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Dynamic and risk multicriteria analyses of project portfolios

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Abstract

The use of project portfolio management is increasingly becoming a tool for promoting the strategy of the organization. Using sophisticated quantitative tools becomes a significant competitive advantage for project portfolio management. Project portfolio management is a dynamic multi-criteria decision-making problem under risk. The paper presents new proposed approaches for analysing the problem. A dynamic version of the analytic network process (ANP) was proposed to capture the network, multi-criteria and dynamic structure of the problem. Risk of project portfolios is measured by multiple criteria. We propose to complete our dynamic ANP model by a decision tree with multiple criteria and an interactive multi-criteria analysis for solving this problem. The procedure is illustrated on an example.

Keywords: Project portfolio; multiple criteria; dynamics; risk

1. Introduction

Project management is the approach to managing resources in order to successful achieve specific project goals. There is a very extensive literature on the management of individual projects and project portfolios (Kerzner, 2022; Turner, 2016). In a rapidly evolving economic world, projects become tools to support goals of the organisation. Projects represent a way to implement the organisation's strategy. The strategic direction of the projects is crucial for the effective use of the organisation's resources. The selection criteria must ensure that each project contributes to strategic goals. Environment is not stable, and it puts pressure on organisations to develop new products faster, cheaper and more error-free. Most project organisations exist in a multi-project environment. Such environment creates relationships of projects and the necessity of sharing resources.

Projects are in accelerating world rhythm the right option of solving problems of lot of organizations. Nothing is permanent, everything is temporary, and that makes pressure on companies to finish new products or services faster, cheaper and definitely not to fail. Risk is a very important factor in project management (De Felice et al., 2017). Strategic alignment of projects is of major importance to effective use of organization resources. Selection criteria need to ensure each project is prioritized and contributes to strategic goals. There is a very extensive literature on the management of individual projects and project portfolios (Fiala, 2003; Larson and Gray, 2013).

Management of the project portfolio ensures that only the most valuable projects are approved and managed. All of the projects selected become part of a project portfolio that balances the total risk for the organization. The key to success in project portfolio management is to select the right projects at the right time (Levine, 2005). Portfolio management is a process evaluated by multiple criteria. This process must improve over time.

To select a portfolio of projects are basically two approaches, one is based on standard methods used in practice, the second approach is based on searching and applying new sophisticated methods based on quantitative analysis. Lot of professionals tried to find sophisticated way to improve techniques for project portfolio management in different ways.

The paper focuses on the problems of project portfolio management solved using sophisticated models and methods. The aim is to develop a general model that would be complemented for specific problem needs such as the analysis of the dynamics and risk of project portfolios. The aim of this paper is to verify the ability to model and solve the project portfolio problem using the Analytic Network Process (ANP) model (Saaty, 2001) enriched with the proposed dynamic version. The organization must decide under risk whether to assign all available resources to present proposals or to reserve a portion of the funds unused for some time and wait for better alternatives that may occur later. We propose to complete our ANP model by a decision tree with multiple criteria and interactive multi-criteria analysis for solving this problem.

The rest of the paper is organized as follows. In Section 2, the project portfolio problem is formulated. The Analytic Network Process (ANP) model is defined and dynamics of this model presented in Section 3. Section 4 analysis risk of project portfolios by multi-criteria analysis of decision trees. Conclusions are summarized in Section 5.

2. Project portfolio

Project portfolio is a set all projects that are realised in the organisation at that time (Levine, 2005). According (Enoch, 2015) the essence to be successful in project portfolio management is to choose the right projects at the right time. Project offices manage project portfolios and serve as bridges between levels of project management structures. The internal and external project opportunities come in time and it is necessary to decide which will be accepted or rejected to create a dynamic project portfolio (Fiala et al., 2014).

The basic objectives of the project portfolio management include:

- The selection of projects to start.
- Interruption or discontinuation of projects.
- Defining priorities for projects.
- Coordinate internal and external sources.
- Optimize the results of the entire project portfolio.

Project opportunities come in time and it is necessary to decide which will be accepted for creating a dynamic portfolio of projects and which will be rejected. The dynamic flow of projects is shown in Figure 1.

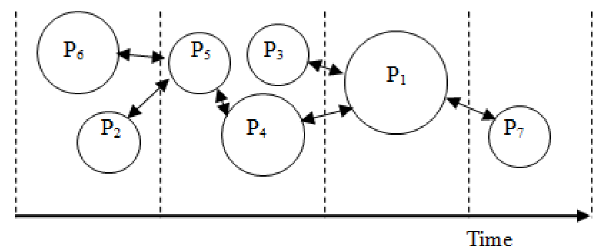

Figure 1. Dynamic flow of project

It is generally expected that the portfolio should be designed in such a way as to maximize the possibility of achieving the strategic goals of the company. This is consistent with the notion that portfolio selection problem is a multi-criteria decision making. The main goal of each project is to increase the value of the organization, so most managers prefer financial criteria for project evaluation. The most commonly used indicators include net present value, internal rate of return, payback period, rate of return. In addition to these financial indicators, however, in selecting a portfolio of projects should be considered other characteristics.

The portfolio management domain encompasses project management oversight at the organization level through the project level. Full insight of all components of the organization is crucial for aligning internal business resources with the requirements of the changing environment. Project portfolios are frequently managed by a project office that serves as a bridge between senior management and project managers and project teams.

3. ANP model

The Analytic Network Process (ANP) is the multi-criteria method (Saaty, 2001) that makes it possible to deal systematically with all kinds of dependence and feedback in the performance system. The ANP approach seems to be very appropriate instrument for project portfolio management. Another issue is the appropriate selection of clusters, which would be the basis of the basic model and their fulfilment by system elements. Another specific problem is the creation of sub-networks in the ANP model characterizing the specific important circumstances of the model. The current economic environment is characterized by significant changes. An important problem of the model will be to capture the dynamics that would represent appropriate changes. Time dependent priorities play an increasingly important role in a rapidly changing environment of network systems. Long-term priorities can be based on time dependent comparisons of system elements.

3.1. Elements of ANP model

The structure of the ANP model for dynamic project portfolio (DPP) is described by clusters of elements connected by their dependence on one another. A cluster groups elements (projects, resources, criteria, time) that share a set of attributes. At least one element in each of these clusters is connected to some element in another cluster. These connections that indicate the flow of influence between the elements are shown in Figure 2.

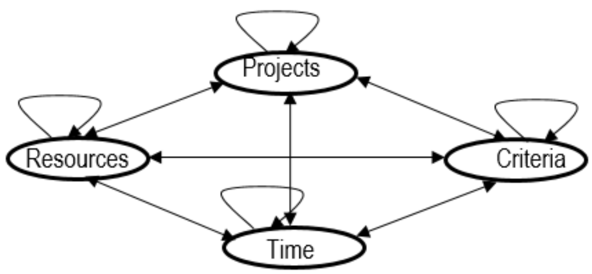

Figure 2. Flows of influence between the elements

The ANP model consists of four basic clusters with their elements and influences:

Projects: This cluster consists of potential alternatives of projects of which will be selected a dynamic portfolio. There are priorities among projects for inclusion in the portfolio. The cluster has connections to all other clusters.

Resources: Resources are necessary for the implementation of projects. Main resources are human resources between which are relations important for creating project teams. The cluster has connections to all other clusters.

Criteria: Projects are evaluated according to criteria which include benefits, opportunities, costs, and risks (BOCR). The cluster has connections to all other clusters.

Time: Time is measured in discrete units. Elements of other clusters vary in time and theirs values depend on the values in previous time periods.

The basic ANP model is completed by specific sub-networks. The sub-networks are used to model important features of the DPP problem. The most important features in our ANP-based framework for DPP management are captured in sub-networks: dynamic flow of projects, time dependent resources.

Dynamic flow of projects: Project opportunities come in time and it is necessary to decide which will be accepted for creating a dynamic portfolio of projects and which will be rejected. The sub-network connects clusters: time and projects.

Time dependent resources: A specific sub-network is devoted to model time dependent amounts of resources. The time dependent amount of resources is given by. The sub-network connects clusters: time, resources and projects

3.2. Dynamics of ANP model

An important characteristic of project portfolio management is dynamics. Time dependent priorities in the ANP model can be expressed by forecasting using pairwise comparison functions (Fiala, 2006; Saaty, 2007). Dynamic extensions of ANP method can work with time-dependent priorities in a networked system.

Judgment matrix in dynamic form

$$\mathbf{A}(t) = \begin{bmatrix} a_{11}(t) & a_{12}(t) \dots & a_{1k}(t) \\ a_{21}(t) & a_{22}(t) \dots & a_{2k}(t) \\ \vdots & \vdots & \vdots \\ a_{k1}(t) & a_{k2}(t) \dots & a_{kk}(t) \end{bmatrix}$$

The elements $a_{ij}(t)$ of the judgment matrix $\mathbf{A}(t)$ express the importance of system element *i* relative to element *j* at time *t*

There are two approaches for time-dependent pairwise comparisons: structural, by including scenarios, functional by explicitly involving time in the judgment process. For the functional dynamics there are analytic or numerical solutions. The problem leads to a time-dependent algebraic equation, the solution of which formally gives the time-dependent eigenvalues of the dynamic judgment matrix $\mathbf{A}(t)$. Another problem is maintaining the reciprocity and transitivity of the elements of the time-dependent matrix A(t). The basic idea with the numerical approach is to obtain the time-dependent principal eigenvector by simulation (Saaty, 2007).Risk of project portfolios

In each period, the project portfolio is reviewed in the line with the strategic objectives of the organization. Management may decide to initiate new projects, but also to end of some others that are currently being implemented. Even if the organization has available funds, it is sometimes better to decide not initiate a new project and wait for better one. The organization have to decide under risk whether to assign all available resources to present proposals or to reserve a portion of the funds unused for some time and wait for better alternatives that may occur later. We propose to use a decision tree with multiple criteria and interactive multi-criteria analysis for solving this problem (Fiala and Majovska, 2019).

3.3. Decision trees

Sequences of partial decisions which follow one another frequently occur in assessing potential projects. They are multi-stage decision processes. The task of the decision maker is to select one of the possible sequences that leads to the best final goal solution. Decision-making takes place in periods $t = 1, 2, \dots, T$. The decision trees are used to solve these problems successfully.

Solution of multi-stage decision problems proceed in two phases. The first phase is the construction of a decision tree and the second phase is its evaluation. The graph tree structure is used by the construction of decision trees that appropriately models the branching options. The decision-maker creates and evaluates its parts in order to find the optimal sequence of decisions. Two types of nodes are considered, decision and chance nodes. The edges of the tree represent branching of decision and chance possibilities. We start with the decision node from which they emanate lines that represent the possible decisions a_i. The ends of these edges are chance nodes on which they rely edges representing s_j possible situations that may occur with conditional probabilities p_j. These edges can be followed by another decision nodes with possible decisions, as well as chance nodes with possible situations, etc. Large decision trees may arise by combining these basic elements. End edges, which are not followed by further decision and chance nodes, represent the possible end sequences of partial decisions that are evaluated.

Evaluation of the decision trees proceed in the opposite direction from the end edges back to the starting node of the decision. The decision-maker selects the decision that cannot affect the occurrence of situations and must consider all situations with their conditional probabilities of occurrence. The decision from possible decisions is always chosen that delivers a better evaluation. Principle of maximizing the expected value is used in the selection. The optimal sequence of decisions is obtained in this manner.

3.4. Multi-criteria analysis

Multi-criteria decision trees (Haimes and Tulsiani, 1990; Nowak and Nowak, 2013) are used to select the most suitable strategy for a dynamic project portfolio management. We use standard methods of multi-criteria decision-making for their analysis (Thakkar, 2021). We will seek a final compromise strategy for dynamic project portfolio selection. We are looking for a strategy to which there is no alternative strategy that is better on at least one criterion and not worse on other criteria. This strategy is called effective. Multi-criteria analysis is at two levels: identification of all effective strategies for dynamic portfolio selection, interactive procedure for determining the final compromise strategy for dynamic portfolio selection.

The following simple procedure can be applied for the identification of effective strategies:

Step 1: Starting from the last period $t = T$, identify sub-effective strategy for all decision nodes of the period T.

Step 2: Go to the previous period $t = t - 1$.

Step 3: Identify strategies that meet the conditions of effectiveness for each decision node of the period t.

Step 4: If $t > 1$, go to step 2, otherwise the procedure stops.

Number of effective strategies can be large. It is possible to use a simple interactive process between the decision maker and solver for the selection of the final compromise strategy from the set of all effective strategies. In each iteration q, a set of strategies $S(q)$ is analysed and the ideal alternative $\mathbf{H}(q)$ (vector of best values according to each criterion) and the anti-ideal alternative $\mathbf{D}(q)$ (vector of worst values according to each criterion) are determined. The decision maker compares between such values may vary criteria values. The decision maker is asked about the aspiration levels of criteria $\mathbf{A}(q)$, which he would accept as a compromise strategy. If the decision-maker is satisfied with the proposed strategy, the process stops.

Interactive process to determine the final compromise strategy has the following steps:

Step 1: Iteration $q = 1$, the set of all analysed strategies $S(1)$ is equal to the set of all effective strategies.

Step 2: Determine the ideal alternative $\mathbf{H}(q)$ and the anti-ideal alternative $\mathbf{D}(q)$.

Step 3: Decision-maker is asked to accept anti-ideal values. If yes, go to Step 8.

Step 4: The decision-maker is asked to propose the aspiration levels $\mathbf{A}(q)$. If not, go to step 6.

Step 5: The decision-maker enters aspiration levels $\mathbf{A}(q)$ and he determines the corresponding set of acceptable strategies $S(q + 1)$. If $S(q + 1) = \emptyset$, go to step 4, otherwise to step 7.

Step 6: The decision-maker is asked which anti-ideal value is unacceptable for him. A new set of strategies is defined $S(q + 1)$which exceed the unacceptable anti-ideal value.

Step 7: Set $q = q + 1$, go to step 2.

Step 8: The decision-maker is asked which criterion should reach the ideal value. The strategy that maximizes this criterion is the resulting compromise one.

3.5. Illustrative example

The procedure is illustrated in a simple example with a selection of a project portfolio in two time periods $t = 1, 2$. In the first period, two projects P_1 and P_2 are evaluated. Limited resources allow you to select only one of these projects. In the second period, there are suggestions for other projects P_3 and P_4 with some probability, at the same time both projects with probability 0.2, only project P_3 with probability 0.5 and only project P_4 with probability 0.3. At this stage, the decision maker can select only one of the P_3 and P_4 projects, or no project, due to the limited resources for implementation. The decision tree for this situation is shown in Figure 3.

Decision node R1 has two possible decisions, a1 corresponds to project selection P1 and a2 corresponds to project selection P2. Situation nodes S1 and S2 describe three possible states of project proposals, simultaneously both projects P3 and P4, only project P3 and only project P4 with given probabilities. Decision node R2 has three possible decisions, a3 corresponds to project selection P3, a4 corresponds to project selection P4 and a5 corresponds to the decision not to select any new project. Decision node R3 has two possible decisions, a6 corresponds to project selection P3 and a7 corresponds to the decision not to select any new project. Decision node R4 has two possible decisions; a8 corresponds to the selection of project P4 and a9 corresponds to the decision not to select a new project. An analogous tree structure for the situation node S2.

Strategies	f_1	f_2	f_3
s_1: $a_1 - a_3 - a_6 - a_8$	73	8.8	12.9
s_2: $a_1 - a_4 - a_6 - a_8$	75	8	13.5
s_3: $a_2 - a_{10} - a_{13} - a_{15}$	63	14.1	16.4
s_4: $a_2 - a_{11} - a_{13} - a_{15}$	65	13.5	14

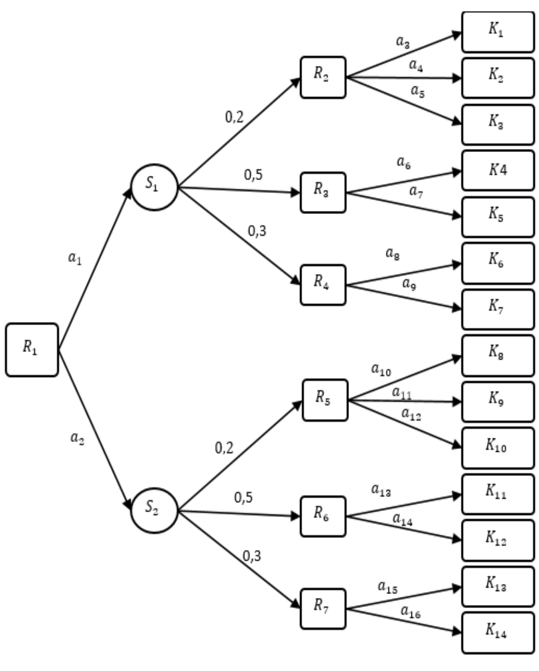

Figure 3. Decision tree for project portfolio selection

The selected portfolio is rated according to three criteria
f_1: NPV - net present value,
f_2: new market revenue percentage,
f_3: new product revenue percentage.

The estimated criteria values are in Table 1 according to the individual end nodes of the decision tree.

Table 1. Criteria values in end nodes

End nodes	f_1	f_2	f_3	End nodes	f_1	f_2	f_3
K_1	70	10	12	**K_8**	60	15	20
K_2	80	6	15	**K_9**	70	12	8
K_3	30	5	8	**K_{10}**	20	7	6
K_4	70	10	12	**K_{11}**	60	15	20
K_5	30	5	8	**K_{12}**	20	7	6
K_6	80	6	15	**K_{13}**	70	12	8
K_7	30	5	8	**K_{14}**	20	7	6

The total number of strategies for this decision tree is twenty-four. According to the procedure for identifying effective strategies, we will determine four effective strategies according to the expected values. These effective strategies are listed in Table 2.

Table 2. Effective strategies

We will use the interactive procedure to determine the final compromise strategy:

1. Iteration q = 1, set of all analyzed strategies $S(1) = \{s_1, s_2, s_3, s_4\}$.

2. $\mathbf{H}(1) = (75; 14.1; 16.4)$, $\mathbf{D}(1) = (63; 8; 12.9)$.

3. The decision maker does not accept anti-ideal values.

4. The decision maker will propose aspiration levels.

5. $\mathbf{A}(1) = (70;8.5;10)$, $S(2) = \{s_1\}$ and the decision maker is satisfied with this strategy.

This strategy selects the P_1 project in the first period and, in the second period, selects the P_3 or P_4 project with the expected criteria values $f_1 = 73$, $f_2 = 8.8$ and $f_3 = 12.9$.

5. Conclusions

Project portfolio management is becoming increasingly popular in practice. It is possible to use standard procedures or to respond to it by capturing very important aspects such as dynamics and risk. In the current environment, the business environment is evolving at an ever-faster pace and these dynamics need to be considered. Every project is original and given the dynamics of development it is also important to capture the riskiness of projects and their portfolios.

The aim of the paper was to capture new trends in a project portfolio management model. These new trends are analyzed using sophisticated quantitative approaches. Popular approaches such as Analytic

Network Process (ANP), multicriteria analysis, and decision trees were used for the analysis. These procedures have been adapted specifically for project portfolio management.

The proposed portfolio management procedure respects the characteristics of the problem:

- Network structure.
- Multi-criteria evaluation.
- Dynamics.
- Risk.

The paper presents an approach for dynamic multi-criteria project portfolio management based on the Ana-lytic Network Process (ANP) model with time dependent priorities. The project portfolio is designed under risk. An interactive method based on multi-criteria decision trees is used for risk evaluation. The procedure has two phases. In the first phase, effective strategies are selected. In the second phase, the preferred strategy is selected using the interactive multi-criteria method. The procedure is flexible and can be modified and generalized. The decision-maker's attitude to risk can be modified, for example, by applying the stochastic dominance rule. Other multi-criteria methods can be used to select the preferred strategy. The selection of the project portfolio is carried out in a number of different application areas.

This procedure has been tested on several examples. We believe that the validation in practice will bring further enrichment of this approach.

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