Fuzzy Analytic Network Process in Evaluating Government-Sponsored Technology R&D Projects

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Abstract

Technology is viewed as one of the major factors determining the competitiveness position of an industry. For the sake of technology competitiveness; however, countries need to encourage private firms to develop technology R&D projects. How to select proper R&D projects to be supported for governments is very important policy. In this study we propose a hierarchical dependence structure for ITDP project selection in Taiwan, and describe how to obtain judgments from the review committee by fuzzy analytic network process. We then discuss the validation process about the fuzzy ANP on ITDP project selection.

Keyword: technology project, fuzzy analytic network process

Introduction

Technology is viewed as one of the major factors determining the competitiveness position of an industry. Private firms may not pursue technology research and development (R & D) projects because (1) R&D scientific and technical frontiers are risky and the chances of failure are high; (2) an individual firm may not have the capabilities required to develop the technology; and (3) private incentives may not be sufficient to induce a firm to undertake the project in the face of difficulties in appropriating the resulting benefits (Feldman & Kelley, 2003a). In many countries, government-sponsored R&D programs prove to be a useful strategy to encourage private firms to undertake R&D projects (NRC, 1996). For example, American government has advocated the Advanced Technology Program (ATP) since 1990 to encourage industry to develop technology R&D projects. ATP has approved 134 R&D projects and totally funds committed are up to US$331 million from 2002 to 2004 (http://www.atp.nist.gov/eao/current.htm, 2004). Korea, Japan, China, and, and many other OECD countries all have launched similar advanced technology programs to encourage private firms to develop core technologies and to secure leading-edge technologies.

Taiwan has similar government-sponsored technology development program (TDP) since 1979, such as Industrial Technology Development Program (ITDP), Small Business Innovation Program (SBIR), etc. In 2003, the TDP budget was NT$17.19 billion, increased by NT$1.33 billion comparing with NT$15.86 billion in 2002, the growth rate was 8.3%. The research budget of TDP is steadily increased by the year (http://doit.moea.gov.tw/newenglish/03_Achievements/exp.asp, 2004). From 2001 to 2004, TDP's actual expenditure was increased from NT$15.17 billion to NT$18.22 billion; manpower devoted to the corporation TDP was increased from 5,561.2 person/year in 1999 to 6,644.9 person/year in 2003. Moreover, TDP has produced 797 patents, 450 patent applications, 1,061 technology transfers, 2,190 technical papers, 622 subcontracted research projects, and 1,595 contracts and industrial services in 2003. With respect to the benefits from applications of R&D results on the industrial sectors, TDP also produced 618 enterprise investments (http://doit.moea.gov.tw/newenglish/03_Achievements/PerfBene.asp,2004).

As governments strive to become more efficient and reduce the cost of services in order to remain competitive, the choice of government-sponsored TDP projects becomes increasingly important (Baltes, Dickson, Sherman, Bauer, & LaGanke, 2002; Hsu, Tzeng & Shyu, 2003; Kelly & Kaarau, 1999; Lahdalma & Salminen, 2001; Meade & Presley, 2002). Due to the funding scale and complexity of technology, the selection of TDP projects can be viewed as a multiple attribute decision that is normally made by a review committee with experts from academia, industry, and government. One crucial problem in multiple attribute decision making is to assess relative importance or weights of different decision criteria within and among decision makers (Ma, Fan, & Huang, 1999). However, these experts who are obviously characterized by diverse states of knowledge often enter the group setting with different assumptions, viewpoints, and interpretations of the issues involved (Mohammed & Ringseis, 2001) and select proposed TDP projects based on evaluation criteria that are not clearly defined. Therefore, the review committee tends to select projects in a consensus way with compromise. An effective mechanism to resolve this kind of cognitive conflict is necessary.

Studies on R & D portfolio selection had been published, and a wide variety of factors related to expert judgment had been identified (Astebro, 2004; Balachandra & Friar, 1997; Baker, Green, & Bean, 1986; Brad & Feinberg, 1989; Cooper, 1981; Horesh & Raz, 1982; Coldrick, Lawson, Ivey, & Lockwood, 2002; Lee & Om, 1996; Lilien & Yoon, 1989; Linton, Walsh, & Morabito, 2002; Madey & Dean, 1985; Meade & Presley, 2002; Ozer, 1999; Santhanam & Kyparisis, 1995; Stewart & Mohamed, 2002; Liberatore, 1987; Liberatore & Titus, 1983; Souder, 1973; Yap & Sounder, 1994; Zacharakis & Meyer, 2000; Zopounidis, 1994)

Subsequently, Perrone (1994) used fuzzy multiple criteria decision model (fuzzy MCDM) to evaluate advanced manufacturing system. Thus, that fuzzy idea incorporated with multiple criteria decision model is suitable for evaluate alternatives. Afterwards, Coffin & Taylor (1996) first presented multiple criteria R&D project selection using fuzzy logic and then a few pioneering studies, e.g., Chan, Chan, & Tang (2000), Perego & Rangone (1998), Prabhu & Vizayakumar (2001), and Hsu, Tseng, & Shyu (2003), formulated theoretical frameworks based on fuzzy multiple criteria method1 to analyze technology selection. In this paper we synthesize previous research findings and propose a theoretical approach, which is based on a fuzzy version of analytical network process (FANP) to government-sponsored R & D project selection.

The outline of the paper will be as follows. We first address a brief description for the decision process of ITDP project selection in Taiwan. Besides that, we introduce background of R & D portfolio selection. Afterwards, we discuss fuzzy set theory and its role in decision-making, which is followed by a brief summary of analytic network process and fuzzy-ANP. Moreover, we propose a hierarchical dependence structure for ITDP project evaluation, and describe how to obtain subjective judgments from the review committee. We then discuss the validation process about the fuzzy ANP on ITDP project selection.

ITDP Project Selection in Taiwan

Industrial Technology Development Program (ITDP), the emphasis of our research, is one of the major technology development programs in Taiwan. The aim of ITDP is to encourage industries to take part in innovative technologies, key technologies and components, and applied research. ITDP supports industrial R & D projects in four main areas: telecommunication

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[1] There was considerable empirical support for fuzzy multiple criteria methods, and researchers have suggested various ways to broaden their applicability (Buckley, Feuring, & Hayahsi, 2001; Chang, 1996; Chen, 2000; Csutora & Buckley, 2001; Deng, 1999; Kwong & Bai, 2002, 2003; Mikhailov, 2003; Zhu, Jing, & Chang, 1999).

& electronics, mechanical engineering & aeronautics, materials & chemical engineering, and biotechnology & pharmaceutical. According to the official data, 588 applications have been filed, and 259 (44%) of them have been approved since 1999. Table 1 shows ITDP investments from 1999 to 2004. Among the 259 sponsored projects, material and chemical engineering kind of projects (38%) and machinery and aerospace kind of projects (38%)account for the largest pool. From 1997 to 2004, ITDP's actual expenditure was increased from NT$2.85 billion to NT$29 billion. Moreover, ITDP has 236 patent granted, 472 patent applied, 1,786 technical reports, 201 technical conferences, NT$634.35 millions for technology introduction and NT$ 761.47 millions for industry academia & research cooperation (http://doit.moea.gov.tw/newenglish/03_Achievements/PerfBene.asp , 2004).

According to Department of Industrial Technology (DOIT), there are 38 experts in ITDP technical advisory committee. The committee includes 7 directors from 4 public research institutes and 31 professors from 11 universities. ITDP project evaluation involves two steps. Experts, including 3 to 5 experts, with domain knowledge in each project arena will first review such as the technical feasibility and the expected returns of ITDP applications independently and score projects, according to decision criteria by DOIT. Technical uncertainties, market risks, and lack of hard data are the reasons why evaluation usually proceeds subjectively and intuitively. The approval/disapproval decision will then be made by overall 38 experts from all four areas in the technical advisory committee meeting aggregately. Since the committee involves experts from various domains, divergent judgments must be taken into account. Thus, the committee, according to decision criteria by DOIT for project selection, tends to review e projects again by experts from all four areas in the technical advisory committee and make decisions in a consensus way with certain degree of compromises.

Table 1 ITDP investment (1999/02-2004/12)

Project areas	No. of projects	Percentage of subsidized cases	Government subsidy	Company R & D expenditure
telecommunication & electronics	117	36%	38.92	106.49
mechanical engineering & aeronautics	47	38%	16.56	49.83
materials & chemical engineering	60	38%	11.42	37.85
biotechnology & pharmaceutical	35	36%	6.98	18.85
Total	259	37%	73.88	213.02

R&D Project selection

Many R&D project selection models and techniques, ranging from complicated quantitative research methods to unstructured peer review, have been proposed in academic studies. They cover overviews on the topic of R&D project selection and are discussed in Baker (1974), Baker & Freeland (1975), Baker & Pound (1964), Danila (1989), Hall & Nauda (1988), Henriksen & Traynor (1999), Liberatore & Titus (1983), Linton, Walsh, & Morabito (2000), Martino (1995), Oral, Kettani, & Lang (1991), Schmidt & Freeland (1992) and Souder & Mandakovic (1986).

R&D project selection methods can be placed into one of the following categories: (1) unstructured peer review and scoring; (2) mathematical programming and portfolio optimization, including integer programming, linear programming, nonlinear programming, goal programming and dynamic programming; (3) economic models, such as internal rate of return, net present value, return on investment, cost-benefit analysis and option pricing theory; (4) decision analysis, including multiattribute utility theory, decision trees, risk analysis, and the analytic hierarchy process; (5) interactive methods, such as Delphi, Q-sort, behavioral decision aids, and decentralized hierarchical modeling and (6) artificial intelligence, including expert systems and fuzzy sets (Henriksen & Traynor, 1999). However, Meade & Presley (2002) indicated that even with the number of proposed models, the R&D selection problem remains problematic and few models have gained wide acceptance. It appears that the trend in applying selection models is to move towards a composite approach of using a number of selection models (Coldrick, Lawson, Ivey, & Lockhood, 2002).

Normally, the decision of government sponsored R&D project is made in multi-criteria environment. Hsu, Tzeng, & Shyu (2004) noted that government sponsored R&D project differs from that of the private sector in two major aspects: (1) government sponsored R&D is by nature a strategic and long term investment and (2) political factors and interest parties always influence the allocation of R&D resources in the public sector. In addition, limitations of existing R&D project selection models are: (1) inadequate treatment of multiple, often interrelated, evaluation criteria; (2) inability to handle non-monetary aspects and inadequate treatment of interrelationships among projects; (3) no explicit recognition and incorporation of the experience and knowledge of the R&D managers; and (4) perceptions by R&D managers that the models are difficult to understand and use (Chien, 2002). Many real-world problems have an interdependent property among the criteria or candidate projects (Saaty, 1996). Meade & Presley (2002) indicated ANP is a potentially valuable method to support the selection of projects in a research and development (R&D) environment. Therefore, the fuzzy analytical network process (fuzzy ANP) is suitable for selection of government subsidized R&D project because fuzzy ANP allows for more complex interrelationships among the decision levels and components in multi-criteria and ambiguity environment.

The Theoretical Framework: Fuzzy Analytic Network Process

Essences of Fuzzy ANP

Saaty (1980) proposed the Analytic Hierarchy Process (AHP) to model complex decision situations. AHP assumes independent hierarchical relationship among decision levels. However, there is more complex interrelationship among the criteria or projects in many real-world decision problems. Saaty & Takizawa (1986) incorporated the dependence and feedback with AHP to handle dependence and independence in AHP. Saaty (1996) proposed Analytic Network Process (ANP) to deal interrelationship among decision levels. The ANP is a mathematical theory that allows decision makers to deal systematically with dependence and feedback. Azis (2003) indicated it is almost a counterpart of influence diagrams in statistical decision analysis based on Bayes theorm. Thus, AHP is a special case of ANP. The ANP has had a handful of applications in literatures (Azhar & Leubg, 1993; Azis, 2003; Hamalainen & Seppalainen, 1986; Lee & Kim, 2000, 2001; Meade & Presley, 2002; Meade & Sarkis, 1999; Partovi, 2001; Partovi & Corredoira, 2002; Sarkis, 2003; Sarkis, Nehman, & Priest, 1996; Shang, Tjader, & Ding, 2004; Tran, Knight, O'neill, & Smith, 2004).

The ANP also utilizes ratio scale measurements based on pairwise comparisons. Unlike a hierarchy, a network spreads out in all directions and its clusters of elements are not arranged in a particular order. In addition, a network allows influence to be transmitted from a cluster to another one (outer dependence) and back either directly from the second cluster or by transiting through intermediate clusters along a path which sometimes can return to the original cluster forming a cycle (Saaty, 1996). ANP allows interdependence within a cluster combined with feedback between clusters (inner dependence). As noted in figure 1, a directed link appears from cluster C4 to the other clusters (C2 and C3). This is so called outer dependence. In other cases, the clusters (C3 and C1) are linked to themselves and a loop link appears. This is so called inner dependence.

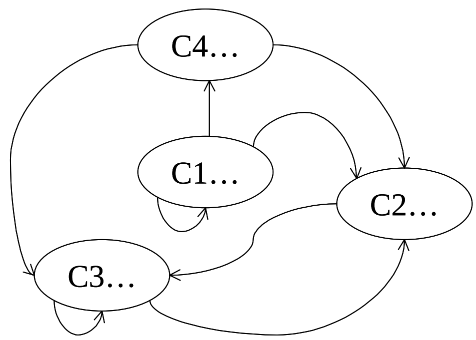

Figure 1 Feedback Network

Decision makers need to construct the network of the decision problem and all of the interrelationships among the elements should be considered. When the elements of a cluster X depend on another cluster Y, we can represent this relation with an arrow from cluster Y to X. All of these relations are evaluated by pairwise comparisons and a supermatrix is obtained by these priority vectors. The supermatrix is raised to power 2k+1 to compute the overall priorities. The ANP analysis through main steps will be reviewed (Sarkis, Nehman, & Priest, 1996): (1) Model construction and problem structuring; (2) Pairwise comparisons matrices of independent component levels; (3) Supermatrix formation; (4) Raising supermatrix to the power 2k+1 to allow convergence of interdependent relationships; (5) Selection of best alternative. When there is only inner dependence within cluster in a network like ITDP model such as figure 2, we can use the approach of Saaty & Takizawa (1986) to deal with dependence of the elements of cluster. The supermatrix for figure 2 as like equation 1. The main steps of approach in Saaty & Takizawa (1986) can be summarized as follows: (1) Model construction and problem structuring; (2) Determine the priorities of the C1, computing w1; (3) Determine the priorities of the C2, computing w2; (4) Determine the inner dependence matrix of C1, computing w3; (5) Determine the inner dependence matrix of C2, computing w4; (6) Determine the dependent priorities of the C1, computing wc1 by wc1= w1* w3; (7) Determine the dependent priorities of the C2, computing wc2 by wc2= w2* w4; (8) Determine overall priorities of the C2, computing wANP by wANP= wc1* wc2.

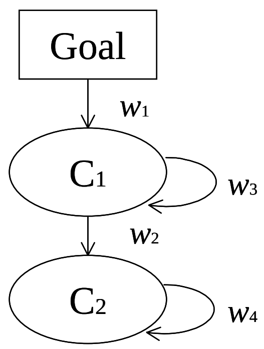

Figure 2 Network with inner dependence

However, the ANP still cannot reflect the human thinking style. In ITDP selection, due to availability and uncertainty of information, evaluator is hard to obtain the precise data for making judgment. Evaluators may tend to make subjective or intuitive judgments based on their knowledge or experience. In general, linguistic variables such as “very important”, “important, or “very unimportant” are used to convey ITDP evaluator’s assessment.

Fuzzy Set Theory

Zadeh (1975) think the approximate reasoning of fuzzy set theory can properly represent linguistic terms. The fuzzy set theory is better approach to convert linguistic variables to fuzzy numbers under ambiguous assessment. Fuzzy set theory resembles human reasoning in its use of approximate information and certainty to generate decisions (Kahraman, Cebeci, & Ruan, 2004). By incorporating fuzzy set theory with ANP, fuzzy analytical network process (fuzzy ANP) allows a more accurate description of the decision-making process. However, a few studies of fuzzy ANP can be found in Buyukozkan, Ertay, Kahraman, & Ruan (2004) and Mikhailov & Singh (2003). The applications of ANP in project selection (Lee & Kim, 2000, 2001; Meade & Presley, 2002; Shang, Tjader, & Ding, 2004) can lend credibility to the ITDP model being proposed. Thus, the application of fuzzy ANP proposed in this study represents a relatively new approach to R&D project selection not currently presented in literatures.

A fuzzy number is a special fuzzy set $F = \{(x, \mu_f(x), x \in R\}$, $R: -\infty < x < \infty$, and its membership function $\mu_f(x)$: R [0, 1], where x represents the ITDP projects. A trapezoidal fuzzy number denoted as $\tilde{M} = (a,b,c,d)$, where $a \le b \le c \le d$, has the following trapezoidal-type membership function 1 and figure 3.

(1)

$$\mu_{\tilde{M}}(x) = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \le x \le b \\ 1 & b < x \le c \\ \frac{d-x}{d-c} & c < x \le d \\ 0 & d < x \end{cases}$$

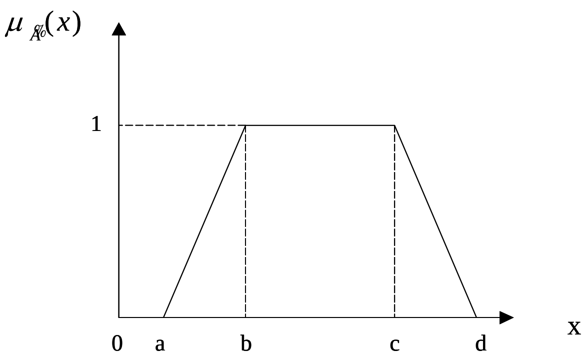

Figure 3: The trapezoidal-type membership function

When $b = c$, the triangular fuzzy number (TFN) denoted as $\tilde{M} = (a,b,d)$ where $a \le b \le d$, has the triangular-type membership function. By defining the interval of confidence level α, the triangular fuzzy number can be described as:

$$\forall \alpha \in [0,1]$$

$$\tilde{M}_\alpha = \left[a^\alpha, d^\alpha\right] = \left[(b-a)\alpha + a, -(d-b)\alpha + d\right]$$

Generally, triangular fuzzy numbers, $\tilde{1}$ to $\tilde{9}$, are used to show subjective pair-wise comparisons of experts in order to capture the vagueness. By using triangular fuzzy numbers, via pairwise comparison, the fuzzy judgment matrix is constructed.

Fuzzy AHP with index of optimism

As noted previously, ITDP model includes inner dependence like figure 2. We need to calculate individual matrix based on components. Pairwise comparison matrices with linguistic data are required. We can use fuzzy AHP approach to obtain priorities of components such as w1, w2, w3 and w4. There are many fuzzy AHP approaches in the literatures and we will utilize Fuzzy AHP with index of optimism (Chen, 1996; Cheng, 1996; Cheng & Mon, 1994; Kwong & Bai, 2002; Lee, 1995; Mon, Chen, & Lin, 1994) because this approach can combine with degree of optimism from decision maker to simulate changes of criteria weighting. The computational procedure of this approach is employed as follows.

Step1: Scaling the relative strength of the criteria and alternatives: According to Saaty's hierarchical analysis, an evaluator needs to compute the weights for each positive reciprocal matrix and then these weights will be combined to obtain the final set of weights for alternatives. Pedrycz (1994) expressed that triangular function is the easiest way to approach the convex function and simplest to explain. Thus, triangular fuzzy number $\tilde{1}$ to $\tilde{9}$ will be employed to indicate the relative strength of the criteria and alternatives in the expert subjective pairwise comparison in same hierarchy.

Step2: Computing the fuzzy judgment matrix: Assume that there are K criteria $C_{1,}C_{2,\ldots}C_K$ with a fuzzy judgment matrix $\tilde{A}_k$ for each C_k, $1 \le k \le K$. Besides that, the evaluator needs to give pairwise comparisons of the criteria to produce a fuzzy judgment matrix $\tilde{E}$. The fuzzy judgment matrix $\tilde{A}_k$ ($\tilde{a}_{ij}$) and $\tilde{E}$($\tilde{e}_{ij}$) are computed by employing triangular fuzzy number via pairwise comparison as noted below.

$$\tilde{A}_k = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1(n-1)} & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2(n-1)} & \tilde{a}_{2n} \\ \vdots & \vdots & & \vdots & \vdots \\ \tilde{a}_{(n-1)1} & \tilde{a}_{(n-1)1} & \cdots & 1 & \tilde{a}_{(n-1)n} \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & \tilde{a}_{n(n-1)} & 1 \end{pmatrix}$$

where $i = j$, $a_{ij} = 1$; where $i \neq j$, $a_{ij} = \tilde{1} \sim \tilde{9}$, $\tilde{9}^{-1} \sim \tilde{1}^{-1}$

$$\tilde{E} = \begin{pmatrix} 1 & \tilde{e}_{12} & \cdots & \tilde{e}_{1(n-1)} & \tilde{e}_{1n} \\ \tilde{e}_{21} & 1 & \cdots & \tilde{e}_{2(n-1)} & \tilde{e}_{2n} \\ \vdots & \vdots & & \vdots & \vdots \\ \tilde{e}_{(n-1)1} & \tilde{e}_{(n-1)1} & \cdots & 1 & \tilde{e}_{(n-1)n} \\ e_{n1} & e_{n2} & \cdots & \tilde{e}_{n(n-1)} & 1 \end{pmatrix}$$

where $i = j$, $e_{ij} = 1$; where $i \neq j$, $e_{ij} = \tilde{1} \sim \tilde{9}$, $\tilde{9}^{-1} \sim \tilde{1}^{-1}$

According to Buckley (1985), assume that multiple evaluators are called $J_{1,\ldots,}J_n$. Each evaluator J_l gives a fuzzy judgment matrix $\tilde{A}_{kl}$ for each criteria C_k and supplies a fuzzy judgment matrix $\tilde{E}_l$ between the criteria. Let $\tilde{A}_{kl} = \left[\tilde{a}_{ij}^{kl}\right]$ and $\tilde{E}_l = \left[\tilde{e}_{ij}^{l}\right]$. The average fuzzy judgment matrix $\tilde{A}_k = \left[\tilde{a}_{ij}^{k}\right]$ and $\tilde{E} = \left[\tilde{e}_{ij}\right]$ are computed as follows: $\tilde{a}_{ij}^{k} = \left(\tilde{a}_{ij}^{k1} \Theta \ldots \Theta \tilde{a}_{ij}^{kn}\right)^{1/n}$ and $\tilde{e}_{ij} = \left(\tilde{e}_{ij}^{1} \Theta \ldots \Theta \tilde{e}_{ij}^{n}\right)^{1/n}$.

Step3: Estimating the degree of satisfaction for $\tilde{A}$ *and* $\tilde{E}$. In this study, we can compute the degree of satisfaction from evaluator by the index of optimism μ. The larger the index μ, the higher the degree of optimism. According to Lee (1995), the index of optimism is a linear convex combination as noted below equation 2 and equation 3.

$$\hat{\tilde{a}}_{ij}^{\alpha} = \mu a^{\alpha}_{iju} + (1-\mu) a^{\alpha}_{ijl}, \forall \mu \in [0,1]$$

(2)

$$\hat{\tilde{e}}_{ij}^{\alpha} = \mu e^{\alpha}_{iju} + (1-\mu) e^{\alpha}_{ijl}, \forall \mu \in [0,1]$$

(3)

While α is fixed, we set the index of optimism μ in order to estimate the degree of satisfaction and then we can present the following matrix $\hat{\tilde{A}}$ and $\hat{\tilde{E}}$ that is a crisp judgment matrix.

$$\tilde{A}^{\alpha} = \begin{pmatrix} 1 & \tilde{a}^{\alpha}_{12} & \cdots & \tilde{a}^{\alpha}_{1(n-1)} & a^{\alpha}{}_{1n} \\ \tilde{a}^{\alpha}_{21} & 1 & \cdots & \tilde{a}^{\alpha}_{2(n-1)} & a^{\alpha}{}_{2n} \\ \vdots & \vdots & & \vdots & \vdots \\ \tilde{a}^{\alpha}_{(n-1)1} & \tilde{a}^{\alpha}_{(n-1)1} & \cdots & 1 & \tilde{a}^{\alpha}_{(n-1)n} \\ a^{\alpha}{}_{n1} & a^{\alpha}{}_{n2} & \cdots & \tilde{a}^{\alpha}_{n(n-1)} & 1 \end{pmatrix}$$

$$\tilde{E}^{\alpha} = \begin{pmatrix} 1 & \tilde{e}^{\alpha}_{12} & \cdots & \tilde{e}^{\alpha}_{1(n-1)} & e^{\alpha}{}_{1n} \\ \tilde{e}^{\alpha}_{21} & 1 & \cdots & \tilde{e}^{\alpha}_{2(n-1)} & \tilde{e}^{\alpha}_{2n} \\ \vdots & \vdots & & \vdots & \vdots \\ \tilde{e}^{\alpha}_{(n-1)1} & \tilde{e}^{\alpha}_{(n-1)1} & \cdots & 1 & \tilde{e}^{\alpha}_{(n-1)n} \\ \tilde{e}^{\alpha}_{n1} & \tilde{e}^{\alpha}_{n2} & \cdots & \tilde{a}^{\alpha}_{n(n-1)} & 1 \end{pmatrix}$$

Step4: Solving fuzzy eigenvalue. A fuzzy eigenvalue λ is a fuzzy number solution to equation4.

$$\tilde{A}^{\alpha}\tilde{x}^{\alpha} = \tilde{\lambda}\tilde{x}^{\alpha}$$

(4)

where $\tilde{A}$ is a n-by-n fuzzy matrix containing fuzzy number $\tilde{a}_{ij}$ and $\tilde{x}$ is a non-zero n-by-1 fuzzy eigenvector containing the fuzzy numbers $\tilde{x}_i$. Then, fuzzy multiplication and addition are performed by using interval arithmetic and α -cuts. Equation 4 is equal to equation 5.

$$[a^{\alpha}{}_{i1l}x_{1l}{}^{\alpha}, a^{\alpha}{}_{i1u}x_{1u}{}^{\alpha}] \oplus \cdots \oplus [a^{\alpha}{}_{inl}x_{nl}{}^{\alpha}, a^{\alpha}{}_{inu}x_{nu}{}^{\alpha}] = [\lambda x_{il}{}^{\alpha}, \lambda x_{iu}{}^{\alpha}]$$

(5)

where

$$\tilde{A}^{\alpha} = [\tilde{a}_{ij}^{\alpha}], \tilde{x}^{\alpha} = (\tilde{x}_1^{\alpha}, \cdots, \tilde{x}_n^{\alpha}),$$

$$a^{\alpha}{}_{ij} = [a^{\alpha}{}_{ijl}, a^{\alpha}{}_{iju}], \tilde{x}_j^{\alpha} = [x_{il}{}^{\alpha}, x_{iu}{}^{\alpha}], \lambda_l{}^{\alpha} = [\lambda_l{}^{\alpha}, \lambda_u{}^{\alpha}]$$

(6)

for $0 < \alpha \le 1$ *and all i, j, where i =1,2,…n, j =1,2…n*

Step5: Determining the weights for criteria and alternatives. The evaluator computes fuzzy weights $\tilde{w}_k = \left(\tilde{w}_{1k,\ldots,}\tilde{w}_{nk}\right)$ for each $\tilde{A}_k^{\alpha}$ and fuzzy weights $\tilde{e}^{\alpha} = \left(\tilde{e}_{1,\ldots,}\tilde{e}_K\right)$ for $\tilde{E}^{\alpha}$. The eigenvector is computed by fixing the μ value and estimating the maximal eigenvalue.

Step6: Ranking the alternatives. The fuzzy AHP is to rank the alternatives across all the criteria. After synthesizing the priorities over all hierarchy, we can obtain the final fuzzy weights for alternative A_j by varying α value. The final alternative ranking is given by the vector $r^T = \left(r_{1,\ldots,}r_n\right)$

where: $r_j = \sum_{k=1}^{K} w_{jk}e_k$

Proposed ITDP Selection Model

The ITDP selection model in Taiwan is proposed in this study. We first propose over 30 criteria[2] for R&D project selection based on R&D studies and technology R&D selection criteria from DOIT to describe the network system of ITDP selection. The ITDP project selection model is then constructed as figure 4.

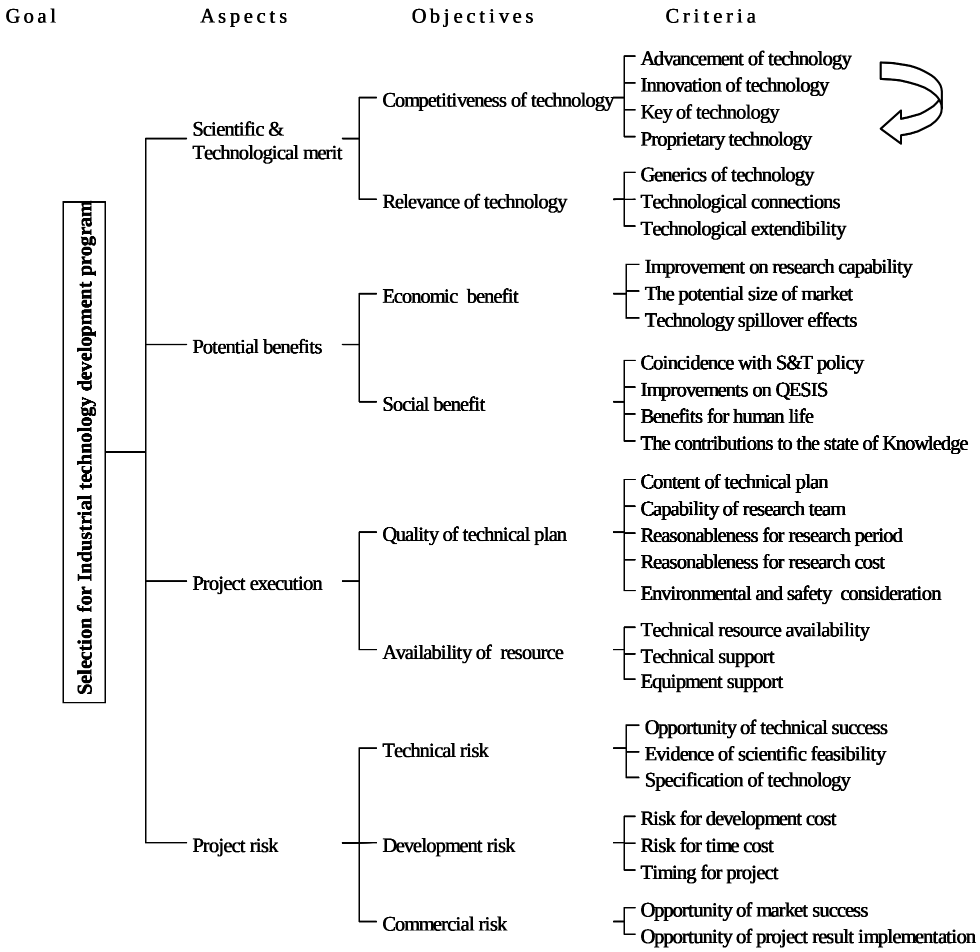

Figure 4: The ITDP selection model

As figure 4 noted, there are four aspects of goal including scientific & technological merit, potential benefits, project execution and project risk.

1. Scientific & technological merit: to judge whether technology is worthy to develop, including the technological competitiveness and the relevance of technology.

2. Potential benefits: Except business themselves benefits, whole nation can gain benefits after ITDP is realized, including economic benefit and social benefit.

3. Project execution: to judge whether ITDP can be executed and implemented, including quality of technical plan and availability of resource.

4. Project risk: to judge what risk can be identified, including technical risk, development

[2] Al-Mazidi & Ghosn, 1997; ATP, 2004; Balachandra & Friar, 1997; Ballesteros & Rico, 2001; Coldrick, Lawson, Ivey, & Lockwood, 2002; David, Toole, & Hall, 2000; Department of Industrial Technology, 2004b; Feldman & Kelley, 2003a, 2003b; Gaber, Rabelo, & Hosny, 1992; Hsu, Tzeng, & Shyu, 2003; Kondo, 2004; Kutlaca, 1997; Lee & Om, 1996; Meade & Presley, 2002; Mustafa, 1991; NSC, 2004; Pandey & Jang, 1996; Stanley, 2004; Stewart & Mohamed, 2002; Santhanam & Kyparisis, 1995; Yapp, 2004.

risk, and commercial risk.

We will invite 25 reviews from ITDP's four advisory committees, including telecommunication & electro-optical, biological science & technology & medication, mechanical engineering, aeronautics & astronautics and materials & chemical engineering, to evaluate the proposed ITDP model. These reviews will be asked to respond to a questionnaire by pairwise comparing the relative importance of criteria. Moreover, we use the triangular fuzzy function to convert subjective judgments of reviewers to be fuzzy judgments. Therefore, we will synthesize the priorities over all levels and overall importance weights of reviews are determined.

Reference

1. Advanced Technology Program. http://www.atp.nist.gov/eao/current.htm; 2004.
2. Astebro T. Key success factors for technological entrepreneurs' R&D projects. IEEE Transactions on Engineering Management 2004; 51(3): 314-3211.
3. Azhar TM, Leubg LC. A multi-attributes life cycle approach to replacements decisions: An application of Saaty's system with feedback method. The Engineering Economist 1993, 38(4): 321-342.
4. Baker NR. R&D project selection models: An assessment. IEEE Transactions on Engineering Management 1974; 21(4): 165-171.
5. Baker, NR, Freeland J. Recent advances in R&D benefit measurement and project selection: where we stand. IEEE Transactions on Engineering Management 1975; EM-11: 124-134.
6. Baker NR, Green SG, Bean AS. Why R&D projects succeed or fail. Research Management 1986; 29(6): 29-34.
7. Baker NR, Pound WH. R&D project selection: Where we stand? IEEE Transactions on Engineering Management 1964; 21(4):124-134.
8. Balachandra R, Friar JH. Factors for success in R&D projects and new product innovation: a contextual framework. IEEE Transactions on Engineering Management 1997; 44 (3): 276-287.
9. Baltes BB, Dickson MW, Sherman MP, Bauer, LaGanke JS. Computer-Mediated Communication and Group Decision Making: A Meta-Analysis. Organizational Behavior and Human Decision Processes 2002; 87(1): 156-179.
10. Brad JF, Feinberg A. A two phase methodology for R&D project selection and system design. IEEE Transactions on Engineering Management 1989; 36(1): 28-36.
11. Buckley JJ. Fuzzy hierarchical analysis. Fuzzy Sets and Systems 1985,17: 233-247.
12. Buckley JJ, Feuring T, Hayashi Y. Fuzzy hierarchical analysis. In Proceedings of IEEE International Fuzzy Systems Conference 1999; 1009-1013; Seoul, Korea.
13. Buyukozkan G, Ertay T, Kahraman C, & Ruan D. Determining the importance weights for the design requirements in the house of quality using the fuzzy analytic

network approach. International Journal of Intelligent Systems 2004, 19: 443-461.

14. Chan FTS, Chan MH, Tang NKH. Evaluation methodologies for technology selection. Journal of Materials Processing Technology 2000; 107: 330-337.
15. Chen CT. Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets and Systems 2000; 114: 1-9.
16. Chen SM. Evaluation weapon system by AHP using fuzzy arithmetic operation. Fuzzy Set and Systems 1996; 77: 265-276.
17. Cheng CH. Evaluation naval tactical missile system by fuzzy AHP based on the grade value of membership function. European Journal of Operation Research 1996; 96: 343-350.
18. Cheng CH, Mon DL. Evaluation weapon system by AHP based on fuzzy scales. Fuzzy Set and Systems 1994; 63:1-10.
19. Chien CF. A portfolio-evaluation framework for selection R&D projects. R&D Management 2002; 32(4): 359-369.
20. Coffin MA, Taylor WT. Multiple criteria R&D project selection and scheduling using fuzzy logic. Computers and Operations Research 1996; 23(3): 207-220.
21. Coldrick S, Lawson CP, Ivey PC, Lockwood C. A Decision Framework for R&D Project Selection. IEEE Engineering Management 2002; 413-418.
22. Cooper R G. An empirically derived new product project selection model. IEEE Transactions on Engineering Management 1981; 28: 54–61.
23. Csutora R, Buckley JJ. Fuzzy hierarchical analysis: the Lambda-Max method. Fuzzy sets and Systems 2001; 120: 181-195.
24. Danila N. Strategic evaluation and selection of R&D project. R&D Management 1989; 19(1): 47-62.
25. Deng H. Multicriteria analysis with fuzzy pairwise comparison. International Journal of Approximate Reasoning 1999; 21: 215-231.
26. Department of Industrial Technology. Achievements of TDP. http://doit.moea.gov.tw/newenglish/03_Achievements/exp.asp; 2004.
27. Department of Industrial Technology. TDP performance and benefit. http://doit.moea.gov.tw/newenglish/03_Achievements/PerfBene.asp; 2004.
28. Feldman MP, Kelly MR. Leveraging research and development: Assessing the impact of the U.S. advanced technology program. Small Business Economics 2003; 20: 153-165.
29. Hall DL, Nauda A. A strategic methodology for IR&D project selection. Engineering Management Conference 1988; 59 – 66.
30. Hamalainen RP, Seppalainen TO The analytic networks process in energy policy planning. Socioeconomic Planning Science 1996. 20(6), 399-405.
31. Henriksen AD, Traynor AJ. A Practical R&D Project-Selection Scoring Tool. IEEE Transactions on Engineering Management 1999; 46(2): 72.
32. Horesh R, Raz B. Technological aspects of project selection. R&D Management 1982; 12(3): 133-140.

33. Hsu YG, Tzeng GH, Shyu JZ. Fuzzy multiple criteria selection of government-sponsored frontier technology R&D projects. R&D Management 2003; 33(5): 539-550.
34. Kahraman C, Cebeci U, Ruan D. Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey. International Journal of Production Economics 2004; 87: 171-184.
35. Kelly JR, Kaarau SJ. Group Decision Making: The Effects of Initial Preferences and Time Pressure. Personality and Social Psychology Bulletin 1999; 25(11): 1342.
36. Kwong C, Bai H. A fuzzy AHP approach to the determination of importance weight of customer requirements in quality function deployment. Journal of Intelligent Manufacturing 2002; 13(5): 367-377.
37. Laarhoven PJM, Pedrycz W. A Fuzzy Extension of Saaty's Priority Theory. Fuzzy Sets and Systems 1983; 11(3): 229-241.
38. Lahdelma R, Salminen P. SMAA-2: Stochasitc Multicriteria Acceptability Analysis for Group Decision Making. Operations Research 2001; 49(3): 444-455.
39. Lee AR. Application of Modified Fuzzy AHP Method to Analyze Bolting Sequence of Structural Joints. UMI Dissertation Service, A Bell & Howell Company; 1995.
40. Lee JW, Kim SH. Using analytic network process and goal programming for interdependent information system project selection. Computer and Operations Research 2000; 27: 367–382.
41. Lee M, Om K. Different Factors Considered in Project Selection at Public and Private R&D Institutes. Technovation 1996; 16(6): 271-276.
42. Liberatore MJ. An extension of the analytic hierarchy process for industrial R&D project selection and resource allocation. IEEE Transactions on Engineering Management 1987; 1: 12–18.
43. Liberatore MJ, Titus GJ The practice management science in R&D project management. Management Science 1983; 29(8): 962-975.
44. Lilien GL, Yoon E. Determinants of new industrial productperformance: A strategic reexamination of the empirical literature. IEEE Transactions on Engineering Management 1989; 36(1): 3-10.
45. Linton JD, Walsh ST, Morabito J. Analysis, ranking and selection of R&D projects in a portfolio. R&D Management 2002; 32(3): 139–148.
46. Ma J, Fan ZP, Huang LH. A subjective and objective integrated approach to determine attribute weights. European Journal of Operational Research 1999; 112(2): 397-404.
47. Madey GR, Dean BV. Strategic planning for investment in R&D using decision analysis and mathematical programming. IEEE Transactions on Engineering Management 1985; 32(2): 84-96.
48. Martino JP. R&D Project Selection. New York: Wiley; 1995.
49. Meade LM, Presley A. R&D Project Selection Using the Analytic Network Process. IEEE Transactions on Engineering Management 2002; 49(1): 59-66.
50. Meade LM, Sarkis J. Analyzing organizational project alternatives for agile

manufacturing processes: An analytical network approach. International Journal of Production Research 1999, 37(2): 241-261.

51. Mikhailov L. Deriving priorities from fuzzy pairwise comparison judgements. Fuzzy Sets and Systems2003; 134: 365-385.
52. Mikhailov L. & Singh M.G. Fuzzy analytic network process and its application to the development od decision support systems. IEEE Transactions on Engineering Management 2003,33(1): 33-41.
53. Mohammed S, Ringseis E. Cognitive diversity and consensus in group decision making: The role of inputs, processes, and outcomes. Organizational Behavior and Human Decision Processes 2001; 85 (2): 310-335.
54. Mon DL, Cheng CH, Lin, JC. Evaluating weapon system using fuzzy analytic hierarchy process based on entropy weight. Fuzzy Sets and Systems 1994; 62: 127-134.
55. NSC. https://web01.nsc.gov.tw/wtp/index.jsp; 2004.
56. Oral, M., Kettani, O., & Lang, P. (1991). A methodology for collective evaluation and selection of industrial R&D projects. Management Science, 37(7), 871-885.
57. Ozer M. A survey of new product evaluation models. Journal of Production Innovation Management 1999; 16: 77–94.
58. Partovi F.Y. An analytic model to quantify strategic service vision. International Journal of Service Industry Management 2001, 12(5): 476-499.
59. Partovi FY, Corredoira RA. Quality function deployment for the good of soccer. European Journal of Operational Research 2002, 137: 642-656.
60. Pedrycz W. Why triangular membership functions? Fuzzy Sets and Systems 1994; 64: 21-30.
61. Perrone G. Fuzzy multiple criteria decision model for the evaluation of AMS. Computer Integrated Manufacturing Systems 1994; 7(4): 228-239.
62. Perego A, Rangone A. A reference framework for the application of MADM fuzzy techniques to selecting AMTS. International Journal of Production Research 1998; 36: 437-458.
63. Prabhu TR, Vizayakumar K. Technology choice using FHDM: A case of iron-making technology. IEEE Transactions on Engineering Management 2001; 48(2): 209-222.
64. Santhanam R, Kyparisis J. A multiple criteria decision model for information system project selection. Computers and Operations Research 1995; 22(8): 807-818.
65. Satty TL. A Analytic Hierarchy Process. New York: McGraw-Hill; 1980.
66. Saaty TL, Takizawa M. Dependence and independence: From linear hierarchies to nonlinear networks. European Journal of Operational Research 1986, 26: 229-237.
67. Sarkis J, Nehman G, Priest J. A system evaluation model for environmental conscious business practices and strategy. IEEE Transaction on Engineering Management 1996, 281-286.
68. Schmidt RL, Freeland JR. Recent progress in modeling R&D project selection process. IEEE Transactions on Engineering Management 1992; 39(2): 189-201.

69. Shang JS, Tjader Y, Ding, Y. A Unified Framework for Multicriteria Evaluation of Transportation Projects. IEEE Transactions on Engineering Management 2004, 51(3): 300-313.
70. Souder WE. Analytical effectiveness of mathematical models for R&D project selection. Management Science 1973; 19(8): 907-923.
71. Souder WE, Mandakovic T. R&D project selection models. Research Management 1986; 29(4): 36–42.
72. Stewart R, Mohamed S. IT/IS Projects Selection Using Multi-Criteria Utility Theory. Logistic information management 2002, 15(4): 254-270.
73. Tran LT, Knight CG, O'neill RV, Smith ER. Integrated environmental assessment of the mid-atlantic region with analytical network process. Environmental Monitoring and Assessment 2004, 94: 263–277.
74. Yap CM, Souder WE. Factors influencing new product success and failure in small entrepreneurial high-technology electronics firms. Journal of Production Innovation Management 1994; 11: 418–432.
75. Zacharakis A, Meyer D. The potential of actuarial decision models: Can they improve the venture capital investment decision? Journal of Business Venturing 2000; 15: 323–46.
76. Zadeh LA. The concept of linguistic variable and its application to approximate reasoning. Information Science 1975; 8(1): 199-249.
77. Zhu KJ, Jing Y, Chang DY. A discussion on extent analysis method and applications of fuzzy AHP. European Journal of Operational Research, 1999; 116: 450-456.
78. Zopounidis C. Venture capital modeling: Evaluation criteria for the appraisal of investment. The Financier ACMT 1994; 1: 54–64.