A Two-dimensional Model for Allocating Resources to R&D Programs by Integrated Subjective and Objective Decision Method

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ABSTRACT

A decision model is developed to help managers select the most appropriate sequences of plans for product research and development (R&D) projects that have strict constraints on budget, time, and resources. In recent years, many organizations have changed from emphasizing discipline to focusing on integrated programs and related outcomes. For decision-maker of these high-profile R&D programs, it is critical to understand which activities are the most important, considering both investment feasibility and cost-effectiveness. This paper proposes a two-dimensional decision model that integrates the analytic hierarchy process (subjective judgment method) and the data envelopment analysis (objective judgment method) for resource allocation. Using the information from these two decision tools, the model develops a two-axis evaluation space for research alternatives. By locating particular activities in this decision space, a program manager can compare and prioritize alternative research investments.
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1. Introduction

A large corporation often faces a decision on the scope of product research and development (R&D) projects. The main considerations for evaluating such projects are budget and timing constraints. Therefore, the selection of a balanced R&D portfolio, combining corporation goals, resources and constraints, is an important but venturesome task (Islei, 1991). Research portfolio analysis and decision models can be effective tools in promoting organizational participation in complex decision processes. This involvement develops a consensus for and an understanding of organizational goals and the associated performance metrics. To achieve the goal, decision models should provide managerial information without the distraction of excessive complexity (Howard, 1988). Specifically, models should provide benefits that exceed the difficulty and effort required for model development, use, and maintenance.

This study proposes integrating two complementary decision tools that have particular promise in R&D management environment: analytic hierarchy process (AHP) and data envelopment analysis (DEA). Major concerns in the two-dimensional decision model are comparing and prioritizing alternative research investments and the best allocation of the corporation's resources to selected projects. This paper is structured as follows. Section 1 is the Introduction. Section 2 describes both the subjective and objective approaches. Section 3 details the proposed two-dimensional decision model. Section 4 describes the application of the proposed model. Section 5 concludes the paper.

2. Related Literature

Literature R&D project evaluation and selection is abundant, and there are hundreds of models using a wide range of mathematically based approaches (Baker and Pound, 1964; Schroder, 1971; Baker and Freeland, 1971; Albala, 1975; Liberatore and Titus, 1986; Souder and Mandakovic, 1986; Roussell, 1991; Poth, Ang and Bai, 2001; Osawa and Murakami, 2002; Meade and Presley, 2002). Various researchers have provided a good review of these approaches to R&D project management. However, very few have focused on examining the degree to which the techniques meet the requirements of the evaluation process (Poth, Ang and Bai, 2001). Poth et al. (2001) found weighting & ranking methods better than benefit-contribution methods. Several approaches have been proposed to determine weights (Hwang, 1987; Saaty, 1980). Most of them can be classified as subjective and objective approaches depending on the information provided. The subjective approaches include methods such as the Analytic Hierarchy Process (AHP) (Saaty, 1980), the Delphi method (Hwang, 1987), and the weighted least square method (Chu, 1979). On the other hand, the objective approaches include models such as the Data Envelopment Analysis (DEA) (Charnes, 1978), the principal component analysis (Fan, 1996), the entropy method (Hwang, 1981) and the multiple objective programming model (Choo, 1985, and Fan, 1996). Subjective approaches determine weights that reflect subjective judgment, but these weights can be influenced by the DMUs. Objective approaches determine weights making use of mathematical models, but they neglect subjective judgment.

This study combines both the subjective weight restriction method and the objective weight restriction method to evaluate investment alternatives using the decision space shown in figure 1.
3. Two-Dimensional Decision Model

This section presents a two-dimensional decision model that achieves organizational goals and evaluates investment alternatives using the decision space shown in figure 1. It also describes the two tools that are integrated to provide the information required by research managers: AHP (subjective weight restriction method) and DEA (objective weight restriction method).

3.1 Subjective weight restriction method

Subjective weight restriction methods currently used are characterized by the subjective setting of weights in the evaluation index by experts according to their own experience. Different scholars and experts may give different weights and thus, subjectivity is the major drawback. Remedial measures such as increasing the numbers of experts, selecting experts properly and so on can overcome this drawback; however, subjectivity remains. The advantage of the subjective weight restriction method is that experts can reasonably identify the weight index that corresponds to the actual problems. Thus, despite the different placement of weights on the index, the method can still determine the order of priority and avoid conflicts between the reality and the index weights, as can occur in the objective weight restriction method. This study uses the AHP described as follows.

Thomas L. Saaty first proposed the AHP in 1971. And over the past few decades, due to research efforts of Saaty et al, an AHP can now be categorized as one of 31 types (Smith, 1989). AHP is considered to be an efficient management tool for modern enterprises.

The strongest function of the AHP is to simplify a complicated system into a hierarchy of processes, each consisting of simple but essential elements. In short, the procedure affects the incentives of each decision making point and the pairwise comparisons between the nominal scales. After the process of quantification, a comparison matrix is established to obtain the
Eigenvector, representing the weight of each hierarchy, and the eigenvalue. From the above, the corresponding strength and weakness of the individual pairwise comparison can be used as information for decision-making. In addition, if factors of AHP are interrelated in many hierarchies, the priority and then the connection are determined to obtain the combined weight of factors in the lowest hierarchy. Combining the consistency indices in all the comparison matrices provides each consistency index and ratio to evaluate on the common recognition of the entire hierarchy.

3.2 Objective weight restriction method

Researchers have been working on objective weight restriction methods (DEA, gray prediction, composition analysis) to avoid the shortcomings of the subjective weight restriction method. The primary data of the objective weight restriction method are the actual figures used in the matrix for evaluation to avoid subjective sources and to ensure that the weights are objectively given. Yet, sometimes the subjective weight may inevitably correspond to the fact. Theoretically, the least important index could have the largest weighting and the most important index may not be the case. Examples can be seen in many DEA analyses.

Accordingly, the subjective weight restriction method has its advantages, and the objective method also has some advantages if the practical situation is neglected. In the real situation, where weights are obtained through either the subjective or the objective method, the difference between the methods tends to be ignored and, therefore, their reliability becomes doubtful.

This study concentrates on the advantage of the integration and objectification of the weight restriction methods in offering more reliable information for decision-making.

4. An Example

This section provides a simple example of DEA in a research management context and integration with AHP to evaluate research activities in the subjective and objective decision space involving feasibility and productivity (figure 1). Consider a decision-maker faced with allocating limited funding for R&D program goals and objectives. There are 10 R&D candidate activities for funding.

First, to illustrate clearly the DEA concept, the percentage of completion is the only output, and each R&D activity is assessed according to the input resources (labor and capital) required to achieve 100% completion. Table 1 presents a summary of the inputs and outputs for the 10 R&D activities.
Table 1 Inputs and outputs of 10 R&D activities

<table>
<thead>
<tr>
<th>R&amp;D alternatives</th>
<th>Output (% complete)</th>
<th>Inputs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Labor</td>
<td>Capital</td>
</tr>
<tr>
<td>A1</td>
<td>100</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>A2</td>
<td>100</td>
<td>2</td>
<td>250</td>
</tr>
<tr>
<td>A3</td>
<td>100</td>
<td>3</td>
<td>225</td>
</tr>
<tr>
<td>A4</td>
<td>100</td>
<td>4</td>
<td>125</td>
</tr>
<tr>
<td>A5</td>
<td>100</td>
<td>5</td>
<td>150</td>
</tr>
<tr>
<td>A6</td>
<td>100</td>
<td>6</td>
<td>150</td>
</tr>
<tr>
<td>A7</td>
<td>100</td>
<td>7</td>
<td>120</td>
</tr>
<tr>
<td>A8</td>
<td>100</td>
<td>8</td>
<td>80</td>
</tr>
<tr>
<td>A9</td>
<td>100</td>
<td>9</td>
<td>100</td>
</tr>
<tr>
<td>A10</td>
<td>100</td>
<td>10</td>
<td>40</td>
</tr>
</tbody>
</table>

Since a uniform output has been selected and two inputs are used in the example, an interpreted graphical representation can be developed easily to provide insight into the DEA results. Figure 2 plots the input data for the R&D alternatives and shows that the productivity frontier is composed of A1, A4 and A10, while the other alternatives are not as efficient and are beyond the frontier.

![Figure 2 productivity frontier of the 10 R&D alternatives](image)

Second, the AHP is employed to evaluate the feasibility of the R&D investment alternatives. Figure 3 shows the AHP hierarchy for our investment alternatives. Our objective is to perform a comparative study of the 10 investment alternatives, which are enumerated at level 3 of the hierarchy in figure 3. At the highest level of the hierarchy, we specify the goal, which is the identification of the feasible R&D investment alternatives. Level 2 of the hierarchy lists the seven major criteria that are critical in determining the cost effectiveness of R&D investment alternatives. Level 3 of the hierarchy lists the 10 investment alternatives.
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Figure 3 AHP hierarchies for feasibility evaluation
To obtain the DEA and AHP solution of this example, IDEAS 5.0 and Expert choice 2000 are used and the results are summarized in Table 2, along with a theoretical set of AHP feasibility ratings. The R&D alternatives values for both the AHP-developed successful feasibility ratings and the DEA objective function values are plotted in figure 3. From the four-quadrant analysis, the decision-maker can draw the following conclusions:

1. R&D A10 is both productive and feasible. It is a very high priority program.
2. R&D A1, A4 and A8 are productive but not feasible, thus having is a low priority for funding.
3. R&D A5, A7 and A9 should be eliminated. They are not productive and not important.
4. R&D A3 and A6 should be targeted for improvement if possible. They are important programs but not cost-effective compared with other programs.

### Table 2 Summary of DEA and AHP values

<table>
<thead>
<tr>
<th>R&amp;D alternatives</th>
<th>Feasible according to AHP method</th>
<th>Cost-effective according to DEA method</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>0.073</td>
<td>1.00000</td>
</tr>
<tr>
<td>A2</td>
<td>0.09</td>
<td>0.75</td>
</tr>
<tr>
<td>A3</td>
<td>0.11</td>
<td>0.75</td>
</tr>
<tr>
<td>A4</td>
<td>0.08</td>
<td>1.00000</td>
</tr>
<tr>
<td>A5</td>
<td>0.16</td>
<td>0.82264</td>
</tr>
<tr>
<td>A6</td>
<td>0.109</td>
<td>0.77305</td>
</tr>
<tr>
<td>A7</td>
<td>0.075</td>
<td>0.82890</td>
</tr>
<tr>
<td>A8</td>
<td>0.094</td>
<td>0.93966</td>
</tr>
<tr>
<td>A9</td>
<td>0.089</td>
<td>0.79853</td>
</tr>
<tr>
<td>A10</td>
<td>0.12</td>
<td>1.00000</td>
</tr>
</tbody>
</table>

![Figure 4 Two-Dimensional Decision space](image)
5. Conclusion

This study introduces a two-dimensional decision model, a planning and scheduling tool that helps decision-maker evaluate and analyze schedules and resource requirements for R&D. By building on the strengths of two simple, yet powerful, decision tools, the model employs AHP and DEA to develop a decision space that identifies critical impact areas for decision-makers. Using AHP, the model identifies the activities that can achieve organizing goals. On the other hand, DEA identifies the activities that are cost-effective and thereby brings the reality of limited budgetary resources into the decision process. Together, these two data elements allow the decision maker to evaluate and compare research alternatives in a two-dimensional space. The proposed two-dimensional model incorporates the following features.

1. An additional benefit of this model is that it reduces subjective judgment.
2. A scientific and systematic product development process to help managers choose the "right" project.
3. A resource allocation plan to help managers perform the "correct" development process.
4. The flexibility of this model makes possible a wide range of application opportunities.

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References


