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Modelling of efficient project portfolios

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Abstract

Projects become tools to support the goals of the organisation. A project portfolio is the set of all projects that are currently being implemented in an organization. Possible projects are characterized by sets of inputs and outputs, where inputs are the resources to implement the project and outputs measure multiple goals of the organization. Data envelopment analysis (DEA) is an appropriate approach to select individual effective projects. The contribution of this paper is to propose a model to measure the effectiveness of the entire project portfolio. An organization has its total resources in limited quantity. Designing a portfolio of efficient projects that does not exceed the limited resources does not always lead to the most efficient portfolio. This paper proposes a new approach to project portfolio design based on the use of an extended DEA model. The constraint on the project portfolio is the total available budget. The performance measure of the designed project portfolio is the efficiency of the portfolio and the effectiveness of the outputs. In practice, this approach results in achieving better outputs with lower inputs in terms of the overall project portfolio. Possible extensions to this approach are formulated and discussed.

Keywords: Project portfolio; multiple objectives; Data Envelopment Analysis

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 (Fiala, 2003; Larson and Gray, 2013; Kerzner, 2013; Enoch, 2015; 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. This environment creates relationships of projects and the necessity of sharing resources.

Project portfolio management and project management differ by a number of projects. Project management focuses on a completion of individual projects, whereas project portfolio management takes into consideration every project and its viability to meeting organisation's goals. Risk is a very important factor in project management (De Felice et al., 2017). The selected projects create a project portfolio that balances the total risk for the organisation. Project portfolio management ensures that only the most appropriate projects are selected and implemented. Acute global competition forces many organizations to seek new management approaches. The process of project selections is considered the most important part of project portfolio management. This should be complemented by periodic examinations of the project portfolio that would determine projects that should be started and rejected. Effective portfolio management contributes to achieving out-performance, making strategy a reality through organisational shift.

The aim of the paper is to propose a decision model, which would be adapted to the specific problem requirements. The problems are not about managing individual projects, but their portfolios where relationships exist among projects through resource sharing. The proposed decision model for project portfolio designing is based on the Data Envelopment Analysis (DEA) model. Project portfolio management is a dynamic process that progressively improves over time. Building feedback at each phase of the process is essential for the improvement.

The rest of the paper is organized as follows. In Section 2, the project portfolio problem is formulated. Using the Data Envelopment Analysis (DEA) for searching efficient projects is summarized in Section 3. Section 4 formulates DEA model for searching efficient project portfolios. Performance analysis of project portfolios proposed in Section 5. Conclusions are summarized in Section 6.

2. Project portfolio management

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 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 main tasks of the project portfolio management are:

- Optimise the whole project portfolio;
- Manage internal and external resources;
- Define project priorities;
- Select accepted projects;
- Terminate unaccepted projects.

There is a strong connection between business strategy and project portfolio management (Meskendahl, 2010). The project portfolio should be designed to help achieve the strategic goals of the organisation. It means the project portfolio design is a multi-criteria decision-making problem. Most managers use financial criteria for project evaluation. In addition to the financial criteria, other criteria should be considered, which include for example:

- Ensuring consistency between strategic and tactical plans.
- Finalize the project on time, within the budget and in the proposed quality.
- Efficient and effective use of resources.
- Ensuring project relationships.
- Dynamic consumption of project resources.

Selection of the project portfolio is essentially carried out by two approaches, the first is based on standard practice methods, and the second is applying new sophisticated methods based on quantitative analysis. The paper focuses on the applying of sophisticated methods.

Many experts have been trying to find a sophisticated way to improve portfolio management techniques. Models with multiple objectives are being solved increasingly with the development of portfolio research (Qi, 2017). Data Envelopment Analysis (DEA) can be used for searching efficient projects and project portfolios (Asosheh et al., 2010; Cook and Green, 2000; Lengacher and Cammarata, 2012). Searching the efficient frontier in the DEA model can be formulated as a multi-objective linear programming problem (Fiala, 2002). Some standard multi-objective linear programming methods can be used for solving the problem. We propose a new approach for project portfolio designing based on the Data Envelopment Analysis (DEA). Resources are allocated in the required amounts while minimising the total budget for the portfolio. The model should evaluate project portfolios according to efficiency and effectiveness. Efficiency is defined as the ratio of outputs and inputs. Outputs measure organisation's achieved goals. Inputs generally refer to human, material, financial, and other resources. Effectiveness is defined as an ability to achieve right goals. We propose to complete our model by periodically repeated inspections of the project portfolio, to change the parameters of the project portfolio design for the next time period, and compute a new design.

The proposed procedure for designing a project portfolio has the following characteristics:

- Linking to goals of the organisation.
- Multi-objective evaluation.
- Evaluation by efficiency and effectiveness.
- Meeting requirements at a minimum budget.
- Time-dependent recalculations.

3. Efficient individual projects

The Data Envelopment Analysis (DEA) is an appropriate instrument for searching for individual efficient projects from a set of all possible projects. Charnes, Cooper, and Rhodes developed the first DEA (Charnes et al., 1978). The DEA model is based on the reduction of the multiple inputs and multiple outputs to that of a single ”virtual” input and a single ”virtual” output using weights. The model searches for the set of weights which maximise the efficiency of the project.

The DEA may be characterized as a method of objective weight assessment. The DEA includes a number of models and methods to evaluating performance (Charnes et al., 2013).

For our problem, there is supposed a set $P = \{P_1, P_2, \ldots, P_n\}$ of n projects each consuming r inputs and producing s outputs; (r, n) -matrix **X** and (s, n) - matrix **Y** are observed input and output measures. The CCR (Charnes, Cooper, and Rhodes, 1978) model with supposed constant return to scale was used for project evaluations. Constant return to scale means that changing the amounts of inputs results in similar changes in the amounts of outputs. For a particular project, the ratio of the single output to the single input provides a measure of efficiency that is a function of the weight multipliers (u, v). The relative efficiency e_k of the project P_k is maximised to the condition that the relative efficiency of each project is less than or equal to one.

A DEA-based approach allows each project to evaluate itself, relative to all the projects under consideration. The formulation leads to a linear fractional programming problem.

$$e_k = \frac{\sum_{i=1}^{s} u_i y_{ik}}{\sum_{j=1}^{r} v_j x_{jk}} \to max, \qquad k = 1, 2, \ldots, n \tag{1}$$
$$\frac{\sum_{i=1}^{s} u_i y_{ih}}{\sum_{j=1}^{r} v_j x_{jh}} \leq 1, h = 1, 2, \ldots, n \tag{2}$$
$$u_i, v_j \geq 0, \qquad i = 1, 2, \ldots, s, \qquad j = 1, 2, \ldots, r \tag{3}$$

If it is possible to find a set of weights for which the efficiency ratio of the project P_k is equal to one, the project P_k will be considered as efficient otherwise it will be considered as inefficient. The set of efficient projects is designed in this way.

Solving this nonlinear nonconvex problem directly is not an efficient approach. The following linear programming problem with new variable weights (u, v) that results from the Charnes - Cooper transformation gives optimal values that will also be optimal for the fractional programming problem.

$$e_k = \sum_{i=1}^{s} u_i y_{ik} \to max, \quad k= 1, 2, \ldots, n, \tag{4}$$
$$\sum_{j=1}^{r} v_j x_{jk} = 1 \tag{5}$$
$$\sum_{i=1}^{s} u_i y_{ih} - \sum_{j=1}^{r} v_j x_{jh} \leq 0, h = 1, 2, \ldots, n \tag{6}$$
$$u_i, v_j \geq 0, \qquad i = 1, 2, \ldots, s, \qquad j = 1, 2, \ldots, r \tag{7}$$

The efficiency scores e_k might be used to rank the projects. Implementing the most effective projects until resources are consumed will not always lead to the most effective portfolio. The reason is the same as for the knapsack problem.

4. Efficient project portfolios

The contribution of this paper is to propose a model to measure the effectiveness of the entire project portfolio. The DEA methodology will be used to measure effectiveness and will be extended not only for individual units (projects) but also for subsets of units (project portfolios).

A portfolio as a subset C of the set of possible projects P $(C \subseteq P)$ can be taken as a single combined project. The combined project is defined by combinations of outputs and combinations of inputs. The combination vector is $\boldsymbol{\lambda} = (\lambda_1, \lambda_2, \ldots, \lambda_n)$ where $\lambda_i = 1$ (the individual project P_i is included in the portfolio) or $\lambda_i = 0$ (the individual project P_i is not included in the portfolio). Total inputs of the combined project denoted as $x_j(C) = \sum_{h=1}^{n} \lambda_h x_{jh}$, $j = 1, 2, \ldots, r$, and total outputs denoted as $y_i(C) = \sum_{h=1}^{n} \lambda_h y_{ih}$, $i = 1, 2, \ldots, s$, are determined by the combination vector $\boldsymbol{\lambda}$. The set of all combined projects is the so-called power set of P and the set is denoted as $R(P)$ where the number of elements in $R(P)$ is $2^n - 1$.

DEA-approach can be used for evaluation of each combined project relative to the power set $R(P)$.

$$e_C = \sum_{i=1}^{s} u_i \sum_{h=1}^{n} \lambda_h y_{ih} \to max \tag{8}$$
$$\sum_{j=1}^{r} v_j \sum_{h=1}^{n} \lambda_h x_{jh} = 1 \tag{9}$$
$$\sum_{i=1}^{s} u_i \sum_{h=1}^{n} \lambda_h y_{ih} - \sum_{j=1}^{r} v_j \sum_{h=1}^{n} \lambda_h x_{jh} \leq 0, \ C \in R(P) \tag{10}$$
$$\lambda_h \in \{0, 1\}, h = 1, 2, \ldots, n \tag{11}$$
$$u_i, v_j \geq 0, \qquad i = 1, 2, \ldots, s, \qquad j = 1, 2, \ldots, r \tag{12}$$

The model (8)-(12) is a non-linear one with variables λ_h, u_i, v_j where λ_h are elements of an unknown project combination vector and u_i, v_j are weights of outputs and inputs. Due to the large number of constraints (10) it is difficult to solve.

Introducing new variables

$$c_{ih} = u_i \lambda_h, d_{jh} = v_j \lambda_h, i = 1, 2, \ldots, s, \quad j = 1, 2, \ldots, r, \quad h = 1, 2, \ldots, n \tag{13}$$

linearizes this problem. The portfolio total inputs and outputs are compared against the set of all portfolios $R(P)$ but it is easy to see that the general constraints (10) are additive combination of constraints for individual projects and it is sufficient to compare them with individual projects from the set P given by the constraint (16) (Cook and Green, 2000). Constraints for combined projects are redundant. The constraints (19) and (20) link new variables c_{ih}, d_{jh} and old variables u_i, v_j, λ_h, where M is a large number. The constraint (19) links the variables c_{ih}, u_i, λ_h. If the binary variable $\lambda_h = 1$, then $0 \leq c_{ih} \leq M, u_i = c_{ih}$ and if the binary variable $\lambda_h = 0$, then $0 \leq u_i \leq M, c_{ih} = 0$. The constraint (20) analogically links the variables d_{jh}, v_j, λ_h.

The problem is then formulated as follows:

$$e_C = \sum_{i=1}^{s} \sum_{h=1}^{n} c_{ih} y_{ih} \to max \tag{14}$$
$$\sum_{j=1}^{r} \sum_{h=1}^{n} d_{jh} x_{jh} = 1 \tag{15}$$
$$\sum_{i=1}^{s} u_i y_{ih} - \sum_{j=1}^{r} v_j x_{jh} \leq 0, h = 1,2, \ldots, n \tag{16}$$
$$\lambda_h \in \{0, 1\}, h = 1, 2, \ldots, n \tag{17}$$
$$u_i, v_j \geq 0, \qquad i = 1, 2, \ldots, s, \qquad j = 1, 2, \ldots, r, \tag{18}$$
$$c_{ih} \geq 0, c_{ih} \leq M\lambda_h, \ u_i \geq c_{ih}, u_i \leq c_{ih} + M(1 - \lambda_h), \quad i = 1, 2, \ldots, s, h = 1,2, \ldots, n \tag{19}$$
$$d_{jh} \geq 0, d_{jh} \leq M\lambda_h, \ v_j \geq d_{jh}, v_j \leq d_{jh} + M(1 - \lambda_h), \quad j = 1, 2, \ldots, r, h = 1, 2, \ldots, n \tag{20}$$

5. Performance analysis of project portfolios

A resource-constrained formulation of the project portfolio problem is introduced. The organisation has its total resources in limited quantities. A vector $b = (b_1, b_2, \dots, b_r)$ captures the available amount of resources. The constraints on limited resource consumption in project portfolios are given as follows

$$x_j(C) = \sum_{h=1}^{n} \lambda_h x_{jh} \leq b_j, \quad j = 1, 2, \dots, r. \tag{21}$$

Adding constraints (21) to the model (14)-(20), only resource available portfolios will be considered. An analysis of the performance of the project portfolio is not only a measure of efficiency but also the effectiveness of outputs (Lengacher and Cammarata, 2012). Total portfolio outputs measure organisation objectives that need to be maximised.

$$y_i(C) = \sum_{h=1}^{n} \lambda_h y_{ih} \rightarrow max, \; i = 1, 2, \dots, s. \tag{22}$$

The maximum total output is achieved for the portfolio of all available projects

$$Y_i = \sum_{h=1}^{n} y_{ih}, \; i = 1, 2, \dots, s. \tag{23}$$

As a measure of effectiveness of the project portfolio outputs, it is possible to take relative indicators

$$f_i(C) = \frac{y_i(C)}{Y_i} = \frac{\sum_{h=1}^{n} \lambda_h y_{ih}}{\sum_{h=1}^{n} y_{ih}} \rightarrow max, i = 1, 2, \dots, s. \tag{24}$$

Adding multiple objectives (24) to the model (14)-(21), the multi-objective linear programming problem for project portfolio is formulated. By given prices p_j of resources and the given budget B the constraints (25) can be added to the model.

$$\sum_{j=1}^{r} p_j b_j \leq B, \tag{25}$$

This problem can be solved by various multi-objective linear programming methods (Thakkar, 2021).

6. Conclusions

An approach for efficient project portfolio designing is proposed in the paper. The approach is based the DEA model. The problem can be formulated as a multi-objective linear binary programming problem. The experiments show that this approach can be an appropriate instrument for analysing project portfolio designing and can produce interesting results in comparison with other approaches. In practice, this approach results in achieving better outputs with lower inputs in terms of the overall project portfolio. The approach can be used for various types of projects. It can also be used for other types of problems.

The basic model allows possible extensions. We can increase the flexibility of the model in several important ways. A dynamisation of the problem is very important but generally difficult. It is easy to track changes of the budget at the time by recalculating the appropriate model for the new budget levels. Some more sophisticated approaches for dynamic versions of the model were studied. It is possible to use a linear parametrisation of the budget depending on time and to analyse time-dependent amount of resources. Technological innovations over time bring improvements to the desired objectives and the better utilisation of available resources. The project portfolio designing can be modelled as a dynamic process. Future work will focus on the more sophisticated elaboration of the dynamic approaches to project portfolio designing.

The approach can be refined with weight restrictions. The Analytic Hierarchy Process (AHP) can be applied for a restriction of weights in the DEA by the decision maker's judgements (Saaty, 1990). Another area to approximate reality is to capture the uncertainty in the data used. It is possible to apply imprecise DEA with interval data for inputs and outputs (Smirlis et al., 2004).

Combinations of the methods for searching an efficient project portfolio and modelling of specific requirements give a powerful approach to capture managerial problems in project portfolio management.

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