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A fuzzy ANP-based approach to R&D project selection: a case study

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Research and development (R&D) project selection is a complex decision-making process. It involves a search of the environment of opportunities, the generation of project options, and the evaluation by different stakeholders of multiple attributes, both qualitative and quantitative. Qualitative attributes are often accompanied by certain ambiguities and vagueness because of the dissimilar perceptions of organizational goals among pluralistic stakeholders, bureaucracy and the functional specialization of organizational members. Such differences in perceptions often hinder the attainment of consensus and coordination. Therefore, failures are frequent in R&D investment planning. To perceive the preferences of the various stakeholders and to map them into an analytical decision-making framework are challenging tasks. Further, risks and uncertainties are also associated with the investments and returns of R&D projects. This paper illustrates an application of fuzzy ANP (analytic network process) along with fuzzy cost analysis in selecting R&D projects. Fuzzy set theory is incorporated to overcome the vagueness in the preferences. The method adopted uses triangular fuzzy numbers for pair-wise comparison and applies extent analysis followed by defuzzification to determine the weights for various attributes.

Keywords: Analytical network process (ANP); Research and development (R&D); Net present value (NPV); Fuzzy set

1. Introduction

Progressive hi-tech companies across the globe are continuously engaged in implementing capital investment projects related to research and development (R&D). R&D projects must be compatible with the company's vision and mission. Wherever possible, such projects should provide benefits (significant added value) for stakeholders, link with the company's expertise and have clear leadership from within, have sound project management and clear objectives in place along with built-in appropriate evaluation resources and have prospects of sustaining itself. The predominant objective of undertaking such projects is to develop new products

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and processes so as to compete in dynamic markets. The challenging tasks involve enabling the organization to choose the right projects, i.e. projects that will lead to success, projects that have a positive cost/benefit, and provide the organization a prioritized list of projects that will improve the chance of success and will have futuristic scope and will have strategic fit and stakeholder involvement. A wide range of criteria, such as strategic fit, capacity, technical feasibility, solution re-use, funding, risks, organizational readiness (culture), opportunity costs, project duration, etc., are used for analysis. The associated risks in undertaking these projects are of huge importance, as the selection of inappropriate projects will result in significant losses of financial and human resources. Therefore, most companies are concerned with the scientific selection of R&D projects. R&D project selection is a crucial task. It is a complicated decision-making process with features of multiple stages, multiple groups of decision-makers, multiple and often-conflicting objectives, and high risk and uncertainty in predicting the future success and impacts (Ghasemzadeh and Archer 2000). Considerable effort has been made in the past several years to help organizations make better decisions in R&D project selection (Martino 1995, Henriksen and Traynor 1999, Ghasemzadeh and Archer 2000, Ibbs and Kwak 2000, Ringuest *et al.* 2000, 2004, Klapka and Pinos 2002, Osawa and Murakami 2002, Tian *et al.* 2002a, b, c, Lawson *et al.* 2004). Most of these studies focus on building decision models and developing decision-making methods. Traditionally, companies use three elements in the selection process: eligibility assessment, scoring using the selection criteria and qualitative appraisal. Henriksen and Traynor (1999) reviewed the literature and classified current decision models and methods into the following categories: unstructured peer review, scoring, mathematical programming, economic model, decision analysis, interactive method, artificial intelligence, and portfolio optimization. To improve the usability of these decision models and methods, current research efforts are deploying decision support systems to support the R&D project selection tasks (Bard *et al.* 1988, Liberatore 1988a, b, Iyigun 1993, Liberatore and Stylianou 1995, Ghasemzadeh and Archer 2000, William and Young 2003, Tiana *et al.* 2005a, b). However, current research on R&D project selection is basically focused on a micro point of view. Also, the decision models proposed are usually effective in facilitating single decision-making tasks with limited participation of decision makers. In practical applications, there is an urgent need to integrate the decision models, methods and decision support systems to facilitate the whole life cycle of the project selection process (Tian *et al.* 2002a, b, c).

2. Literature review

The project selection decision involves discrete criteria and uncertainties in different circumstances and has led to the development of a wide variety of decision support tools. Turner and Cochrane (1993) and Payne (1995) have proposed goals and metrics for projects with well-defined objectives and methods. Golabi (1987) used multi-attribute utility theory (MAUT) to construct value functions and further maximized the total value of projects using integer linear programming (ILP). Bard *et al.* (1988) proposed an interactive decision support system (DSS) for screening existing projects and evaluating new ones, and optimized the selection using mixed nonlinear integer programming (NLIP) and thus maximized the expected return. Iyigium (1993) used the Delphi method for project selection and an interactive DSS for resource allocation. Stewart (1991) also introduced an interactive decision support system (DSS) to solve a nonlinear multi-attribute optimization problem in portfolio planning, and the resulting ILP was solved using a heuristic algorithm. Traditionally, net present value (NPV), internal rate of return (IRR) and pay back period have largely been used as investment appraisal techniques. Further, Rzasa *et al.* (1990) proposed rigorous portfolio planning based on the expected NPV. Chui and Chan (1994) used the expected NPV to evaluate the conditions for an R&D project's success or failure, and selected the optimal project. Hess (1993) proposed decision trees for evaluating newer projects that incorporated all the qualitative criteria into a single expression. The aforementioned NPV and IRR methods calculate the annual cash flow values based on estimated parameters for all the alternatives. These values are then evaluated to assess the economic feasibility of the proposed alternatives. The success of these mathematical models depends upon the accuracy of the deterministic cash flow values (benefits and cost), and the life of the project as projected by the organization. These mathematical models merely consider the financial viability of the project. To incorporate non-quantitative factors such as strategic benefit, government policies, etc., an evaluation technique termed the analytic hierarchy process (AHP) (Saaty 1980) has been widely used. AHP is, in a sense, superior to mathematical models because the parameters used in this approach (i.e. preferences of the decision makers) are less uncertain compared with the parameters of mathematical models. Liberatore (1988b) used an expert support system (ESS) based on AHP and explicitly linked it to strategic planning and finally used a spreadsheet model for rating projects. Brenner (1994) proposed methods for the informal rating of projects by project champions using AHP. The reason behind the wide acceptance of AHP is its ability to capture more intangible factors and its handling of different measures and effects. Further, it can effectively integrate the evaluation of all the phases of the project life cycle. AHP structures a complex decision into a hierarchy of elements, and then establish shares of influence or relative weights among the elements through a sequential process of pair-wise comparison. These weights are then used to obtain the overall single score of the alternatives.

In a multi-project environment the success of an R&D project does not depend wholly on the project management team alone, since none of the functional managers can be omitted from the decision-making process. For example, in a manufacturing organization it is necessary to predict the most likely time and cost to be incurred for making a product and, without marketing personnel, the probability of marketing success and a competitive position in the market after successful completion of the project cannot be predicted in advance. Engineers and scientists can help to assess technical factors such as the overall technological strength and skills required for completion of the project. The models proposed in the literature deal either with each phase of the project life cycle, or with the entire life cycle independently, which leads to poor overall performance. Too often, on completion of the project, the market for the project no longer exists, or the technology used has become obsolete and the project no longer meets the strategic objectives of the organization. Thus, to analyse project alternatives, a feedback loop is necessary for each of these functional organizations at each level of maturity of the project. The analytical techniques used for project selection presented in the literature do not encompass such features.

In order to overcome the above drawbacks, Meade and Presley (2002) introduced the analytic network process (ANP) proposed by Saaty (1996) as another approach for the selection of R&D projects. ANP is a more general form of AHP. In AHP, a decision is pursued using a unidirectional hierarchical relationship among the decision levels, whereas ANP (Saaty and Takiawz 1986) is used to assess a dynamic multi-directional relationship among the decision attributes. With the advent of globalization, a R&D organization has to proceed in line with other competitive market changes so that there is perfect coordination between the various functional enterprises. ANP's dynamic interdependent framework embraces these attributes. The needs and desires of different stakeholders can easily be reconciled and integrated in the decision framework using ANP as it allows a feedback relationship among the different levels.

Further, in the context of R&D project selection, of the large number of approaches that have been proposed in the past, very few have gained wide acceptance, as most of them address either monetary or non-monetary aspects. A project will be viable financially if the expected returns exceed the forecasted investment in the R&D project. This can be analysed through the estimated annual cash flow values of the different project alternatives. However, by considering only monetary aspects, crucial non-monetary factors (Lopez and Flavell 1998) related to project selection, such as the strategic needs of the company, market needs, government policies, ecological policies, etc., are neglected. For example, changes in environmental regulations may have devastating effects on R&D projects. Hence, such factors need to be carefully analysed for each R&D alternative. In AHP/ANP, the non-monetary aspects can easily be tackled in a hierarchy. While using analytic methods as the project selection tool, decision makers have to express their preferences for various decision attributes of R&D projects using pair-wise comparison matrices, keeping in mind the company's overall interest. Human judgment varies from person to person, as human perception always contains a certain degree of vagueness and ambiguity. In addition, in order to consider the monetary aspects, the annual cash flow values have to be estimated. A significant amount of risk and uncertainty is associated with each of the parameters needed to calculate cash flow values. As a lot of uncertainty is associated with estimating cash flow values, conventional deterministic cash flow models are not effective in tackling monetary factors. Hence, the earlier methods, such as mathematical programming models, economic models, interactive models and analytical models, tend to be less effective.

The fuzzy set theory introduced by Zimmermann (1996) is suitable for dealing with the uncertainty and imprecision associated with information concerning various parameters. Human judgment is generally characterized by vague language, like 'equally', 'moderately', 'strongly', 'very strongly', 'extremely' and a 'significant degree' of investment. Using such language, decision makers quantify uncertain events and objects. Fuzzy theory enables decision makers to tackle the ambiguities involved in the process of the linguistic assessment of the data. Subsequently, a multi-criterion decision method can be applied to linguistic assessments to determine the best alternative.

Liang and Wang (1991) applied a fuzzy multi-criterion decision-making method to facility site selection, Prabhu and Vizayakumar (1996) used a fuzzy hierarchical decision-making method (FHDM) for technology choice, and Chui and Chan (1994) proposed fuzzy cash flow analysis using present worth criteria for calculating NPV and IRR. Kaufmann and Gupta (1988) proposed a fuzzy mathematical model for project selection. Lueng (1980) proposed a fuzzy sets procedure for project selection and Choobineh (1993) proposed an index for ordering fuzzy numbers.

The proposed approach simultaneously addresses the issue of combining both monetary and non-monetary aspects using fuzzy ANP along with fuzzy cash flow analysis. In fuzzy ANP, the linguistic assessment is converted to triangular fuzzy numbers. These triangular fuzzy numbers are used to build a pair-wise comparison matrix for the ANP and, by applying extent analysis (Chan 1996, Jhu *et al.* 1999, Chan *et al.* 2003), one can obtain the weights for attributes on each level. In fuzzy ANP, weights are more simple to calculate than for conventional ANP. These weights can be integrated to determine the best project to be selected. Several authors have applied the fuzzy ANP-based approach to solve complex decision-making scenarios (Lee and Kim 2000, Karsak *et al.* 2002, Bozdag *et al.* 2003, Emblemsvåg and Tonning 2003, Büyüközkan *et al.* 2004a, b, Kahraman *et al.* 2004, Tran *et al.* 2004, Chung *et al.* 2005, Lefley and Sarkis 2005).

In the following section we illustrate the conceptual model used for project selection. We also identify the critical attributes necessary for decision making. Section 4 describes the proposed approach used for decision making. The background of the proposed methodology is given in section 5 and concluding remarks are given in section 6.

3. Proposed model and approach

The approach discussed in this paper for the selection of R&D projects has been tested for the case of the iron and steel industry in South East Asia. The marketing department sends the sales forecast for rolled product sales in the near future. To meet the demand, the company is considering carrying out R&D projects compatible with its new product development strategy. The company has some options for carrying out the R&D process: to opt for advancement of its previous products, or to opt for basic research that assists in bringing drastic changes or expansion to its product lines or to carry out some management-related R&D, so that the prices of existing product lines can be brought down.

For a company contemplating a major expansion or upgrading of its product lines, the uncertainty and risk associated with the success of a R&D project poses the dilemma that the company may be vulnerable or even worse off if the selection of the project is an implementation failure. It follows that the analysis of a problem of this nature requires a model capable of encompassing all the attributes of a R&D project and the interrelationships between them. Here, the whole problem of R&D project selection has been analysed and the interrelationships among the different factors have been taken into account.

In this paper, R&D options are evaluated on four hierarchical levels: (i) the different enterprise functions; (ii) the different phases through which the R&D project passes; (iii) the decision-making criteria; and (iv) their attributes and sub-attributes. The attributes and criteria presented in this model are mostly available in the literature. The objective of modeling the hierarchical framework is to select the best project from the available options. The proposed framework for R&D project selection is depicted in figure 1, which shows a five-level hierarchy for the various criteria relevant to project selection. In this framework, arrows pointing in a single direction show the direct relationships between two levels, whereas two-way arrows represent the interdependencies between two levels. The goal is placed at the top of the hierarchy and is subsequently maintained in accordance with the priority. Different levels of the hierarchy are illustrated in the following subsections.

3.1 *Different phases of a R&D project*

Any R&D project can be divided into three phases: basic, applied and development. The importance of various attributes and criteria varies with the phase in the project life. For example, technological and general attributes are of more importance in the basic phase, whereas market attributes are of more importance in the development phase. The main objective behind the inclusion of this level is to evaluate the various decision criteria separately for different phases and to integrate the various biases of the stakeholders. The basic activities of the three phases are illustrated as follows.

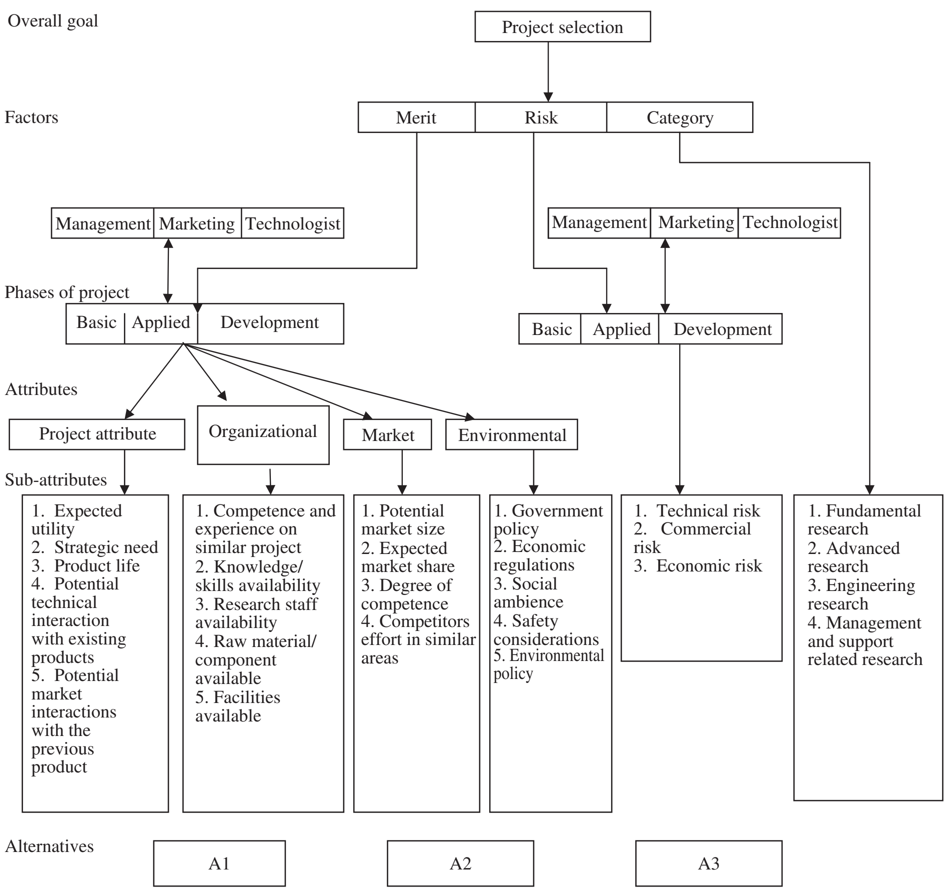

Figure 1. Analytic network framework showing the various attributes of project selection.

3.1.1 Basic phase. In this phase, knowledge concerning the technology is collected. To acquire technical and marketing assistance in the future, the new product to be developed is correlated with previous products. In this phase, different surveys are made and all the resources necessary for the research are collected. It includes various laboratory studies, related process plans, an economic evaluation of different process plans, etc.

3.1.2 Applied phase. In this phase, laboratory research is carried out to develop technology and process plans for the development of the new product. Feasibility studies and economic evaluations of the new technology are conducted in this phase.

3.1.3 Development phase. This is the final phase of a R&D project. The technology developed in the applied phase is used for the development of the new product. In this phase, design, quality, and procurement issues related to product manufacture are considered.

3.2 *Different factors affecting decision making*

Decision making is affected by three factors, namely merit, risk and category.

3.2.1 Merit. This represents the expected benefits of the R&D project realized by the organization. Keeping in mind the various inherent constraints, every organization looks for a new project that will suit its needs. The merit of an R&D project can be gauged by assessing the alternatives on a set of attributes. These attributes can be broadly classified into four categories.

- **Project attributes.** These are the general characteristics of a proposed alternative. It includes the expected utility of the project, the strategic benefit of the project to the organization, product life before obsolescence, potential technical interaction with existing products, and potential market interactions with existing products.
- **Organizational attributes.** These attributes judge the organizational constraints. It includes the efficiency of the management staff, the skilled labour available, the research staff available, raw material and component availability, and the reliability of the available machinery.
- **Market attributes.** These attributes scrutinize the various market limits. These include potential market size, expected market share received after successful completion of the project, degree of competition in a similar field, and the efforts of competitors in similar areas.
- **Environmental attributes.** These attributes take into account various ambient factors. It encompasses government policies, economic regulations, social ambiance, safety considerations and environmental considerations.

3.2.2 Risk. It is an uphill task to predict the success or failure of a project in advance, as a large amount of uncertainty is associated with them. In addition, a large amount of resources is involved in R&D activities, hence a huge risk is associated with these projects. The more the risk, the less likely the project will be selected. Risk can be classified into three sub-categories.

- **Technical risk.** This considers the probability of not being able to meet the technical requirements.
- **Economic risk.** This takes into account the probability of not being able to produce the required quantity at the required cost.
- **Commercial risk.** This focuses on the probability of not being able to attain the required sales volume.

3.2.3 Category. According to the strategic needs and preferences of the stakeholders, organizations are always inclined towards certain categories of projects. The classification of these kinds of R&D projects can be made in four ways.

- **Fundamental research.** Research to be carried out keeping in mind future R&D activities.
- **Advanced research.** For upgrading existing technology.
- **Engineering research.** To develop new and innovative products.
- **Management research.** Research that gives support to management and production processes.

3.3 *Enterprise functions*

These are another set of levels placed in the hierarchy. Enterprise functions of the company comprise management personnel, marketing personnel and technologists. These stakeholders affect the selection of the project, as they help to synchronize the R&D strategy of the company keeping in view market demands. In the proposed framework, interdependency exists only between the various enterprise functions and different phases of an R&D project. Differences in opinion of enterprise functions relative to various phases of a R&D project give rise to interdependency between the two levels. For example, the basic phase is of more interest to technologists, whereas marketing personnel are more interested in the development phase.

The aforementioned attributes and criteria are used to develop the framework for the company. The technologists, marketing personnel, and management staff of the company can decide these criteria jointly. Also, the hierarchy can easily be customized according to the needs of a particular company. Details of the proposed methodology are described in the following section.

4. Background of solution methodology

In the proposed methodology, fuzzy ANP with fuzzy cost analysis has been used to solve the problem of R&D project selection. Fuzzy ANP as a tool provides a framework that includes corporate strategy, qualitative benefits, risks and the desires of different stakeholders. It is very useful in circumstances where there is a high degree of interdependence between various attributes of the project, i.e. when the result of one criterion also affects the others. In this approach, pair-wise comparison matrices are formed between various attributes of each level with the help of triangular fuzzy numbers. By applying extent analysis (Dong and Wong 1987, Kwang and Bai 2002) followed by defuzzification, one can obtain weights for each of the attributes.

Fuzzy ANP can easily accommodate the interrelationships existing among the functional enterprises with the different phases of project life. The concept of supermatrices is employed to obtain the composite weights that overcome the existing interrelationships.

Cash flow models are employed to analyse the financial viability of the project. Earlier models generally employ crisp data to generate cash flow models. However, a large amount of uncertainty is associated with various parameters of the cash flow model, and thus there is a need for fuzzy theory. The values of parameters such as the initial investment required, maintenance expenses, revenue, etc. are transformed into triangular fuzzy numbers and are used to calculate fuzzy cash flow values. Annual cash flow values are used to determine NPV values and subsequently to calculate the weights for the financial viability of each of the alternatives. The alternative with maximum benefit in monetary terms has the highest weight.

5. Solution methodology

After the hierarchical ordering of attributes in an ANP framework, the preferences of the decision makers are given as suggested by Saaty (1996). Each of the components on a given level is compared on a pair-wise comparison basis. The comparison of attributes is conducted with respect to their immediate upper level criterion. This upper level criterion acts as a controlling condition for the comparison among the attributes.

Prior to the introduction of the solution methodology, the notation used is given in table 1.

Saaty (1980) suggested a scale of 1–9 to quantify the preferences of decision makers. When comparing component i (column element in the matrix) with component j (row element in the matrix) a score of 1 represents indifference between the two, a score of 3 represents weakly preferred, 5 depicts a strong preference, 7 depicts a very strong preference and 9 represents the absolute preference of i over j. The above scale of 1–9 is precise and explicit. However, the human perception concerning project attributes is ambiguous and complex, and cannot be expressed in definite numbers, thus the use of definite numbers is not very judicious.

Fuzzy set theory introduced by Zadeh (1965, 1976) has proved to be very useful for modeling the kind of uncertainty associated with vagueness. Fuzzy theory provides numerous methods to represent the qualitative judgment of the decision maker as quantitative data. Triangular fuzzy numbers are used in this paper to assess the preferences of decision makers.

In the pair-wise comparison of attributes, decision makers use triangular fuzzy numbers to express their preferences. Similar to the scale of 1–9 suggested by Saaty (1980), a scale of M_1 to M_9 can be defined for triangular fuzzy numbers. This scale is depicted in figure 2.

When comparing attribute i with attribute j, a scale of M_1 to M_9 is used: M_1 represents equality among the compared attributes; M_3 presents a moderate preference of i over j; M_5 depicts a strong preference of i over j; M_7 portrays a very strong preference of i over j; and M_9 represents the absolute preference of i over j, where

$$M_i = (l_i, m_i, n_i), \quad i = 1, 2, \dots, 9.$$

Table 1. Notation.

M_i	Triangular fuzzy numbers showing Saaty's scale of 1–9
l_i	Lowest limit of the triangular fuzzy number
m_i	Most likely value of the triangular fuzzy number
n_i	Upper limit of the triangular fuzzy number
a_{ij}	Comparison of component i with respect to j
D_i	Fuzzy synthetic degree with respect to the ith object
B_i	The relative impact weight of criterion i
A_{ji}	The relative priority weight for attribute j of criterion i
E_{kji}	The relative importance weight for sub-attribute k of attribute j of criterion i
S_{mkji}	The relative impact of alternative m on sub-attribute k of attribute j of criterion i
C_{mj}	Net total cash flow values of project alternative at the end of year j
R_{mj}	Revenue of project alternative at the end of year of j
O_{mj}	Operating expenses of technology m at the end of year j
D_{mj}	Amount of depreciation of project alternative m at the end of year j
T_m	Tax rate of project alternative m
I_m	Investment cost of project alternative m
P_{mj}	Incremental tax credit of project alternative m in year j
NPV	Net present value
β	Discount rate
η	Life of project A_i

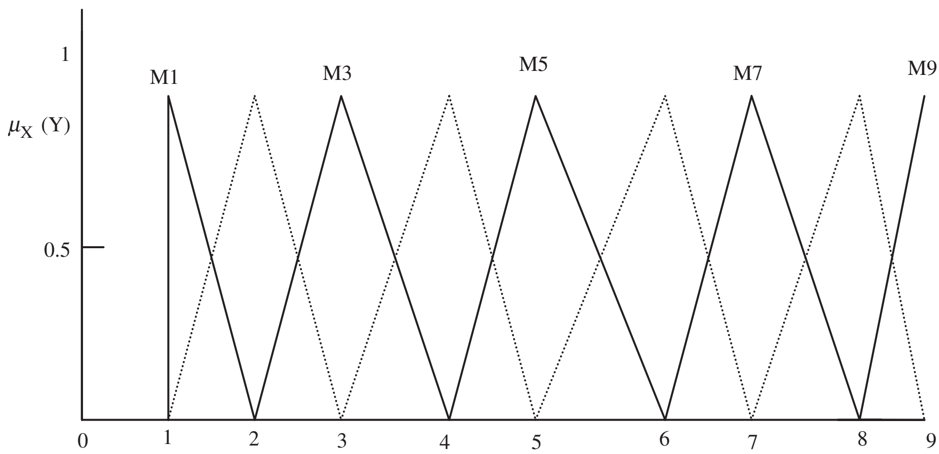

Figure 2. Membership functions of the triangular numbers.

For the assessment of decision maker preferences, pair-wise comparison matrices are formed using triangular fuzzy numbers (l_i, m_i, n_i). The element a_{ij} represents the comparison of component i (row element) with component j (column element), whereas the reciprocal value, i.e. $1/a_{ij}$, is assigned to the element a_{ji}. The value of $(1, 1, 1)$ is assigned to element a_{ii}. The preferences of decision makers are obtained by comparing the attributes with respect to the upper level control criterion. It compares each of the attributes with all the attributes present on the same level.

5.1 *Calculation of the weights for each of the attributes*

Once the pair-wise comparison matrices are formed, weighted vectors for all the matrices are calculated. To select the best R&D project, weight vectors have to be calculated for the individual level of the hierarchy. The extension principle provides a general method for using crisp mathematical concepts to address fuzzy quantities. Extent analysis determines the image of the object on the goal, i.e. suppose there is a set of elements in universe X that forms a fuzzy set A, then the image of fuzzy set A on X under mapping f determines the extent to which A satisfies the goal

$$\mu_X(y) = \underset{\vee f(x)=y}{\vee} \mu_A(x). \tag{1}$$

Now, if there are m objects for pair-wise comparison in a matrix, m extent analysis values for each object can be obtained as follows:

$$X_{gi}^1, X_{gi}^2, \ldots, X_{gi}^m, \quad i = 1, 2, 3, \ldots, n,$$

where, X_{gi}^j $(j = 1, 2, 3, \ldots, m)$ are triangular fuzzy numbers.

In extent analysis, a synthetic evaluation of the hierarchy is made. The term 'synthetic' denotes the process of evaluation, where several individual elements and components of a matrix are synthesized into an aggregate form. The value of the fuzzy synthetic degree with respect to the ith object is defined as

$$D_i = \sum_{j}^{m} X_{gi}^j \otimes \left[\sum_{i}^{n} \sum_{j}^{m} X_{gi}^j \right]^{-1}. \tag{2a}$$

Similarly, fuzzy synthetic values for each level of the hierarchy can be obtained using the above definition, i.e. for level k,

$$D_i^k = \sum_{j=1}^{n} a_{ij}^k \otimes \left(\sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij}^k \right)^{-1}, \quad i = 1, 2, 3, \ldots, n, \tag{2b}$$

where D_i^k are the fuzzy synthetic degree values of each element i in the kth level, and a_{ij}^k is an element of the fuzzy judgment matrix of the kth level.

The weights are then obtained by defuzzifying the synthetic degree values using the formula

$$w_i = \frac{l_i + 2m_i + n_i}{4}. \tag{2c}$$

5.2 *Interdependent components*

Interdependencies occur when the direction of influence of the components between two levels of the hierarchy is not unidirectional. When considering the impact of interdependency, the components of two interdependent levels are viewed as controlling components for one another. To determine the composite weights of two interdependent levels, ANP proposes the formation of a supermatrix. This allows a resolution of the effects of interdependencies that exist in the hierarchy. Then the weight vectors for each of the matrices are calculated and placed in the supermatrix. In order to obtain a long-term stable set of weights, the resulting matrix needs to be column stochastic. For convergence of the matrix to occur, the supermatrix is arbitrarily raised to large powers until the entries are stable.

After calculating the weights for all the attributes using the above formulation, the desirability index, 'D_{Ai}', is calculated. This index shows the impact of a particular alternative,

$$\text{Desirability index} = \sum\sum\sum\sum B_i A_{ji} E_{kji} S_{mkji}. \tag{3}$$

5.3 *Cost analysis*

In order to select the best project, it is imperative to integrate the desirability index obtained for the subjective attributes with the total cost. To do so, a cost analysis is performed using the fuzzy cash flow method.

When generating the cash flow model the available data are generally uncertain and vague. Hence, use of the deterministic cash flow model is not effective in assisting the decision maker to select the most appropriate R&D project. Therefore, in this paper fuzzy set theory is applied to the cash flow model in order to cope with the ambiguous data. The following equation is employed for the total cash flow model:

$$C_{mj} = (R_{mj} - O_{mj}) - (R_{mj} - O_{mj} - D_{mj})T_m - I_m + P_{mj}. \tag{4}$$

The net present value (NPV) of the project can be determined using the values of the cash flow model. The equation employed to calculate NPV is

$$\text{NPV}_{Ai} = \sum \frac{C_{mj}}{(1+\beta)^{\eta}}, \tag{5}$$

where NPV_{Ai} is the net present value of project A_i.

The fuzzy total cost is converted into dimensionless indices to ensure compatibility between monetary and non-monetary criteria. Based on the aforementioned principle, the fuzzy weighting can be determined by normalizing the fuzzy NPV values. The alternative with the maximum NPV obtains the highest weight in monetary aspects.

Using equation (5), the fuzzy net present value of the alternatives can be enumerated. After the fuzzy NPV value for each of the alternatives is obtained the fuzzy weightings are obtained by normalizing their values. These fuzzy weightings can be defuzzified to obtain crisp weights. Crisp values can be obtained by employing the formula

$$W_{Ai} = \frac{(l + 2m + n)}{4}. \tag{6}$$

Now, to select the best alternative among all the choices available, the overall desirability index for each alternative is calculated. For this, the desirability indices of the subjective criteria are multiplied by the weights obtained by considering the monetary aspects of each of the alternatives

$$OD_{Ai} = D_{Ai} * W_{Ai}, \tag{7}$$

where D_{Ai} is the desirability index of alternative A_i with respect to the subjective attributes and W_{Ai} is the weight with regard to the monetary aspects.

6. Example

The case considered here is a R&D project selection problem. The various criteria and sub-criteria affecting the decision problem are depicted in figure 1. Three possible alternatives have been identified. The aim of the decision maker is to select the most appropriate alternative to satisfy the requirements of the organization. Table 2 lists the opinions of the decision maker in terms of triangular fuzzy numbers 1–9. In table 2, the opinion regarding the *basic phase* of the project is presented. Similar matrices are also enumerated for the other levels of the decision phase.

Using equations (2*a*)–(2*c*) the weights are obtained by defuzzifying the synthetic degrees (table 3).

After the weights are determined for all levels of the hierarchy, an analysis is performed to obtain the interdependencies among the levels of the hierarchy or within it. In this case study, interdependency occurs between the various phases of the project and different enterprise functions. Tables 4 and 5 list the matrices showing the interrelationships among the different levels of the hierarchy.

Now we form the supermatrix to even out the effects of the interdependencies among the '*phases of project life*' and '*enterprise functions*'. To determine the relative impact of the 'enterprise functions' on the phases of the project, six pair-wise comparison matrices are required. These matrices are for the pair-wise comparison of the different phases of the project with respect to each of the enterprise functions, and *vice versa*. Then the weight vectors for each of the matrices are calculated and

Table 2. Pair-wise comparison matrix for attributes of merit in the basic phase.

Basic	Project attribute	Organizational attribute	Market attribute	Environmental attribute
Project attribute	(1,1,1)	(6,7,7)	(1,2,3)	(7,7,8)
Organizational attribute	(1/7,1/7,1/6)	(1,1,1)	(1/5,1/4,1/3)	(5,6,7)
Market attribute	(1/3,1/2,1)	(3,4,5)	(1,1,1)	(6,7,8)
Environmental attribute	(1/8,1/7,1/7)	(1/7,1/6,1/5)	(1/8,1/7,1/6)	(1,1,1)

Table 3. Weights of the different attributes given in table 2.

W_1	W_2	W_3	W_4
0.448	0.196	0.3335	0.038

Table 4. Matrix for the weights of the relative importance of enterprise functions for phases of a R&D project life.

	Basic	Applied	Development
Management	0.0717	0.0754	0.0698
Marketing	0.3809	0.6079	0.5815
Technologists	0.5474	0.3167	0.3507

Table 5. Matrix for the weights of the relative importance of the phases of a R&D project on enterprise functions.

	Management	Marketing	Technologists
Basic	0.0719	0.0657	0.5742
Applied	0.3775	0.3425	0.3407
Development	0.5506	0.5918	0.085

Table 6. Initial supermatrix compiled from matrices 2 and 3 for ‘enterprise functions’ and ‘phases of R&D projects’.

	Basic	Applied	Development	Management	Marketing	Technogists
Management	0.0717	0.0754	0.0678	0	0	0
Marketing	0.3809	0.6079	0.5815	0	0	0
Technologists	0.5474	0.3167	0.3507	0	0	0
Basic	0	0	0	0.0719	0.0657	0.5742
Applied	0	0	0	0.3775	0.3425	0.3407
Development	0	0	0	0.5506	0.5918	0.085

Table 7. Converged supermatrix to long-term weights.

	Basic	Applied	Development	Management	Marketing	Technologists
Management	0.0725	0.0725	0.0725	0	0	0
Marketing	0.5823	0.5823	0.5823	0	0	0
Technologist	0.3452	0.3452	0.3452	0	0	0
Basic	0	0	0	0.2632	0.2632	0.2632
Applied	0	0	0	0.3508	0.3508	0.3508
Development	0	0	0	0.2632	0.2632	0.2632

Table 8. Final weights of the alternatives.

OD_{A1}	OD_{A2}	OD_{A3}
0.10846	0.09277	0.10625

placed in the supermatrix, as shown in table 6. Table 7 lists the converged weights obtained after raising the powers of the ‘*supermatrix*’.

In this case study, convergence occurs at the 16th power of the original matrix. Using equation (3), the desirability index D_{Ai} is determined for all the alternatives. Their values are $D_{A1} = 0.3625$, $D_{A2} = 0.3017$ and $D_{A3} = 0.27$. The net present value of the alternatives can be calculated using equations (4) and (5), giving values of $(182\,980, 199\,287, 215\,510)$ for alternative 1, $(254\,300, 257\,000, 279\,570)$ for alternative 2, and $(187\,390, 194\,217, 243\,369)$ for alternative 3. The weights are determined after defuzzification of the net present values of the alternatives. The weights corresponding to the different alternatives are $W_{A1} = 0.299$, $W_{A2} = 0.393$ and $W_{A3} = 0.306$. The final weights of the alternatives can be determined using equation (7) and are given in table 8. It is evident that alternative A_1 is the best among the three.

7. Discussion and conclusions

The quest to devise an efficient method for selecting an R&D project is a continuous process. In this research, we have focused our attention on tackling the uncertainty and ambiguity associated with the various variables of R&D project selection, and integrating the monetary and non-monetary aspects of project selection. This paper presents an effective method for performing R&D project selection based on the attributes and criteria that serve the purpose of the company. The case study provides an example of the application of the methodology to a real-life situation. The methodology presents a more accurate mode for eliciting the preferences of decision makers. Further, the model is capable of addressing effectively the ambiguity associated with the preferences of the decision maker by using fuzzy set theory for pair-wise comparison of the attributes.

The ANP methodology provides a framework for integrating all the strategic arguments related to project selection, such as market needs, government regulations, organizational capacity, etc. For project selection, these strategic affairs must be integrated with the cost analysis of the project. Since the feasibility of the project cannot be predicted without an economic evaluation, the cost analysis is performed implicitly using the fuzzy cash flow method. We have approached the project selection problem from a macro rather than a micro point of view, i.e. from the perspective of organizational decision making rather than the perspective of a single decision maker or unit. This approach aims to develop a framework to facilitate the whole life cycle of the R&D project selection process.

The major contributions of this research are as follows. First, an ANP framework for R&D project selection has been proposed with the goal of extending the current literature in the field. The framework includes a group-based modeling method that facilitates the R&D project selection process, and a corresponding ANP architecture that supports and coordinates the work of decision-making groups. Second, this paper presents an application of the proposed framework to a real project selection system. This research presents a method that differentiates itself from the existing methods by addressing the support available to the decision-making groups of organizations in the R&D project selection process. In conclusion, this model provides a qualitative and quantitative assessment of the attributes of a project encompassing the nonlinear relationships among interdependent levels. A major contribution of this work is to provide a methodology for assessing the ambiguities present in the preferences of the decision maker.

However, the model presented here does not consider all the possible factors and criteria associated with project selection. The attributes, criteria and interactions between the attributes presented in the framework are specific to a particular organization. However, this model can be applied across numerous enterprises and projects of various kinds. The methodology can easily be adapted to different situations by adjusting the different levels of the hierarchy and their related attributes.

The future scope of this work will be to increase the efficacy of the proposed methodology by the introduction of another feedback loop so that the regret factor can be analysed. Another enhancement would be to adopt consensus support systems to determine the weights associated with the various attributes of R&D projects.

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