Technovation 34 (2014) 54–63

Contents lists available at ScienceDirect

Technovation

journal homepage: www.elsevier.com/locate/technovation

Selecting balanced portfolios of R&D projects with interdependencies: A Cross-Entropy based methodology

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ARTICLE INFO

Available online 2 October 2013

Keywords:
R&D project portfolio selection
Portfolio values
Risk analysis
Resource interdependencies
Cross-Entropy (CE)

ABSTRACT

The intensive growth of technology makes firms rely on research and development (R&D) activities in order to adapt to technology changes in an ever-changing and uncertain environment. Due to R&D budget constraints and limited resources, firms are often forced to select a subset of all candidate projects by means of project portfolio selection techniques mitigating the corresponding risks and enhancing the overall value of portfolio. Projects' interdependencies and types were rarely considered in existing models of R&D portfolio selection that may result in selecting wrong projects. This flaw hinders the projects alignment with corporate objectives and strategy and leads to excessive risk and missing the promised values. In this paper, a balanced set of R&D project evaluation criteria was proposed. Next, to construct R&D project portfolio, a 0–1 nonlinear mathematical programming method for balancing portfolio values and risks was proposed, in which research projects' interdependencies, types and other constraints were all considered. Finally, a Cross-Entropy algorithm was developed to solve the proposed model and results were reported. The algorithm proved to be very effective in terms of solution quality and computational time. The proposed algorithm especially suits large scale instances while exact approaches are doomed to fail.

1. Introduction

Increasing complexity of technologies along with their rapid growth is forcing firms to rely on research and development (R&D) as a survival tool to achieve a strong competitive position in future. The importance of R&D as one of the main contributors to sustainable growth in highly industrialized economies is undisputable among economists, especially in the context of the modern knowledge based economies (Santamaría et al., 2010). Considering these leading factors, there has been an increasing interest in the area of portfolio selection of R&D projects, in recent years.

In many organizations, we face with projects approved but do not deliver the promised values. These projects may not be in sync with corporate goals or have excessive risks. Also, there are projects that are approved solely because of the political power of some stakeholders. There are some other projects which are failing in an early stage; yet, they are continued until total failure is recognized and the team admits that the product cannot be delivered. So, the main question is what should be done to avoid these kinds of problems.

It is worth noting that the question in project portfolio selection is not: "how to do projects correctly?", but another side of this question should be asked: "how to do the correct projects?" By selecting correct research development projects, future course of action of an organization will be accurately determined. While choosing one project over another, we prioritize projects and clarify the pecking order of organizational objectives. The priority is also utilized to allocate limited resources among the projects. The selection is thus beyond evaluation of projects.

Upper management periodically reviews research programs and projects to assess progress and determine contribution of each to the corporation's goals (Bard et al., 1988). Project portfolio selection techniques are powerful tools which provide senior managers with the possibility of analyzing R&D projects in a systematic manner and optimizing a company's long-term growth and profitability. In other words, the needs for aligning project selection framework with corporate objectives, considering values and risks of proposed projects and integrating different stakeholders' needs and desires make firms move from project management paradigm towards project portfolio management paradigm.

In analyzing a portfolio, a desirable combination is a balanced portfolio defined as an assortment of projects that enables a company to achieve growth and profit objectives associated with

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http://dx.doi.org/10.1016/j.technovation.2013.09.001

its corporate strategy without exposing the company to undue risks (Hill and Jones, 1992). Given varying levels of uncertainties faced by firms, underestimating uncertainty can lead to strategies that neither defend against the threats nor take advantage of the opportunities provided by higher levels of uncertainty (Courtney et al., 1997). Furthermore, Mikkola (2001) described some advantages provided by the portfolio approach for R&D management:

- Relative strengths and weaknesses of each project are surfaced.
- Decisions regarding capital investment allocation, project selection, prioritization and resource allocation are facilitated.
- Dynamics of the projects are revealed.
- Projects are tied to business level performances.
- Systematic analysis of the projects is encouraged.
- Relative graphical positioning of the projects makes the evaluation process easier to be understood by non-technical managers,
- Consensus is emphasized,
- Gaps and future development opportunities are highlighted.

In line with various advantages of project portfolio selection, it is always a challenging issue in R&D management. Even though many studies have been done in this regard, nature of this topic is very broad such that there are always opportunities for future works (Iamratanakul et al., 2008).

A wide variety of project portfolio selection models have been assembled over the years including linear programming, scoring models and checklists (Coldrick et al., 2005). Many early selection models were based on an optimization approach, which usually involved conversion of the attributes of a project into a single monetary value. There is little information on the application of these early models to project selection decisions (Coldrick et al., 2005). Moore and Baker (1969) suggested that the models were not entirely suitable for R&D type project portfolio selection due to the lack of input data. In spite of many proposed models' complexity and problems of application, a survey by Cooper et al. (2001) on the uses of portfolio management models concluded that it is greatly beneficial to use some forms of portfolio selection tools or systems.

So, the objective of this paper is to develop a framework for systematically selecting and adjusting R&D project portfolio which could most likely support the achievement of the organization's goals aligned with the strategies and minimize portfolio risk within the organization's resource (people and funding) constraints while considering projects' interdependencies and interactions.

Lack of comprehensive project portfolio selection model that could integrate corporate objectives and its project portfolio through an evaluation framework which combines qualitative and quantitative criteria motivated proposing this model.

The paper is organized as follows. First, some issues on R&D project portfolio selection literature and this research conceptual framework are discussed. Second, the concept of a balanced portfolio and evaluation framework is explained followed by the development of a mathematical model considering projects' values, risks and interdependencies. Section 4 presents an overview on Cross-Entropy algorithm and its implementation. Computational results of applying Cross-Entropy algorithm are presented and discussed in Section 5. Finally, conclusions are reported in Section 6.

2. Literature review and R&D project portfolio conceptual framework

R&D project portfolio selection is a concept based on the former financial investment theory. The original theory of the portfolio was developed for financial investors in stock markets. Markowitz's (1952) "Portfolio Selection" was based on the diversifications of risks. Diversification of single investment risk in a portfolio reduces risks overall, but, will not generally eliminate them. The Markowitz's portfolio theory asserted that, "The whole is greater than the sum of the parts". Mapping this concept in project management field, researchers introduced theoretical foundations for project portfolio. Meanwhile, this framework was deployed in R&D project portfolio management. Although we can learn from the financial portfolio theory, it is worth to mention that project portfolios are different from financial portfolios because projects have no market price despite financial assets (Casault et al., 2013).

The problem of allocating resources to arrive at an optimum portfolio of R&D projects has been examined extensively by a number of researchers (Bard et al., 1988). The literature on R&D project portfolio selection is extensive and dates back to the 1950s (Santiago and Vakili, 2005). Many early selection models were based on linear programming, scoring models and checklists (Tidd et al., 2005; Coldrick et al., 2005). These models usually involved conversion of the attributes of a project into a single monetary value (Coldrick et al., 2005).

Reviewing the literature on R&D project portfolio selection reveals two schools of thoughts on how to classify the approaches for research project/portfolio selection (Iamratanakul et al., 2008). Iamratanakul et al. (2008) argued that the first school of thought is mainly influenced by Baker, Freeland, and Pound providing quantitative approaches to project selection and resource allocation up to the early 1990s. Generally, these formulations amounted to static mathematical programming problems, the solutions of which are to provide optimal recommendations for management. These approaches have been criticized for their inability in capturing dynamic nature of the decision making process and tacit information available for decision makers as well as for the "black box" solution they provide that are not generally very insightful (Santiago and Vakili, 2005). The second school of project portfolio selection methodologies is influenced by Souder, Mandakovic and Gupta and tackle with the problem of project selection by qualitative techniques, such as using bubble diagrams, scoring models for project ranking and selecting. For details on this two R&D project portfolio selection schools of thoughts, see (Iamratanakul et al., 2008; Baker and Freeland, 1975; Baker and Pound, 1964; Santiago and Bifano, 2005; Gupta and Mandakovic, 1992). While introducing an integrated synthesis of these two schools of thought, Heidenberger and Stummer (1999) categorized project portfolio selection models to 6 dimensions of benefit measurement methods, mathematical programming approaches, simulation and heuristics models, cognitive emulation approaches, real options, and ad hoc models.

The extensive research done in this area has led to many techniques that can be used for selecting R&D project portfolio. Below, a summary of the related research is reviewed. Ghasemzadeh and Archer (2000) used the Decision Support System (DSS) for project portfolio selection. Tian et al. (2005) proposed an Organizational Decision Support System (ODSS) for R&D project selection. Coldrick et al. (2005) reviewed development of a project selection and evaluation tool that could be applied to a wide range of research decisions. Eilat et al. (2006) applied Data Envelopment Analysis (DEA) and Balanced Score Card (BSC) approach for constructing and evaluating the R&D project portfolio. A recursive version of DEA was applied by Linton et al. (2007) to compare projects using several efficiency frontiers. Fang et al. (2008) proposed a scenario generation approach for the mixed single-stage R&D projects and multi-stage securities portfolio selection problem. Huang et al. (2008) presented a fuzzy analytic hierarchy process method for R&D project selection. R&D portfolio selection problem as a fuzzy zero–one integer programming model which could handle both uncertain and flexible parameters was formulated by Wang and Hwang (2007) and Carlsson et al. (2007).