

Probing Performance Evaluation for NPD Process by Using Fuzzy MCDM Approach

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Abstract: Due to the rapid changing marketplace, technology, equipment and raw materials, companies pursuit competitiveness by the new product and new product development (NPD) process for the purpose of innovation, high quality, and speed to the market. It is a gradual trend that the product life cycle is becoming shorter. The product manager intends to achieve the highest customer satisfaction, product value and product continuity. Therefore, to evaluate performance of NPD becomes a critical issue on the NPD process selection which is considered in many different uncertain aspects. Thus, this situation can be regarded as a fuzzy multiple criteria decision-making (FMCDM) problem, so the vagueness and uncertainty of subjective perception could be considered. In this paper, the non-additive (called super-additive) fuzzy integral is used to deal with evaluation of fuzzy MCDM problems particularly while there is dependence among the selected criteria. We can evaluate the quality performance of NPD process according to the result of empirical analysis. Consequently, DEMATEL is used to explore the relevance for the selected criteria of NPD process which is used to find the directions of problem-solving. The results of this study will provide NPD project team a guidance to satisfy the customer needs and creative the value of enterprise business.

Keywords: New product development (NPD), fuzzy multiple criteria decision-making (FMCDM), fuzzy integral, DEMATEL

I. INTRODUCTION

Due to the rapid changing marketplace, technology, equipment and raw materials, companies try to seek competitiveness by the product and new product development (NPD) process for the purpose of innovation, high quality, and speed to the market. It is a gradual trend that the product life cycle is becoming shorter. The manager intends to achieve the highest customer satisfaction, product value and product continuity. For the company, to select and evaluate is greatly critical on the NPD process which needs to be considered in different aspects [1]. As a result the high quality of NPD process has become the critical success factors of new product development.

Garvin (1984) thinks quality improvement is beneficial for market expansion and cost reduction, so the appropriate and high quality NPD process can provide the enterprise sustainable business. Its can increase the sense of reliance of product for obtaining the positive impression to create a good product (brand) image [5]. In 1987, the International Organization for Standardization (ISO) released ISO 9000 series of quality management system and quality assurance standards, most companies are using this standard to improve the process quality of enterprise. The enterprises of various

fields that 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.

The development of new products and services involves an integrated set of unique activities. U.S. Product Development and 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, check and execute a formal written review of the mission results under the appropriate stage of NPD process [27].

This study is based on ISO 9000:2008 quality management system to explore the evaluation indexes for the quality of NPD process [25]. The purpose here is to construct a model that not only considers in the presence of intangible attributes and uncertainty such has inter-dependent characteristics between attributes. First, a fuzzy integral is applied to integrate the performance rating of attributes in each criterion. The results can obtain the total performance of each dimension for the case study. Second, DEMATEL is used to construct the relevance for the evaluated criteria. Then, the manager can find the direction of problem-solving from DEMATEL. The results of this study will provide NPD team a guidance to satisfy the customer needs and create the value of sustainable business.

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. The result and discussions is in Section 5. Finally, conclusion is presented in Section 6.

II. LITERATURE RELATED ON NPD PROCESS

This section is aimed to understand the evaluation indexes 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 requires strict quality management as a basis. We use ISO9000 series of quality management system standards to explore the related evaluation indexes of process quality.

A. The new product development (NPD)

Sampson (1970) 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" [2]. Souder (1988) defined the new product is based

on the view of business as “it has never owned products in previous” [7]. Kolter (1994) 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 [8]. In addition, it is including an old product introduced in a new market or packaged and marketed in 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 [12].

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 [13]. Therefore, the managers reduce and control the uncertainty activities before the next phase is implemented according to the integrity of information. It can ensure to improve the performance and quality of NPD.

B. New product development (NPD) process

From the past product idea to the new product development starts with the cumulative ideas. The idea generation is a NPD process in which creative thinking is used to produce large amount of ideas for new products. Therefore, NPD process may be accepted as a dynamic process in which each decision-making on each stage must be evaluated, selected, and prioritized. All the stages of the process are affected by uncertain, changing information and dynamic opportunities [18]. It is greatly complex and widely which is combined by many different aspects. The NPD process not only evaluates the gathered ideas but also has a specific purpose, which involve the whole of the enterprise including its customer, cost, time, technical, raw materials, regulatory requirement and the person in charge. Furthermore, the management of ideas is also very important at this stage due to the large number of ideas to be selected and their diversity.

Urban and Hauser (1980) defined the NPD process as: (1) opportunity identification phase; (2) design phase; (3) testing phase; (4) listed phase [4]. Cooper (1994, 1996) 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 [9][11]. To overview of the NPD process concept which is extended by the concept of stage and gate. A “Stage-Gate Process” is a conceptual and operational roadmap for moving a new-product project from idea to launch. Stage-Gate divides the effort into distinct stages separated by management decision gates. Cross-functional teams must successfully complete a prescribed set of related cross-functional tasks in each stage prior to obtaining management approval to proceed to the next stage of product development [14].

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 the concept of stage and gate, which is divided into five parts for 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, these NPD phases combine with the design review [3,10,13,14].

C. The evaluation indexes for NPD process

We explore the evaluation indexes of NPD process according to the ISO 9000:2008 quality management system [23][15]. Through the expert questionnaires select and evaluate the evaluation indexes according to its properties which is selected and divided into fifteen criteria, the result as shown in Table 1.

III. DEVELOPING AN EVALUATION MODEL FOR NPD PROCESS

In this paper, the fuzzy integral is used to combines the efficient value of those related attributes and to develop a new combining performance value [20]. Then, DEMATEL is used to explore the affect and relevance for the criteria of each dimension respectively which can provide the product manager to find the directions of problem-solving for the performance gaps of NPD process [28].

A. Regrouping the evaluation indexes of NPD process by fuzzy integral

The traditional multi-criteria decision-making evaluation is based on the assumption that each attribute is independent with the evaluation of multiple attributes executed by simply weighting the relative importance and performance of each [20][10]. The integrated performance is measured by weighting and performance for each attribute. In the real world, there are some inter-dependent characteristics between attributes. Therefore, partitioning the type of fuzzy integral has to be applied on these related attributes to regroup a new hierarchy system [20][3].

TABLE I. THE EVALUATION INDEXES OF NPD PROCESS [23][15]

Criteria for the process quality
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
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
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

B. λ -Fuzzy measure

Fuzzy measure is a set function, let g_λ be a λ fuzzy measure which is defined on a power set $P(x)$, for the finite set $X = \{x_1, x_2, \dots, x_n\}$ [16]. The fuzzy measure has the following property [19] [22]:

$$\forall A, B \in P(x), \quad A \cap B = \emptyset,$$

$$g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A)g_\lambda(B) \quad (1)$$

for $-1 < \lambda < \infty$

The

density of the fuzzy measure $g_i = g_\lambda(\{x_i\})$ can be formulated as

$$\begin{aligned} g_\lambda(\{x_1, x_2, \dots, x_n\}) &= \sum_{i=1}^n g_i + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^n g_{i_1} g_{i_2} \\ &\quad + \dots + \lambda^{n-1} g_1 g_2 \dots g_n, \\ &= \frac{1}{\lambda} \left| \prod_{i=1}^n (1 + \lambda g_i) - 1 \right| \end{aligned} \quad (2)$$

for $-1 < \lambda < \infty$

Base on these properties, one of the three following situations will be sustained for a specific case with two attributes, x_1 and x_2 .

- (a) If $\lambda > 0$, then $g_\lambda(A \cup B) > g_\lambda(A) + g_\lambda(B)$: this implies that x_1 and x_2 have multiplicative effect in $\{A, B\}$.
- (b) If $\lambda = 0$, then $g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B)$: this implies that x_1 and x_2 have additive effect in $\{A, B\}$.
- (c) If $\lambda < 0$, then $g_\lambda(A \cup B) < g_\lambda(A) + g_\lambda(B)$: this implies that x_1 and x_2 have substitutive effect in $\{A, B\}$.

C. Fuzzy integral

Let h be a measurable set function defined on the fuzzy measurable space, and supposing that $h(x_1) \geq h(x_2) \geq \dots \geq h(x_n)$, then the fuzzy integral of fuzzy measure $g(\cdot)$ with respect to $h(\cdot)$ can be defined as Eq. (3)

[6] and the concept of fuzzy integral as shown in Fig. 1 [20][22]:

$$\begin{aligned} \int h dg &= h(x_n)g(H_n) + [h(x_{n-1}) - h(x_n)] \\ &\quad g(H_{n-1}) + \dots + [h(x_1) - h(x_2)]g(H_1) \\ &= h(x_n)[g(H_n) - g(H_{n-1})] + h(x_{n-1}) \\ &\quad [g(H_{n-1}) - g(H_{n-2})] + \dots + h(x_1)g(H_1), \end{aligned}$$

(3) where $H_1 = \{x_1\}$, $H_2 = \{x_1, x_2\}$, ..., $H_n = \{x_1, x_2, \dots, x_n\} = X$.

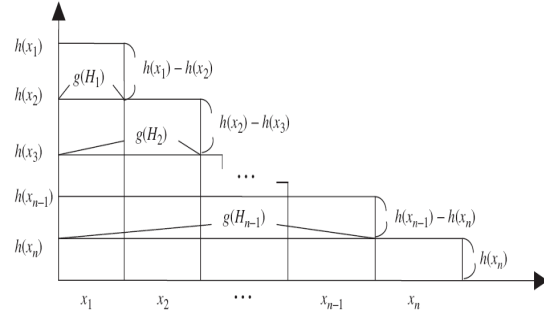


Figure 1. Concept of fuzzy integral [20] [22]

Using the fuzzy integral to formulae the original data, not only can fewer and more representative factors be extracted to describe the system, but the interactions between attributes can be considered. Furthermore, we used $\int h dg = a_i(d)$ as the integrated performance value of the common-factor C_d for the case study.

D. 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 that can effectively understand the complex structure and provide viable options of problem-solving [21].

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 standard. The second step is to calculate initial matrix, using pair of degree of interaction to obtain directly effecting matrix $Z = [z_{ij}]_{n \times n}$, where z_{ij} represents the degree of effect on i factor effects j factor [24][26].

$$Z = \begin{bmatrix} z_{11} & \dots & z_{1j} & \dots & z_{1n} \\ \vdots & & \vdots & & \vdots \\ z_{i1} & \dots & z_{ij} & \dots & z_{in} \\ \vdots & & \vdots & & \vdots \\ z_{n1} & \dots & z_{nj} & \dots & z_{nn} \end{bmatrix} \quad (4)$$

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 Eqs. (2) and (3). Its diagonal is 0, and maximum sum of row or column is 1.

$$X = sZ \quad (5)$$

$$s = \min \left[\frac{1}{\max_i \sum_{j=1}^n |z_{ij}|}, \frac{1}{\max_j \sum_{i=1}^n |z_{ij}|} \right] \quad (6)$$

$i, j = 1, 2, \dots, n$

The forth step is to obtain the total influence matrix T . It can be obtained by $T = X + X^2 + \dots + X^m = X(I - X)^{-1}$, where I is the identity matrix. The fifth step is to obtain prominence and

relation. To sum of each row and column of the total influence matrix $T = [t_{ij}]$. Its will obtain the sum of all rows (vector $r = (r_1, \dots, r_i, \dots, r_n)$) and the sum of all columns (vector $d = (d_1, \dots, d_j, \dots, d_n)$).

If r_i represents the sum of all rows of the total influence matrix T , meaning directly or indirectly influence degree; d_j represents the sum of all columns of the total influence matrix T , meaning influence or be influenced other criteria. r_i represents the factor i which will influence other factors, d_j represents the factor j that is influenced by other factors. According to the definition, $r_i + d_j$ presents the degree of relationship between the factors, meaning “prominence”; $r_i - d_j$ presents the degree of influence and influenced for the factors, meaning “relation” [21][17].

IV. Empirical analysis for the case study

In this section, we evaluate the performance of NPD processes within a case study of company A. We will consider the overall impact in product manufacturing and developing that may have potential problems and risks in the NPD process. Through the expert questionnaires, we classify the evaluation indexes according to its properties which is selected and divided into five dimensions of fifteen criteria, as shown in Fig.2.

A. To obtain the assessment value by fuzzy measure

Here fuzzy measure and fuzzy integral are used to determine the problem of NPD performance evaluation for human subjective decision-making issues. In the table2, we obtain the results of fuzzy measure which illustrates that the criterion “Confirmation of customer needs and assessment of production costs (C_{13})” is most important attribute of customer needs included (C_{13} =0.74). And the set values are obtained respectively according to those evaluated value of attributes.

Consequently, the non-additive fuzzy integral model is used to calculate the assessment value (C_d) for each dimension. Furthermore, the performance value for each dimension is calculated as shown in Table 3. The result shows dimension “Customer needs (D_1)” is the highest performance value (D_1 =0.920) than others; “Product design (D_3)” is the lowest performance value than others (D_3 =0.865). The priority of performance value for each dimension is following: D_1 (Customer needs) > D_4 (Process planning) > D_5 (Product Logistics) > D_2 (Environment) > D_3 (Product design).

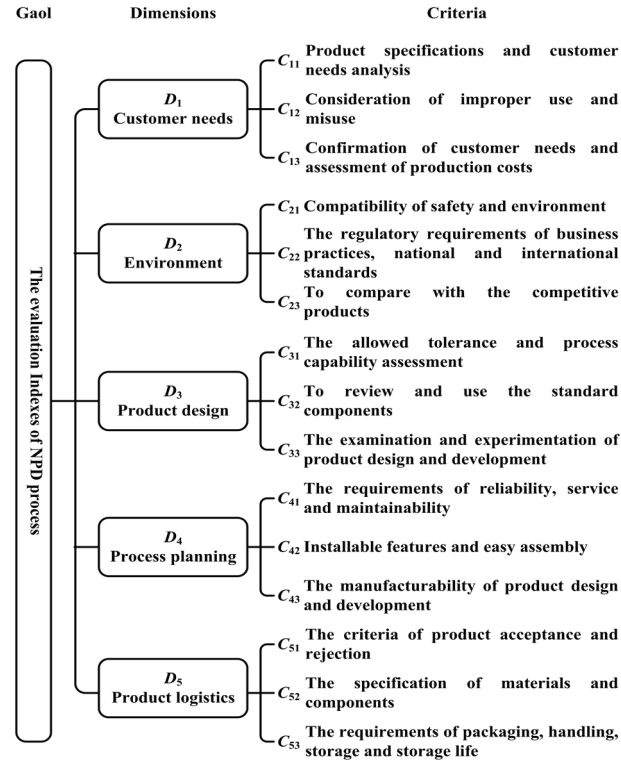


Figure 2. The assessment hierarchy system

TABLE II. FUZZY MEASURE $g(\cdot)$ OF EACH CRITERIA

Fuzzy measure of criteria	
D_1 Customer needs ($\lambda = -0.91$)	
$C_{11} = 0.63$	$\{C_{11}, C_{12}\} = 0.79$
$C_{12} = 0.38$	$\{C_{12}, C_{13}\} = 0.87$
$C_{13} = 0.74$	$\{C_{11}, C_{13}\} = 0.95$
	$\{C_{11}, C_{12}, C_{13}\} = 1$
D_2 Environment ($\lambda = -0.85$)	
$C_{21} = 0.57$	$\{C_{21}, C_{22}\} = 0.82$
$C_{22} = 0.49$	$\{C_{22}, C_{23}\} = 0.84$
$C_{23} = 0.60$	$\{C_{21}, C_{23}\} = 0.88$
	$\{C_{21}, C_{22}, C_{23}\} = 1$
D_3 Product design ($\lambda = -0.81$)	
$C_{31} = 0.62$	$\{C_{31}, C_{32}\} = 0.83$
$C_{32} = 0.43$	$\{C_{32}, C_{33}\} = 0.77$
$C_{33} = 0.52$	$\{C_{31}, C_{33}\} = 0.88$
	$\{C_{31}, C_{32}, C_{33}\} = 1$
D_4 Process planning ($\lambda = -0.92$)	
$C_{41} = 0.65$	$\{C_{41}, C_{42}\} = 0.90$
$C_{42} = 0.63$	$\{C_{42}, C_{43}\} = 0.87$
$C_{43} = 0.58$	$\{C_{41}, C_{43}\} = 0.88$

Fuzzy measure of criteria	
$\{C_{41}, C_{42}, C_{43}\} = 1$	
D_5 Product logistics ($\lambda = -0.94$)	
$C_{51} = 0.55$	$\{C_{51}, C_{52}\} = 0.87$
$C_{52} = 0.66$	$\{C_{52}, C_{53}\} = 0.93$
$C_{53} = 0.72$	$\{C_{51}, C_{53}\} = 0.90$
$\{C_{51}, C_{52}, C_{53}\} = 1$	

B. To obtain the total performance by fuzzy integral

We used fuzzy integral to obtain the total performance base on the assessment value from fuzzy measure. The result demonstrates that dimensions “Environment (D_2)” and “Product design (D_3)” are the performance gaps with total performance 0.907 from Fuzzy Integral as illustrated in Table 3.

TABLE III. TO OBTAIN THE TOTAL PERFORMANCE BY FUZZY INTEGRAL

The case study of company A			
Dimensions	Fuzzy measure of dimensions	Assessment value (C_d)	Performance ranking
$\lambda = -0.99$			
D_1	0.584	0.920	1
D_2	0.556	0.874	4
D_3	0.524	0.865	5
D_4	0.619	0.890	2
D_5	0.642	0.887	3
Total performance		0.907	
$\{D1, D2\} = 0.82$		$\{D2, D4\} = 0.84$	
$\{D1, D3\} = 0.81$		$\{D2, D5\} = 0.85$	
$\{D1, D4\} = 0.85$		$\{D3, D4\} = 0.82$	
$\{D1, D5\} = 0.86$		$\{D3, D5\} = 0.83$	
$\{D2, D3\} = 0.79$		$\{D4, D5\} = 0.87$	
$\{D1, D2, D3\} = 0.92$		$\{D2, D3, D5\} = 0.93$	
$\{D1, D2, D4\} = 0.94$		$\{D3, D4, D5\} = 0.94$	
$\{D1, D2, D5\} = 0.94$		$\{D1, D2, D3, D4\} = 0.94$	
$\{D1, D3, D4\} = 0.93$		$\{D1, D2, D3, D5\} = 0.94$	
$\{D1, D3, D5\} = 0.93$		$\{D1, D2, D4, D5\} = 0.99$	
$\{D1, D4, D5\} = 0.95$		$\{D2, D3, D4, D5\} = 0.77$	
$\{D2, D3, D4\} = 0.93$		$\{D1, D2, D3, D4, D5\} = 1$	

C. Constructing the network by DEMATEL

In this section, DEMATEL is applied to explore the inter-relationship between the criteria. According to the empirical analysis, we obtain the influence degree of each criterion as shown in Table 4. Based on the results of fuzzy integral, we build the network about “Environment (D_2)” and “Product design (D_3)” which are proved by the empirical analysis from DEMATEL as illustrated in Fig. 3 and Fig. 4.

TABLE IV. THE DEGREE OF INFLUENCE FOR EACH CRITERION

T	r	d	$r + d$	$r - d$
C_{11}	8.861	8.701	17.562	0.160
C_{12}	8.378	8.096	16.474	0.282
C_{13}	8.636	7.846	16.482	0.791
C_{21}	8.426	8.643	17.069	-0.218
C_{22}	7.737	9.209	16.947	-1.472
C_{23}	9.083	8.506	17.589	0.577
C_{31}	9.310	8.571	17.881	0.739
C_{32}	8.074	8.282	16.357	-0.208
C_{33}	8.418	8.504	16.922	-0.086
C_{41}	9.038	9.446	18.484	-0.409
C_{42}	8.848	8.564	17.412	0.285
C_{43}	8.351	8.818	17.169	-0.468
C_{51}	8.873	8.443	17.316	0.429
C_{52}	7.028	9.225	16.253	-2.197
C_{53}	8.563	6.770	15.333	1.793

Within the dimension “environment (D_2)”, criterion C_{23} is the highest impact of the strength of relation that means the most important influencing factors; C_{22} is all the factors that affects the least degree of other factors according to the total influential prominence ($r_i + d_i$). Furthermore, we also found that C_{23} is the highest degree of impact relationship which affects other factors directly; and C_{22} is the most vulnerable influence factor to compare with other criteria according to the influential relation ($r_i - d_i$).

The result also illustrates that criterion “The regulatory requirements of business practices, national and international standards (C_{22})” needs for prior improvement. The product manager can improve the performance gap form the criterion “To compare with the competitive products (C_{23})” which could then effectively improve the entire performance of this dimension.

In the dimension “product design (D_3)”, the criterion C_{31} is the highest impact of the strength of relation that means the most important influencing factors; C_{32} is all the factors that affects the least degree of other factors according to the total influential prominence ($r_i + d_i$). Furthermore, we also found that C_{31} is the highest degree of impact relationship that affect

other factors directly; and C_{32} is the most vulnerable impact factor to compare with other criteria according to the influential relation ($r_i - d_i$).

The result illustrates that criterion “To review and use the standard components (C_{32})” needs for prior improvement. The product manager can improve the performance gap begin with the criterion “The allowed tolerance and process capability assessment (C_{31})” which can effectively improve the entire performance of this dimension D_3 .

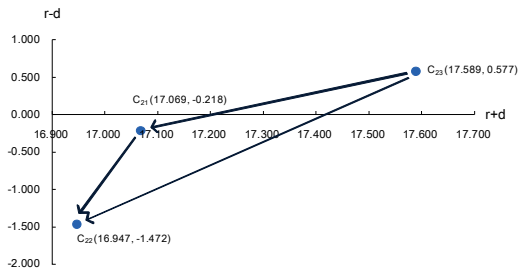


Figure 3. the Shown the interrelationship of D_2

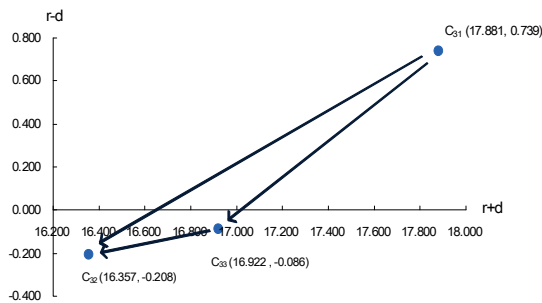


Figure 4. the Shown the interrelationship of D_3

V. Results and discussions

In this paper, we use fuzzy integral to integrate the performance rating of attributes for performance evaluation quality of the NPD process. Furthermore, we combine with the results of to obtain the total performance of NPD process for the case study. Consequently, we use DEMATEL to explore the relevance for the considered criteria of NPD process which is used to find the directions of problem-solving respectively.

According to the results of empirical analysis and the literature review to the past research, the study illustrates that shows “customer needs (D_1)”, “process planning (D_4)” and “product logistics (D_5)” are the critical dimensions in NPD process quality [28]. In addition, we can know D_2 (Environment) and D_3 (Product design) both are the lowest performance value than others. The manager can improve the performance through the criteria of “To compare with the competitive products (C_{23})” and “The allowed tolerance and process capability assessment (C_{31})” which can improve the performance efficiency.

VI. Conclusion

In our study, we find that “customer needs”, “process planning” and “product logistics” are still the critical indexes for performance assessment of the NPD process according to the empirical analysis. In case study of company A, we obtain the total performance is greatly near to the highest expect value, but the performance for the dimension of “environment (D_2)” and “product design (D_3)” are low. In the real word, the manager may take into those dimensions which can support the company to improve the entire NPD process efficiency in order to exceed the aspire level. The results from this study will provide an NPD project team a guidance to satisfy the customer needs and create the value of sustainable business.

ACKNOWLEDGEMENTS: NSC 99-2632-H-424-001-MY3

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