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PROBING THE INNOVATIVE QUALITY SYSTEM STRUCTURE MODEL FOR NPD PROCESS BASED ON COMBINING DANP WITH MCDM MODEL

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Abstract. *In the highly competitive environment, new product development, technology, equipment and raw materials have progressed rapidly. It is a gradual trend that competitors continuously innovate on their product and product life cycle becomes shorter. The manager intends to achieve the highest customer satisfaction, product value and product continuity. In this study, we develop an effective quality assessment system to manage quality of new product development (NPD) process. First, the quality factors related to NPD process are selected by expert questionnaires. Second, the DEMATEL approach is used to explore the relevance of the quality factors of NPD process. Then, the DEMATEL is combined with ANP method to a new DANP approach to calculate the influential weights of quality factors. Finally, VIKOR is used to evaluate and improve the total performance of NPD process by using empirical analysis on a case study, to find out the performance gaps and to improve its scores. The results of this study will provide NPD team a guidance to continuously improve, track and meet the quality assurance of NPD process; consequently, the customers' needs can be satisfied.*
Keywords: New product development (NPD) process, Decision making trial and evaluation laboratory (DEMATEL), DEMATEL-based ANP (DANP), VIKOR

1. **Introduction.** In the highly competitive environment, new product development, technology, equipment and raw materials have progressed rapidly. It is a gradual trend that competitors continuously innovate on their product and product life cycle becomes shorter. The customers need diversity, innovation, functionality and design in various levels of demand conditions in order to pursue higher quality of the product. From overview of market demand and competitive intense environment, the enterprise is enforced to innovate on its new product development (NPD) process with high quality assurance in order to create sustainable value of enterprises and products [1]. As a result the high quality of NPD process has become the critical success factors of new product development.

Garvin (1984) [2] thinks quality improvement is beneficial for market expansion and cost reduction. It can increase the sense of reliance of product for obtaining the positive impression to create a good product (brand) image. In 1987, the International Organization for Standardization (ISO) released ISO 9000 series of quality management and quality assurance standards, and most companies are using this standard to improve the quality of products or services. The enterprises of various fields can review standard of ISO quality management through the procedures and conduct a series mission of the "process quality" for supervision, control, tracking and continuous improvement according to the design review standards and ISO quality management, but often assume these standards are independent, and do not provide any method for solving these problems and how to improve the gaps in these standards to achieve aspiration level when these standards are interdependent in real world.

U.S. Product Development Management Association (PDMA) proposed the NPD process with a clear definition as "a clear mission and the steps show that is from the concept to the marketable products or services required standardized methods". The manager should plan and execute a formal written review of the design results under the appropriate stage of NPD process [3].

This study is based on ISO 9000:2008 quality management system [4] which is combined with design review process to explore the quality factors of NPD process. We construct the innovation process and system thinking model according to the results of empirical analysis. The purpose is to discover and predict the problems and shortcomings of the NPD process, and how to improve these problems and shortcomings for satisfying the customers' needs. The result of this study will provide NPD team a guidance to continuously improve, track and meet the quality assurance of NPD process; consequently, the customers' needs can be satisfied.

The reminder of this paper is organized as follows. In Section 2, literature review on quality of NPD process is introduced. In Section 3, NPD process performance evaluation model is developed. An empirical case analysis for NPD process is illustrated to show our proposed model in Section 4. Finally, conclusions are presented in Section 5.

2. **Literature Review on Quality of NPD Process.** This section is aimed to understand the process quality factors related to NPD process. It is collected, selected, analyzed, simulated and tested by the literature of the past new product development with expert questionnaires to find problems that require strict quality management as a basis. We use ISO9000 series of quality management system standards to explore the related quality factors which are integrated with the design review and verification to assess the quality performance of NPD process from literature review.

2.1. **The new product development (NPD).** Sampson (1970) [5] proposed the view of consumer to explain the new product that is defined as "it has to meet new demands, requirements or desires that is more significant than other products". Souder (1988) [6] defined the new product is based on the view of business as "it has never owned products in previous". Kolter (1994) [7] proposed the view of product characteristic to explain the new product who divided the types of new product as: (1) internal development of original product; (2) improved product; (3) modified product; (4) new brand. Overview of the scholar defines the new product to explain that opens up an entirely new market and adapts or replaces an existing product. In addition, it is including an old product introduced in a new market or packaged and marketed in a different way.

According to above all, the new product development (NPD) is a process which is designed to develop, test and consider the viability of products which are new to the market in order to ensure the growth or survival of the organization. The primary impact of the environment is to drive the types of new product changes which help speed products through development, and improve process efficiency and overall NPD effectiveness [8].

NPD involves a series of organization and connects the activities closely which is significantly for the input of manpower and financial capability. They believe the quality and up to 80% of NPD costs that has decided in the product design stage [9]. Therefore, the managers reduce and control the uncertainty activities before the next phase is implemented according to the integrity of information (information fusion). It can ensure to improve the performance and quality of NPD.

2.2. **New product development (NPD) process.** NPD process may be accepted as a dynamic process in which each decision-making on each stage must be evaluated, selected, prioritized, and improved. All the stages of the process are affected by uncertain, changing information and dynamic opportunities [10]. U.S. Product Development Management Association (PDMA) proposed a clear definition of NPD process as "NPD process is a clear mission and the steps to show that is from the concept of ideas to marketable products or services required standardized methods" [3]. Urban and Hauser (1980) [11] defined the NPD process as: (1) opportunity identification phase; (2) design phase; (3) testing phase; (4) listed phase. Cooper (1994, 1996) [12] proposed the definition of NPD process as: (1) the ideas of product; (2) initial assessment; (3) concept design; (4) product development; (5) product testing; (6) engineering trial production; (7) mass production and listed.

Today organizations have developed many different variations and varieties from the original concept of NPD process. In this paper, we propose a critical NPD process according to the NPD process definition from several scholars, which is divided into ten phases as: (1) customer needs analysis; (2) conceptual design; (3) conceptual development; (4) preliminary design; (5) design and evaluation; (6) detail design; (7) product run and test; (8) pre-mass production run and test; (9) mass production listing; (10) transference. We also create a quality assessment system of NPD based on these NPD phases as shown in Figure 1.

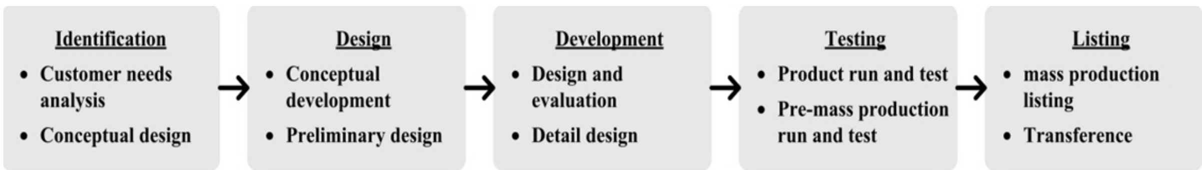

FIGURE 1. The new product development (NPD) process [3,10,13]

2.3. **Design review and verification on NPD process.** Design review (DR) is a critical and collaborative process between NPD processes. The manager is continuously to supervise and control the design targets until these goals are being met and design-related requirements are satisfied. DR is also a mechanism for ensuring design standards in the product design activities that is a kind of "breadth" review including the entire design surface. According to ISO 8420 [14] it is defined as: "DR is a formal, documented, easy to understand and a systematic review in the product design which is to assess the design requirements, to meet the capacity of requirements and has been satisfied". Furthermore, it is used to identify the problem and provide the improved countermeasures.

DR is not only supervision for the product quality, but also extended to the overall design quality control, and product design verification and validation. Therefore, it includes the review of systems, subsystems and components for the entire NPD activities [15]. The main purpose of design review is to evaluate the capacity of product design and development to meet product requirements and to clarify the other related issues of process control, production and raw materials procurement. Moreover, DR is also used to assess the product specifications to meet the intended operation or the adequacy of users' needs, and to review the consistency of product design and specification requirements.

Consequently, according to customers' needs analysis, DR is used to find optimal product design to confirm the product development and to meet customers' needs. DR can support the NPD team to meet the expected time, expected quality and expected budget requirements and the efficient execution for a series mission of NPD. It can be combined by various professional people (called experts) with the team forces to participate in the NPD.

DR is emphasis on assessment and re-examine for product design and related services to ensure the listed product quality and to improve the optimum cost. It is to use a variety of professionals brainstorming to ensure the design for meeting the standards in consistency, accessibility, usability, internationalize-ability, etc. The process of DR and verification can find out the defect of product and to modify/improve the product specification in time, so that the product can meet original requirements under the economical and efficient situations [16]. According to NPD tasks of different phases timing, the DR is divided into six steps as: (1) conceptual design review; (2) preliminary design review; (3) detailed design review; (4) critical design review; (5) final design review; (6) special review. Except for the tasks of NPD phases, other tasks of different timing requirement can be through a special review. Consequently, a design review system of NPD based on these steps is illustrated in Figure 2.

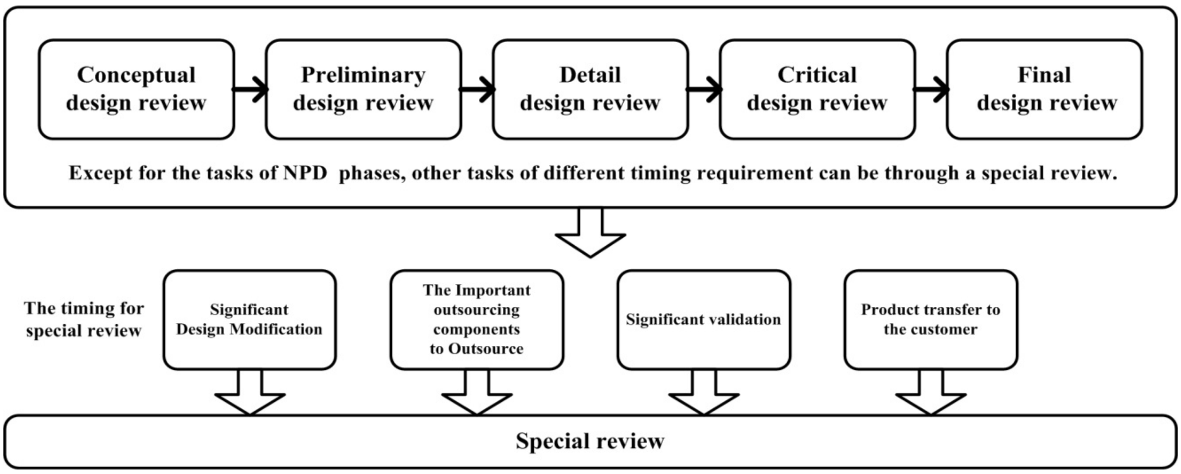

FIGURE 2. The design review (DR) process [4,14,17-19]

2.4. **The quality factors of NPD process.** According to the literature review, we define the quality of NPD process as "the quality of NPD process is a clear mission and the steps to fulfill the product or service being contented degree" [3,20,21]. We explore the quality factors of NPD process according to the ISO 9000:2008 quality management system [4,22]. Through the expert questionnaires the quality factors of NPD process are selected and divided into three dimensions of fifteen criteria, the result as shown in Table 1.

3. **Developing NPD Process Performance Evaluation Model.** To develop a NPD process performance evaluation model, we use the expert questionnaires to select the quality factors of NPD process. Then, DEMATEL is used to confirm the effect on each factor and to explore the relevance of the quality parameters. Consequently, DEMATEL is combined with ANP method to a new DANP approach to calculate the influential weights of quality factors. Ou Yang et al. (2008) [23] propose these methods to solve the dependence and feedback problems to suit the real world. It is more suitable in real word applications than the traditional ones.

Table 1. Criteria of evaluation

Dimensions	Criteria
D_1 Customer needs and satisfaction	C_1 Product specifications and customer needs analysis C_2 Compatibility of safety and environment C_3 The regulatory requirements of business practices, national and international standards C_4 To compare with the competitive products C_5 Consideration of improper use and misuse
D_2 Product specifications and requirements	C_6 The requirements of reliability, service and maintainability C_7 The allowed tolerance and process capability assessment C_8 The criteria of product acceptance and rejection C_9 Installable features and easy assembly C_{10} To review and use the standard components
D_3 Process planning and requirements	C_{11} The manufacturability of product design and development C_{12} The examination and experimentation of product design and development C_{13} The specification of materials and components C_{14} The requirements of packaging, handling, storage and storage life C_{15} Confirmation of customer needs and assessment of production costs

Finally, VIKOR is used to evaluate and improve the total performance of NPD process by using empirical case analysis, to find out the performance gaps and to improve its scores. So this section will be divided into four subsections: in Subsection 3.1 a network relationship by DEMATEL is built, in Subsection 3.2 the influential weights by using DANP are calculated, in Subsection 3.3 VIKOR method is used to evaluate and improve the total performance, and the last subsection is to construct the innovation process of NPD according to empirical analysis results.

3.1. **Building a network relationship by DEMATEL.** DEMATEL is an analytical method of structural model. It is mainly used to solve all kinds of complex problems to clarify the essential of the problem. It uses matrix and related math theories to calculate the cause and effect on each element in the degree. This method is widely used to solve various types of complex studies that can effectively understand the complex structure and provide viable options of problem-solving [24].

DEMATEL is divided into five steps. The first step is to confirm the system has n elements and develop the evaluating scale, using pair of dimensions to compare and also using evaluating scale 0, 1, 2, 3, 4, which in turn represents no effect (0), low effect (1), medium effect (2), high effect (3), and extremely high effect (4) as measuring standards in interdependence and feedback and feedback. The second step is to calculate initial matrix, using pair of degree of interaction/interdependence to obtain directly effecting matrix $\boldsymbol{Z} = [z_{ij}]_{n\times n}$, where z_{ij} represents the degree of effect on i factor effects j factor [25,27].

$$\boldsymbol{Z} = \begin{bmatrix} z_{11} & \cdots & z_{1j} & \cdots & z_{1n} \\ \vdots & & \vdots & & \vdots \\ z_{i1} & \cdots & z_{ij} & \cdots & z_{in} \\ \vdots & & \vdots & & \vdots \\ z_{n1} & \cdots & z_{nj} & \cdots & z_{nn} \end{bmatrix} \quad (1)$$

When the elements of i have a direct effect on the elements of j, then $z_{ij} \neq 0$, opposite $z_{ij} = 0$. The third step is to normalize the matrix. It can be obtained from Equations (2) and (3). Its diagonal is 0, and maximum sum of row or column is 1.

$$\boldsymbol{X} = s\boldsymbol{Z} \tag{2}$$

$$s = \min\left[\frac{1}{\max_i \sum_{j=1}^{n} |z_{ij}|}, \frac{1}{\max_j \sum_{i=1}^{n} |z_{ij}|}\right], \quad i, j = 1, 2, \ldots, n \tag{3}$$

The fourth step is to obtain the total influence matrix $\boldsymbol{T}$. It can be obtained by $\boldsymbol{T} = \boldsymbol{X} + \boldsymbol{X}^2 + \cdots + \boldsymbol{X}^h = \boldsymbol{X}(\boldsymbol{I} - \boldsymbol{X})^{-1}$, when $\lim_{h\to\infty} \boldsymbol{X}^h = [0]_{n\times n}$, where $\boldsymbol{I}$ is the identity matrix, $\boldsymbol{X} = [x_{ij}]_{n\times n}$, $0 \leq x_{ij} < 1$, $0 < \sum_{j=1}^{n} x_{ij} \leq 1$, $0 < \sum_{i=1}^{n} x_{ij} \leq 1$. If at least one row or column of summation is equal to 1 (but not all) in $\sum_{j=1}^{n} x_{ij}$ and $\sum_{i=1}^{n} x_{ij}$, then we can guarantee $\lim_{h\to\infty} \boldsymbol{X}^h = [0]_{n\times n}$.

The fifth step is to obtain prominence and relation. To sum of each row and column of the total influence matrix $\boldsymbol{T} = [t_{ij}]_{n\times n}$. It will obtain the sum of all rows (vector $\boldsymbol{r} = r_1, \ldots, r_i, \ldots, r_n$) and the sum of all columns (vector $\boldsymbol{d} = (d_1, \ldots, d_j, \ldots, d_n)$).

$$\boldsymbol{T} = [t_{ij}]_{n\times n}, \quad i, j = 1, 2, \ldots, n \tag{4}$$

$$\boldsymbol{r} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [t_{i.}]_{n\times 1} = (r_1, \ldots, r_i, \ldots, r_n)' \tag{5}$$

$$\boldsymbol{c} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} = [t_{.j}]_{n\times 1} = (c_1, \ldots, c_j, \ldots, c_n)' \tag{6}$$

If r_i represents the sum of all rows of the total influence matrix $\boldsymbol{T}$, meaning directly or indirectly influence degree; d_j represents the sum of all columns of the total influence matrix $\boldsymbol{T}$, meaning influence or be influenced other criteria. r_i represents the factor which will influence other factors, d_j represents the factor that is influenced by other factors. According to the definition when $i = j$, $r_i + d_i$ presents the degree of total relationship between the factors, meaning "prominence"; $r_i - d_i$ presents the degree of influence and influenced for the factors, meaning "influential relation" [24,28].

3.2. **To find the influential weights by DANP model.** We not only use DEMATEL to confirm the interacting relationship with each factor, but also want to obtain the most accurate influential weights. Then, we can find DANP that can serve this purpose based on basic concept of ANP by Saaty (1996) [29]. The purpose of ANP can be to solve the dependence and feedback problems of criteria. Therefore, we apply the characteristics of basic ANP concept to combining with DEMATEL to solve this kind of problems. It will yield a more practical result. DANP can be divided into following steps [30]. The fist step is to develop the structure of the problem questions. The problem questions are clearly described then break them down to level structure. The second step is to develop Unweighted Supermatrix, normalize each level (dimension/cluster) with total degree of influence that obtains from the total influence matrix $\boldsymbol{T}$ of DEMATEL as shown in Equation (4).

$$
\boldsymbol{T}_c = \begin{array}{c} \\ D_1 \; c_{11}, c_{12}, \ldots, c_{1m_1} \\ \vdots \\ D_i \; c_{i1}, c_{i2}, \ldots, c_{im_i} \\ \vdots \\ D_n \; c_{n1}, c_{n2}, \ldots, c_{nm_n} \end{array}
\begin{array}{c} \begin{array}{ccccc} D_1 & & D_j & & D_n \\ c_{11}\ldots c_{1m_1} & \cdots & c_{j1}\ldots c_{jm_j} & \cdots & c_{n1}\ldots c_{nm_n} \end{array} \\
\begin{bmatrix} \boldsymbol{T}_c^{11} & \cdots & \boldsymbol{T}_c^{1j} & \cdots & \boldsymbol{T}_c^{1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{i1} & \cdots & \boldsymbol{T}_c^{ij} & \cdots & \boldsymbol{T}_c^{in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{n1} & \cdots & \boldsymbol{T}_c^{nj} & \cdots & \boldsymbol{T}_c^{nn} \end{bmatrix} \end{array} \tag{7}
$$

Normalize $\boldsymbol{T}_c$ with total degree of effect will be obtained $\boldsymbol{T}_c^{\alpha}$ by dimensions/clusters as shown in Equation (8).

$$
\boldsymbol{T}_c^{\alpha} = \begin{array}{c} \\ D_1 \; c_{11}, c_{12}, \ldots, c_{1m_1} \\ \vdots \\ D_i \; c_{i1}, c_{i2}, \ldots, c_{im_i} \\ \vdots \\ D_n \; c_{n1}, c_{n2}, \ldots, c_{nm_n} \end{array}
\begin{array}{c} \begin{array}{ccccc} D_1 & & D_j & & D_n \\ c_{11}\ldots c_{1m_1} & \cdots & c_{j1}\ldots c_{jm_j} & \cdots & c_{n1}\ldots c_{nm_n} \end{array} \\
\begin{bmatrix} \boldsymbol{T}_c^{\alpha 11} & \cdots & \boldsymbol{T}_c^{\alpha 1j} & \cdots & \boldsymbol{T}_c^{\alpha 1n} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{\alpha i1} & \cdots & \boldsymbol{T}_c^{\alpha ij} & \cdots & \boldsymbol{T}_c^{\alpha in} \\ \vdots & & \vdots & & \vdots \\ \boldsymbol{T}_c^{\alpha n1} & \cdots & \boldsymbol{T}_c^{\alpha nj} & \cdots & \boldsymbol{T}_c^{\alpha nn} \end{bmatrix} \end{array} \tag{8}
$$

Normalize $\boldsymbol{T}_c^{\alpha 11}$ will be obtained by Equations (9) and (10) in dimension 1, and repeat that to obtain $\boldsymbol{T}_c^{\alpha nn}$ in dimension n.

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

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

And then, total effect matrix is normalized into Supermatrix according to the dimensions in interdependent relationship to obtain Unweighted Supermatrix as shown in Equation (11).

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

In addition, we will be obtained matrix $\boldsymbol{W}^{11}$ by Equation (12). If blank or 0 shown in the matrix means the dimension or criteria is independent, according to the same fashion will be obtained matrix $\boldsymbol{W}^{nn}$.

$$\boldsymbol{W}^{11} = (\boldsymbol{T}^{11})' = \begin{array}{c} \\ c_{11} \\ \vdots \\ c_{1j} \\ \vdots \\ c_{1m_1} \end{array} \begin{array}{c} c_{11} \cdots c_{1i} \cdots c_{1m_1} \\ \begin{bmatrix} t_{c_{11}}^{\alpha 11} & \cdots & t_{c_{i1}}^{\alpha 11} & \cdots & t_{c_{m_1 1}}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c_{1j}}^{\alpha 11} & \cdots & t_{c_{ij}}^{\alpha 11} & \cdots & t_{c_{m_1 j}}^{\alpha 11} \\ \vdots & & \vdots & & \vdots \\ t_{c_{1m_1}}^{\alpha 11} & \cdots & t_{c_{im_1}}^{\alpha 11} & \cdots & t_{c_{m_1 m_1}}^{\alpha 11} \end{bmatrix} \end{array} \tag{12}$$

The third step is to obtain Weight Supermatrix, make dimensions total effect relationship matrix $\boldsymbol{T}_D$ as Equation (10). Let each dimension of matrix $\boldsymbol{T}_D$ be normalized with total degree of effect to obtain $\boldsymbol{T}_D^\alpha$ by dimensions, the result as Equations (13) and (14).

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

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

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

Then, drive the normalized $\boldsymbol{T}_D^\alpha$ into Unweight Supermatrix $\boldsymbol{W}$ to obtain Weight Supermatrix $\boldsymbol{W}^\alpha$, the result as shown in Equation (15).

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

The fourth step is to obtain limit supermatrix. The weighted supermatrix is multiplied by itself multiple times to obtain the limit supermatrix (the concept based on Markov Chain). Then, the influential weights of each criterion can be obtained by $\lim_{z\to\infty}(\boldsymbol{W}^\alpha)^z$; in other word, the influential weights of ANP can be obtained and denoted the limit supermatrix $\boldsymbol{W}^\alpha$ with power z (z representing any number for power); we call this process as DANP.

3.3. **Evaluating the total performance by VIKOR.** VIKOR was developed by Opricovic (1998) [30]; it uses the concept of compromise to evaluate the standards of different projects in the competition from MCDM model. It based on the basic concept of the Positive-ideal (or the Aspiration level) solution and Negative-ideal (or the Worst value) solution, we can put the results in order. It is better to close the positive-ideal point (the aspired level) and farther to the negative-ideal point (the worst value). VIKOR can be divided into the following steps:

The first step is to check the best value f_j^* and the worse value f_j^- in assessment criteria of the quality factors to modify the traditional approach. In this paper there f_j^* represents the positive-ideal point, which means the expert gives the scores of the best value (aspiration levels) in each criterion and f_j^- represents the negative-ideal point, which means the expert gives the scores of the worst values in each criterion. We use Equations (16) and (17) to obtain the results.

$$f_j^* = \max_k f_{kj}, \quad j = 1, 2, \ldots, n \text{ (traditional approach)}$$
$$\text{or setting the aspired levels, vector } \boldsymbol{f}^* = (f_1^*, f_2^*, \ldots, f_n^*) \tag{16}$$
$$f_j^- = \min_k f_{kj}, \quad j = 1, 2, \ldots, n \text{ (traditional approach)}$$
$$\text{or setting the worst values, vector } \boldsymbol{f}^- = (f_1^-, f_2^-, \ldots, f_n^-) \tag{17}$$

The second step is to calculate the mean of group utility S_k and maximal regret Q_k. There S_k represents the ratios of gap distance to the aspiration level, and it means the synthesized gaps for all criteria; w_j represents the relative influential weights of the criteria from DANP; r_{kj} represents the ratios of normalized the gap distance to the aspiration level, and Q_k represents the ratios of gap distance to the worst value; in other words it means the maximal gap in k criteria for priority improvement. Those values can be computed respectively by Equations (18) and (19).

$$S_k = \sum_{j=1}^{n} w_j r_{kj} = \sum_{j=1}^{n} w_j \left(|f_j^* - f_{kj}|\right) / \left(|f_j^* - f_j^-|\right) \tag{18}$$
$$Q_k = \max_j \{r_{kj} | j = 1, 2, \ldots, n\} \tag{19}$$

The third step is to obtain the comprehensive indicator R_k and sorting results. The values can be computed respectively by Equation (20).

$$R_k = v(S_k - S^*)/(S^- - S^*) + (1 - v)(Q_k - Q^*)/(Q^- - Q^*) \tag{20}$$

Those values derived from $S^* = \min_k S_k$ or setting $S^* = 0$ (the aspiration level), $S^- = \max_k S_k$ or setting $S^- = 1$ (the worst situation); $Q^* = \min_k Q_k$ or setting $Q^* = 0$ (the aspiration level), and $Q^- = \max_k Q_k$ or setting $Q^- = 1$ (the worst situation). Therefore, when $S^* = 0$ and $S^- = 1$, and $Q^* = 0$ and $Q^- = 1$, we can re-write Equation (17) as $R_k = vS_k + (1 - v)Q_k$. Weight $v = 1$ represents only to be consider the average gap (average regret) weight and weight $v = 0$ represents only to be consider the max gap to be prior improvement. It can provide the decision-makers by experts. Generally $v = 0.5$, it could be adjusted depending on the situation.

3.4. **Data collection.** According to ISO 9001 [31] it specifies requirements for a quality management system where an organization needs to demonstrate its ability to provide products that fulfill customer and applicable regulatory requirements and aims to enhance customer satisfaction. Besides, the data collection of this study uses ISO9000 series of quality management systems standards, the design review, and expert interviews to select quality factors of NPD process as the basis. The main survey objects engage for the NPD and quality control audits within related areas of experts or scholars who have more than two years project management experience of average within the person of company A in real case.

4. **Empirical Case Analysis for NPD Process.** This Section will be exploring the quality assessment for NPD process within the case study of company A. We will consider the product manufacturing and testing that may have potential problems and risks in the NPD process. And, we also must take into consideration about the problem that users consider in using the products. So we evaluate the degree of preference to determine the weight of various factors and to identify the critical quality factors of NPD process according to the empirical analysis. Through the literature of the past NPD by the collection, analysis, simulation and testing find problem spots, this process requires a strict quality management as a basis.

4.1. **Constructing the network by DEMATEL.** In this paper, we have confirmed DEMATEL decision-making structure, and analyzed three dimensions with fifteen quality criteria of NPD process. According to the expert questionnaires, we obtain the total effect matrix $\boldsymbol{T}$ of dimensions and criteria such as shown in Table 2 to Table 4. We can find the cognition and opinion from experts in three dimensions, and the relationship between the extents of the impact can also be found which is compared with other dimensions as shown in Table 2.

According to the total influential prominence $(r_i + d_i)$, "the product specifications and requirements (D_2)" is the highest impact of the strength of relation that means the most important influencing factors; in addition, "the process planning and requirements (D_3)" is all the factors that affect the least degree of other factors. According to the influential relation $(r_i - d_i)$, we can also find "product specifications and requirement (D_2)" and "process planning and requirements (D_3)" both are the highest degree of impact relationship that affect other factors directly. D_2 and D_3 also have the interact characteristics. Otherwise, "customer needs and satisfaction (D_1)" is the most vulnerable to impact that compare with other dimensions.

TABLE 2. The total effect matrix of $\boldsymbol{T}$ and sum of effects on dimensions

Dimensions	D_1	D_2	D_3	r_i	d_i	$r_i + d_i$	$r_i - d_i$
D_1 Customer needs and satisfaction	0.63	0.65	0.62	1.90	1.95	3.85	−0.05
D_2 Product specifications and requirement	0.67	0.66	0.65	1.98	1.96	3.94	0.02
D_3 Process planning and requirements	0.64	0.65	0.60	1.89	1.86	3.75	0.02

TABLE 3. The total influence matrix of $\boldsymbol{T}_c$ for criteria

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
C_1	0.62	0.66	0.70	0.69	0.65	0.73	0.67	0.67	0.69	0.64	0.70	0.67	0.72	0.53	0.65
C_2	0.64	0.58	0.68	0.65	0.62	0.70	0.64	0.64	0.65	0.62	0.65	0.63	0.68	0.50	0.61
C_3	0.66	0.68	0.63	0.66	0.63	0.71	0.66	0.65	0.66	0.63	0.66	0.65	0.69	0.52	0.65
C_4	0.65	0.64	0.67	0.59	0.60	0.70	0.64	0.63	0.67	0.61	0.67	0.64	0.68	0.51	0.62
C_5	0.62	0.60	0.62	0.59	0.51	0.66	0.59	0.57	0.59	0.56	0.60	0.58	0.62	0.46	0.57
C_6	0.71	0.70	0.73	0.71	0.66	0.68	0.69	0.68	0.70	0.66	0.71	0.69	0.74	0.55	0.67
C_7	0.70	0.70	0.74	0.71	0.66	0.76	0.64	0.71	0.73	0.68	0.73	0.70	0.77	0.56	0.69
C_8	0.63	0.62	0.65	0.62	0.58	0.67	0.62	0.55	0.64	0.59	0.62	0.61	0.65	0.48	0.59
C_9	0.65	0.63	0.66	0.65	0.60	0.68	0.64	0.63	0.59	0.62	0.65	0.62	0.68	0.50	0.61
C_{10}	0.69	0.70	0.73	0.69	0.66	0.75	0.69	0.69	0.71	0.60	0.70	0.68	0.74	0.54	0.67
C_{11}	0.67	0.68	0.71	0.69	0.64	0.74	0.68	0.67	0.70	0.65	0.63	0.67	0.72	0.53	0.64
C_{12}	0.64	0.64	0.67	0.66	0.60	0.70	0.64	0.63	0.66	0.61	0.65	0.57	0.69	0.49	0.60
C_{13}	0.68	0.69	0.72	0.69	0.63	0.74	0.68	0.67	0.69	0.65	0.70	0.67	0.65	0.53	0.66
C_{14}	0.54	0.53	0.57	0.55	0.51	0.59	0.54	0.54	0.54	0.51	0.53	0.52	0.56	0.38	0.49
C_{15}	0.66	0.66	0.70	0.67	0.63	0.72	0.66	0.64	0.67	0.63	0.66	0.64	0.69	0.50	0.57

TABLE 4. The sum of effects, the weight and ranking of each criterion

Criteria	r_i	d_i	$r_i + d_i$	$r_i - d_i$	Degree of importance (Global weight)	Ranking
D_1					**0.337**	**2**
C_1	9.98	9.76	19.74	0.23	0.068	3
C_2	9.48	9.72	19.20	−0.23	0.067	4
C_3	9.75	10.18	19.93	−0.43	0.071	1
C_4	9.52	9.82	19.34	−0.30	0.068	2
C_5	8.75	9.18	17.92	−0.43	0.064	5
D_2					**0.340**	**1**
C_6	10.26	10.53	20.80	−0.27	0.073	1
C_7	10.49	9.69	20.19	0.80	0.067	3
C_8	9.11	9.57	18.69	−0.46	0.066	4
C_9	9.43	9.89	19.32	−0.46	0.069	2
C_{10}	10.23	9.26	19.49	0.97	0.064	5
D_3					**0.323**	**3**
C_{11}	10.02	9.87	19.88	0.15	0.068	2
C_{12}	9.46	9.53	18.99	−0.06	0.066	3
C_{13}	10.04	10.28	20.33	−0.24	0.071	1
C_{14}	7.90	7.58	15.48	0.32	0.053	5
C_{15}	9.71	9.29	19.00	0.42	0.064	4

According to Table 3, we can obtain all the criteria of the impact of relations with each factor. And then, Table 4 shows the relationship between the extent of the impact that can find directly or indirectly effect to compare with other criteria. "The requirements of reliability, service and maintainability (C_6)" is the most important considerations criteria; in addition, "the requirements of packaging, handling, storage and storage life (C_{14})" is the impact of all criteria in the least degree of other criteria.

Furthermore, we can also find in Table 4 that "to review and use the standard components (C_{10})" is the highest degree of impact relationship in all the criteria. Otherwise, "the criteria of product acceptance and rejection (C_8)", "installable features and easy assembly (C_9)" are the most vulnerable to impact of criteria that compare with other criteria.

4.2. **Calculating the influential weights by DANP model.** We not only use DEMATEL to confirm the interdependent relationship with the criteria, but also expect to obtain the most accurate influential weights. The purpose of ANP is to solve the dependence and feedback problems of each criterion [29]. Therefore, we structure the quality assessment model by DEMATEL which combine with ANP to DANP model to obtain the influential weight of each criterion as shown in Table 4.

In addition, we can find the criteria the critical factors in quality assessment of NPD process which is including the requirements of reliability, service and maintainability (C_6), the regulatory requirements of business practices, national and international standards (C_3) and the specification of materials and components (C_{13}). Furthermore, we use the ranking of degree of influential weights that is not cross-dimension. And then, the influential weights combine with DEMATEL model to evaluate the priority improvement of problem-solving.

4.3. **Evaluating and improving the total performance by VIKOR.** In this paper, we structure an innovation process of NPD process according to DEMATEL model, and through the case study of company A evaluate and improve the total performance of NPD process by using VIKOR through DEMATEL method as shown in Table 5. The scores of each criterion and total gap (S_k) of company A is obtained by using the relative influential weights from DANP to multiply the gap (r_{kj}). Consequently, we can obtain the total performance of company A according to the score values.

Then, we can also obtain the maximal regret (Q_k) which shows the specification of materials and components (C_{13}) is the maximal gap in all the criteria for priority improvement. Otherwise, product specifications and customer needs analysis (C_1) is the minimal gap to compare with other criteria.

In addition, we will obtain the comprehensive indicator (R_k) which value of v can make decisions by the expert that is defined as $v = 0.5$ in this paper. We obtain the result of the comprehensive indicator (R_k) is 0.41 less than 0.5 that represents company A must improve the gap of total performance in NPD process. Furthermore, the manager can find the problem-solving points according to the DEMATEL model and combine with DANP.

Table 5. The performance evaluation of case study by VIKOR

Dimensions /Criteria	Local Weights	Global weights (by DANP)	Case study of company A	
			Scores	Gaps (r_{kj})
D_1	**0.337(2)**		**2.900**	**0.275**
C_1	0.201	0.068(3)	3.750	0.063
C_2	0.200	0.067(4)	3.000	0.250
C_3	0.209	0.071(1)	2.500	0.375
C_4	0.202	0.068(2)	3.000	0.250
C_5	0.189	0.064(5)	2.250	0.438
D_2	**0.340(1)**		**2.650**	**0.338**
C_6	0.215	0.073(1)	2.500	0.375
C_7	0.198	0.067(3)	2.250	0.438
C_8	0.195	0.066(4)	2.750	0.313
C_9	0.202	0.069(2)	3.250	0.188
C_{10}	0.189	0.064(5)	2.500	0.375
D_3	**0.323(3)**		**2.600**	**0.350**
C_{11}	0.212	0.068(2)	2.500	0.375
C_{12}	0.205	0.066(3)	2.750	0.313
C_{13}	0.221	0.071(1)	2.000	0.500
C_{14}	0.163	0.053(5)	3.250	0.188
C_{15}	0.200	0.064(4)	2.500	0.375
Total performances		–	**2.718**	–
Total gap (S_k)		–	–	**0.320**

4.4. **Results and discussions.** The entire result is proved by the empirical analysis as shown in Figure 3 and Figure 4. Figure 3 illustrates the relationship of each dimension and criterion. According to this system structure model, we restructure an innovative NPD process which combines DR with system thinking model for the product manager to ensure the quality assurance and consistence in NPD process as shown in Figure 4. This system structure model is a comprehensive and systematic examination of the design to evaluate the adequacy of the design requirements and the capability of the design in order to meet these requirements and to identify problems [31]. In this model (Figure 4) is divided

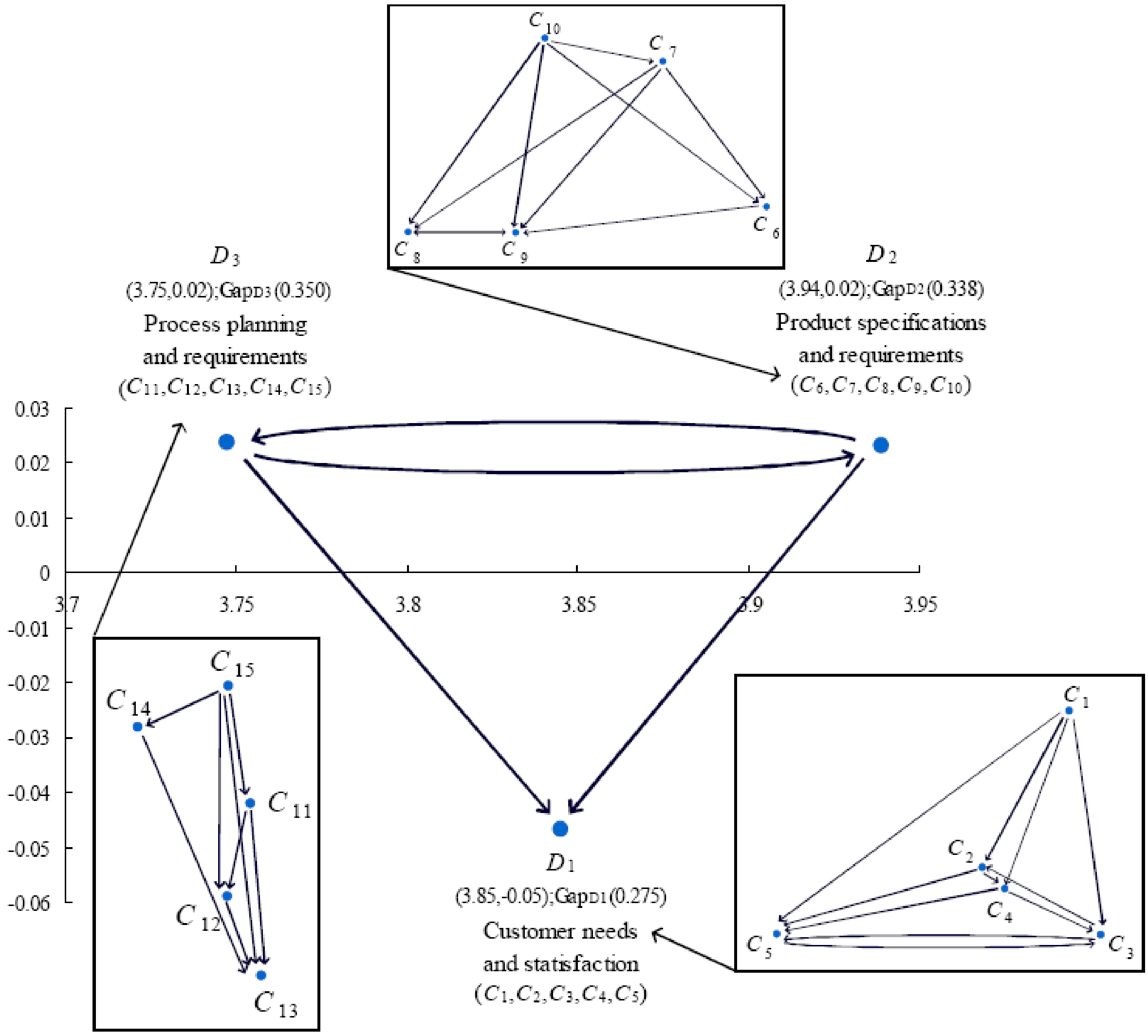

FIGURE 3. The relationship of each dimension and criterion

into three parts: the upper part is NPD process into five phases; the intermediate part is the structure of NPD design criteria; the bottom part is DR process into five stages. In addition, the special review is divided into four parts which is including significant design modification, the importance components to outsource, significant validation and product transfer to the customer according to the different timing to conduct.

The first phase is "identification phase" divided into two steps of "customer needs analysis" and "conceptual design" to confirm the needs from the customer or other stakeholders. Holt et al. (1984) [32] indicate the customer need assessment is understood broadly as the activities concerned with the recognition, gathering and clarification of customer needs and their importance to determine need specifications and objectives for the new products. This phase shows the criteria of design review including "product specifications and customer needs analysis (C_1)", "compatibility of safety and environment (C_2)" and "comparative with the competitive products (C_4)". This stage applies "conceptual design review" to checking the process quality. The purpose of this step is to ensure the initial design direction maps to the product goals and user needs, and to review the design for alignment with broader initiatives and possible integration with other product designs.

The second phase is "design phase" divided into two steps of "conceptual development" and "preliminary design" to develop the concept for the new product and to transfer the

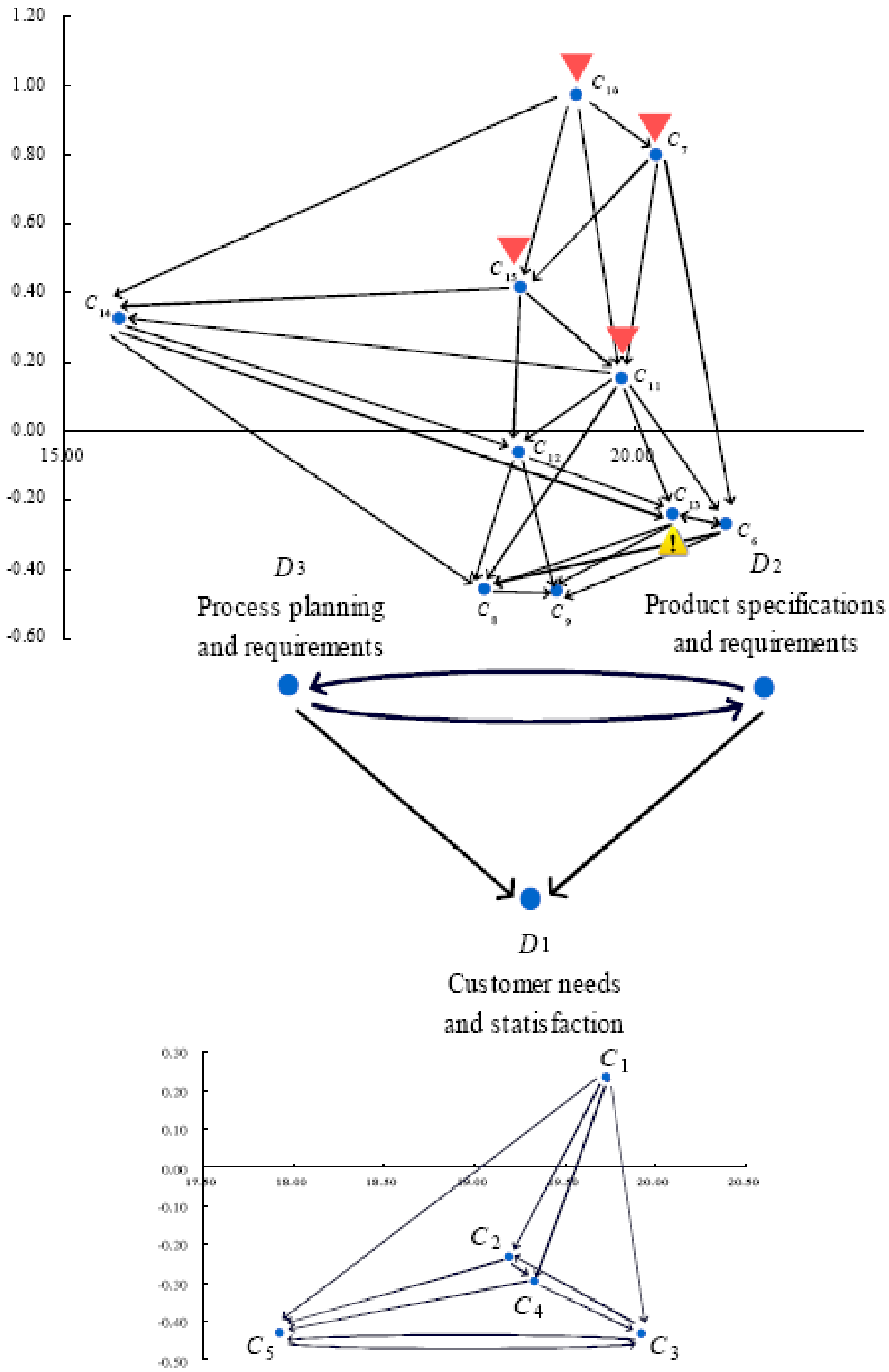

Figure 4. The interrelationship of D_2 and D_3 to influence D_1

conceptual product of customer needs into the specific product design requirements. This phase shows the criteria of design review including "the regulatory requirements of business practices, national and international standards (C_3)", "the consideration of improper use and misuse (C_5)", "the requirements of reliability, service and maintainability (C_6)" and "the manufacturability of product design and development (C_{11})". This stage applies "preliminary design review" to repeating checking the product according to the product levels including the product specifications, assembly combinations and conceptual design.

The purpose is to ensure customer needs is covered and satisfied. It can through sample run to check the materials, specifications, and to confirm the feasibility of product development in order to meet the initial requirements of product. The purpose is to reduce the uncertainty of NPD and to confirm quality and safety of product.

The third phase is "development phase" divided into two steps of "design and evaluation" and "detail design" to design and evaluate for the product requirements. This phase shows the criteria of design review including "installable features and easy assembly (C_9)", "to review and use the standard components (C_{10})", "the specification of materials and components (C_{13})" and "confirmation of customer needs and assessment of production costs (C_{15})". This stage applies "detail design review" to checking process quality whose purpose is to review specific interaction behaviors and to provide guidance to designers on problematic issues in order to confirm its meets required design standards.

The fourth phase "testing phase" divided into two steps of "product run and test" and "pre-mass production run and test" to evaluate the result of product test and to ensure the manufacturability of NPD. This phase shows the criteria of design review including "the allowed tolerance and process capability assessment (C_7)", "product acceptance and rejection (C_8)" and "the examination and experimentation of product design and development (C_{12})". This stage applies "critical design review" to checking quality of process whose purpose is to verify the comprehensive design work, so that the products can transfer to the production and listed.

The final phase "listed phase" divided into two steps of "mass production listing" and "transference" to supervise the listed product quality. This phase shows the criteria of design review including "the requirements of packaging, handling, storage and storage life (C_{14})". This stage applies the kind of "final design review" to checking whole process quality of NPD whose purpose is through the criteria of rejection and acceptance to meet the requirements according to these standards of above all. Through the rigorous review standards ensure the customer needs and requirements definition for the quality of NPD process.

Furthermore, we could find the maximal regret (Q_k) to illustrate "the specification of materials and components (C_{13})" is the maximal performance gap in all the criteria according to the result of empirical case analysis. It is also affected by criteria in this dimension as shown in Figure 3. Then, we can find the spot of problem-solving in Figure 3 and Figure 4. Illustrated by "the requirements of reliability, service and maintainability (C_6)", "the allowed tolerance and process capability assessment (C_7)", "to review and use the standard component (C_{10})", "the requirements of packaging, handling, storage and storage life (C_{14})", "confirmation of customer needs and assessment of production costs (C_{15})". It can combine with design review of different phases to check the materials and components that will improve the quality performance of NPD process for company A.

5. **Conclusion.** The diagram shown in Figure 4 illustrates the relationship between the innovative NPD process and DR with system thinking model. In this system structure model of intermediate part is the system thinking model of NPD design criteria using DEMATEL relationship for the basis. We restructure this innovative NPD design criteria structure model according to the result of empirical analysis whose purpose is to discover and predict the problems and shortcomings of the NPD process. The result of this study will provide NPD team a guidance to continuously improve, track and meet the quality assurance of NPD process; consequently, the customer needs can be satisfied and the new product requirements can be covered.

According to the DEMATEL model (Figure 3), we could recognize the interrelationship of each dimension and criterion. Furthermore, the dimensions of "process planning and requirements (D_2)" and "product specifications and requirements (D_3)" have a significant interrelationship as shown in Figure 5. This system structure model illustrates that the criterion of "the specification of materials and components (C_{13})" is the maximal performance gap. From Figure 5, we could not only find the problem-solving points but also find

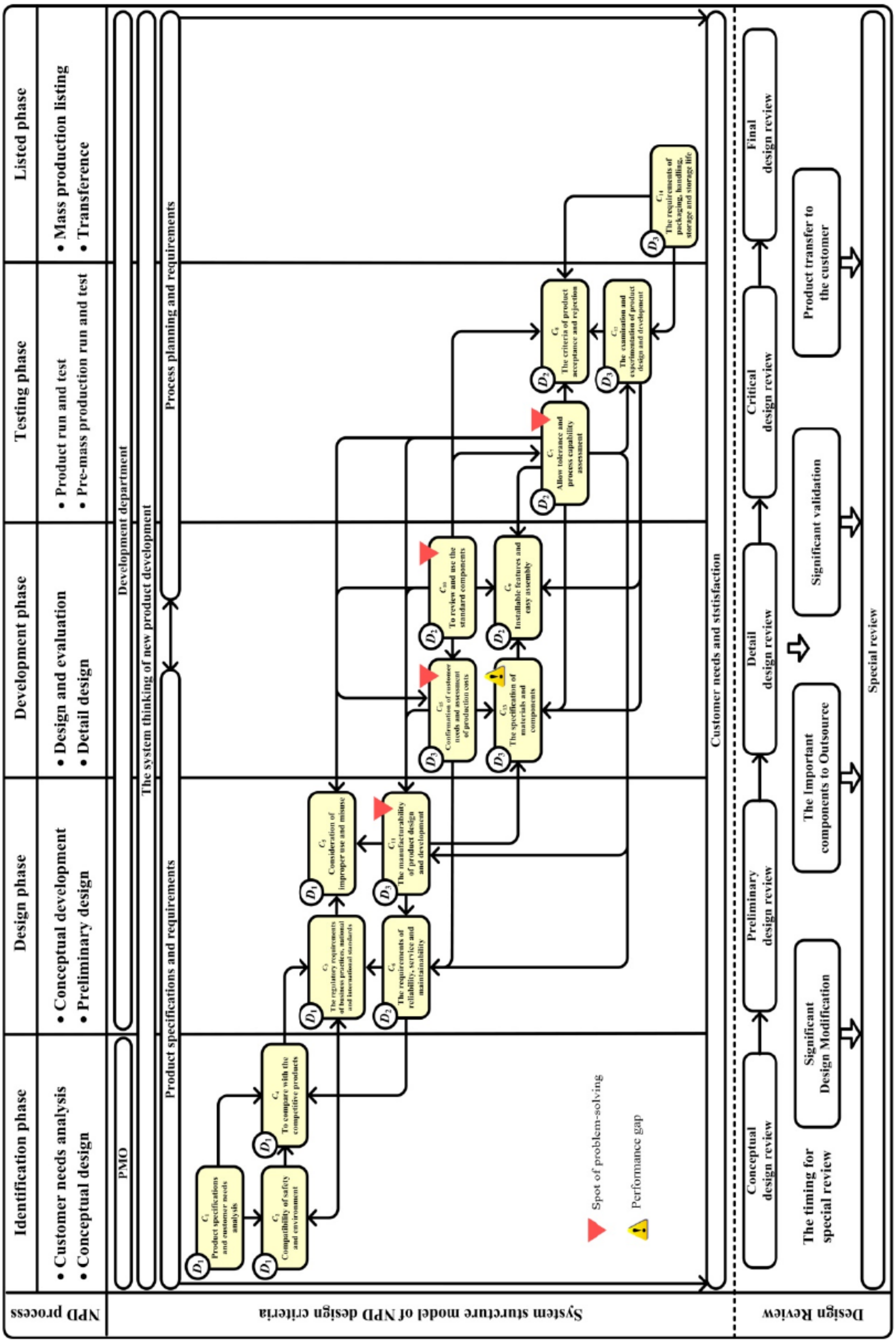

FIGURE 5. The innovative quality system structure model of NPD design criteria by integrating NPD process and the system thinking model

the following criterion of "the allowed tolerance and process capability assessment (C_7)", "to review and use the standard component (C_{10})", "the manufacturability of product design and development (C_{11})" and "confirmation of customer needs and assessment of production costs (C_{15})" have extremely interrelationship between each other. According to the effect relationship of these criteria, could the quality criterion of "the specification of materials and components (C_{13})" be directly improved in order to reduce the performance gap. Furthermore, this performance gap must also be improved by the criteria of "the allowed tolerance and process capability assessment (C_7)", "to review and use the standard component (C_{10})", "the manufacturability of product design and development (C_{11})" and "confirmation of customer needs and assessment of production costs (C_{15})".

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