Projects Portfolio Selection Framework Combining MCDA UTASTAR Method with 0–1 Multi-Objective Programming

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Abstract The evaluation of projects portfolio effectiveness is a complex and diverse topic linked to the strategic planning, the efficiency of project implementation teams, the social and economic environment, the availability of resources etc. The appropriate projects selection constitutes one of the key points to ensure the total portfolio success by including different selection criteria regards not only to projects efficiency but also to their effectiveness. Efficiency reflects whether the project management team used effectively the organization's resources in order to accomplish the initial plan and project goals, while effectiveness determines whether the results of a project meet the objectives set by the organization's top management team. In this chapter we are discussing an approach for the selection and evaluation of projects portfolio based on two multicriteria methodological frames: (a) The Multi Criteria UTA(*) method of Disaggregation—Aggregation approach (D-A) with which the alternative actions are evaluated according to the business strategic objectives and (b) the Multi-objective (0–1) Linear Programming techniques, which are utilised to select a subset of the alternative projects considering the estimated with the D-A approach multicriteria global values of the alternative projects, the additional objectives related to the external environment, the internal and external policy restrictions, the availability of resources and the specific market conditions. The incorporation of stochastic criteria into the analysis to evaluate the alternative projects under uncertainty is also presented in the following sections. The aforementioned approaches are illustrated through a case study concerning the projects portfolio selection of a contraction firm.

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1 Introduction

The project management together with an efficient projects selection is important for the competitiveness of organizations within the today's dynamic and unpredictable environment. The last decades, firms and organizations, which are projects process organised, are focusing on the effective projects portfolio selection in order to group them together for the achievement of the organizational strategic objectives and for an effective allocation of the available resources (human, material, cash flow).

The effectiveness and the total success of the projects are related not only to the implementation factors (Atkinson 1999; Ika 2009; Patanakul and Milosevic 2009; Westerveld 2003; Yu et al. 2005) but also to parameters measured mainly after the project's completion. The performance on these parameters is influenced by a suitable portfolio selection linking the strategy with projects in order the project management team to manage them accordingly and then track their contribution to the firm's development and change. Managing a projects portfolio, measuring and tracking their progress and assessing their future impacts and benefits include dynamic features such as the uncertainty, the complexity, the time, the risk, the influence of the stakeholders involved, the influence of external factors, the interaction with other projects at the organization-enterprise level, the viability of the original plan, the degree of projects alignment with the strategic objectives, etc. Moreover, each project is unique with different goals and inputs requiring different project management techniques (Shenhar and Dvir 2007) to efficiently implement them and balance the various conflicting parameters within an environment that is continuously changing. The successful implementation of a project and/or a portfolio of projects according to the initial plan is a prerequisite for an overall project success. For this reason, it is necessary to analyse the feasibility of the projects desired outcomes in accordance with the available resources and policy restrictions during the selection phase. Therefore, the selection process needs to include criteria related to efficiency in addition to criteria that estimates the project results after the project life cycle and for different stakeholder perspectives.

In general, the selection of the projects portfolio (APM 2012; PMI 2008) constitutes a semi-structured decision problem as:

- The outcomes of projects cannot be precisely predicted due to the uncertainties characterizing the operational environment.
- The undertaken projects reserves resources resulting to availability limitations and leading to the exclusion of other projects.
- There are a lot of conflicting and competitive factors to be taken into consideration for the selection of the projects (income, quality, preparation for the future, etc.).
- There is no a step by step procedure that can fit to all cases for the projects evaluation by taking into account different point of views without compromises among the selection criteria.

The selection process of projects' portfolios, especially in the cases where the needs of a later assessment are considered, faces specific challenges which should be tackled under a well-defined and sound methodological approach. These challenges are summarised in the following points:

- *Linearity:* A lot of existing models aggregate the criteria in a linear way without taking into consideration the possible variation in their relative importance at different level of performance on each criterion. Criteria weights and non-linear criteria functions should be part of the project selection process in order the models to be closer to the real world leading to more realistic final selections.
- *Consistent family of criteria:* Another important point to be taken into account when modelling project selection problems is the need to use a consistent family of criteria (monotony, proficiency, non-redundancy) (Bouyssou 1990). This ensures not only that there is no criterion that will probably affect the project evaluation process at a later stage, but also that the criteria are independent of each other and the same result from a point of view is not taken twice.
- *Different criteria for each case:* Each project is unique and the factors determining its effectiveness vary for each case. So, a comprehensive selection methodology should allow each decision maker groups to determine the important parameters of each project based on their experience and the available knowledge.
- *Management of qualitative parameters:* There is a need to follow reliable processes of managing the quality parameters in the problem of project selection. It is not a solution to turn all the parameters into cost and sum them together. The process should describe how exactly the quality and quantitative parameters are synthesized into a final conclusion and ensure that a realistic and rational model is utilised.
- *Linking efficiency to strategic goals:* The overall success of projects is directly linked to the defined strategic goals. Influenced by the work of Shenhar et al. (2001), projects should be evaluated on the basis of the achievements according to the strategic goals that triggered them. Their effectiveness shall be estimated based on the reasons that led to their selection. Therefore, at the selection stage, the criteria to be selected should reflect this necessary link with the strategic objectives.
- *Management of uncertainty:* Uncertainty related to a project is met during the implementation stages and also after the implementation while evaluating its effectiveness. It is not certain from the beginning that the assumptions that were considered at the initial analysis will continue to be valid in future stages. So, there is a necessity to include the uncertainty at the selection stage.
- *Evaluating the satisfaction of stakeholders:* A major problem in the evaluation of projects is the different views and perceptions of the stakeholders involved about effectiveness. Different outcomes have different importance for the organization—company, the management team, the customers, the society and the wider external environment. For that reason, the involvement of stake-

holders at the selection stage or at least the analysis and incorporation of their needs is essential.

In the methodological framework outlined in a subsequent section, these challenges are effectively addressed through a structured project selection process that aids with appropriate tools the decision of the top management team and/or the portfolio manager. Specifically, an approach is discussed, which links the evaluation criteria during the selection process to the strategic objectives of an organization by modelling the preferences of the decision-maker on the alternative projects. The synthesis of the qualitative and quantitative parameters in a reliable manner for the project selection problem is implemented through estimated value functions taking into account their non-linear form and relative importance. This is achieved by utilising multi-criteria methods, which are further used to check the consistency of the used criteria through a process of iterations and feedbacks. Also, the methodological framework under discussion allows the decision analysts to include stochastic criteria in the analysis for the selection parameters under uncertainty.

As already mentioned, the business strategic goals need to be included in the portfolio selection process conforming to the new trends in the project management discipline. The project management is becoming more strategic and business oriented (Shenhar 2015) and the project managers have been characterized by Shenhar et al. (2001) as the new strategic leaders. Therefore, the linking of the available projects to the strategy and the management of the complexity of projects selection process are vital points, which require further research.

The chapter consists of an introduction and four more sections. The second section includes a background for project selection in the project management literature and an overview of the notions of effectiveness and efficiency. The proposed methodological framework for projects portfolio selection is presented in the third section of the chapter. Then, in the fourth section an illustration example is developed for the analytical presentation of the methodological framework. Finally, some concluding remarks together with further exploitations are presented in the last section.

2 Background in Projects Portfolio Selection

Portfolio managers are responsible for the selection, prioritization and control of the organisation’s projects and programmes in regards with its strategic goals and resources capacity (APM Body of Knowledge 2012). The selected portfolio needs to be balanced according to the taken risks, resources usage, cash flow capacity and linked to the business strategic objectives. Therefore, several selection methods have been developed and proposed over the years to aid firms and organisations prioritize and organize their projects. These methods generally fall into the two following broad categories (Iyigun 1993; PMI 2004):

- **Benefit measurement methods**, which are focusing on the development of a measurement system estimating the potential benefits for each project. These methods are the most common approaches used in practice and the majority of them are benefit contribution or economic models. Specifically, in these models the benefits and predicted value of each project is estimated and presented in terms of Benefit Cost Analysis (BCA), Return on Investment (ROI), Discounted Cash Flow Analysis, Net Present Value (NPV), Opportunity Cost, etc. Moving away from the financial models, another type of methods included in this category are the Scoring Models which conclude to an overall project score through the aggregation of different weighted criteria. These models could be a separate category, especially in the case where Multi-Criteria Decision Aid (MCDA) methods has been utilised. In the methodology presented in Sect. 3, the multi-criteria Disaggregation—Aggregation UTA methods are used to estimate an additive value system leading to a projects prioritization (criteria weights, marginal utility functions).
- **Constrained optimization methods**, which are mathematical models and algorithms aiding the decision maker to determine an optimal set of actions. These methods are suitable for large and complex selection processes in order to ensure that the selected projects comply with the organization's resources constraints and the external restrictions (market regulation, laws, etc.). Methods and techniques included in this category are linear programming, non-linear programming, dynamic programming, integer programming, multi-objective programming, stochastic programming and fuzzy mathematical programming.

The bibliography work of Supachart Iamratanakul et al. (2008) identifies another four categories in addition to the above two, which are the Simulation and Heuristics Models, Cognitive Emulation Approaches (decision-tree approaches, statistical approaches, etc.), Real Options and Ad Hoc Models. The detailed description of the above methodologies exceeds the purpose of this chapter book and emphasis will be given to important points of the selection process. One of them, which mentioned previously, is the integration of the needs and desires of various stakeholders in the analysis. Stakeholders could influence the projects positively or negatively and early identification of them will be beneficial to assess their impact (Hill 2009). Apart from their impact to projects, stakeholders are important from the perspective of their satisfaction. Van Aken (1996) defines that a project is successful when the satisfaction of all stakeholders has been met. Therefore, the ideal situation is to involve the various stakeholders during project selection process and link the projects to their needs and interests. Although, this is not achievable in all the cases and impossible to include all stakeholders during the project selection phase, a stakeholders analysis by mapping their interest and power or influence (Eden and Ackermann 1998) could aid the selection team to estimate the risks and feasibility for each project.

Another parameter which affects the selection process in practice is the perception of top management team for project success. The projects selection criteria and the evaluation criteria of project success are the two sides of the same coin.

For example, if a project is characterized as successful when it is implemented in time, within the budget constraints and according to the quality standards, then the selection process will emphasize more on the operational point of view. On the other hand, if project success is linked to criteria such as the end-user's satisfaction, the organizational benefits, the project personnel satisfaction, the client satisfaction, etc., the selection criteria will focus more to the strategic objectives and the various stakeholders. Jugdev and Muller (2005) explain that "the project management can have strategic value when a clear connection is made between how efficiently and effectively project is done and how the project's products and services provide business value". At this point, in order to avoid any confusion, the following concepts should be distinguished:

- Efficiency: expresses if the organization's resources were used effectively to achieve the project objectives and whether or not the project management team has successfully implemented the initial plan. It focuses mainly on criteria related to the implementation of the projects, such as the "golden" triangle, risk management, etc.
- Effectiveness: focuses on the results of the project after the implementation and expresses the achievements in regards with the business and strategic objectives. It is related to the success of the final product including the customer and end-user satisfaction, the added business value, the benefits to various stakeholders, etc.

The total project success is achieved when both efficiency and effectiveness are ensured (Baccarini 1999). Therefore, the project selection process needed to include those parameters that will ensure the projects efficiency and those that examine the projects effectiveness. It is important for the total project success to link the effectiveness parameters to the projects through the selection process in order the project management team to focus on delivering the business and strategic value that is expected from the undertaken projects. Shenhar et al. (1997, 2001) explain that effectiveness has three dimensions: (1) the customer satisfaction which can be measured a few weeks after project execution, (2) the company's short-term benefits (e.g. earnings, market share) which can be measured after 1 or 2 years, and (3) long-term benefits which can be estimated after about 4 or 5 years. The long term benefits of a project are not easily determined. A selection process, which includes long-term parameters (preparation of the business for future challenges), could help to relate directly the long-term impacts to the added business value. Also, every dimension of project effectiveness does not have the same weight through the time, but it changes. In the short term, the top management team is more interested in the effective implementation of the project by satisfying the original plan. After implementation, the importance of the project management efficiency begins to decrease to a point where the impact on the client will dominate. Finally, in the medium and long term, interest is shifting respectively to direct and indirect business benefits (Fig. 1). Therefore, it is clear that projects are so important for the overall business success in short-term and long term and a structured and detailed selection process could ensure that this could be achieved.

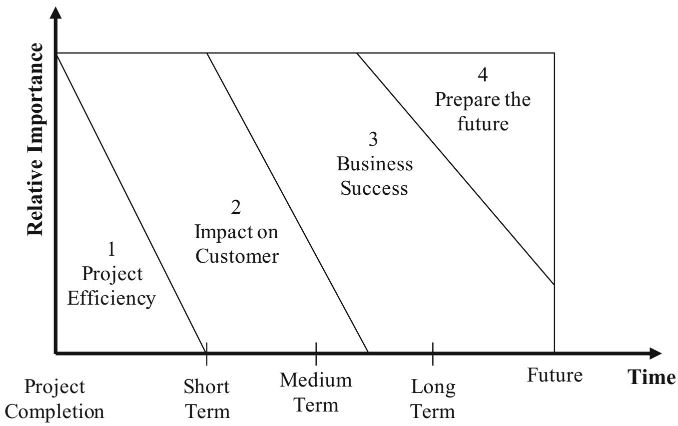


Fig. 1 Relative importance of success dimensions through time (Shenhar et al. 2001)

One question that usually needs to be addressed at the projects selection phase is in what extend and how detail the analysis of the above parameters will be sufficient. This depends mainly from the nature and type of the alternative projects which have some interest for the top management team. Several classifications exist in the literature to distinguish the projects that could help the management team to determine the critical parameters and the level of the analysis required. Five project types has been developed from Westerveld and Gaya Walters (2001) based on the desired project goals set at the selection phase and the external factors influencing the project implementation. These project types are:

I. Product Orientation Projects: are the ones which are considered as a synthesis of different disciplines for the achievement of an end product defined by the client. An example is the restoration of the drainage system in a school building. In this category, emphasis is given to the cost, time and quality (iron triangle).
II. Tool Orientation Projects: are the ones which are considered as a process that leads to an end product by using the appropriate tools and techniques to maximise the efficiency of the resources usage. Emphasis is given to the iron triangle and the resources restrictions. An example is the mechanical equipment maintenance needed to be done for the whole train fleet of an organisation. The key point is the minimization of the inactive time of maintenance personnel and simultaneously to ensure no impact to the organisation operations.
III. System Orientation Projects: are the ones which are considered as a system of contracting partners and project organisation that leads to an end defined product including the demands of users and various stakeholders. An example is the building of a new school by taking into account the needs of residents, families and teachers in the initial design.
IV. Strategy Orientation Projects: are the ones which are considered as an organisation from directly involved parties that targets to fulfill the needs of a client

and end—user under external stakeholder restrictions. The satisfaction of the client, the end users, the contracting partners and the project personnel (internal project stakeholders) is critical for the overall project success.

V. Total Project Management Projects: requiring general management of all stakeholders to meet their needs. For example, many different groups, such as local residents, government partners, builders, etc. were involved in the pedestrian and touristic regeneration of the historic center of Athens. Balancing their needs is an important parameter for the success of the project.

It is clear that "one size does not fit all the projects" (Shenhar et al. 2001) and there is not a set of selection criteria that can be used in all the cases. The Multi-Criteria analysis and the Decision Theory have a lot to offer in this field, especially if the available knowledge from the project management is utilised for the formulation and construction of the decision problem. Decision making treats every case separately according to each business characteristics, the external environment and the preferences of the decision maker by linking the strategy to the projects. In the next section a methodological framework in respect to the project management requirements is discussed in detail.

3 Methodological Framework for Projects Portfolio Selection

Following several works in which a combination of multicriteria approaches are suggested (Badri et al. 2001; Mavrotas et al. 2003, 2006), we are discussing a methodological approach for the selection of projects' portfolio, which on the one hand links the selection criteria to the organizational strategic objectives and on the other supports the handling of factors influenced by the external environment and business restrictions. The methodological approach under discussion is based on a synergistic exploitation of the Multicriteria Disaggregation—Aggregation UTA (*) method (Siskos 1980, 1983; Siskos et al. 1993) and the Multi-objective Linear Programming techniques (Ehrgott and Wiecek 2005; Evans and Steuer 1973; Korhonen 2005; Korhonen and Wallenius 1990; Zeleny 1974). Also, special treatments are applied in order to handle the uncertainty on project parameters and outcomes.

The methodological framework under discussion is based on two Multicriteria Decision Aid approaches: (a) the Disaggregation—Aggregation UTA methods with which an additive value system is estimated linking directly the potential outcomes of alternative projects with the business strategic orientations and (b) the Multi-Objective (0–1) Linear Programming techniques (MOLP) which allows the projects selection by taking into account the decision maker's preferences, parameters related to the external environment (e.g. economical risk, political uncertainty, market competitiveness, social needs) and the constraints due to resources availability, policy restrictions or business situation. The framework for the projects portfolio selection consists of two phases: (1) evaluation of projects utility functions, (2)

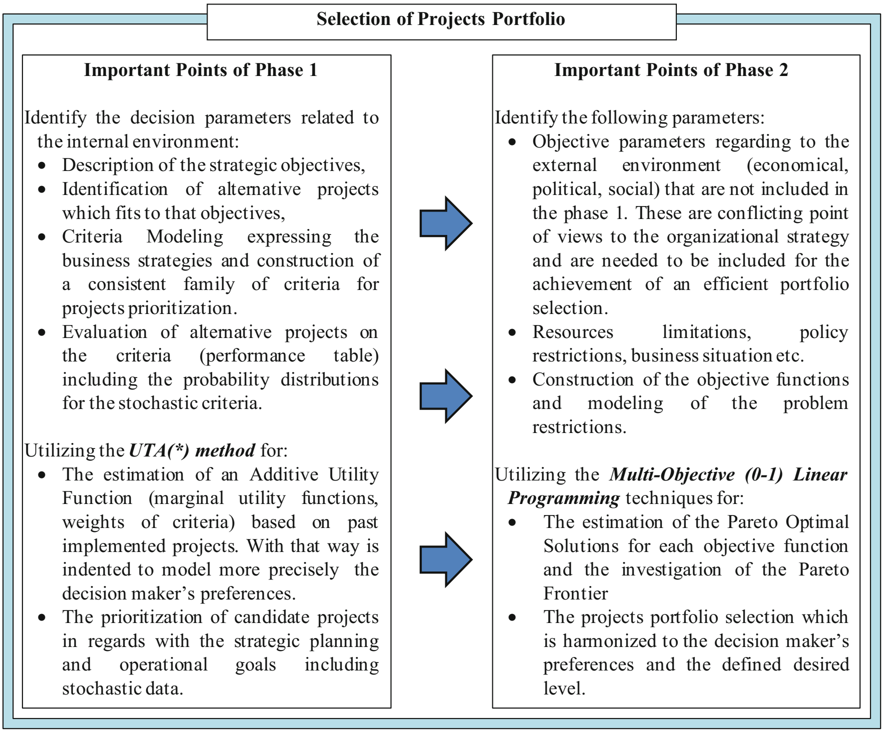


Fig. 2 Illustration of the important points of the proposed approach for Projects Portfolio Selection

selection of project (or portfolio of projects) using multiple objectives. These two phases together with the respective outcomes are presented in Fig. 2.

In the first phase of the proposed approach the UTA(*) is utilized in order to achieve the assessment of a value system encapsulating the evaluators' preferences that is described in the following formulae:

$$U(g) = \sum_{i=1}^{n} p_i u_i\left(g_i\right)$$
$$u\left(g_{i*}\right) = 0,\ u\left(g_{i*}\right) = 1, \text{for i} = 1, 2, \ldots, \text{n}$$
$$\sum_{\text{i}=1}^{\text{n}} \text{p}_\text{i} = 1,\ p_i \geq 0, \text{for i} = 1, 2, \ldots, \text{n}$$

where $\text{g} = (\text{g}_1, \text{g}_2, \ldots, \text{g}_\text{n})$ is the performance vector of an alternative project on the n criteria; g_{i*} and $g_i{}^*$ are respectively the least and most preferable levels of the criterion g_i; $u_i(g_i)$ and p_i are the value of the performance g_i and the relative weight of the i-th criterion (Keeney 1996; Keeney and Raiffa 1976).

This value system can be obtained utilizing the MINORA system (Siskos et al. 1993) the spine of which is the disaggregation-aggregation UTA (*) method. In Fig. 2 the major steps of the methodological frame are presented, which are described in the following:

(a) **Criteria Modeling:** Criteria Modeling is crucial for the evaluation process resulting in a consistent family of criteria (Bouyssou 1990) so as to provide a supplemented view of the alternative projects regarding its performance. This set of criteria allows us, to measure the consistency and appropriateness of the alternative projects with respect to the three principles that ensure the consistency of the criteria family (Roy 1985).
(b) **Construct the set of alternative projects:** Let's define $A = \{a_j, j = 1, 2, \ldots, m\}$ as the finite set of all those alternative actions to be considered and evaluated by the decision-maker within the decision-making process, which will eventually lead to the selection of one of these actions (Roy and Bouyssou 1993). A project is considered to belong to the set A if it is likely to take place.
(c) **Projects evaluation on the criteria:** The evaluation of the projects on the consistent family of criteria takes places into this procedure. A set of rules and techniques, designed during the criteria modeling procedure, has to be followed in order to assign the corresponding values of the projects for every criterion.
(d) **Selection of the reference set:** From the total number of the alternative projects a small number is selected (reference set). The members of the reference set have to be representative of the whole set of alternative projects in order to take into account the different aspects of them. Also, they have to be known to the DMs so as to express their preferences fluently. In order to ensure the above mentioned requirements in this proposed approach we use a set of previous implemented projects which constitute the reference set for the assessment of the additive value which will be further used for the evaluation of the alternative projects under consideration.
(e) **DMs' pre-ranking of the reference set:** The DMs express their global preferences by rank ordering (weak order) the alternative projects of the reference set.
(f) **Assessment of the Evaluation Model:** The UTA (*) method estimates the weighting factors p_i as well as the value functions $u(g)$ (piecewise linear) of the criteria using special linear programming techniques. Suppose a ranking (weak order) is given on a set of reference projects $A_r = (a_1, a_2, \ldots, a_k)$, where the objects are rearranged in such a way that a_1 is the head and a_k is the tail of the ranking and for every pair of consecutive projects for evaluation (a_m, a_{m+1}) holds either $a_m P a_{m+1}$ (preference) or $a_m I a_{m+1}$ (indifference).

UTA(*) solves the linear program below which, because of the transitivity of the (P,I) preference system has k constraints only. Special post-optimality analysis techniques are also applied to test the stability of the estimated weights

(Grigoroudis and Siskos 2002; Jacquet-Lagreze and Siskos 1982; Siskos and Yannacopoulos 1985):

$$\begin{cases} [\min] F, F = \sum_{i=1}^{k} \left(\sigma^{+}(a_i) + \sigma^{-}(a_i)\right) \\ Subject\ to: \\ \sum_{i=1}^{n} p_i u_i \left[g_i(a_m)\right] \text{-}\sigma^{+}(a_m) + \sigma^{-}(a_m) - \sum_{i=1}^{n} p_i u_i \left[g_i(a_{m+1})\right] + \sigma^{+}(a_{m+1}) \text{-}\sigma^{-}(a_{m+1}) \geq \delta \ if\ a_m P a_{m+1} \\ \qquad or \\ \sum_{i=1}^{n} p_i u_i \left[g_i(a_m)\right] \text{-}\sigma^{+}(a_m) + \sigma^{-}(a_m) - \sum_{i=1}^{n} p_i u_i \left[g_i(a_{m+1})\right] + \sigma^{+}(a_{m+1}) \text{-}\sigma^{-}(a_{m+1}) = 0 \ if\ a_m I a_{m+1} \\ \text{for } m = 1, 2, \ldots, k\text{-}1 \\ \sum_{i=1}^{n} p_i = 1, \quad p_i \geq 0, \text{ for } i = 1, 2, \ldots, n \\ \sigma^{+}(a_j) \geq 0, \quad \sigma^{-}(a_j) \geq 0, \gamma\iota\alpha\ j = 1, 2, \ldots, k \end{cases}$$

where δ is a small positive number; $g_i(a_m)$ the evaluation of the a_m object on the *i*-th criterion and $u^i[g^i(a^m)]$ the corresponding marginal value; and $\sigma^+(a_j)$, $\sigma^-(a_j)$ the under (over)estimation errors concerning the *j*-th object.

The additive value model is applied into the reference set for the estimation of the marginal values, the global values of the alternative projects and the produced ranking by the global values. If there is a significant uncertainty on at least one of the criteria, the evaluation of the alternative projects will be achieved by transforming these criteria into stochastic ones in the extrapolation step. In that case the marginal utility of the criterion g_i for the project a will be estimated from the following formulae:

$$u_i(g_i(\alpha)) = \sum_{T=1}^{q_i} d_i^{\alpha}\left(g_i^T\right) u_i\left(g_i^T\right)$$
$$d_i^{\alpha}\left(g_i^T\right) \leq 1, d_i^{\alpha}\left(g_i^T\right) \geq 0, \ for\ T = 1, 2, \ldots, q_i$$
$$\sum_{T=1}^{q_i} d_i^{\alpha}\left(g_i^T\right) = 1$$

where q_i and d_i^{α} are respectively the number of possible values and the distributional evaluation of the alternative project α on the *i*-th criterion, $d_i^{\alpha}\left(g_i^T\right)$ is the probability that the performance of project a on the *i*-the criterion is g_i^T and $u_i\left(g_i^T\right)$ is the marginal utility function estimated with UTA(*) previously.

(g) **Feedbacks**: The final accepted additive value model is assessed through iterative procedures. During this process the current additive value model is presented and analyzed to the DMs as well as the inconsistencies (over and under-estimation errors). Every iteration leads to a modification of the parameters influencing this parameters related to the additive value model (criteria, evaluation of the alternative actions on the criteria, reference set, pre-ranking). Finally an acceptable additive value model is assessed. Also, through trade off analysis procedures, the evaluation model can be modified so as to eliminate specific and crucial over and under–estimation errors.

(h) **Robustness analysis**: This is an important step before the adoption of additive value model. The robustness of the preference model is influenced by both the preferences of the decision maker and the choices made within the preference modelling process (set of criteria, evaluation of the alternative actions on the criteria, selecting a set of reference actions). Whenever solving a Linear Problem of a Multi-Criteria model, it is necessary to assess the robustness of the n-dimensional subspace of solutions. An important goal is to assess indices that can express the level of robustness of this n-dimensional subspace (Mavrotas et al. 2015; Tsotsolas and Alexopoulos 2017).

(i) **Extrapolation:** The assessed additive model is used in order to assign a value (utility) to the alternative projects under consideration. The utility of every project constitutes the sum of the marginal utilities of the criteria for this object. This value system is used in order to rank order the whole set of evaluation projects. Also, the ordinal regression curve is designed, providing a visual way to picture the results.

In the second phase the selection of projects portfolio is achieved with the utilization of the Multi-Objective (0–1) Linear Programming techniques (MOLP) (Ehrgott and Wiecek 2005; Evans and Steuer 1973; Korhonen 2005; Korhonen and Wallenius 1990; Zeleny 1974). The purpose of implementing MOLP is to identify those projects which are closest to the desired objective goals given by the decision maker for both internal and external environment. The major steps of this methodological frame are described below:

(a) **Construction of the objective functions:** The first objective goal is the maximization of the global utilities estimated in the previous phase of the proposed methodological frame. Other objective functions related to the external environment (economical, political, social, etc.) are identified by taking into account the firm's nature and activity.

(b) **Modeling the restrictions of the selection problem:** In this step the resources requirements and the policy restrictions of the alternative projects are identified. The linear functions related to these constraints are also constructed.

(c) **Calculation of the pay-off table:** The aim of this step is to estimate the projects that optimize each objective function under the portfolio restrictions. The extreme pareto (Ehrgott 2012) optimal solutions are identified by solving the h linear problems presented below:

$$\text{Max } \left(Z_1 = U\ (a_1)\, x_1 + U\ (a_2)\, x_2 + \cdots + U_\lambda\, (a_\lambda)\, x_\lambda\right)$$

$$(\text{Min}/\text{Max})\, Z_I = g_I\,(x) = c_{I1}x_1 + c_{I2}x_2 + \cdots + c_{I\lambda}x_\lambda,\ I = 2, \ldots, h$$

subjected to

$$a_{11}x_1 + a_{12}x_2 + \cdots + a_{1\lambda}x_\lambda\ (\geq)\ (\leq)\ (=)\ b_1$$

$$a_{21}x_1 + a_{22}x_2 + \cdots + a_{2\lambda}x_\lambda\ (\geq)\ (\leq)\ (=)\ b_2$$

$$\ldots..$$

$$\alpha_{\zeta 1}x_1 + a_{\zeta 2}x_2 + \cdots + a_{\zeta\lambda}x_\lambda\ (\geq)\ (\leq)\ (=)\ b_\zeta$$

$$x_j = \{0, 1\},\ j = 1, 2, \ldots, \lambda,\ I = 1, 2, \ldots, h$$

MIN/MAX	$g_1(x)$	$g_2(x)$	...	$g_h(x)$	$X = \{x_1, x_2, .. x_\lambda\}$
$g_1(x)$	$g_{11}(x)$	$g_{12}(x)$	...	$g_{1h}(x)$	x_1
$g_2(x)$	$g_{21}(x)$	$g_{22}(x)$	...	$g_{2h}(x)$	x_2
⋮	⋮	⋮	⋮	⋮	⋮
$g_h(x)$	$g_{h1}(x)$		...	$g_{hh}(x)$	x_λ
MIN	$g_1'(x)$	$g_2'(x)$	...	$g_h'(x)$	
MAX	$g_1''(x)$	$g_1''(x)$	...	$g_h''(x)$	

Fig. 3 General form of the pay-off table

where λ the total number of the alternative projects, I the number of the objective functions, ζ the number of the restriction functions, $U(a_j)$ the global utility of the alternative project a_j, c_{Ij} the performance of project j on the I-th objective function. The values of $x_j = \{0,1\}$ are indentified, where $x_j = 1$ if the project is selected and $x_j = 0$ if the project is not selected.

From the solution of the above linear problems a pay-off table (Fig. 3) is created which includes, for each linear problem solved (optimizing the corresponding objective function), the vector x (indicate the selected projects for each solution), the values of the objective functions g_I (x), and the equivalent maximum—minimum of the objective functions.

(d) **Define the desired levels for each Objective function:** The decision maker is asked to determine the desired levels $Z_{I\text{-target}}$ for each objective function (Z_I) within the range of maximum and minimum values estimated in the previous step ($Z_{I\text{-min}}$, $Z_{I\text{-max}}$).

(e) **Implementation of the desired goals technique for the portfolio selection:** In this step the optimal pareto solution closest to the desired goals defined previously by the decision maker is investigated. Therefore, a 0–1 LP is formed where the objective functions become restriction functions and the variables $d_i^+, d_i^-, i = 1, 2, \ldots, h$ are additionally introduced. These variables represent the difference of the values on the objective functions from the desired ones. The aim of solving this linear program is to achieve the smallest overall deviation from the defined targets. The errors are normalized by the factors:

$$r_I = \frac{\max Z_I}{Z_I}$$

The following Linear Problem is solved:

$$(\text{Min})\ \Sigma = r_1(d_1^+ + d_1^-) + r_2(d_2^+ + d_2^-) + \ldots + r_h(d_h^+ + d_h^-)$$

Subjected to

$$c_{11}x_1 + c_{12}x_2 + \ldots + c_{1\lambda}x_\lambda - d_1^+ + d_1^- = Z_1$$
$$c_{21}x_1 + c_{22}x_2 + \ldots + c_{2\lambda}x_\lambda - d_2^+ + d_2^- = Z_2$$
$$\ldots$$
$$c_{h1}x_1 + c_{h2}x_2 + \ldots + c_{h\lambda}x_\lambda - d_h^+ + d_h^- = Z_h$$
$$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1\lambda}x_\lambda\ (\geq)\ (\leq)\ (=)\ b_1$$
$$a_{21}x_1 + a_{22}x_2 + \ldots + a_{2\lambda}x_\lambda\ (\geq)\ (\leq)\ (=)\ b_2$$
$$\ldots$$
$$a_{\zeta 1}x_1 + a_{\zeta 2}x_2 + \ldots + a_{\zeta\lambda}x_\lambda\ (\geq)\ (\leq)\ (=)\ b_\zeta$$
$$x_j = \{0, 1\}, j = 1, 2, \ldots, \lambda \ \kappa\alpha\iota \ d_I^+ \geq 0, d_I^- \geq 0, I = 1, 2, \ldots, h$$
$$c_{11} = U(a_1), c_{12} = U(a_2), \ldots, c_{1\lambda} = U(a_\lambda),$$

The results are presented to the decision-maker and if he is satisfied, then the procedure is finished. If he is not satisfied or the errors are significant, then the decision-maker may proceed to revisions of the desired goals until a satisfactory and acceptable solution is calculated.

4 The Case Study

The above described Multi-criteria approach was used for the projects evaluation of a small Greek construction company which intends to design the bidding plan for the next year. The decision maker indentifies a set of 10 alternative projects that fits to the company's profile and business plan, while a set of 12 previous implemented projects had been selected for the estimation of the additive utility model in order to provide projects with known results to the DM for the easier expression of his preferences. The crucial aims of this case study are the projects prioritization, the projects selection and the portfolio optimization in accordance with the strategic objectives, the internal—external environment and the resources restrictions, respectively.

The criteria used had been divided into two categories. The one category is related to the internal environment points of view and includes the following criteria:

- Expected net income (K€, increasing preference), which is a stochastic criterion that takes into account uncertainty on the estimation of a precise value for the net-income. For the net income of every project a Gaussian distribution was estimated with a mean value and a standard deviation (see Table 1).
- Knowhow (scale 1–5, increasing preference), which is a qualitative criterion indicating the level of firm's existing knowledge and specialization about each project.
- Future perspectives (scale 1–5, increasing preference), which is a qualitative criterion specifying the potential opportunities that could be produced from the undertaken of each project under consideration.

- Additional Strategic Elements (scale 1–5, increasing preference). It is a qualitative criterion, which measures the projects correlation to the firm's strategy excluding the above three point of views.

The second category is related to the external environment and includes the following two criteria:

- Business Risk (scale 1–5, decreasing preference), which is a qualitative criterion measuring the risk not to achieve the expected project outcome and the possible influence of the external environment to project execution.
- Competition (scale 1–5, decreasing preference). It is a qualitative criterion indicating the competitiveness in the market from other construction companies which could bid for the same projects.

Important parameter for the selection of the projects is the capability to implement them efficiently. The main restrictions are related to the available resources (human and material) and cash flow limitations, which border the number of projects to be selected for implementation. The decision maker defines three key resources categories for the achievement of an effective project management and efficient portfolio implementation. These categories are the following:

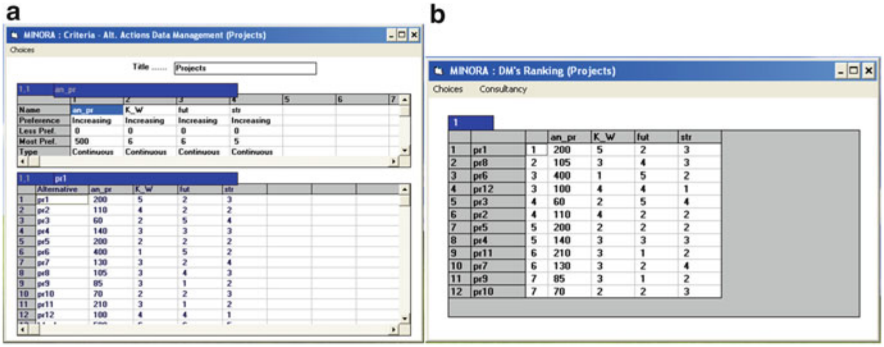
- Type A—Average monthly work load (man/months). The accepted total monthly workload is varied between 40 and 50 man/months.
- Type B—Required equipment and machinery, which are distinguished into three categories. For the category B1, B2 and B3 the maximum availability for the year is five, four and three, respectively. Also, for the rational utilization of the available resources a minimum value of three, two and one is correspondingly indicated to the three categories.
- Type C—Cash flow monthly restriction (K€). This restriction is direct related to the required liquidity for the projects implementation. The decision maker indentifies a maximum available cash flow to 220 K€ according to the additional firm's liabilities.

The decision maker had indentified an additional policy restriction that the total expected net income (mean value) and the average standard deviation for the undertaken projects shall be more than 750 K€ and less than the average standard deviation of all alternative projects, respectively.

The rating of the potential alternative projects (referred with code names p1, p2, ..., p10) together with the resources requirements are presented in Table 1. A set of iterative procedures has been implemented for the construction of a consistent family of criteria according to the strategic planning (internal environment) and for the representative modeling of decision maker's preferences. The additive value model was assessed by utilizing the UTA(*) method in the MINORA system and was based on DMs pre-ranking of 12 past projects (referred with the code names pr1, pr2, ..., pr12). The performance table of these projects to the consistent family of criteria and the decision maker's ranking are illustrated in Fig. 4, respectively. The final accepted value model is presented in Figs. 5a, b, 6a, b, 7, 8a (marginal

Table 1 Rating of potential alternative projects to the selection criteria and resources requirements

	Internal environment				External environment		Resource Type 3				
Projects	Expected Net Income $N(m_j,\sigma_j)$	Knowhow	Future	Strategy	Business Risk (R_j)	Competition (C_j)	A (a_j)	B1 (b_{1j})	B2 (b_{2j})	B3 (b_{3j})	C (c_j)
p1	N(130,10)	3	2	2	2	4	11	1	0.5	0	25
p2	N(420,15)	2	3	3	4	2	18	0	1	1	80
p3	N(80,7)	4	1	2	3	3	5	2	0	0	15
p4	N(200,10)	1	5	3	1	5	12	1	1	0	50
p5	N(300,9)	3	2	2	5	1	15	0	1	0	90
p6	N(170,5)	4	3	3	3	2	13	0	1.5	0.5	32
p7	N(350,20)	5	3	2	2	3	21	1	0	0	40
p8	N(230,18)	1	2	5	2	2	7	1	0	0	22
p9	N(95,12)	4	5	1	3	4	8	1	0	1	15
p10	N(145,10)	2	2	2	1	3	11	0	1	2	18



	1	2	3	4	5	6	7
Name	an_pr	K_W	fut	str			
Preference	Increasing	Increasing	Increasing	Increasing			
Less Pref.	0	0	0	0			
Most Pref.	500	6	6	5			
Type	Continuous	Continuous	Continuous	Continuous			

	Alternative	an_pr	K_W	fut	str
1	pr1	200	5	2	3
2	pr2	110	4	2	2
3	pr3	60	2	5	4
4	pr4	140	3	3	3
5	pr5	200	2	2	2
6	pr6	400	1	5	2
7	pr7	130	3	2	4
8	pr8	105	3	4	3
9	pr9	85	3	1	2
10	pr10	70	2	2	3
11	pr11	210	3	1	2
12	pr12	100	4	4	1

			an_pr	K_W	fut	str
1	pr1	1	200	5	2	3
2	pr8	2	105	3	4	3
3	pr6	3	400	1	5	2
4	pr12	3	100	4	4	1
5	pr3	4	60	2	5	4
6	pr2	4	110	4	2	2
7	pr5	5	200	2	2	2
8	pr4	5	140	3	3	3
9	pr11	6	210	3	1	2
10	pr7	6	130	3	2	4
11	pr9	7	85	3	1	2
12	pr10	7	70	2	2	3

Fig. 4 (**a**) Past Projects Performance Table and (**b**) DM's Ranking

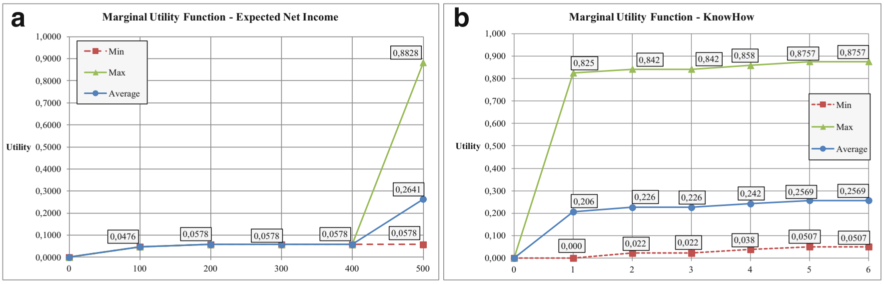


Fig. 5 Value function of the criteria (**a**) "Expected Net Income" and (**b**) "KnowHow"

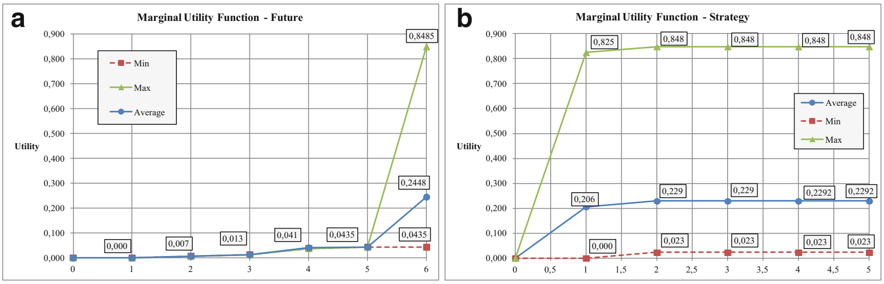


Fig. 6 Value function of the criteria (**a**) "Future" and (**b**) "Strategy"

utility functions, weights of the criteria and ordinal regression curve). This assessed additive utility model was used for the evaluation of the 10 alternative projects according to the firm's strategy. The marginal utility of the stochastic criterion Expected Net Income together with the Gaussian distribution of each project and the global utilities are presented in Figs. 8a and 9, respectively.

In the second phase according to the proposed methodology, the selection of projects portfolio is accomplished by taking into account the global utilities (Fig. 9),

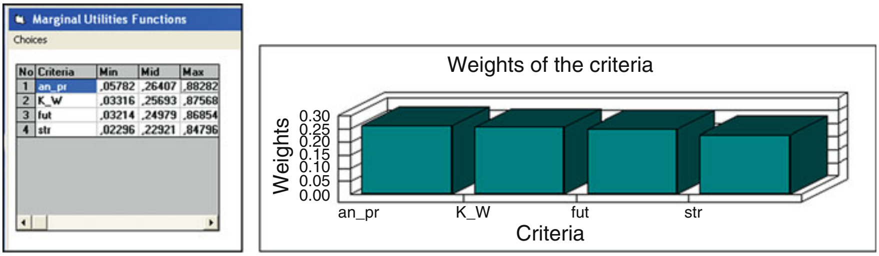


Fig. 7 The estimated weights of the criteria

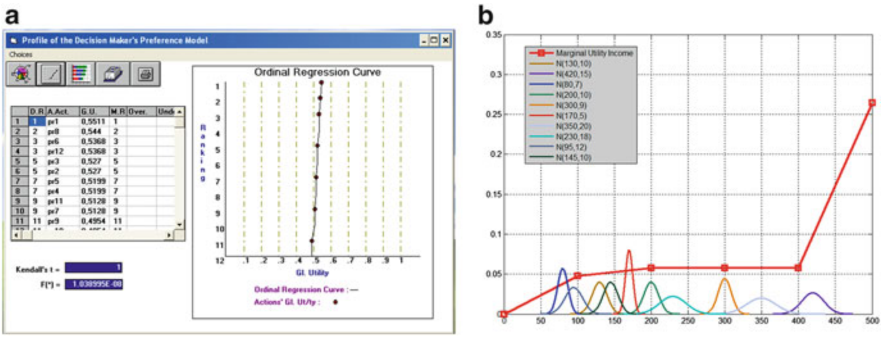


Fig. 8 (**a**) Ordinal Regression Curve and (**b**) Gaussian distributions for each alternative project

No	A. Actions	G.U.
1	p7	0,572505
2	p2	0,548397
3	p6	0,539224
4	p4	0,536797
5	p9	0,536037
6	p5	0,530075
7	p10	0,514275
8	p1	0,512775
9	p3	0,509359
10	p8	0,503402

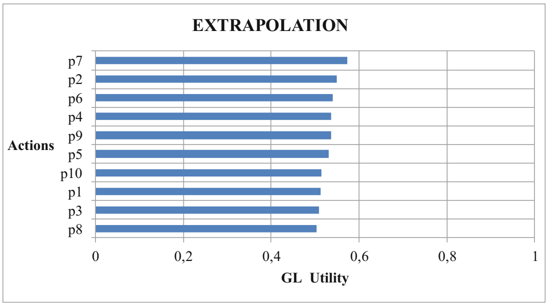


Fig. 9 Extrapolation to the whole set of jobs

the parameters related to the external environment (Table 1, Business Risk and Competition) and the resources availability (Table 1). Therefore, the following Multi-Objective Linear Programming Problem was created:

Let $x = (x_1, x_2, \ldots, x_{10})$ the vector of the unknown values, $x_j \in \{0,1\}$:

$$\text{Maximize Global Utilities}: g1\ (x) = U_1x_1 + U_2x_2 + \cdots + U_{10}x_{10}$$

$$\text{Minimize Business Risk}: g2\ (x) = R_1x_1 + R_2x_2 + \cdots + R_{10}x_{10}$$

$$\text{Minimize Competition}: g3\ (x) = C_1x_1 + C2x_2 + \cdots + C_{10}x_{10}$$

Subjected to conditions concerning (the values of a_j, b_{ij}, c_j are presented in Table 1):

- **Resources Restrictions:**

Resource A ($40 \le A \le 50$):	$a_1x_1 + a_2x_2 + \cdots + a_{10}x_{10} \ge 40$ $a_1x_1 + a_2x_2 + \cdots + a_{10}x_{10} \le 50$
Resource B ($3 \le B1 \le 5$):	$b_{11}x_1 + b_{12}x_2 + \cdots + b_{110}x_{10} \ge 3$ $b_{11}x_1 + b_{12}x_2 + \cdots + b_{110}x_{10} \le 5$
($2 \le B2 \le 4$):	$b_{21}x_1 + b_{22}x_2 + \cdots + b_{210}x_{10} \ge 2$ $b_{21}x_1 + b_{22}x_2 + \cdots + b_{210}x_{10} \le 4$
($2 \le B3 \le 4$):	$b_{31}x_1 + b_{32}x_2 + \cdots + b_{310}x_{10} \ge 1$ $b_{31}x_1 + b_{32}x_2 + \cdots + b_{310}x_{10} \le 3$
Resource C (C ≤ 220 K€):	$c_1x_1 + c_2x_2 + \ldots + c_{10}x_{10} \le 220$

- **Business Policy Restrictions**

(1) Expected Total Net Income (mean value) ≥ 750 K€:	$m_1x_1 + m_2x_2 + \ldots + m_{10}x_{10} \ge 750$
(2) The average SD of the undertaken projects ≤ Total average SD of all alternative projects:	$\frac{1}{k}\left(\sigma_1x_1 + \sigma_2x_2 + \cdots + \sigma_{10}x_{10}\right) \le \frac{1}{10}\sum_{j=1}^{10}\sigma_j = 11,6$

k: the number of selected projects

$x_j \ge 0, j = 1, 2, \ldots, 10$

The pay-off table (Fig. 10) has been calculated by solving the three linear programming problems (Maximize Global Utilities Minimize Business Risk and Minimize Competition subjected respectively to conditions). Then, a pareto optimal solution closer to decision maker's desired level is estimated, by using the desired goals method. The desired level is the following point (Global Utilities, Business Risk, Competition) = (2.35, 11, 12). The decision maker accepted the indicated projects' selection due to high political and economical uncertainty. Higher utility values can be achieved only by significant increase of business risk and competition. The last policy condition has been checked manually after the estimation of the selected portfolio. The average standard deviation of the selected projects is less than the average standard deviation of all alternative projects and equal to 9.25.

Projects	project 1	project 2	project 3	project 4	project 5	project 6	project 7	project 8	project 9	project 10	Utility	Business Risk	Competition
Max_U	0	1	1	1	0	0	0	1	1	0	2,634	13	16
Min_Risk	0	0	1	1	0	0	1	0	0	1	2,133	7	14
Min_Competition	0	1	1	0	1	0	0	1	0	0	2,091	14	8
Desired Level 1	0	1	1	1	0	1	0	0	0	0	2,134	11	12

Fig. 10 Pay—off Table—Selection of Projects Portfolio with Desired Goal Method

5 Conclusions

The contribution of the proposed methodological frame is focused on specific issues for an effective projects' selection supporting portfolio managers in this area. A structured process is provided to evaluate the alternative projects by taking into consideration the strategic planning, the risks of the external environment, the availability of business resources and the uncertainty of the future outcomes. The synergetic utilization of multicriteria disaggregation—aggregation methods with the multi-objective linear programming techniques allows the complexity management of projects selection problem with the active participation of the DM.

Also, the utilisation of the proposed approach cannot be bordered only to construction firms. The last decades, firms are organized into a project based form because this kind of structure provides flexibility in the internal operation and supports the effective utilisation of the available resources, the operational cost reduction and the achievement of higher quality results. Appropriate adaptations of the proposed methodological frame can be applied in firms and organizations following projects oriented operational structures.

This research work constitutes one step forward in the research of an efficient portfolio selection method aiming to link the desired strategic goals with the expected project achievements. One direction of future research is the exploitation of the proposed approach to support strategic decision making teams (Montibeller and Franco 2010) by checking the feasibility of alternative strategic plans through the direct interaction between the organizational governance and the executive managers. The enriched of the proposed process with the robustness analysis techniques is another future perspective.

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