the procedure was applied is only a part of company's business. Manager stated that its use in a wider context requires taking into account the need to balance the portfolio. As he said, in practice a step-by-step procedure is often used. It starts from analyzing large, strategic projects, and then supplementing the portfolio by smaller proposals. However, he stated that such approach not always is efficient, as decisions on executing large projects may preclude implementing smaller, but very important projects.

The experience gained in the experiment described in this paper will be used in our further research. We are going to propose a procedure which takes into account the requirements formulated by the manager. We want to use dynamic programming approach that allows taking into account the dynamic nature of the project portfolio construction process.

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