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Exploring a Risk Evaluation Model for New Product Development Project

Meng-Jong Kuan[1], Yee Ming Chen[2,*]
[1]*Department of Business and Entrepreneurial Management, Kainan University, Taiwan, R.O.C.*
[2]*Innovation Center for Big Data and Digital Convergence and Department of Industrial Engineering and Management Yuan Ze University, Tao-Yuan, Taiwan, R.O.C*

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Abstract

In the highly competitive environment, new product development (NPD) has progressed rapidly. NPD not only has become a strong driving force in successfully competing among enterprises but also has been accomplishing its innovations at a shortened life cycle. Effective development of the customer's required new products has always been the goal of a project organization in a company. However, new product development projects are influenced by social environment, technology, personnel, time, scope, cost, management, and many uncertainties during the process of project implementation. These uncertainties results to the high project risk, giving more chances for the projects to fail. This article explores the risk evaluation model of NPD project, in which the risk factors are sorted out into three risk dimensions with 10 appraisal criteria. Fuzzy decision making trial and evaluation laboratory (DEMATEL) of multiple criteria decision making (MCDM) is applied to establish a structure model of project risk evaluation system, and analytical network process (ANP) is also used to weigh the dimension and criteria. From the system structure model of project risk, we were able to realize the priority of risk criteria within the dimensions and consequently to improve effective risk management of the NPD project.

Keywords: new product development (NPD), risk evaluation model, fuzzy DEMATEL (decision making trial and evaluation laboratory), DANP (DEMATEL-based ANP), VIKOR (Višekriterijumsko kompromisno rangiranje)

1 Introduction

With the world moving towards the knowledge of the economy era, new product development has become an important resource for the survival and growth of an enterprise. In keeping a sustainable business, more and more new product development projects are performed to keep a high competitiveness of the enterprise. A successful operation of these new product development projects is essential in maintaining the existence and growth of the enterprise in this densely-competitive market environment. Thus, an enterprise's research and development sector is an important key for survival. In meeting this goal, variety of new products are developed through accomplishments of multiple projects in a very short time and limited resources. The best profit are obtained by establishing the right project management environment in which project organizations quickly meets the customer's demands and appearing better than its competitors.

Product development is a high-risk activity of every enterprise due to long time investment, uncertainty, complexity, and uniqueness of the NPD project. Along with these attributes are the risks faced by the NPD project implementation, such as social environment, resources, schedule management, technology and other significant factors. These risks have increased the difficulty of managing every NPD project and thus translate into additional potential losses.

For a more effective implementation of the NPD projects under uncertain situation, a risk assessment system for NPD project is necessary for a project organization. In this study, used Fuzzy DEMATEL (Fuzzy Decision Making Trial and Evaluation Laboratory, DEMATEL) methods are applied to establish a system structure model for a NPD risk assessment system. Consequently, VIKOR is applied to evaluate the performance gap of NPD risk management

[*] Corresponding author.
Email: chenyeeming@saturn.yzu.edu.tw (Y. M. Chen).

in order to find out the key criterion for continuous improvement to obtain the maximum project benefit. The process is illustrated in Figure 1.

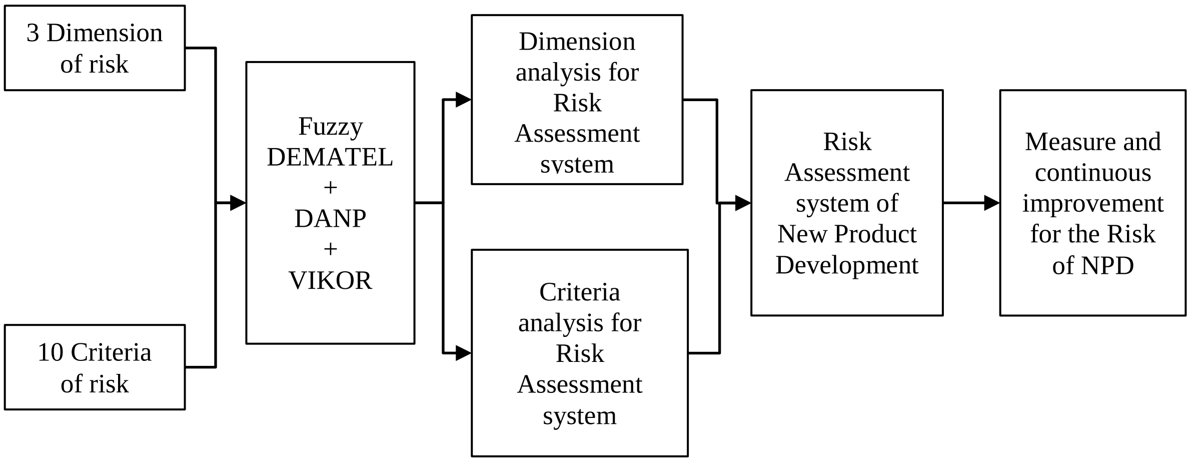

Figure 1: Study process

2 Literature Review on Risk of New Product Development

2.1 The New Product Development

A product is a set of benefits offered for exchange and can either be tangible (that is, something physical you can touch) or intangible (like a service, experience, or belief). A new product is such which structure, function, and material has significantly enhanced from its original. In addition, a product derived after improvement of an existing product and continues the company's brand style is also new products. Also, a new specie added to a company's existing product line can also be considered a new product. From the industry's standpoint, as long as the market view something as a "new" product, regardless of how long the product is available in the market, can be called a "new product". Montoya-Weiss [17] stated that the enterprises should continuously introduce new products to the market in order to maintain a competitive position in the market. New products share five common characteristics: (1) relativity of the new product; (2) timeliness of new product; (3) originality of new product; (4) proactiveness of the new product; and (5) availability of the new product. From a business perspective, a new product can be defined as: any product or service that an enterprise will make available to the market having an obvious difference from the original and fundamental products or services. They can be new by having new applications or carrying out a new theory, or by possessing new structures, materials or technology; or any unprecedented product. Millett [15] pointed out that if a company's research and development for product innovation result to product obsolescence, the market will be replaced by other companies with more innovative products.

In business and engineering, NPD is the term used to describe the complete process of bringing a new product to market. To reduce the uncertainty of new product development, NPD should be an information process engaged in new product development activities [4, 7]. There are two parallel paths involved in the NPD process: one involves the idea generation, product design and detail engineering; the other involves market research and marketing analysis. Companies typically see new product development as the first stage in generating and commercializing new products within the overall strategic process of product life cycle management used to maintain or grow their market share. The enterprises need innovative products in the era of new product development risks and improve the means to avoid the risks of wasting of money, time and resources.

2.2 The Risk of New Product Development

New product development is a high-risk activity, due to the increased investment, long duration of completion, uncertainty, complexity, and uniqueness of the new product development project [1]. These risks, if well-handled by the project manager, can be turned into an opportunity and yield positive results. In the other hand, when these risks are not properly identified, the project organization has to spend more cost and time in dealing with them. In the project management, a risk is defined as: “it can affect projects or multiple targets with uncertainty”.

Project risk management process consists of four steps: risk identification, risk assessment, risk handling and risk monitoring. Many papers in the past have explored the technical aspects of the impact on NPD focusing on technical strategy, personnel and technical capabilities of NPD [8]. To face the limited resources, constantly-evolving technology and the rapidly-changing environmental needs, it is necessary to consider the risk impact of new product development process.

In the early stage of a ne product development, there is an unclear concept about the project, and yet the project still needs to be performed, requiring urgent needs for resources like people, material, cost and time [3]. Uncertainty of a vision for a project causes wrong methods of execution, instability and lack of support, and eventually results to errors, interruptions, and even failure, which all translate to heavy losses. Thus, it is important that the enterprise explores the risk of new product development, which helps in implementing NPD projects effectively. This can be made possible by establishing a risk assessment system for NPD projects to evaluate and reduce the risk impact on NPD. These risks of new product development can be due to the business internal environment as well as the uncertainties in external environmental. With the risks created by the uncertainties in production and management complexity, the business performance becomes limited and may lead to the failure of new product development project from achieving the investment return; or worst, failure of the project. If these hidden risks are not identified, they will cause losses by the NPD Projects.

NPD projects involve high cost and inherent uncertainties making their cost of risk also higher, and should be given high priority. In general, these high-cost risks are influenced by uncertainty of project schedule, uncertainty of cost estimation, material cost, and shortage of resources. These results to unstable quality, and lower profits, thus the risk of schedule and people must also be considered in NPD project [2].

2.3 Criteria of the Risk Assessment for NPD

With the NPD risk clearly associated with income, there is at one end the risk of loss, and on the other end the risk of income. One of the big challenges in business is realizing the essential improvement items, and should be determined at the soonest possible time. The risk-related criteria have interactive relationship. Table 1 discusses the 3 dimensions and 10 criteria in the risk assessment system for New Product Development, including relevance among dimensions and criteria.

Table 1: Risk assessment criteria for NPD

Dimensions	Criteria
Schedule (S)	scope creep (S_1) progress rate (S_2) estimate of completion (S_3)
Cost (C)	cost variance (C_1) quality (C_2) income (C_3)
People (P)	technology of development (P_1) tire of personnel (P_2) design changes (P_3) rework (P_4)

3 Building a Hybrid Fuzzy MCDM Approach

In this research, Fuzzy MCDM approach is used to build an evaluation system structure model [9]. Fuzzy DEMATEL is used to understand the cause and effect and degree of impact. Decision Making Trial and Evaluation Laboratory (DEMATEL), which originated in Battelle Memorial Institute of Geneva in 1971~1976, is provided in order to realize scientific and human services programs and determine the true relevance of social factors in a mathematical theory based on matrix-related methods [6, 25]. This method is effective because it considers the nature of the factors associated with the extent of affecting the structure and consequently helps simplify the system structure of real social complexity and provide an orientation for improving the system performance.

On the other hand, real social phenomena have blurred the semantic nature of clarity. Thus, in addition to assessing the correlation between the properties and their effects, the fuzzy nature of the research process should be considered. With this, this research applies the fuzzy decision-making trial and evaluation laboratory method to establish the system structure model of the critical success factor for the assessment system.

3.1 Using Fuzzy DEMATEL Technique to Establish System Structure Model

According to existing literature, the known methods which use computers as a tool to study the structural analysis model and presenting the network map correlation models are Strategic Decision Making (SEM) method, Information Systems and Decision Sciences (ISM) method, and DEMATEL method. Tzeng et al. [11, 23, 26] pointed out that the DEMATEL can effectively solve the complicated different view-points of social problems and can easily understand the complex causal structure. Proposed in our study [10] is a hybrid MCDM framework combined with DEMATEL-based ANP supporting the sustain reform technological innovation capability in the R&D sector in order to face high-tech market competition and social responsibility vendor selection process in new task situations. The aim of this study is extending fuzzy DEMATEL model for NPD project to find to obtain the maximum project benefit. The fuzzy DEMATEL model can be established by observing the relationship between the two criteria using mathematical theory of matrices. The calculation of DEMATEL could be divided into five steps:

Step 1: To calculate the direct-influence matrix using scores. The experts are asked to indicate the direct effect that they believe factor i will have on factor j as indicated by fuzzy. The contextual relationships between the factors can be shown in Figure 2. Thus, the matrix of direct relations can be obtained. In the DEMATEL formulation, respondents indicate the degree of direct influence on a scale of 0, 1, 2, 3 and 4, which represent “Complete no influence (0)”, “Low influence (1)”, “Medium influence (2)”, “High influence (3)” and “Very high influence (4)” by experts, respectively.

Step 2: To normalize the direct-influence matrix. Based on the direct-influence of matrix, the normalized direct-relation matrix is acquired using Eqs. (1) and (2).

$$\tilde{\boldsymbol{D}} = \tilde{\boldsymbol{A}} / k \tag{1}$$

$$k = \max\left\{\max_i \sum_{j=1}^{n} h_{ij}, \max_j \sum_{i=1}^{n} h_{ij}\right\}, \quad i, j \in \{1, 2, ..., n\} \tag{2}$$

Step 3: To obtain the total-influence matrix. Once the normalized direct-influence matrix D is obtained, the total-influence matrix of NRM can be obtained by using Eq. (3), which denotes the identity matrix.

$$\begin{gathered} \tilde{\boldsymbol{T}} = \tilde{\boldsymbol{D}} + \tilde{\boldsymbol{D}}^2 + \tilde{\boldsymbol{D}}^3 + \cdots + \tilde{\boldsymbol{D}}^k = \tilde{\boldsymbol{D}}(\boldsymbol{I} + \tilde{\boldsymbol{D}} + \tilde{\boldsymbol{D}}^2 + \cdots + \tilde{\boldsymbol{D}}^{k-1})[(\boldsymbol{I} - \tilde{\boldsymbol{D}})(\boldsymbol{I} - \tilde{\boldsymbol{D}})^{-1}] = \tilde{\boldsymbol{D}}(\boldsymbol{I} - \tilde{\boldsymbol{D}}^k)(\boldsymbol{I} - \tilde{\boldsymbol{D}})^{-1} \\ \tilde{\boldsymbol{T}} = \tilde{\boldsymbol{D}}(\boldsymbol{I} - \tilde{\boldsymbol{D}})^{-1}, \text{ when } k \to \infty, \ \tilde{\boldsymbol{D}}^k = [0]_{n\times n} \end{gathered} \tag{3}$$

where $\tilde{\boldsymbol{D}} = [\tilde{d}_{ij}]_{n\times n} = [(d_{ij}^l, d_{ij}^m, d_{ij}^h)]_{n\times n}$, $0 \le \tilde{d}_{ij} < 1$, $0 < \sum_{j=1}^{n} d_{ij}^h \le 1$, $0 < \sum_{i=1}^{n} d_{ij}^h \le 1$. If at least one row or column of summation is equal to 1(but not all) in $\sum_{j=1}^{n} d_{ij}^h$ and $\sum_{i=1}^{n} d_{ij}^h$, then it can be guaranteed that $\lim_{k\to\infty} \boldsymbol{D}^k = [0]_{n\times n}$. And $\tilde{\boldsymbol{T}} = [\tilde{t}_{ij}]$ can be attained.

Step 4: To analyze the results. In this stage, the sum of rows $\sum_{j=1}^{n} \tilde{t}_{ij} = \tilde{t}_i$ and the sum of columns $\sum_{i=1}^{n} \tilde{t}_{ij} = \tilde{t}_j$ are separately expressed as vector $\tilde{\boldsymbol{r}} = (\tilde{r}_1, ..., \tilde{r}_i, ..., \tilde{r}_n)'$ and vector $\tilde{\boldsymbol{c}} = (\tilde{c}_1, ..., \tilde{c}_j, ..., \tilde{c}_n)'$ by using Eqs. (4), (5), and (6).

Let $i = j$ and $i, j \in \{1, 2, ..., n\}$; the horizontal axis vector ($\tilde{\boldsymbol{r}} + \tilde{\boldsymbol{c}}$) is then created by adding $\tilde{\boldsymbol{r}}$ to $\tilde{\boldsymbol{c}}$, which illustrates the importance of the criterion. Similarly, the vertical axis vector ($\tilde{\boldsymbol{r}}$ - $\tilde{\boldsymbol{c}}$) is constructed by deducting $\tilde{\boldsymbol{r}}$ from $\tilde{\boldsymbol{c}}$, which may separate criteria and group them into a cause group and an effect group. In general, when ($\tilde{\boldsymbol{r}}$ - $\tilde{\boldsymbol{c}}$) is positive, the criterion is part of the cause group. In contrast, if vector ($\tilde{\boldsymbol{r}}$ - $\tilde{\boldsymbol{c}}$) is negative, the criterion is part of the effect group. Therefore, the causal graph can be achieved by mapping the dataset of vectors ($\tilde{\boldsymbol{r}} + \tilde{\boldsymbol{c}}$, $\tilde{\boldsymbol{r}}$ - $\tilde{\boldsymbol{c}}$), providing a valuable approach to decision making.

$$\tilde{\boldsymbol{T}} = [\tilde{t}_{ij}]_{n\times n}, \ i, j = 1, 2, ..., n \tag{4}$$

$$\tilde{\boldsymbol{r}} = \left[\sum_{j=1}^{n} \tilde{t}_{ij}\right]_{n\times 1} = \left[\tilde{t}_{i\cdot}\right]_{n\times 1} = (\tilde{r}_1, ..., \tilde{r}_i, ..., \tilde{r}_n)' \tag{5}$$

$$\tilde{\boldsymbol{c}} = \left[\sum_{i=1}^{n} \tilde{t}_{ij} \right]'_{1\times n} = [\tilde{t}_{\cdot j}]_{n\times 1} = (\tilde{c}_1, ..., \tilde{c}_j, ..., \tilde{c}_n)' \tag{6}$$

where vector $\tilde{\boldsymbol{r}}$ and vector $\tilde{\boldsymbol{c}}$ express the sum of the rows and the sum of the columns from total-influence matrix $\tilde{\boldsymbol{T}} = [\tilde{t}_{ij}]_{n\times n}$, respectively, and the use of superscript denotes transpose.

3.2 Using DANP Method to Calculate the Influential Weights of Criteria

Saaty [19, 20] proposed ANP (Analytical Network Process) by extending the Analytic Hierarchy Process (AHP). The difference of ANP from AHP is that it sees the criteria independent, while AHP considers the dependence and feedback relation in each criterion. In other words, ANP is a general form of Analytic Hierarchy Process [12]. It also means that AHP is a special case of ANP. In fact, the dimensions formed by the criteria have not only the influence in the same level, but also the influences in different levels. In reality, it is not a linear bottom up and breakdown hierarchy, but is more like a network. The purpose of ANP is to predict the internal relationship between criteria, goals, and alternatives. Through an evaluation scale doing the pair-wise comparison, we can obtain the weight of cluster and every element after influencing each other. In this study, we use the method that combines DEMATEL technique and basic concept of ANP which is called DANP (DEMATEL-based ANP). DANP uses DEMATEL technique to confirm the degree of influence between each cluster. Furthermore, it uses the total relationship matrix T obtained from DEMATEL that contains “dynamic influential relationship weights”. It then makes use of the total relationship matrix T unto the super-matrix in ANP to recognize the relation and importance which influence the management and development of a project team; thus meeting the requirement of our research topic in the real world [13,14,16]. The following are the DANP operation steps:

Step 1: Use DEMATEL method to establish evaluation index system of influential relationship, which is the system structure model.

Step 2: Establish Unweighted Super-matrix. Based on the influence matrix $\boldsymbol{T}$, each criterion t_{ij} of influence matrix $\boldsymbol{T}$ can show network information on how the degree of criterion i affects criterion j; and thus the network relation map (NRM) can be obtained. The influence matrix $\boldsymbol{T}$ can be divided into T_D based on dimensions, and T_C based on criteria.

$$\boldsymbol{T}_C = \begin{array}{c} \\ D_1 \begin{smallmatrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{smallmatrix} \\ \vdots \\ D_i \begin{smallmatrix} c_{i1} \\ c_{i2} \\ \vdots \\ c_{im_i} \end{smallmatrix} \\ \vdots \\ D_n \begin{smallmatrix} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{smallmatrix} \end{array} \overset{\begin{array}{ccccc} D_1 & \cdots & D_i & \cdots & D_n \\ c_{11}\cdots c_{1m_1} & \cdots & c_{i1}\cdots c_{im_i} & \cdots & c_{n1}\cdots c_{nm_n} \end{array}}{\begin{bmatrix} \boldsymbol{T}_C^{11} & \cdots & \boldsymbol{T}_C^{1j} & \cdots & \boldsymbol{T}_C^{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_C^{i1} & \cdots & \boldsymbol{T}_C^{ij} & \cdots & \boldsymbol{T}_C^{in} \\ \vdots & & \vdots & \ddots & \vdots \\ \boldsymbol{T}_C^{n1} & \cdots & \boldsymbol{T}_C^{nj} & \cdots & \boldsymbol{T}_C^{nn} \end{bmatrix}} \tag{7}$$

Then, to normalize $\mathbf{T}_C$ with the total degree of effect and to obtain $\mathbf{T}_C^{\alpha}$ as shown in Eq. (8):

$$\boldsymbol{T}_C^{\alpha} = \begin{array}{c} \\ D_1 \begin{smallmatrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{smallmatrix} \\ \vdots \\ D_i \begin{smallmatrix} c_{i1} \\ c_{i2} \\ \vdots \\ c_{imi} \end{smallmatrix} \\ \vdots \\ D_n \begin{smallmatrix} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{smallmatrix} \end{array} \overset{\begin{array}{ccccc} D_1 & \cdots & D_i & \cdots & D_n \\ c_{11}\cdots c_{1m_1} & \cdots & c_{i1}\cdots c_{im_i} & \cdots & c_{n1}\cdots c_{nm_n} \end{array}}{\begin{bmatrix} \boldsymbol{T}_C^{\alpha 11} & \cdots & \boldsymbol{T}_C^{\alpha 1j} & \cdots & \boldsymbol{T}_C^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_C^{\alpha i1} & \cdots & \boldsymbol{T}_C^{\alpha ij} & \cdots & \boldsymbol{T}_C^{\alpha in} \\ \vdots & & \vdots & \ddots & \vdots \\ \boldsymbol{T}_C^{\alpha n1} & \cdots & \boldsymbol{T}_C^{\alpha nj} & \cdots & \boldsymbol{T}_C^{\alpha nn} \end{bmatrix}}. \tag{8}$$

The method of normalization that can be obtained $\boldsymbol{T}_c^{\alpha 11}$ is shown in Eqs. (9) and (10), this can be repeated to be obtain $\boldsymbol{T}_c^{\alpha nn}$

$$d_i^{11} = \sum_{j=1}^{m_1} t_{c\,ij}^{\,11}\,, i = 1, 2, ..., m_1 \tag{9}$$

$$\mathbf{T}_c^{\alpha 11} = \begin{bmatrix} t_{c\,11}^{\,11}/d_1^{11} & \cdots & t_{c\,1j}^{\,11}/d_1^{11} & \cdots & t_{c\,1m_1}^{\,11}/d_1^{11} \\ \vdots & & \vdots & & \vdots \\ t_{c\,i1}^{\,11}/d_i^{11} & \cdots & t_{c\,ij}^{\,11}/d_i^{11} & \cdots & t_{c\,im_1}^{\,11}/d_i^{11} \\ \vdots & & \vdots & & \vdots \\ t_{c\,m_1 1}^{\,11}/d_{m_1}^{11} & \cdots & t_{c\,m_1 j}^{\,11}/d_{m_1}^{11} & \cdots & t_{c\,m_1 m_1}^{\,11}/d_{m_1}^{11} \end{bmatrix} = \begin{bmatrix} t_{c\,11}^{\alpha 11} & \cdots & t_{c\,1j}^{\alpha 11} & \cdots & t_{c\,1m_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c\,i1}^{\alpha 11} & \cdots & t_{c\,ij}^{\alpha 11} & \cdots & t_{c\,im_1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c\,m_1 1}^{\alpha 11} & \cdots & t_{c\,m_1 1}^{\alpha 11} & \cdots & t_{c\,m_1 m_1}^{\alpha 11} \end{bmatrix} \tag{10}$$

After this, the total effect matrix is normalized into a supermatrix by dimensions according to the dependent relationship within the group; this results to obtaining the unweighted supermatrix as shown in Eq. (11).

$$W = (\boldsymbol{T}_c^{\alpha})' = \begin{array}{c} \\ \\ D_1 \; \begin{matrix} c_{11} \\ c_{12} \\ \vdots \\ c_{1m_1} \end{matrix} \\ \vdots \\ D_j \; \begin{matrix} c_{j1} \\ c_{j2} \\ \vdots \\ c_{jm_j} \end{matrix} \\ \vdots \\ D_n \; \begin{matrix} c_{n1} \\ c_{n2} \\ \vdots \\ c_{nm_n} \end{matrix} \end{array} \begin{array}{c} \begin{matrix} D_1 & \cdots & D_i & \cdots & D_n \\ c_{11} \cdots c_{1m_1} & \cdots & c_{i1} \cdots c_{im_i} & \cdots & c_{n1} \cdots c_{nm_n} \end{matrix} \\ \begin{bmatrix} W^{11} & \cdots & W^{i1} & \cdots & W^{n1} \\ \vdots & & \vdots & & \vdots \\ W^{1j} & \cdots & W^{ij} & \cdots & W^{nj} \\ \vdots & & \vdots & & \vdots \\ W^{1n} & \cdots & W^{in} & \cdots & W^{nn} \end{bmatrix} \end{array} \tag{11}$$

Furthermore, matrices $\mathbf{W}^{11}$ can be obtained by Eq. (12). If a blank space or 0 appears in the matrix, then the group or criterion is independent. In the same way, the matrix $\mathbf{W}^{nn}$ can be obtained.

$$W^{11} = (\boldsymbol{T}^{11})' = \begin{array}{c} \\ c_{11} \\ \vdots \\ c_{1j} \\ \vdots \\ c_{1m_1} \end{array} \begin{array}{c} \begin{matrix} c_{11} & \cdots & c_{1i} & \cdots & c_{1m_1} \end{matrix} \\ \begin{bmatrix} t_{c11}^{\alpha 11} & \cdots & t_{ci1}^{\alpha 11} & \cdots & t_{cm_1 1}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c1j}^{\alpha 11} & \cdots & t_{cij}^{\alpha 11} & \cdots & t_{cm_1 j}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c1m_1}^{\alpha 11} & \cdots & t_{cim_1}^{\alpha 11} & \cdots & t_{cm_1 m_1}^{\alpha 11} \end{bmatrix} \end{array} \tag{12}$$

Step 3: Obtain the Weighted Supermatrix by deriving the matrix of the total effect of dimensions using Eq. (13).

$$d_i = \sum_{j=1}^{n} t_D^{ij}, \quad i = 1, 2, ..., n$$

$$\mathbf{T}_D = \begin{bmatrix} t_D^{11} & \cdots & t_D^{1j} & \cdots & t_D^{1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{i1} & \cdots & t_D^{ij} & \cdots & t_D^{in} \\ \vdots & & \vdots & & \vdots \\ t_D^{n1} & \cdots & t_D^{nj} & \cdots & t_D^{nn} \end{bmatrix} \tag{13}$$

Then, $\mathbf{T}_D$ is normalized to obtain $\mathbf{T}_D^{\alpha}$, as shown in Eq. (14).

$$\mathbf{T}_D^{\alpha}=\begin{bmatrix} t_D^{11}/d_1 & \cdots & t_D^{1j}/d_1 & \cdots & t_D^{1n}/d_1 \\ \vdots & & \vdots & & \vdots \\ t_D^{i1}/d_2 & \cdots & t_D^{ij}/d_2 & \cdots & t_D^{in}/d_2 \\ \vdots & & \vdots & & \vdots \\ t_D^{n1}/d_n & \cdots & t_D^{nj}/d_n & \cdots & t_D^{nn}/d_n \end{bmatrix} = \begin{bmatrix} t_D^{\alpha 11} & \cdots & t_D^{\alpha 1j} & \cdots & t_D^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha i1} & \cdots & t_D^{\alpha ij} & \cdots & t_D^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha n1} & \cdots & t_D^{\alpha nj} & \cdots & t_D^{\alpha nn} \end{bmatrix} \tag{14}$$

Then, the normalized $\boldsymbol{T}_D^{\alpha}$ is transformed into the Unweighted Supermatrix $\boldsymbol{W}$ to obtain the Weighted Supermatrix $\boldsymbol{W}^{\alpha}$, as shown in Eq. (15).

$$\boldsymbol{W}^{\alpha}=\boldsymbol{T}_D^{\alpha}\boldsymbol{W}=\begin{bmatrix} t_D^{\alpha 11}\times\boldsymbol{W}^{11} & \cdots & t_D^{\alpha i1}\times\boldsymbol{W}^{i1} & \cdots & t_D^{\alpha n1}\times\boldsymbol{W}^{n1} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1j}\times\boldsymbol{W}^{1j} & \cdots & t_D^{\alpha ij}\times\boldsymbol{W}^{ij} & \cdots & t_D^{\alpha nj}\times\boldsymbol{W}^{nj} \\ \vdots & & \vdots & & \vdots \\ t_D^{\alpha 1n}\times\boldsymbol{W}^{1n} & \cdots & t_D^{\alpha in}\times\boldsymbol{W}^{in} & \cdots & t_D^{\alpha nn}\times\boldsymbol{W}^{nn} \end{bmatrix} \tag{15}$$

Step 4: Obtain the Limit Supermatrix by DANP. Let the Weighted Spuermatrix $\boldsymbol{W}^{\alpha}$ multiply itself multiple times to obtain the Limit Supermatrix. Then, the DANP weights of each criterion can be obtained by $\lim_{z\to\infty}(\mathbf{W}^{\alpha})^z$, where z represents any number for power [18, 24].

3.3 Using VIKOR to Find the Best Project

VIKOR (Višekriterijumsko kompromisno rangiranje) a method proposed by Opricovic [21, 22], is a method of decision making on compromise solution programming. In this research, it uses a compromise concept to sort the multi-project to see how close the project is to Positive-ideal solution (setting the aspiration level). The closer the project is to the ideal solution (aspiration level), the better. On the contrary, the closer it is to the Negative-ideal solution, the worst. VIKOR could be divided into 3 steps:

Step 1: To confirm the ideal solution (aspiration level) and negative ideal solution (the worst level), and to confirm the best and worst value, which can be could obtained from Eqs. (7) and (8). f_j^* is the aspiration level of criterion j, and f_j^- is the worst value of criterion *j*. If every criterion in the project gets the aspiration level, it means that the project gets best performance in every criterion and approaches the aspiration level. Eqs. (16) and (17) are then used to obtain the results.

$f_j^*=\max_k f_{kj},\ j=1,2,...,n$ (traditional approach) or as method in this research: setting the aspiration levels vector.

$$\boldsymbol{f}^*=(f_1^*,...,f_j^*,...,f_n^*) \tag{16}$$

$f_j^-=\min_k f_{kj},\ j=1,2,...,n$ (traditional approach) or as method in this research: setting the worst values vector.

$$\boldsymbol{f}^-=(f_1^-,...,f_j^-,...,f_n^-) \tag{17}$$

Development of the VIKOR method begins with the following form of the L_p _metric:

$$L_k^p=\left\{\sum_{j=1}^{n}[w_j(\left|f_j^*-f_{kj}\right|)/(\left|f_j^*-f_j^-\right|)]^p\right\}^{1/p} \tag{18}$$

where $1\le p\le\infty$; $k=1,2,...,m$ and the influential weights w_j is derived from the DANP. VIKOR method is used to formulate the ranking and gap measure, $L_k^{p=1}$ (as S_k) and $L_k^{p=\infty}$ (as Q_k).

$$S_k=L_k^{p=1}=\sum_{j=1}^{n}[w_j(\left|f_j^*-f_{kj}\right|)/(\left|f_j^*-f_j^-\right|)] \tag{19}$$

$$Q_k=L_k^{p=\infty}=\max_j\left\{(\left|f_j^*-f_{kj}\right|)/(\left|f_j^*-f_j^-\right|)\,\middle|\,j=1,2,...,n\right\} \tag{20}$$

Step 2: Calculate the mean of the group utility S_k (which represents the integrated average gap for all criteria) and maximal regret Q_k (which represents the maximal gap in *k* alternative of special criterion for improvement priority). In Eq. (22), w_j represents the influential weights of the criteria from DANP.

$$r_{kj} = (|f_j^* - f_{kj}|)/(|f_j^* - f_j^-|) \tag{21}$$

which represents the normalized gap (the normalized ratios of distance to the aspired level) of k alternative in j criterion. These values can be computed by Eqs. (18) and (19), respectively.

$$S_k = \sum_{j=1}^{n} w_j r_{kj} = \sum_{j=1}^{n} w_j \left(|f_j^* - f_{kj}|\right) / \left(|f_j^* - f_j^-|\right) \tag{22}$$

$$Q_k = \max_j \{ r_{kj} \mid j = 1, 2, ..., n \} \tag{23}$$

Step 3: Obtain the comprehensive indicator and sort out the results. The values can be computed by Eq. (24).

$$R_k = v(S_k - S^*)/(S^- - S^*) + (1-v)(Q_k - Q^*)/(Q^- - Q^*) \tag{24}$$

Eq. (20) can be re-written as $R_k = vS_k + (1-v)Q_k$, when $S^* = 0$ and $Q^* = 0$ (i.e., all criteria have achieved the aspired level) and $S^- = 1$ and $Q^- = 1$ (i.e., the worst situation).

4 Empirical Analysis of NPD Risk Assessment System

In this paper, experts' questionnaires are used in the DEMATEL approach. The questionnaire was made after a comparative analysis of quantitative elements and those associated to it. This questionnaires process conducts 3 dimensions and 10 criteria for the risk assessment of NPD as illustrated in Table 1. This paper has explored a risk assessment system for NPD, in which the dimensions and criteria are established as a system structure model with the weighted value calculated by ANP. Finally, by using VIKOR to measure the gap of the criteria performance, I can be observed that there is a big gap between the most ideal solution (aspiration level) and the best performance. It enables determination of which criterion has the biggest gap and we prioritize its improvement. However, solving only this specific part may not entirely solve the problem. Thus, it is important to trace back from the cause and effect relationship graph so that the problem can be finally solved. As a result, the experts can continuously solve and improve the NPD Risk Assessment System.

4.1 Dimension Analysis for Risk Assessment Model of NPD

According to the experts' questionnaires in DEMATEL, the risk assessment system for NPD as a network relation map (NRP) or system structure model is obtained as shown in Figure 2. The dimension ***P*** "People" is the most influencing factor, and is influencing two dimension: ***C*** "Cost" and ***S*** "Schedule". The second influencing factor is dimension ***S*** "Schedule" which influences dimension ***C*** "Cost". Thus, the dimension ***C*** "Cost" is the most influenced factor.

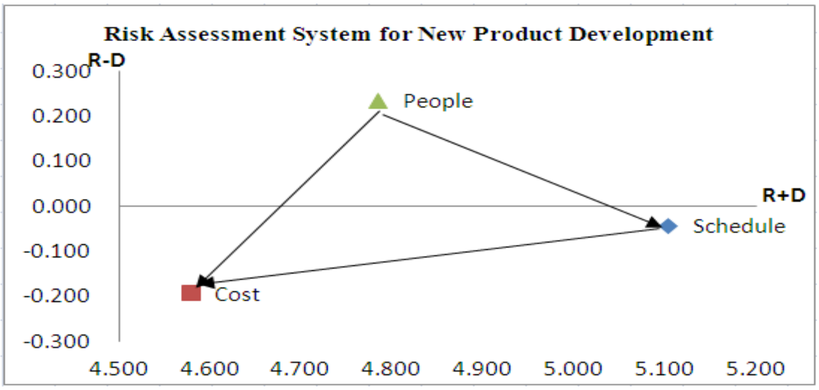

Figure 2: The network relation map of dimensions of the risk assessment system for NPD

In Figure 2, showing the risk assessment system of NPD model, we can recognize that the dimension ***P*** "people" is critical effect factor in the NPD risk assessment system for NPD, and which influences the effectiveness of cost and schedule, and thus ultimately influences achievement of New Product Development. This means that the quality of people for the project management is the most important factor which influences the project performance and risks.

4.2 Criteria Analysis for Risk Assessment System of NPD

In the dimension of ***S*** "Schedule", as shown in Figure 3, the criterion of S_1 "scope creep" is the influencing factor on the criteria S_2 "progress rate" and S3 "estimate of completion". The criterion of S_2 "progress rate" influences S_3 "estimate of completion". In the dimension of ***S***, to avoid the risk due to schedule delay, project manager should pay more attention in reducing scope creep and to grasp the scope of project effectiveness in the dateline by effectively estimating the completion of project.

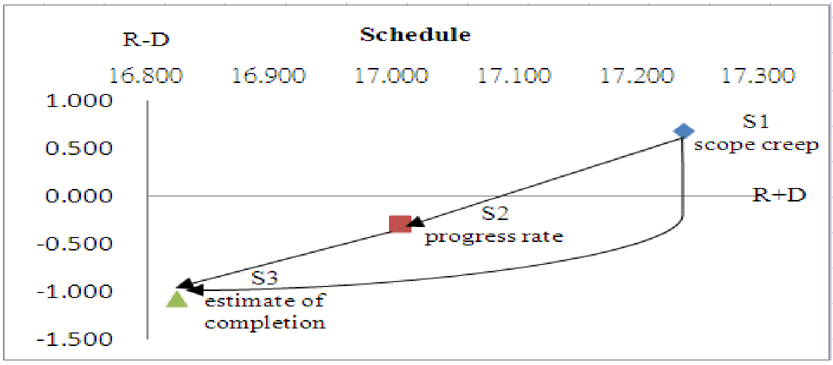

Figure 3: The network relation map of criteria in the dimension "Schedule"

In the dimension of ***C*** "Cost", as shown in Figure 4, the criterion "quality" is the influencing factor of criteria of "cost variance" and "income". The criterion "cost variance" influences the criterion "income". Therefore, the most influencing factor is the "quality" in the dimension of cost for the NPD project.

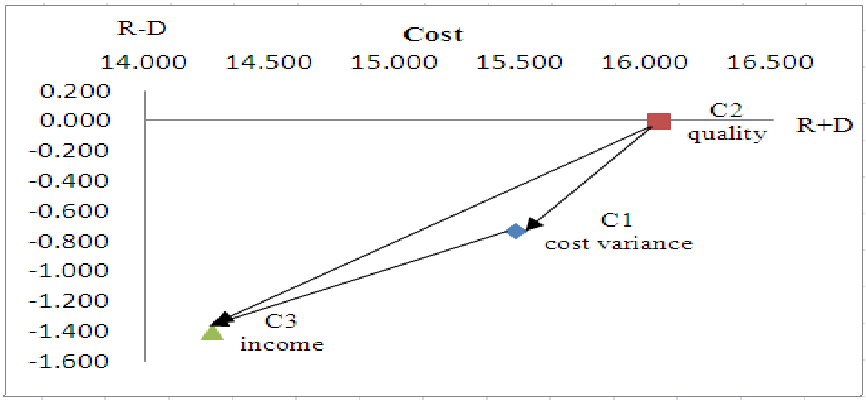

Figure 4: The network relation map of criteria in the dimension "Cost"

In the dimension of P "People", as shown in Figure 5, the criterion P_1 "technology of development" is the influencing factor of criteria P_3 "design changes", P_4 "rework" and P_2 "tire of personnel". The criterion of P3 "design changes" influences the criteria P_4 "rework" and P_2 "tire of personnel". And the criterion P4 "rework" influences the criterion P_2 "tire of personnel". Therefore, in the dimension of People, the "technology of development" enables technology innovation, and creates the best design; but it will also cause the risk of the "tire of personnel" and "rework" which then will reduce the project quality.

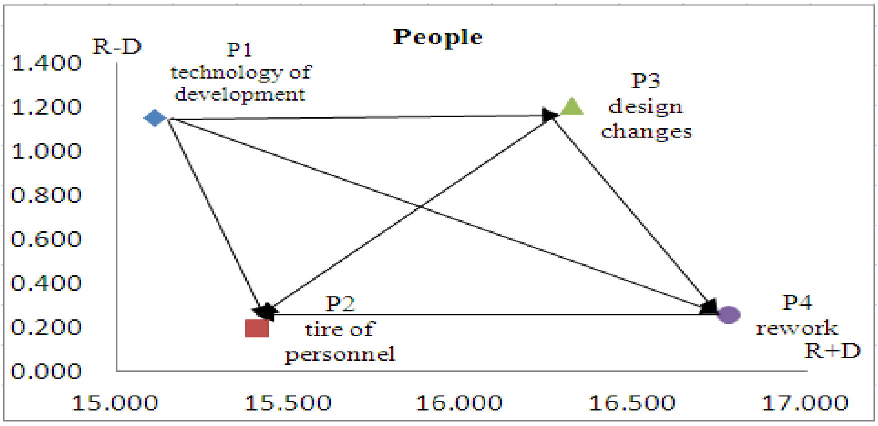

Figure 5: The network relation map of criteria in the dimension “People”

4.3 Risk Performance of NPD Product

In the study, VIKOR method was used to evaluate the company’s performance of the NPD risk assessment system and the result is shown in Table 2. In this case it can be found that the maximal regret is the criterion C_2 “quality”. Also, it can be concluded that the influence model driven from DEMATEL to find the dimension P “people” should to be improved first.

Table 2: Company A performance

Dimension and Criteria		Global Weight (by ANP)	The Risk Assessment System of Company A	
			Gap (r_{kj})	Performance (S_k)
Schedule		0.3555	—	0.1031
	S_1scope creep	0.1140	0.375	0.0427
	S_2progress rate	0.1187	0.250	0.0297
	S_3estimate of completion	0.1228	0.250	0.0307
Cost		0.3297	—	0.1509
	C_1cost variance	0.1116	0.375	0.0419
	C_2quality	0.1104	0.500	0.0552
	C_3income	0.1077	0.500	0.0539
People		0.3148	—	0.1008
	P_1 technology of development	0.0724	0.125	0.0091
	P_2tire of personnel	0.0787	0.250	0.0197
	P_3design changes	0.0783	0.375	0.0294
	P_4rework	0.0854	0.500	0.0427
Maximal Regret (Q_k)				0.0552 (C_2)
Total Performance Gap				0.3548

5 Conclusions

The risk assessment system of NPD project includes three dimensions: schedule, cost and people. The most influencing factor is the dimension ***P*** “people”. Currently, the knowledge of the risk for new product development is limited. Normally, the factors that have interrelation and influence with each other are considered, but not the cause and effect relationship and influence degrees. In this paper, the NPD risk assessment system model is established and the weights of criteria are obtained by using the Fuzzy DEMATEL based ANP approach. In addition, VIKOR is applied to evaluate the performance gap of NPD risk management from NPD risk assessment system in order to find out the key criterion to improve in order to obtain the maximum project benefit.

From the empirical analysis, it was realized that the dimension ***P*** "people" is the most influencing factor, and the most influenced factor is the dimension ***C*** "cost" in the risk assessment system of NPD. This shows that if you want to improve the dimensions of ***C*** "cost", you can focus your improvement of the performance of dimension ***P*** "people" and then the "cost" performance can be improved consequently. The activities of people will influence the cost. By effectively managing people in a project organization, the risks related to project cost and schedule can be improved.

Following the study, VIKOR can be combined to calculate the performance and gap for risk assessment system of new product development, and to find out the key criteria to improve in order to obtain the maximum project benefit.

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