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An ANP approach for R&D project evaluation based on interdependencies between research objectives and evaluation criteria

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ABSTRACT

As countries strive to become more efficient in investing limited resources in various national R&D projects, the evaluation of project has become increasingly important. However, due to the heterogeneity of the objectives of national R&D programs, few studies have been conducted on comparing programs on the basis of performance. This study explores the application of the analytic network process (ANP) approach for the evaluation of R&D projects that are elements of programs with heterogeneous objectives. The ANP produced the final priorities of projects with respect to benefits and costs when there are interdependencies between programs and evaluation criteria. The paper provides value to practitioners by providing a generic model for project evaluation. For researchers, the paper demonstrates a novel application of ANP under specific situation of heterogeneous objectives. The ANP approach is tested against empirical data drawn from R&D projects sponsored by the Korean government.

1. Introduction

As R&D is a major force driving national competitive advantage, governments in many countries have increased the level of R&D investment by sponsoring R&D projects. Due to the scale of funding, the complexity of technology, and the heterogeneity of objectives, the evaluation of government-sponsored projects is usually viewed as a multiple criteria decision-making (MCDM) problem.

A large number of methods and techniques exist in the literature for the application of multiple criteria approaches to R&D project evaluation [10]. Approaches tend to be either qualitative or quantitative, ranging from unstructured peer review, which is normally made by a review committee with experts from academia, industry, and government, to sophisticated mathematical programming, including integer programming, linear programming, nonlinear programming, goal programming, dynamic programming, and portfolio optimization. Overviews on the topic of R&D project evaluation may be found in Henriksen and Traynor [8], Martino [12], and Steele [19].

Most studies in R&D project evaluation are in the private sector. However, a government-sponsored project differs from those in the private sector because government-sponsored R&D project is by nature a strategic and long-term investment. Government investment in R&D seeks to influence the private sector to make investments in technological fields important to the country as a whole. Investments led by government therefore address issues of national policy that are promulgated through a variety of outcomes, such as publishing academic papers for basic research field, issuing patents and developing prototypes for applied research field, and providing funds and researchers for R&D human resource development field. This variety of outcomes is due to the heterogeneity of the objectives of national R&D programs. Table 1 represents various national R&D programs in Korea and their objectives. Each program is composed of several R&D projects. This heterogeneity of the objectives of national R&D programs makes it intractably difficult to compare the relative performance of various government-sponsored R&D projects which belong to different programs. Consequently there have been few attempts to measure, at the same time and in the same context, the performance of several R&D projects that are elements of different government-sponsored programs.

The performance of a R&D project should be measured based on the unique characteristics of R&D programs to which the projects belong. Also, to incorporate several input/output variables of a project and produce a single measure for performance comparison, the relative importance of variables needs to be determined and fixed. This study presents an evaluation decision model with multiple criteria that assesses R&D projects that are elements of R&D programs with heterogeneous objectives. In this paper, it is assumed that interdependency exist between programs (Table 1) and evaluation criteria (Table 2). For example, the importance of a certain program may vary depending on which criterion (for example, academic journal publication) is considered because each program is initiated with its own main objective. Also, the importance of a certain criterion may vary depending on which program is considered as well. Thus, this interrelationship between programs and evaluation criteria needs

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Table 1
Descriptions of R&D programs and their objectives.

1. Basic S&T research program (G1)
Theoretical/experimental research for long-term critical basic science development
2. Public welfare research program (G2)
Research and development for improvement of citizen's welfare and quality of life such as SOC(social overhead capital), energy, environmental and medical issues.
3. Short-term industrial research program (G3)
Research for launching new commercial technology or product in the short term
4. Mid/long-term industrial research program (G4)
Applied scientific research for development of critical technology for commercialization in the mid/long term
5. Human resource development program (G5)
Program for S&T professional human resource development centered in a college or a graduate school in a university
6. Research environment development program (G6)
Research center support program for development of R&D infrastructure and public R&D facility provision

to be mirrored in evaluation of alternative projects which have their own program membership.

The purpose of this study is to solve the interdependency issue between programs and evaluation criteria by using analytic network process (ANP). The ANP is a generalization of the analytic hierarchy process (AHP), which is one of the most widely used MCDM methods [16]. AHP in general have however certain limitations since not every problem can be defined as a hierarchical model. It is true that an extension of AHP allows the representation of more complicated relationships through the ANP [14]. That enhances the expressive power of this MCDM methodology. The ANP allows for more complex interrelationships among factors because it replaces the hierarchy in the AHP with a network. It is therefore capable of providing priorities of projects that capture network relationships among factors such as programs and evaluation criteria. Most ANP applications in the literature deal with the interdependency among evaluation criteria themselves, and the alternatives are supposed to be in homogeneous set (in the same R&D program). However, it becomes a difficult task to determine the fixed importance of variables if the heterogeneity of different programs' objectives is involved. The aim of this paper is that, in order to overcome these limitations, we tried to incorporate the heterogeneous sets of alternatives and decision criteria by a wise use of ANP considering the interactions between the several decision criteria and several objectives of heterogeneous sets(programs) of alternatives(projects). This study also analyzes the costs and benefits associated with network relationships between fourteen kinds of R&D projects in various government-led programs. The resulting preference index supports efficiency in the development of national R&D policy.

The remainder of this paper is organized as follows. Section 2 reviews the analytic network process (ANP), the methodology underlying the proposed approach. Section 3 describes the heterogeneous nature of Korean government sponsored R&D. Section 4 details the proposed approach and Section 5 reports the results of the application of ANP. Some concluding remarks are made in Section 6.

Table 2
Description of evaluative criteria.

Cost sub-network
Funds (I1): total amount of funds given to a project
Researchers (I2): number of Ph.D. researchers on a project
Benefit sub-network
Academic papers (O1)
SCI papers (O11): number of scientific and technical articles published or accepted in journals listed on SCI (science citation index)
Non-SCI papers (O12): number of scientific and technical articles published or accepted in journals not listed on SCI
Patents (O2)
Applied patents (O21): number of patents applications registered at patent offices
Granted patents (O22): number of patents registered in patent offices
Human resource development (O3): number of students graduated with master or Ph.D. degree.

2. Analytic network process methodology

2.1. Brief description of ANP

The analytic network process was developed by Saaty [16] as a generalization of the analytic hierarchy process (AHP) [15], one of the most widely used multiple criteria decision-making (MCDM) methods. The AHP decomposes a problem into several levels that make up a hierarchy in which each decision element is supposed to be independent. The ANP extends the AHP to problems with dependence and feedback. It allows for more complex interrelationships among decision elements by replacing a hierarchy in the AHP with a network [13].

The network relationship of ANP method does not only present the relationship between decision elements, but also calculate the relative weightings (eigenvectors) of each decision element. The result of these computations forms a supermatrix. Finally, after the computation of the relationship of the supermatrix and the comprehensive evaluations, it is possible to derive the interdependence of each valuation criteria and options and the weighting of priorities. The higher the priority weightings, the more priority will be placed. In this manner, it is possible to select the most appropriate decision alternative. In recent years, there have been many applications of the ANP in a variety of problems such as quality [1], logistics [9], purchasing [4], strategy [21], production [11], project management [2], and product design [20].

Appendix A summarizes a simple example of ANP application.

2.2. Benefits and costs

In decision-making, there are criteria that are opposite in direction to other criteria, such as criteria in benefits (B) versus those in costs (C), and criteria in opportunities (O) versus those in risks (R). Therefore, Saaty [17] presented a model to synthesize the priorities of alternatives by combining the priorities of alternatives under B, O, C and R using four formulas; additive, probabilistic additive, subtractive and multiplicative. All except multiplicative formula require the normalized weights of categories B, O, C and R which represent relative importance of categories.

The BOCR concept is applied in various studies, including Erdogmus et al. [5], Feglar et al. [6], and Saaty and Shang [18]. Under the BOCR concept, pair-wise comparison questions ask which alternative is most beneficial under each sub-criterion in the benefits (B) sub-network, or has the best opportunity under each sub-criterion in the opportunities (O) sub-network [17]. In addition, the pair-wise comparison questions ask which alternative is riskiest under each sub-criterion in the risks (R) sub-network or most costly under each sub-criterion in the costs (C) sub-network. The weights of alternatives are first combined according to the weights of sub-criteria for each sub-network. The weights of alternatives under B, O, C and R are further combined to get a single outcome for each alternative using the aforementioned four formulae.

In this study, we applied only two categories of criteria, benefits (B) and costs (C), and used the multiplicative formula to get a single outcome since the normalized weights of evaluative categories were not obtained due to the vagueness of the managerial judgments on which category is more important.

The relative priority for each project is $P_i = B_i / C_i$, where B_i and C_i represent the synthesized results of project i under the categories B and C, respectively.