Analytic Network Process Applied to R&D Project Selection

Murad Habib, Raza Khan and **Javaid L. Piracha**

Abstract— Research and development (R&D) project selection is a complex decision-making process. Risks and uncertainties are also associated with the investments and returns of R&D projects. This research paper illustrates an application of ANP (analytic network process). The analytic network process (ANP) is presented as a potentially valuable method to support the selection of projects in a research and development (R&D) environment. The AHP (Analytic Hierarchy Process) is employed to break down large unstructured decision problems into manageable and measurable components. The ANP, as the general form of AHP, is powerful to deal with complex decisions where interdependence exists in a decision model. The research paper discusses the use of the ANP, a general form of Saaty's analytic Network process, as a model to evaluate the value of competing R&D projects.

The research paper concludes with a case study describing the implementation of this model at a small high-tech company, including data based on the actual use of the decision making model. The case study helps to verify that ANP is an effective and efficient decision-making tool.

A major contribution of this work is to provide a methodology for assessing the best project. Also author introduce first time 'innovation' factor in a new model for R&D project selection using ANP method. Despite a number of publications applying AHP in project selection, this is probably the first time that an attempt has been made to apply ANP in an electronics project selection.

Keywords-component; Analytic hierarchy process, analytic network process, multi criteria decision-making, project selection, R&D management, and R&D projects.

I. INTRODUCTION

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 because of the different perceptions of organizational goals between stakeholders, bureaucracy and the functional specialization of organizational members. Such differences in perceptions often hinder the attainment of compromise and coordination. Therefore, failures are frequent in R&D investment planning. To identify the first choice of the various stakeholders and to map those into an analytical decision-making framework are challenging tasks. Further,

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risks and uncertainties are also associated with the investments and returns of R&D projects.

For many firms, especially those that depend on innovation to stay in business, the key to continued competitiveness lies in their ability to develop and implement new products and processes. For these organizations, research and development (R&D) is an integral function within the strategic management framework. Even firms with excellent technical skills must work within the limits of available funding and resources. R&D project selection and funding decisions, then, are critical if the organization is to stay in business. While there are many mathematical decision-making approaches proposed for this decision, literature suggests that few are actually being used. Major criticisms of these techniques include their inability to consider strategic factors and their mathematical complexity [1], [9], [16]. In the current business environment of rapid change, R&D is an investment companies make in their future. Companies need tools that can help determine the best allocation of resources. This research paper discusses the application of the analytic network process (ANP), a multi attribute approach for decision making that allows for the transformation of qualitative values into quantitative values and performing analysis on them. The ANP is a relatively simple, sensitive approach that can be accepted by managers and other decision-makers. The model presented in this research paper is an understandable approach utilizing both quantitative and qualitative assessments affecting to the decision of which alternative should be followed. The decision model is capable of taking into consideration multiple dimensions of information into the analysis, a powerful and necessary characteristic for any strategic evaluation. The research paper first reviews the nature of the R&D project selection problem including its nature and needs. It discusses the various criteria on which the selection decision is made and how these criteria relate. After a brief review of ANP, a multi attribute selection framework represented as an ANP model is presented. A case example using data from an application of the model at a small high-tech company is presented. The ANP strategic decision-making tool assisted the company in reaching the decision to upgrade their current system versus investing in the development of a new system. The case study helps to verify that ANP is an effective and efficient decision-making tool. As a conclusion, the research paper discusses limitations and possible extensions to the model. The research paper concludes with a case study describing the implementation of this model at a small high-tech company, including data based on the actual use of the decision making model.

2.0.1 Proposed model and approach

Case Study

The model was developed and validated with the input of a small high-tech company named as **Pak Electron limited**. The company designs and manufactures digital electronics meter for electricity measurement. At the time of the model, the company was trying to decide between three development options to address the demand of the marketplace. The options were to develop digital electronics meter for electricity measurement, automatic meter reading, and prepaid digital meter. Due to funding and resource constraints, only one option could be pursued. Once a decision was made, the company was committed to pursuing that course of action.

The approach discussed in this research paper for the selection of R&D projects has been tested for the case of the electronics manufacturing industry in Pakistan. The marketing department sends the sales forecast for turned over product sales in the near future.

For a company considering a major expansion or upgrading of its product lines, the uncertainty and risk associated with the success of a R&D project creates the problem that the company may be helpless 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 surrounding all the attributes of an 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 research 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 proposed framework for R&D project selection is described 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 afterward maintained in accordance with the priority. Different levels of the hierarchy are illustrated in the following subsections.

2.0.2 Decision Model Development

The first step is to construct a model to be evaluated. This example uses the factors to develop a model that openly considers many of the R&D selection issues found in literature and practice. The model is summarized in Fig. 1. The relevant criteria and alternatives are structured in the form of a hierarchy. More "strategic" decisions are shown higher in the hierarchy. The topmost elements are decomposed into subcomponents and attributes. The model development requires the development of attributes at each level and a definition of their relationships. In this example, the only interdependence or feedback occurs between user & product) (actors & phases of project) market potential & marketing decision makers as shown by the two headed arrow. In this

case, the three actors of "*management, marketing, and technologist*" all may have some degree of interdependence with the three basic phases of research, "*basic, applied, and development*". The other single arrows indicate a one-way relationship. The topmost or overall goal is to pick the best project. We are seeking to determine which of several alternatives (shown at the bottom of the hierarchy) would best support the realization of this goal. Since we cannot directly assess the alternatives versus the goal, the intermediate levels of the hierarchy are developed.

3.1 Different phases of an 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 area of this level is to estimate the various decision criteria separately for different phases and to integrate the various preconceptions of the stakeholders. The basic activities of the three phases are illustrated as follows.

3.1.1 Basic phase.

In this phase, knowledge concerning the technology is collected. To get technical and marketing assistance in the future, the new product to be developed is associated with previous products. In this phase, different surveys are made and all the resources necessary for the research are collected. The research may concern some technology with the aim of improving an existing product or process or may be investigated with the possibility of leading to new products or processes. Often, the research is conducted simply for the sake of understanding a particular technology.

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 an 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 four factors, namely merit, risk, cost, 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 five 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 analyze the various market limits. These include potential market size, expected market share received after successful completion of the project, *relationship with user*, and the efforts of competitors in similar areas. Probability of market success of product; product life cycle; number and strength of competitors;

. Technical attributes. These attributes related to the project itself and the technology being investigated. Specific measures include: probability of technical success; existence of project champion; existence of required competence; availability of available resources (Resource); applicability to other products and processes; time to market.

. Environmental attributes. These attributes take into account various ambient factors. It includes government policies, economic regulations, social atmosphere, safety considerations, and environmental considerations.

3.2.2 Risk.

It is a rising 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.
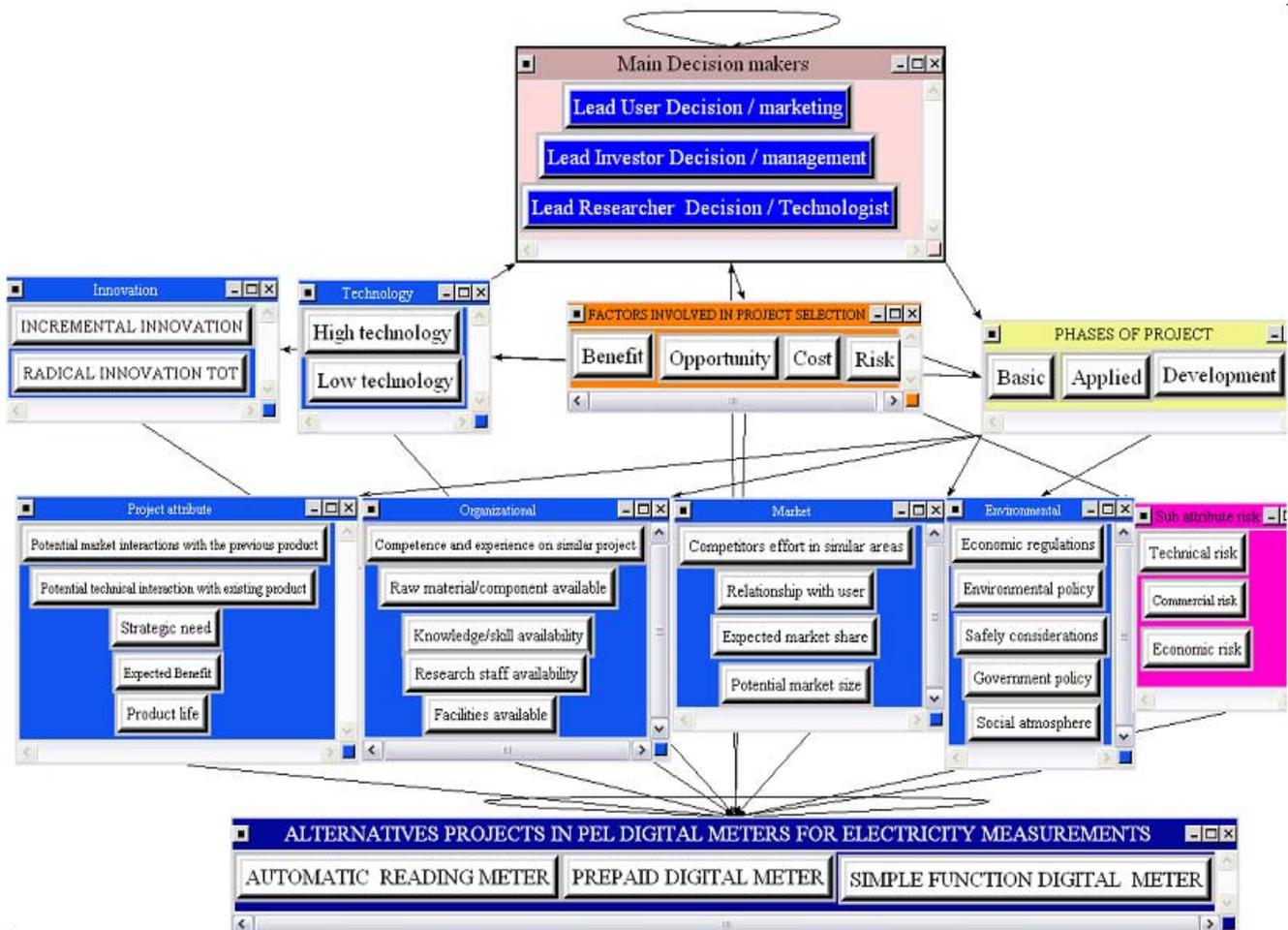

Figure 1. Analytic network framework showing the various attributes of project selection

. 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.

John H. Friar suggests that there are three major groups of appropriate variables for successful new product innovation and R&D projects:

• Nature of the innovation; • Nature of the market; • Nature of the technology.

3.2.3 NATURE OF THE INNOVATION

We will consider two levels of innovation—incremental and radical. An incremental innovation is one where the basic technology and product configuration remain essentially the same and only minor modifications are made to the performance, flexibility, appearance, and other characteristics. The incremental innovation is usually attempted in a well-established market. A radical innovation one where the technology is considerably different from the earlier product. In the case of radical innovation, the market may not exist at all. The product design in such cases may based solely on the creative natures of the designer understanding user needs through understanding with the user world.

The nature of the innovation has different effects on market and organization factors affecting the success of the new product or R&D project. In the case of a radical innovation it is much harder, if not impossible, to forecast and perform early analyses on customer needs, market size, market growth, and competition. Consequently, using formal market analysis is relatively less important. On the other hand, an incremental innovation requires a thorough market analysis of an existing market.

3.2.4 Nature of the Market

The nature of the market for a new product can be categorized into two types—existing and new. Whether a company is innovating in an existing market or trying to create a completely new market will cause differences in factors. In the former case, the new product meets an existing need but with some improvements, and therefore the market uncertainty is relatively low. The market analyses for the two types are completely different. Likewise, the quality of the information one can discover about the market and customers will differ so that the meaning of some factors will change.

3.2.5 NATURE OF THE TECHNOLOGY

Although classifying technology is hard, one useful classification is high tech versus low tech. The uncertainties in market and technology are different for the two groups. Link found differences in factors depending on whether the setting was high tech. In the high-tech field, the technology is developing very rapidly, and so new product introductions

come quickly. The applications and customers may not yet be determined if the technologies are still emerging.

3.2.6 Opportunities

Under Customer-related opportunities, we identified two clusters: Customer base and Marketing.

Customer base includes nodes: Grow into other countries using TOT transfer technology. By meeting (exceeding) customer business needs and requirements through technology, a firm has an opportunity to better retain its existing customers.

Marketing includes nodes: Agile, quick response to customer requirements and new features/functionality. New features/functionality in an application can be marketed and present another customer-based opportunity for the firm.
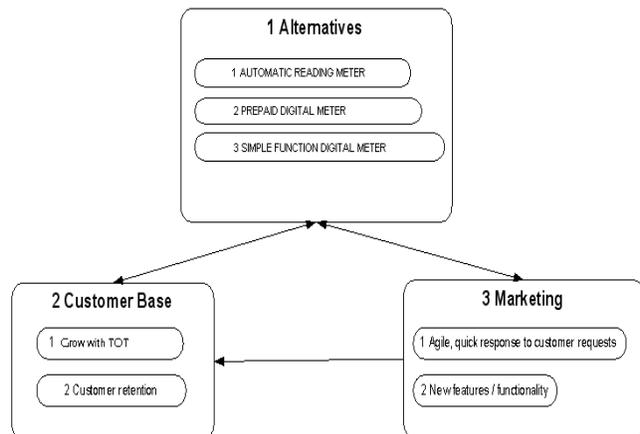

Figure B. Clusters with elements under Customer-related Opportunities

3.3 Costs

Under Economic costs, there are three clusters: Financial, Operational, and Resources These clusters include the following nodes.

Financial nodes: Assets, Personnel, and Legal. Assets refer to the cost of retaining IT infrastructure for things such as R&D equipments. A personnel refers to the retention of costs for things such as salaries, health insurance, pension benefits; Legal refers to the accumulation of costs associated with contract negotiations.

Operational nodes: Time to finish project/job, Use of project management, Knowledge transfer during requirements definition, Control/influence over human resources, and Fast time-to-market. In terms of cost, the first four items' cost increases with transfer technology. They are interrelated with or without transfer technology.

Resources nodes: Knowledge of latest technologies and availability. Without transfer technology, these two items become costs; resources with knowledge of the latest technologies may not be available quickly.
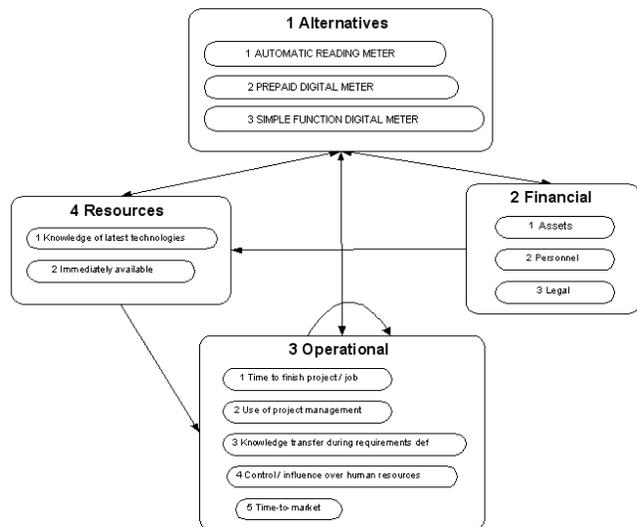
Figure A. Clusters with elements under Economic Costs

4.0. Pair wise Comparisons

Extracting favorite of various components and factors requires a series of pair wise comparisons where the decision maker will compare two components at a time with respect to an upper level "control" criterion. In the case study, the components of Phase of Research are "*basic, applied and development.*" In ANP, like AHP, pair wise comparisons of the elements in each level are conducted with respect to their relative importance toward their control criterion. Saaty [22] has suggested a scale of 1 to 9 when comparing two components, with a score of 1 representing indifference between the two components and 9 being overpowering authority of the component under consideration (row component in the matrix) over the comparison component (column component in the matrix). In our example, if a component has some level of weaker impact the range of scores will be from 1 to 1/9, where 1 represents indifference and 1/9 being an overpowering authority by a column element over the row element. When a judgment is assigned to a pair in the (i,j) position, the reciprocal value is automatically assigned in the (j,i) position.

Basic	Tech	Mktg	Org	eVector
Technical	1	2	6	0.23
Market	5	1	7	0.708
Organizational	0.167	0.143	1	0.062
				1

That is, if a_{ij} is a matrix value assigned to the relationship of component *i* to component *j,* then a_{ji} is equal to $1/a_{ij}$ (or $a_{ji} = 1$). Since many of these values are strategic, additional strategic group decision-making tools such as scenario planning or the Delphi approach can be utilized to assign meaningful values to these pair wise

comparisons. Once the pair wise comparisons are completed, the local priority vector W (defined as the eVector in the example figures) is computed as the unique solution to

$$Aw = \lambda_{\max} w \qquad (1)$$

Where $\lambda_{\max}$ is the largest Eigenvalue of the matrix A. Saaty provides several algorithms for approximating w. In this research paper, a two stage algorithm that involved forming a new $n \times n$ matrix by dividing each element in a column by the sum of the column elements and then summing the elements in each row of the resultant matrix and dividing by the n elements in the row. This is referred to as the process of averaging over normalized columns. This is represented as

$$w_i = \frac{\sum_{i=1}^{I} \left(\frac{a_{ij}}{\sum_{j=1}^{J} a_{ij}} \right)}{J} \qquad (2)$$

Where
Wi   weighted priority for component;
J   index number of columns (components);
I   index number of rows (components).

In the assessment process, inconsistencies may occur. For an explanation of inconsistency in a matrix of pair wise comparisons and how to calculate it, see Saaty[22].

TABLE II
BASIC STAGE OF RESEARCH PAIRWISE COMPARISON MATRIX FOR ACTORS AND EIGENVECTOR (RELATIVE IMPORTANCE/IMPACT WEIGHTS)

Basic	Mgt	Marketing	Tech	eVector
Management	1.000	0.143	0.125	0.054
Marketing	7.000	1.000	0.167	0.213
Technologist	8.000	6.000	1.000	0.734
				1.000

TABLE III
INITIAL SUPERMATRIX M COMPILED FROM MATRICES A AND B FOR STAGE OF RESEARCH AND ACTOR LINKAGES

	Basic	Applied	Develop	Mgt	Mrkt	Tech
Mgt	0.054	0.066	0.065	0	0	0
Mrkt	0.213	0.735	0.734	0	0	0
Tech	0.734	0.199	0.201	0	0	0
Basic	0	0	0	0.062	0.055	0.650
Applied	0	0	0	0.353	0.188	0.287
Develop	0	0	0	0.585	0.757	0.063

TABLE IV
SUPERMATRIX CONVERGENCE TO "LONG TERM" WEIGHTS AT M^{31}

	Basic	Applied	Develop	Mgt	Mrkt	Tech
Mgt	0.065	0.065	0.065	0	0	0
Mrkt	0.700	0.700	0.700	0	0	0
Tech	0.235	0.235	0.235	0	0	0
Basic	0	0	0	0.305	0.305	0.305
Applied	0	0	0	0.279	0.279	0.279
Develop	0	0	0	0.416	0.416	0.416

When one uses the simplified algorithm mentioned above to compute the priority vector there is no calculation of the inconsistency. An example of the pair wise comparison matrix within the *Basic* stage of research is shown in Table I. The weightings are obtained from the decision maker by asking a

series of comparison questions. For this matrix in Table I, the decision maker was asked questions such as: "During the *Basic* stage of research, which element is more important: Technical or Marketing?"

Marketing is considered to be 5 times more important than technical and a judgment of 5 is entered in the cell at the intersection of the Marketing row and Tech column. Technical is the row component and Marketing is the column component. The reciprocal judgment of 0.200 (1/5) is entered in the (Tech, Marketing) cell. The pair wise comparison approach is used to populate the matrix with the diagonal elements being 1, that is, an element is equally preferred to itself. The priorities for this matrix are shown as the last column in Table I (labeled eVector). In this stage of research, the Marketing category received the highest rating (0.708). In this company, even at early stages of research, marketing factors are the most important in determining whether a project proceeds or not (probably not an unusual or unreasonable situation).

4.2. Analyze Measures

In this illustration, no interdependence between the actors and the measures is assumed to exist. Similar pair wise comparisons to those made earlier are conducted for the measures relative to the actor to determine their relative importance weight calculation (or eigenvector determination). There are three separate pair wise comparison matrices (technical, market, and organizational) that have to be developed for this step in the analysis. Table V shows one of those matrices. In this case, the performance of the alternatives on each of the technical metrics is established through pair wise comparing the alternatives against each other with respect to that metric, for example "Potential market size" as shown in the figure below. The resulting vector shows the priorities of the alternatives on that metric. The alternative with the largest priority is perceived to be best on the metric. The synthesis of the results across all the metrics gives the best overall alternative. For the company in question, all of the metrics with the exception of the presence of a project champion were found to be fairly close to each other in importance. The lack of significance for the Project Champion can probably be attributed to the small size of the company.

Observation and Results
5.1 Synthesis - Getting the Results

The results for the alternatives are obtained with the Synthesis command in the Main Model View. Select the Computations/Synthesize command, or click the shortcut icon

 to see the final results:

5.2 RESULTS FROM THE SYNTHESIS COMMAND

The *Normal* column presents the results in the form of priorities. This is the usual way to report on results. The *Ideals* column is obtained from the *Normal* column by dividing each of its entries by the largest value in the column. The *Raw* column is read directly from the Limit Super matrix. In a hierarchical model such as this one the *Raw* column and the *Normal* column are the same.

5.3 OBSERVATION

These results show that the Automatic meter reading the best choice for this decision maker. The "Ideal" column shows the results divided by the largest value so that the best choice has a priority of 1.0. The others are in the same proportion as in "Normal" and are interpreted this way: The Automatic is best (1.000), the Prepaid is 73.7 % as good, and the Simple is 67.8% as good.

6 Conclusions

The purpose of this research paper was to present a method for R&D project selection that allows for the consideration of important interactions among decision levels and criteria. The methodology uses the ANP for this evaluation. A model of the R&D project selection process developed from literature and adapted for a small high-tech company was presented. The company acted as a case study for validation of the model and approach. The research paper provides value to practitioners by providing a standard model for project selection and to researchers by demonstrating a new application of ANP. This strategic decision making tool assisted the company in comparing the R&D question of upgrading their current system by designing simple function meter or investing in the development of a new system as form of prepaid and automatic meter reading. The model suggested the development of Automatic reading meter, which is the option that the company pursued. The case study helps to verify that ANP is an effective and efficient decision-making tool. In fact, this is one of the strengths of AHP and ANP: the ability to adapt a basic framework to a particular situation. A decision criterion that a company considers crucial can easily be added to the generic model. In addition, the weighting given each component in the model is dependent on the decision maker(s) evaluating the component. For example, an project stressing competitive advantage through innovation would likely end up with criteria and weighting different from an enterprise seeking to compete as a low cost provider of

proven technology. Despite a number of publications applying AHP in project selection, this is probably the first time that an attempt has been made to apply ANP in project selection.

This research 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 extracting the preferences of decision makers. 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 research paper presents an application of the proposed framework to a real project selection system. In conclusion, this model provides a qualitative and quantitative assessment of the attributes of a project surrounding the nonlinear relationships among interdependent levels. *A major contribution of this work is to provide a methodology for assessing the best project. Also author introduce first time innovation factor in the ANP model.* The company and decision-maker involved in the case study were generally pleased with the approach.

After pair-wise comparisons of the alternatives and ratings comparisons of the merits, our model shows that Alternative #1: "Auto matic reading meter," is the best choice. The main driver for this result is the financial benefits. Using background research and personal interviews to describe this model and compare and rate its nodes, we are not surprised by this outcome.

Table 'A' overall Outcome

Alternative Rankings

Graphic	Alternatives	Total	Normal	Ideal	Ranking
	AUTOMATIC READING METER	0.1497	0.4152	1.0000	1
	PREPAID DIGITAL METER	0.1091	0.3026	0.7288	2
	SIMPLE FUNCTION DIGITAL METER	0.1018	0.2822	0.6798	3

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