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A fuzzy hybrid project portfolio selection method using Data Envelopment Analysis, TOPSIS and Integer Programming

Madjid Tavana[a,b,*], Mehdi Keramatpour[c], Francisco J. Santos-Arteaga[d], Esmail Ghorbaniane[c]

[a] Business Systems and Analytics Department, Distinguished Chair of Business Analytics, La Salle University, Philadelphia, PA 19141, USA
[b] Business Information Systems Department, Faculty of Business Administration and Economics, University of Paderborn, D-33098 Paderborn, Germany
[c] Department of Industrial Engineering, Islamic Azad University, Qazvin Branch, Qazvin, Iran
[d] Instituto Complutense de Estudios Internacionales, Universidad Complutense de Madrid, Campus de Somosaguas, 28223 Pozuelo, Spain

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ABSTRACT

Project selection and resource allocation are critical issues in project-based organizations. These organizations are required to plan, evaluate, and control their projects in accordance with the organizational mission and objectives. In this study, we propose a three-stage hybrid method for selecting an optimal combination of projects. We obtain the maximum fitness between the final selection and the project initial rankings while considering various organizational objectives. The proposed model is comprised of three stages and each stage is composed of several steps and procedures. We use Data Envelopment Analysis (DEA) for the initial screening, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for ranking the projects, and linear Integer Programming (IP) for selecting the most suitable project portfolio in a fuzzy environment according to organizational objectives. Finally, a case study is used to demonstrate the applicability of the proposed method and exhibit the efficacy of the algorithms and procedures.

1. Introduction

Most organizations often need to evaluate multiple program proposals or projects competing for scarce resources (e.g., money, manpower, equipment) and subsequently select those projects that best satisfy conflicting objectives or opposing group interests (Zanakis, Mandakovic, Gupta, Sahay, & Hong, 1995). As the number of projects increases, the decision process becomes much more complicated because of (Belton & Stewart, 2002; Kirkwood, 1997):

- Multiple and contradictory goals (criteria)
- Contrasting qualitative and quantitative goals
- Dependent projects
- Uncertainty in the data with regards to specific criteria
- Organizational requirements and constraints, and/or
- A large number of feasible portfolios.

A stand-alone multiple-criteria ranking method may not be sufficient to solve complex real-life problems with specific requirements and constraints (Badri, Davis, & Davis, 2001; Santhanam, Muralidhar, & Scniederjans, 1989). In addition, these methods do not generally consider the interaction among projects with common resources. Several methods have been proposed in the literature to overcome these problems. Most of these methods are classified as Integer Programming (IP), or, more specifically, 0–1 programming methods (a binary variable is assigned to each project so that if the project is selected, $x_i = 1$; otherwise, $x_i = 0$). IP and mixed IP (MIP) models are usually used to solve single objective problems (Kyparisis, Gupta, & Ip, 1996; Melachrinoudis & Kozanidis, 2002; Pisinger, 2001; Santhanam & Kyparisis, 1995).

Zero-one goal programming is generally used to combine the evaluation criteria when applying multiple-criteria ranking methods (Albright, 1975; Badri et al., 2001; Fandel & Gal, 2001; Kwak & Lee, 1998; Mukherjee & Bera, 1995; Santhanam & Kyparisis, 1996; Santhanam et al., 1989; Zanakis et al., 1995). Some researchers also have used Data Envelopment Analysis (DEA) to solve these problems (Cook & Green, 2000; Oral, Kettani, & Cinar, 2001; Oral, Kettani, & Lang, 1991). Another method commonly used to solve these problems is a two-phase approach where a multi-criteria evaluation is carried out in the first phase to evaluate each project individually.

An IP model is then applied to the project evaluation data in order to calculate the objective function and constraints (Abu-Taleb & Mareschal, 1995; Golabi, Kirkwood, & Sicherman, 1981; Mavrotas, Diakoulaki, & Caloghirou, 2006; Mavrotas, Diakoulaki, & Capros, 2003).

* Corresponding author at: Business Systems and Analytics Department, Distinguished Chair of Business Analytics, La Salle University, Philadelphia, PA 19141, United States. Tel.: +1 215 951 1129; fax: +1 267 295 2854.

E-mail addresses: tavana@lasalle.edu (M. Tavana), mehdikeramat@gmail.com (M. Keramatpour), fransant@ucm.es (F.J. Santos-Arteaga), esmail.ghorbanian@gmail.com (E. Ghorbaniane).

URL: http://tavana.us/ (M. Tavana)

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These models however tend to solve the last phase in the portfolio selection process without ensuring that the final selected portfolio fits the organizational objectives and requirements. In summary, a general framework is needed to address the following gaps in the project portfolio selection (PPS) literature:

(1) Several methods have been proposed in the existing literature for project evaluation and portfolio selection that are not comprehensive and are only used for specific phases of the evaluation and selection process.
(2) There is no method reported in the literature that can ensure the compatibility of the selected portfolio with the organizational mission and objectives.
(3) The IP model proposed in this study can be considered a knapsack problem with several constraints. Stewart (1991) constitutes one of the first applications of a (non-linear) knapsack model to address multi-criteria optimization problems. The main weakness of this type of approach is that it does not preserve the ranking of the projects based on their multi-criteria scores. This ranking is not preserved because the budget constraints and the objective function which search for the best combination of projects are not considered when the ranking is determined. Projects with low scores and low costs may be preferred to the projects with higher costs (Cook & Green, 2000; Mavrotas et al., 2006; Tobin, 1999).

The main objective of the method introduced in this paper is to adapt standard multiple-criteria decision making methods to the information transmission and decision processes taking place at different levels within an organization. That is, the intuitive initial selection of processes via DEA together with the TOPSIS valuations are included to mimic different information and decision making stages within the PPS process of an organization. However, we are also aware of the fact that, due to this flexibility, inconsistencies can easily arise between the objectives defined in the initial evaluation stages and any additional modifications implemented by other members of the organization afterward.

For example, assume that projects *A*, *B* and *C* have multi-criteria scores of 0.65, 0.4 and 0.3 and costs of \$50,000, \$20,000 and \$25,000 respectively. Assuming that the multi criteria scores are the objective function coefficients, the combination of projects *B* and *C* is preferred to project *A* because their aggregate score is $0.3 + 0.4 > 0.65$ and their aggregate cost is $25{,}000 + 20{,}000 < 50{,}000$.

IP modeling selects projects *B* and *C* instead of project *A* although their individual scores are lower than the score of *A*. This is because using IP's formulation one can compare a combination of projects with a single project. In order to apply the IP method to the problem under consideration in this study, we adjust the final result using the multi-criteria score obtained for each project. Therefore, if option *A* is not selected, while other options with the same criteria (same type of evaluation, same department) and multi-index scores are selected, the promoter of option *A* can raise a logical objection to the process.

The method proposed in this study defines the individual scores of each project as the main selection criterion and prevents the inevitable integration caused by the interaction of the objective function and the constraints in the IP model. This will be achieved by replacing the scores of the main criteria with augmented scores. The proposed three-stage approach provides the maximum fitness between the final selection and the project initial ranking by considering the relevant organizational objectives and requirements.

That is, our model accounts explicitly for the information received at different levels within an organization. Lengthy evaluation processes, with information and constraints introduced at different levels of the organization during the decision process, tend to distort the initial organizational objectives. Our main contribution, besides the systematic design of the organizational decision process, is given by the novel algorithm defining the augmented scores that preserve the initial rankings assigned by the decision makers (DMs) when new constraints are introduced at a second level within the organization. These additional constraints, together with the knapsack structure of the final IP optimization problem, would lead to a set of portfolio solutions composed by projects other than those highly valued based on the initial organizational objectives. We have defined the entire decision structure so that the initial objectives are emphasized and maintained throughout the process.

The rest of this paper is organized as follows: in Section 2, the PPS literature is discussed. The proposed method is introduced in Section 3. In Section 4, a case study is used to demonstrate the applicability of the proposed method and exhibit the efficacy of the algorithms and procedures. Finally, in Section 5, basic conclusions and further research directions are presented.

2. Project portfolio selection

A project is a complex effort with well-defined objectives, schedule, and budget, and is composed of interrelated tasks performed by various organizational units (Archibald, 1992). A project portfolio is a collection of projects that are put together for a particular organization. These projects generally compete for scarce resources (e.g., people, finances, and time). PPS is the process of selecting a portfolio of projects from available project proposals without exceeding available organizational resources or violating organizational constraints and requirements. A wide range of divergent techniques have been proposed in the literature for estimating, evaluating, and choosing individual projects (e.g., economic return, decision tree, simulation, etc.). Salo, Keisler, and Morton (2011) review extensively the literature on portfolio decision analysis, which provides a sound methodological basis to account for the complex environment faced by DMs while allowing for the best possible resource allocation decision.

PPS methods involve the simultaneous consideration and ranking of a number of projects according to particular criteria. The most highly ranked projects are then selected for a portfolio without exceeding available organizational resources. Archer and Ghasemzade (1999) have classified these methods into five distinct groups including: ad hoc methods, comparative approaches, scoring methods, portfolio matrices, and optimization methods. They emphasize that portfolio selection is usually a committee process, often associated with multiple and conflicting criteria, and projects may be highly interdependent. They also argue that among the published project portfolio section methodologies, little progress has been made toward achieving an integrated framework and decomposing the selection process into a structured and logical series of activities that involve participation of a committee. Similarly, Iamratanakul, Patanakul, and Milosevic (2008) also categorized the project selection models into several groups including: scoring methods, economic methods (e.g., payback method, net present value, and internal rate of return), mathematical programming, real options analysis, simulation modeling, and heuristics methods. They emphasize that each methodology alone does not address all of the aspects of PPS. For more information about PPS models, the interested reader is referred to Archer and Ghasemzade (1999), Ehrgott, Klamroth, and Schwehm (2004), Graves and Ringuest (2003) and Iamratanakul et al. (2008).

3. Proposed method

The method proposed in this study is a comprehensive framework that integrates fuzzy TOPSIS, DEA and linear IP in a very structured and systematic framework. The proposed hybrid framework covers all the necessary steps in PPS from project creation to the final selection. The general multi-stage framework proposed in this study is adopted from the PPS research conducted by Archer and Ghasemzade (1999). Fig. 1 presents a schematic view of the hybrid