Evaluation of New Product Development Alternatives Considering Interrelationships among Decision Criteria

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***Abstract*—In electronic industry, technologies are progressing rapidly nowadays. To maintain market competition with comparative advantages, an enterprise must continuously develop various new products. This research focuses on the initial stages of the new product development (NPD), which involves generating and screening NPD alternatives. A multiple criteria decision making (MCDM) model considering interrelations among selection criteria is developed. The proposed MCDM model employs the fuzzy Delphi method to filter the performance evaluation criteria. Since the criteria are considered to be interdependent by decision-makers, the gray relation analysis (GRA) is applied to identify the interactive relationships among criteria within each aspect. Two methods are used to calculate the synthetic utility score for each alternative. The first method evaluates the alternatives using an ANP model with relation-structure derived from GRA, whereas the second method rates the alternatives using non-additive fuzzy integral. An empirical example of the medical display monitor industry is provided to show the feasibility and effectiveness of the proposed model. The two evaluation methods achieve the same ranking of the alternatives.**

***Index Terms*—Analytic Network Process; New Product Development; Gray Relation Analysis; Fuzzy Integral; Medical Display Monitor**

I. INTRODUCTION

To maintain their competence in this drastically competitive business environment, enterprises require strong marketing power, well-integrated organizations, and effective and efficient capacities in research and development (R&D) to develop innovative products. This situation becomes more stringent for electronic products industry. The enterprises are forced to invest in constantly developing new products and introducing them into markets. A survey done by Product Development and Management Association (PDMA) reveals that there were more than 50% of the sales coming from new products in successful companies [1]. In business and engineering, new product development (NPD) is the process of introducing a new product to the market. Generally speaking, the NPD comprises a number of stages, beginning with idea generation and screening, market analysis, product concept, technical implementation, and ending with commercialization and product pricing [2]. The NPD must be successfully implemented in most stages of product lifecycle management (PLM) [3]. This research focuses on the initial stages of the NPD [4], which includes generating and screening ideas. Multiple criteria decision making (MCDM) is an effective technique in solving the NPD selection problem, since the MCDM can utilize group decision making (GDM) methods to prioritize alternatives using expert opinions on criteria weighting and alternative ratings. The MCDM processes involve a series of steps: identifying the problems, constructing the preferences, evaluating the alternatives, and determining the best alternatives [5].

Among various MDCM methods, analytic hierarchy process (AHP) [6] is a common and practical method, which prioritizes alternatives based on relative importance of criteria and relative performance of alternatives. The AHP process consists of three phases: decomposition, comparative judgment, and synthesizing [7]. The first phase decomposes a complicated problem into a multilevel hierarchical structure consisting of a goal, perspectives, criteria, and alternatives, using the knowledge and experience of the expert/decision team. The hierarchical structure shows the relationships of the four levels from top to bottom. The second phase performs pairwise comparisons to derive relative importance or performance of the elements in each hierarchical level. In the last phase, the AHP prioritizes alternatives in the lowest hierarchical level using an aggregation method. Normally, the weighted sum method is used for aggregating and determining the best alternative. The theoretical background and mathematical concept of the AHP methodology have already been introduced in several books and articles [8, 9]. Omkarprasad and Sushil [10] analyzed the applicability of AHP, and reviewed 150 articles published in highly appraised journals since 2003. They categorized the articles based on applications by "selection", "evaluation", "benefit-cost analysis", "allocations", "planning and development", "priority and ranking", "decision making", "forecasting", and "health and related fields". Xiu and Chen [11] studied outsource logistics selection problem, and proposed a MCDM model combining AHP and information entropy to evaluate the candidate suppliers.

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They showed that the model is useful and effective in practice through an application example of an agricultural-products processing enterprise. Lahby et al. [12] considered the selection of a radio access network with the objective of optimizing quality service anywhere at any time. They proposed a ranking method that uses fuzzy AHP to calculate the criteria weights and then employs Mahalanobis distance to evaluate the alternatives. Based on simulation results, they concluded that the Mahalanobis distance can reduce the ranking abnormality, and provide a better ranking on alternatives than several common methods such as TOPSIS, GRA (gray relation analysis), and DIA (distance to ideal alternative). Tzeng et al. [13] presented a hybrid MCDM model based on factor analysis and DEMATEL, and validated their model via two e-learning programs. Their study used factor analysis to identify the main aspects of e-learning program and to generate independent factors for further evaluation by the AHP method. The DMATEL is then applied to illustrate the interrelations among criteria, and find the central criteria to represent the effectiveness of each aspect. Non-additive methods, fuzzy measure and fuzzy integral are used to calculate the weights of dependent criteria and the satisfaction value for each alternative.

The analytic network process (ANP) is a generalization of the AHP [14]. The ANP allows more complex interrelationships among decision levels and criteria. For instance, not only does the importance of the criteria determine the importance of the alternatives in a hierarchy, but the importance of the alternatives may also have impact on the importance of the criteria. Saaty [14] proposed the “supermatrix” technique, which uses Markov chain convergence theory to synthesize ratio scale.

The ANP has been extensively applied to solve various MCDM problems. The following studies [15-17] employed ANP to solve R&D project selection problems. Shyur [18] combined ANP and a modified TOPSIS to evaluate and select the commercial-off-the-self (COTS) products for software development projects. In this study, ANP is used to obtain criteria weights, but not to evaluate the alternatives, so that the number of pairwise comparisons can be significantly reduced. The modified TOPSIS uses a newly defined weighted Euclidean distance to rank competing products, based on overall evaluation results for multiple criteria. Dağdeviren [19] also adopted the same approach to solve personnel selection problems in manufacturing systems. Azimi et al. [20] employed SWOT technique to build an ANP model and used TOPSIS to rank the strategies of mining sectors. Lu and Pei [21] developed an ANP model to evaluate the security of power network information system. The software Super Decision was applied to verify the feasibility and effectiveness of the proposed model. Wu et al. [22] presented a hybrid MCDM that combines fuzzy Delphi method, ANP and TOPSIS for supplier selection, and applied the model to a real life situation. Hidayanto et al. [23] conducted a research work on the risk of ERP implementation in small- and medium-sizes enterprises, and proposed a fuzzy ANP to examine the implementation readiness of these business organizations. They applied the ANP model to a software developer company, and provided suggestions for this case company. Liou and Chuang [24] studied the outsourcing provider selection problem, and developed a hybrid MCDM model consisting of DEMATEL, ANP, and VIKOR to prioritize the alternatives. In their model, the DEMATEL builds a relation-structure among criteria, the ANP determines the relative criteria weights that consider dependence and feedback, and the VIKOR ranks the alternatives. A similar approach was adopted to solve the supplier selection problem [25] and technology selection for organic LED product [26].

Many MCDM methods integrate the rating scores of alternatives and their corresponding criteria weights with the weighted sum method or weighted product method. While these aggregation methods are applied, preferential independence among criteria is assumed [27, 28]. Preferential independence implies that the preference outcome of one criterion is not influenced by the outcomes of the remaining criteria. However, the criteria are usually interactive in practical MCDM problems [29]. The distinguishing feature of fuzzy integral is that it is able to represent a certain kind of interaction between criteria, ranging from substitutive to multiplicative effects [30]. Yang et al. [31] studied the vendor selection problem and proposed an integrated fuzzy MCDM, which uses interpretive structural modeling (ISM) to map the relationships among the subcriteria, and then applies non-additive fuzzy integral to obtain the fuzzy synthetic performance of each common criterion. Liou and Tzeng [32] presented a non-additive model for evaluating airline service quality. Their study applied factor analysis to extract independent common factors and then used fuzzy integral to integrate the performance ratings of interdependent criteria in each common factor.

This paper presents a MCDM model for the problem of selecting a new product to develop. The fuzzy Delphi method [33] is utilized to filter the criteria of each aspect, whereas the GRA is used to build a relations-structure among criteria of each aspect. Two methods are applied to obtain the synthetic utility scores based on the relation-structure. Method 1 first calculates global criteria weights for the ANP established by GRA, and then the additive method is employed to compute the global rating scores of the alternatives. Method 2 uses non-additive methods, fuzzy measure and fuzzy integral to calculate the synthetic scores of the interactive criteria within each aspect for each alternative, and determine the global rating of each alternative based on the resulting synthetic scores and the AHP criteria weights.

The proposed model is illustrated through an empirical example from the Medical display monitors (MDMs) industry: Selecting a type of color calibration device (CCD) that is most beneficial for the case company to develop. MDMs have been extensively used in medical organizations in recent years. These monitors must provide precise and stable images, so that patients can be diagnosed and treated both efficiently and effectively.

The CCD provides measurement and correction functions for MDM to achieve high quality performance, including high resolution, steady luminous intensity and gray scale, and accurate color temperature. Therefore, the development of CCD is crucial to MDM manufacturers. Compared to general purpose display monitors, MDMs have stricter technological requirements. On the other hand, the profit margins of MDMs are usually larger.

The paper is organized as follows: Section II describes the hybrid MCDM models; Section III presents a case study; Section IV concludes the paper.

II. PROPOSED METHODS

This research proposes a hierarchical MCDM model with two non-linear methods for calculating synthetic scores of alternatives. The flow chart of the MCDM model is shown in Fig. 1. Method 1 synthesizes the scores using the criteria weights of the ANP, where the relation-structure is constructed by GRA. Method 2 applies non-additive fuzzy measure and fuzzy integral to calculate the synthetic utility values of each alternative. The two aggregation methods are detailed below.

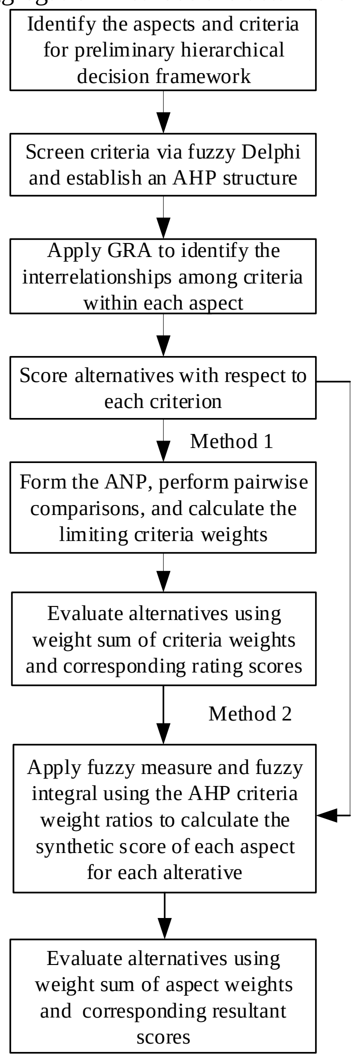

Figure 1. Flow chart of MCDM with two calculation methods

Let $\{P_1, \ldots, P_i, \ldots, P_M\}$ be the number of aspects, and $\{C_{ij} \in P_i\}$ be the criteria of aspect $P_i, i = 1, \ldots, I$. Further, let w_{ij}^{ANP} be the global weight of criterion C_{ij} under ANP, w_{ij}^{AHP} be the local weight of criterion C_{ij} and W_i^{AHP} be the global weight of aspect P_i under AHP, and $\bar{s}_{ij}^{m}$ be the geometric mean of the scores evaluated by the experts for alternative A_m on criterion C_{ij}. Method 1 calculates the synthetic score of A_m using the additive measure, $\sum_{i,j} \bar{s}_{ij}^{m} \cdot w_{ij}^{ANP}$. On the other hand, Method 2 considers the interrelation among criteria within each aspect, and uses non-additive fuzzy integral to calculate the synthetic scores. Let y_i^m denote the non-additive synthetic score of A_m on aspect P_i. Then the synthetic value of alternative A_m is $\sum_i y_i^m \cdot W_i^{AHP}$. Section II.A describes the application of GRA in establishing the interrelations among criteria, and Section II.B introduces the non-additive fuzzy integral method.

A. Gray Relation Analysis

Gray relation analysis (GRA) method is applied to determine the interrelations among criteria within the same aspect. Table 1 presents the GRA calculation process using an aspect containing four criteria, C_1, C_2, C_3, C_4. The notation $x_{ij}(k)$ denotes the influential strength of C_i against C_j, as assessed by expert k. Clearly, $x_{jj}(k) = 1$ for any C_j and expert k. The symbol $\Delta_{ij}(k) = 1 - x_{ij}(k)$ is the gap to the perfect influential strength of C_i against C_j based on the assessment by expert k. The gray relation coefficient (GRC) by expert k of C_i against C_j can be calculated via the following formula:

$$\gamma_{ij}(k) = \frac{Min_{i\neq j,k}\Delta_{ij}(k) + \xi \cdot Max_{i\neq j,k}\Delta_{ij}(k)}{\Delta_{ij}(k) + \xi \cdot Max_{i\neq j,k}\Delta_{ij}(k)} \quad i \neq j, k = 1, \ldots, n \quad (1)$$

where ξ is the distinguishing coefficient and usually takes a value of 0.5. The gray relation grade γ_{ij} represents the average influential strength of C_i against C_j assessed by the experts. An ANP can be derived from AHP and GRA by setting a threshold value for the gray relation grades to form a criteria relation-structure.

B. Fuzzy Integral

Method 2 applies fuzzy measure (e.g., λ-fuzzy measure; [34]) and fuzzy integral to obtain the synthetic utilities with interdependence among criteria. When considering the substitutive and multiplicative effects, decision-makers usually combine fuzzy measure and fuzzy integral to integrate information and evaluate alternatives. The following describes several properties of the fuzzy measure and the fuzzy integral.

Let $P(X)$ denote the power set of criteria X. A fuzzy measure g over $X = \{x_1, \ldots, x_m\}$ is a function g: $P(X) \rightarrow [0,1]$ satisfying the following conditions:

1) $g(\phi) = 0$, $g(X) = 1$;
2) For all A, $B \in P(X)$, if $A \subseteq B$ then $g(A) \leq g(B)$ (monotonicity)

For any two disjoint sets A and B, $A \cap B = \phi$, the value of the fuzzy integral on its union is computed as follows:

$$g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda \cdot g_\lambda(A) \cdot g_\lambda(B) \quad (2)$$

TABLE I. CALCULATION OF GRAY RELATION GRADES

Expert Criterion	E_1 … E_n	E_1 … E_n	$\gamma_{i2}(k)=\frac{(Min_{j,k}\Delta_{j2}(k)+\xi\cdot Max_{j,k}\Delta_{j2}(k))}{(\Delta_{i2}+\xi\cdot Max_{j,k}\Delta_{j2}(k))}$
C_2	1 … 1		
C_1	$x_{12}(1)\ldots x_{12}(n)$	$\Delta_{12}(1)$ …. $\Delta_{12}(n)$	$\gamma_{12}=\sum_{k=1,\ldots,n}\gamma_{12}(k)/n$
C_3	$x_{32}(1)$ … $x_{32}(n)$	$\Delta_{32}(1)$ … $\Delta_{32}(n)$	$\gamma_{32}=\sum_{k=1,\ldots,n}\gamma_{32}(k)/n$
C_4	$x_{42}(1)$ … $x_{42}(n)$	$\Delta_{42}(1)$ … $\Delta_{42}(n)$	$\gamma_{42}=\sum_{k=1,\ldots,n}\gamma_{42}(k)/n$

where $\lambda \in (-1, \infty)$. The parameter λ is used to describe an "interaction" between combined elements or sets. If $\lambda = 0$, then expression (2) reduces to the additive measure. If $\lambda > 0$, we obtain $g_\lambda(A\cup B) > g_\lambda(A)+g_\lambda(B)$. This indicates a synergy or multiplicative effect, meaning that the preferred values of A and B will boost a greater effect than the sum of the values generated by A and B separately. If $\lambda < 0$, we obtain $g_\lambda(A\cup B) < g_\lambda(A) + g_\lambda(B)$ and it leads to a substitutive effect [5].

One means to obtain the value of λ can be observed from the method by Chu et al. [35]. Let $X = \{x_1, \ldots, x_m\}$ and denote the λ-fuzzy measure $g_\lambda(\{x_i\}) = g_i$, and $g_\lambda(\{x_1, x_2\}) = g_1 + g_2 + \lambda\cdot g_1\cdot g_2$. Furthermore,

$$g_\lambda(\{x_1,\ldots,x_m\}) = \sum_{i=1}^{m} g_1 + \lambda\cdot\sum_{i=1}^{m-1}\sum_{j=i+1}^{m} g_i\cdot g_j + \cdots + \lambda^{m-1} g_1 \ldots g_m \quad (3)$$

and $g_\lambda(\{x_1,\ldots,x_m\}) = 1$, $g_i = c\cdot w_i$, where w_i are the AHP criteria weights without normalization. The constant c and optimal λ can be estimated based on utility preference $g_i = u(x_1^-, \ldots, x_{i-1}^-, x_i^*, x_{i+1}^-, \ldots, x_m^-)$, which implies the best outcome for criterion C_i and worst outcome for the other criteria.

The fuzzy integral can be calculated by formula (4), and the concept is shown in Fig. 2.

$$\int h\cdot \mathrm{d}g = h(x_n)\cdot\big(g(H_n)-g(H_{n-1})\big) + h(x_{n-1})\cdot[g(H_{n-1}) - gHn-2+\ldots+h(x1)\cdot g(H1) \quad (4)$$

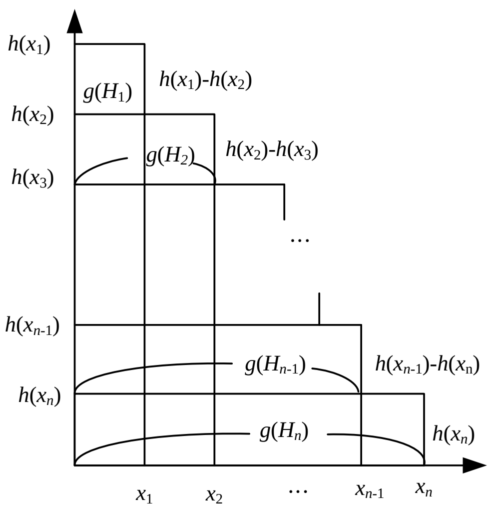

Figure 2. Basic concept for calculating synthetic scores using fuzzy integral

III. CASE STUDY

The proposed model is illustrated through an empirical example in the LCD industry. The color calibration device (CCD) is important auxiliary equipment to the performance of MDM. MDM must display precise and stable imaging during diagnoses and treatments. The CCD provides measurement and correction functions for MDM to achieve high quality performance, including high resolution, steady luminous intensity and gray scale, and accurate color temperature. Therefore, the development of the CCD is essential to MDM manufacturers.

The case company is a subsidiary of a well-established international LCD producer in Taiwan. Thus, the company's relations & corporate support, including local hospitals and large medical centers, are its main advantages. In the case study, ten experts and/or managers from diverse organizations in the company, such as R&D, IT, Marketing, and Product Planning, were invited to provide their valuable opinions and assessments. In addition to the experts, ten product-related sales agents were requested to appraise the alternatives with respect to each criterion. The max-min fuzzy Delphi method [33] is employed to screen the criteria. Subsequently, a three-level hierarchical structure is established and given as follows.

Level 1: Goal (G) – Determine the device to be developed.

Level 2: Aspects (P) – Technical Capability (P_1); Marketing Environment (P_2); Organizational Management (P_3).

Level 3: Aspect (P_1) – Technology Patent (C_{11}); Product Accreditation (C_{12}); Customization Capacity (C_{13}); R&D Capability (C_{14}).

Aspect (P_2) – Product Profitability (C_{21}); Competitiveness (C_{22}); Consumer Preference (C_{23}); Brand Image (C_{24}).

Aspect (P_3) – Relations & Corporate Support (C_{31}); Integration Ability (C_{32}); Marketing Capability (C_{33})

The GRA is then applied to establish the relation-structure of the criteria and form an ANP. The threshold is set to 0.7 for gray relation grades to confirm the relationship between two criteria. Table 2 presents the calculation results of gray relation grades for criteria in aspect P_1, using the method described in Section II.A. The results indicate that there are two pairs of interrelated criteria, $\{C_{11}, C_{12}\}$ and $\{C_{13}, C_{14}\}$. The resulting ANP structure is shown in Fig. 3, where $\{C_{21}, C_{22}, C_{23}\}$ and $\{C_{31}, C_{32}\}$ are another two interdependent set of criteria, and $\{C_{24}\}$ and $\{C_{33}\}$ each is preferentially independent of all other criteria. The relative dependence strength of one criterion to another is given in the three block submatricies on the right hand side of Table 3, based on the group opinions. For example, criterion C_{31} retains 86.4% of its AHP relative weight 0.120 and gains 14.2% of C_{32}'s AHP weight 0.415, resulting in a modulated weight of 0.162 as shown in Table 4.

Three types of CCD are proposed for development, with their key features described below:

A_1: Front sensor – size: 18 x 10 mm; weight: 30g; built-in USB; automatic control; technical difficulty: moderate; current market share: 30%; precision degree: 15%; applicable MDM: 19-27 inch; investment: USD100,000; estimated selling price: USD1,000; warranty: 3 years.

A_2: Color sensor – size: 68 x 41 mm; weight: 140g; external USB; manual control; technical difficulty: low; current market share: 60%; precision degree: 5%; applicable MDM: 19-60 inch; investment: USD60,000; estimated selling price: USD300; warranty: 1 year.

A_3: Swing sensor – size: 117 x 29 x 96 mm; weight: 160g; external USB; automatic control; technical difficulty: high; current market share: 10%; precision degree: 10%; applicable MDM: 19-27 inch; investment: USD150,000; estimated selling price: USD1,200; warranty: 2 years.

A selection of the three alternatives will indicate which competitive advantages the company currently possesses, and which marketing strategy the company should adopt. From the company standpoint each alternative has its advantages and weaknesses. The technology threshold to successfully develop alternative A_1 is moderate, and thus the development risk can be controlled. The built-in USB feature will become the competitive advantage in the market. The technological task of alternative A_2 is relatively easy. Therefore, its development risk is low and the new product A_2 can be quickly introduced to market. Since the development risk of A_2 is low, there are many competitors and the product price will be critical to the success of the A_2 introduction. Finally, alternative A_3 is technically difficult, and has high development risk and low probability of success. However, if successful, A_3 will be the most beneficial alternative, as the company will become a pioneer of the CCD technology field.

TABLE II. GRAY RELATION GRADES OF P_1

$\xi = 0.5$	C_{11}	C_{12}	C_{13}	C_{14}
C_{11}	1	0.729	0.342	0.345
C_{12}	0.762	1	0.397	0.381
C_{13}	0.357	0.402	1	0.853
C_{14}	0.340	0.348	0.750	1

Table 4 shows the calculation results of the ANP model. The calculation process is as follows. The first step is to apply the AHP calculation to find the relative weights of three aspects with respect to the goal, and the relative weights of criteria with respect to each aspect, respectively denoted by W_P and W_C^{AHP}. Table 3 shows these the relative weights of W_C^{AHP} ; $W_{C_1}^{AHP} = [0.140, 0.389, 0.354, 0.117]$, $W_{C_2}^{AHP} = [0.270, 0.447, 0.141, 0.143]$, $W_{C_3}^{AHP} = [0.120, 0.415, 0.465]$. The next step is to determine the relative weight matrix based on the interdependence among criteria. The right hand side of Table 3 displays this matrix, which consists of three independent submatrices. Since C_{11} and C_{12} are interdependent, the combined relative weights of C_{11} with respect to P_1 is $[0.883\ 0.238][0.140\ 0.389]^{\mathrm{T}} = 0.216$, which is $w_{C_{11}}^{ANP}$ as shown in Table 4. In addition, the relative weight of C_{24} with respect to aspect P_2 is not modulated since the criterion C_{24} is independent of all other criteria. In other words, $w_{C_{24}}^{ANP} = w_{C_{24}}^{AHP} = 0.143$. Similarly, $w_{33}^{AHP} = w_{33}^{ANP} = 0.465$. For criterion C_{11}, the geometric mean of the group scores for alternative A_1, A_2, and A_3 are 77.81, 80.95, and 90.16, which generate global rating scores for A_1, A_2, and A_3 as 6.521, 6.784, and 7.556, respectively. As a consequence, the ANP model prioritizes three alternatives as $A_1 > A_3 > A_2$.

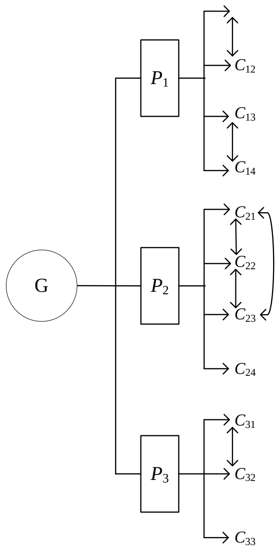

Figure 3. ANP structure obtained by GRA

Table 5 shows the synthetic scores using the AHP criteria weights and weighted sum method (WSM). The result indicates that the ranking of alternatives is $A_1 > A_2 > A_3$. However, the ranking is $A_1 > A_3 > A_2$ when non-additive fuzzy integral is used. The non-additive ranking is the same as the ANP ranking. To perform the fuzzy integral calculation, we use the method introduced in Section II.B. For instance, the AHP weight ratio of C_{11} and C_{12} is 0.140:0.389. Let $g_{11} = c{\cdot}0.140$ and $g_{12} = c{\cdot}0.389$. These two criteria are concluded by the experts to possess multiplicative effect, and thus $\lambda > 0\ and\ g_{11} + g_{12} < 1$. The experts determined the utility value to be $u(100,0) = 100 \cdot c{\cdot}0.140 = 25.7$, which results in $g_{11} = 0.257, g_{12} = 0.713$, and $\lambda = 0.15$. Similar approaches are applied to the other three interactive sets of criteria, but among them, the three criteria $\{C_{21}, C_{22}, C_{23}\}$ are judged to be substitutive. The synthetic utility value of A1 on $\{C_{11}, C_{12}\}$ is 77.671 + (80.534-77.671)·0.257 = 79.713, and global utility value is 79.713·0.529·0.3879 = 16.357.

TABLE III. RELATIVE WEIGHTS OF CRITERIA UNDER EACH ASPECT AND INTERDEPENDENCE WEIGHTS AMONG CRITERIA

	P_1	P_2	P_3	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}	C_{33}
C_{11}	0.140	0	0	0.883	0.238	0	0	0	0	0	0	0	0	0
C_{12}	0.389	0	0	0.117	0.762	0	0	0	0	0	0	0	0	0
C_{13}	0.354	0	0	0	0	0.758	0.187	0	0	0	0	0	0	0
C_{14}	0.117	0	0	0	0	0.242	0.813	0	0	0	0	0	0	0
C_{21}	0	0.270	0	0	0	0	0	0.509	0.122	0.157	0	0	0	0
C_{22}	0	0.447	0	0	0	0	0	0.400	0.734	0.416	0	0	0	0
C_{23}	0	0.141	0	0	0	0	0	0.091	0.144	0.428	0	0	0	0
C_{24}	0	0.143	0	0	0	0	0	0	0	0	1.000	0	0	0
C_{31}	0	0	0.120	0	0	0	0	0	0	0	0	0.864	0.142	0
C_{32}	0	0	0.415	0	0	0	0	0	0	0	0	0.136	0.858	0
C_{33}	0	0	0.465	0	0	0	0	0	0	0	0	0	0	1.000

TABLE IV. NUMERICAL RESULTS OF ANP MODEL

Aspects and Criteria	ANP weights		Scores of alternatives		
	W_P	W_C^{ANP}	A_1	A_2	A_3
Technical Capability (P_1)	0.388				
-Technology patent (C_{11})		0.216	6.521	6.784	7.556
-Product accreditation (C_{12})		0.313	9.771	7.785	11.207
-Customization capacity (C_{13})		0.290	8.547	10.023	9.651
-R&D capability (C_{14})		0.181	5.565	3.771	5.294
Marketing Environment (P_2)	0.324				
-Product profitability (C_{21})		0.214	3.937	5.751	4.494
-Competitiveness (C_{22})		0.494	10.585	11.252	14.157
-Consumer preference (C_{23})		0.149	4.501	3.946	2.880
-Brand image (C_{24})		0.143	4.540	2.489	3.903
Organizational management (P_3)	0.288				
-Relations & corporate support (C_{31})		0.162	4.361	2.499	2.443
-Integration ability (C_{32})		0.373	9.965	10.445	7.268
-Marketing capability (C_{33})		0.465	10.743	10.706	7.402
Synthetic score			79.036	75.451	76.255
Ranking			(1)	(3)	(2)

TABLE V. NUMERICAL RESULTS OF AHP WITH WSM AND AHP WITH FUZZY INTEGRAL

Aspects/Criteria	AHP Weights		Weighted sum method			Fuzzy integral				
	W_P	W_C^{AHP}	A_1	A_2	A_3	W_C^{AHP}	λ	A_1	A_2	A_3
P_1	0.388									
- C_{11}		0.140	4.218	4.389	4.888	0.529	0.150	16.357	14.044	19.300
- C_{12}		0.389	12.152	9.681	13.938					
- C_{13}		0.354	10.425	12.226	11.773	0.471	0.140	14.244	12.241	14.494
- C_{14}		0.117	3.602	2.441	3.426					
P_2	0.324									
- C_{21}		0.270	4.967	7.255	5.670	0.857	-0.250	19.852	19.932	19.482
- C_{22}		0.447	9.564	10.167	12.791					
- C_{23}		0.141	4.251	3.727	2.720					
- C_{24}		0.143	4.540	2.489	3.903	0.143	0.000	4.540	2.489	3.903
P_3	0.288									
- C_{31}		0.120	3.216	1.843	1.802	0.535	0.240	13.995	14.650	10.068
- C_{32}		0.415	11.105	11.640	8.099					
- C_{33}		0.465	10.743	11.161	7.089	0.465	0.000	10.743	10.706	7.402
Synthetic scores			78.784	77.019	76.099			79.731	74.063	74.749
Ranking			(1)	(2)	(3)			(1)	(3)	(2)

IV. CONCLUSIONS

The MDMs have been commonly used in medical service centers, and are increasingly important for medical diagnosis and treatment. The CCD is a crucial component for the functional quality of MDM. This study presents two MCDM models considering interrelations among criteria, with the objective of selecting the most suitable CCD to develop for a company competing in the MDM market. The case company is a subsidiary of a well-established international LCD producer.

The presented MCDM models are characterized by two features: (1) GRA is applied to establish the interrelations among criteria within each aspect; (2) Two non-linear aggregation methods are used to evaluate the CCD alternatives: ANP and non-additive fuzzy integral. These two methods suggest that the case company should select a CCD with moderate technological challenge as its first choice, and then a CCD with high technological task as its second choice. The latter has high risk, but the company will gain significant benefit if it succeeds. This conclusion is different from the traditional AHP method in the second choice, which suggests that the company should develop a CCD with a low technological difficulty.

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