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Project portfolio selection and planning with fuzzy constraints

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A B S T R A C T

Selecting a project portfolio is a complex process involving many factors and considerations from the time it is proposed to the time the project portfolio is finally selected. Given that making a good selection is of crucial importance, it is essential to develop well-founded mathematical models to lead the organization to its final goal. To achieve this, such models have to reflect as closely as possible both the real situation of the organization as well as its targets and preferences.

However, since the process of selecting and implementing project portfolios occurs in real environments and not in laboratories, uncertainty and a lack of knowledge regarding some data is always an important issue due to the strong interdependence between the projects and the political, economic, social, and legal conditions in which they are carried out.

In this work, a mathematical model is proposed which extends the classical approach incorporating the inherent uncertainty to these problems. We have handled this uncertainty, vagueness and/or imprecision through the use of fuzzy parameters, which allow representation of information not fully known by the decision makers. The model combines selecting and planning project portfolios, specifies different relationships between projects (synergies, incompatibilities, time order, etc.) and other important constraints appearing in real situations. Moreover, a resolution procedure is developed which obtains, simultaneously, the optimal portfolio and the range for the confidence levels associated to it. An illustrative example and a real application are given in order to show the potentiality of the approach. The results are complemented with graphical tools, which show the usefulness of the proposed model to assist the decision makers.

1. Introduction

Organizations typically pursue a wide variety of objectives that cannot easily be achieved by a single project. Therefore, groups of projects (i.e. portfolios) that share a limited number of resources over a given period of time have to be selected (Archer and Ghasemzadeh, 1999). A project portfolio is the set of projects selected that can achieve the established objectives (Li et al., 2016).

There is a wealth of literature on the many methods used in the field of project portfolio selection (see for instance Heidenberger and Stummer, 1999; Iamratanakul et al., 2008). One set of widely used techniques focuses on the ranking of the investment required for each proposal with the aim at then distributing the budget until it is fully spent (e.g. financial methods (Silvola, 2006), scoring methods (Lawson et al., 2006), Analytical Hierarchy Process (Feng et al., 2011), and multiple attribute utility theory (Duarte and Reis, 2006)). However, these approaches are not always feasible for three main reasons:

a) They usually only take into account budget constraints. However, organizations have to deal with other constraints related to staff and resources as well as political, social, and environmental factors that also act as constraints (Mavrotas et al., 2008).
b) The dynamic nature of the process is not usually taken into account. Budget constraints usually refer to one period of time with all the selected projects usually starting at the same time. This is quite restrictive because a degree of flexibility regarding implementation or execution time may lead to a better distribution of resources (Jafarzadeh et al., 2015).
c) There may be complementarity and incompatibility relationships as well as synergies between the candidate projects such that they are not independent of each other; thus, the best projects when taken individually may not necessarily form the best set when taken as a group (Chien, 2002)).

Consequently, selecting the projects that best match the needs, requirements, and objectives of an organization is a complex task.

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Multiple factors have to be taken into account throughout the decision process. All this has led to growing interest in other techniques derived from mathematical programming that are able to better incorporate a greater degree of complexity (Rabbani et al., 2010). Our study is framed within these mathematical programming methods trying to handle the above described limitations of other mathematical programming approaches. In addition, it takes into account the vague or even unknown nature of the data providing an alternative perspective for different levels of uncertainty to the rational (technocratic) solution (Martinsuo, 2013).

Concretely, in this paper, we propose a model to select and schedule, simultaneously, an optimum project portfolio among several proposals, taking into account that some parameters are fuzzy numbers. We have incorporated different interactions between some of the candidate projects, the possibility of transferring cash resources not consumed in one period to the next period, and the different temporal availability of resources or other requirements appearing in real situations. In addition, a theoretical analysis is performed to obtain, simultaneously, all the optimal solutions and the range for the confidence levels associated with each of them. The strength of this approach is to inform decision makers about how variation in confidence levels affects the optimal portfolio allowing them to make the decision on more accurate information.

The paper is structured as follows: a review about the use of mathematical programming to select and schedule an optimal portfolio is presented in Section 2; In Section 3 a description of the project portfolio selection model is provided. Section 4 deals with the parametric analyse of the solution of the problem, and an illustrative example is showed in Section 5. In Section 6, a real application to test the proposed approach is provided. The conclusions are presented in the final section.

2. Review of mathematical programming applied to project portfolio selection

The use of mathematical programming models in project management goes back to the study by Weingartner (1966), who generalized the work carried out by Lorie and Savage (1955) and formalized it as a linear programming model. In addition, he also studied project interdependencies due to incompatibility or complementarity relationships, which can be incorporated in the model as additional constraints. Subsequently, synergies derived from running more than one project simultaneously were also taken into account as this led to a better sharing of costs and/or benefits. These relationships are modelled by including additional terms when assessing a given portfolio, and may have an effect on the objective functions and/or the resource constraints, as described in the studies by Czajkowski and Jones (1986), Schmidt (1993), Dickinson et al. (2001), Zuluaga et al. (2007), Medaglia et al. (2007), Rabbani et al. (2010), Solak et al. (2010), Tofighian and Naderi (2015) among others. These studies only cover synergies between two projects. On the other hand, Santhanam and Kyparisis (1995) and, in a more general sense, Stummer and Heidenberger (2003), Carazo et al. (2010) and Li et al. (2016) have proposed models where the synergies are generalized to sets of projects. The model presented in the next section follows this latter approach.

Organizations seek solutions that enable them to plan their resources over several time periods. In other words, they seek to develop policies that favour stability and continuity allowing them to reach their overall economic, social and environmental objectives in the medium and long term. For this reason, managers face the challenging task of having to simultaneously select projects and plan them within the planning horizon best suited to the organization. The literature on this topic is scarce (Naderi, 2013), probably due to the complexity involved in simultaneously selecting and scheduling the best projects. However, adding flexibility regarding the starting point of the projects (including the time factor in the model) can lead to precedence relationships between some of them. In other words, some projects can only start if their predecessors have already finished or a certain number of time periods have passed since the predecessor project started. This is illustrated in studies by Ghasemzadeh et al. (1999), Rabbani et al. (2010), and Emami et al. (2016). The time factor also enables a better distribution of monetary resources; if some resources are not used up in a given period of the planning horizon they can be transferred to the next period (Zuluaga et al., 2007; Medaglia et al., 2008; Jafarzadeh et al., 2015). It is worth noting that some studies take into account a planning horizon during project selection, but they assume that all the projects begin in the first period (see Dickinson et al., 2001; Stummer and Heidenberger, 2003; Doerner et al., 2004, 2006).

On the other hand, as the projects are selected before they are actually implemented, the information available may be characterized by imprecision and uncertainty. In particular, the budgets or the resources required by each project and the expected benefits may vary considerable, since their value is simply estimated before the projects are running. In this sense, uncertainty regarding certain parameters in the model has to be taken into account in such a way that the solutions obtained are reliable even within contexts characterized by change.

In recent years, there has been an increase in studies on scheduling and selecting project portfolios that use fuzzy techniques to deal with uncertainty. Due to the lack of historical data it has become usual to resort to experts who, based on their own experience, suggest modal values and the variation interval expected regarding unknown parameters (Wang and Hwang, 2007). In fact, many aggregation techniques have been developed to obtain these values when more than one expert is involved or when the expert's opinions have been given at different stages (Yager, 2004). In any case, this leads to the description of each of these values as a fuzzy number where the membership function contains information about the degree of truth of the parameter.

The abovementioned parameters can be found both in the constraints and/or in the objective functions in the projects portfolio selection problem. Some authors propose flexible programming approaches to deal with uncertainty in the constraints (e.g. Pereira, 1988; Kuchta, 2000; Machacha and Bhattacharya, 2000; Mohamed and McCowan, 2001; Carlsson et al., 2007; Ke and Liu, 2007). Other authors apply possibilistic programming techniques (e.g. Wang and Hwang, 2007; Hasuike et al., 2009; Mohagheghi et al., 2015; Liu and Liu, 2017; Tavana et al., 2015).

Other interesting approach which incorporates uncertainty into the projects selection model is due to Chang and Lee (2012). These authors took the model developed by Cook and Green (2000) as their starting point and modified it by using triangular fuzzy numbers. In this way, they obtained a fuzzy data envelopment analysis (FDEA) model in which constraints are added to the objective function as penalties.

Nevertheless, depending on the type of problem addressed, most of these studies have focused on portfolio selection alone and have not included scheduling. In fact, only Ke and Liu (2007) and Bhattacharyya et al. (2011) developed models addressing both project portfolio selection and scheduling. With synergies something similar occurs. As commented before, very few studies have dealt with the issue of potential synergies between projects. For example, Wang and Hwang (2007) included synergies but only between two projects. Fernandez and Navarro (2002) circumvented the issue by arguing that synergies can be included in the model by creating a new project that would combine the information pertaining to the new synergy. Bhattacharyya et al. (2011) included synergies using a polynomial model, which involves a high computational cost. Tabrizi et al. (2016) consider the projects synergy and sourcing options under information ambiguity. Finally, none of the studies previously described include additional constraints in the models, such as precedence relationships, which are of great relevance to this problem.

In this context, our aim was to develop a model that brings together as many features as possible, taking into account different types of constraints and the uncertainty associated with certain parameters.