Design process by integrating DEMATEL, and ANP methods

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Abstract

Product design planning is typically carried out by assessments on product functions by considering customer demands. The connection between product series is an important factor which affects consumers' subjective perception. To optimise a product design, the structural relationship between product functions was determined in this study by the DEMATEL method so as to weigh the market connections and the importance of a product's influence. The analytic network process (ANP) method was also use to create product designs based on the market segmentation consideration. The mutual relationship obtained from the modularization during the development process of new product designs can be combined with the new product features obtained from the systematic grouping methods. Based on the results of the case study, the capability of developing innovative product series can be enhanced.

Key words: product module; DEMATEL; analytic network process

Introduction

The objective of this study is to satisfy the market demand for the product systematized design and to help a designer select the optimal product concept and assess related problems. It is expected to reduce the risk of having various products in a unified form while the market demand may possibly be neglected. This study aims at satisfying various customer requirements on the highly competitive market under limited time and resources. The most relevant design conceptual idea can be determined and a designer can effectively master the relationship between consumer needs and critical product series attributes. However, during the selection and assessment of design concepts, the subjective perception typically affects the selection and thus a designer may fail to make a clear and definite decision.

With the benefit of a strategic decision and assessment method by using the decision-making trial and evaluating laboratory (DEMATEL) approach, it is different from conventional multi-criteria decision making method which usually assumes that the criteria are independent of each other. **Wu and Tsai** [1] proposed that the DEMATEL approach can further help decision-makers confirm the causal relationships among designs and also proposed an evaluation method for the measurement and a strategic decision testing by DEMATEL. **Tseng and Wu et al.** [1,3] proposed to integrate different aspects of thinking into a single reason and influence. For combining with hybrid evaluation method of the strategic decision testing and assessment by the DEMATEL technique, **Shen** [2] used the ANP method to build related techniques for selecting models. Wu [7] combined the ANP method with the DEMATEL method based on solution packages so as to assist in the necessary assessments and selection of knowledge management strategies. In addition, the DEMATEL method can transform the relationship between a conversion factor and its standardisation effect into a visualized interpretive structural model. It can also serve as a standard method for determining the dependency or correlation between a factor and its effect. **Tseng** [3] proposed a mixed ANP method for the analysis from the dependency aspect. A strategic decision testing and assessment by the DEMATEL approach was used to clarify the correlation and the fuzzy set theory was used for the assessment of the uncertainty. The results justified the real effects on the assessment of samples and the analysis of the assessment results provided a definite assessment of the key standard management performance. **Hsu** [4] determined the key factors which affect designs and investigated the causal relationship between standard factors. Since a design problem involves a multi-criteria decision, he used a model which was created from the results of integrating the factor analysis and the DEMATEL method. The DEMATEL method is used for the simplicity and the visualization of the correlation between standards so as to make a decision. Yeh et al. [5] applied the DEMATEL method and the ANP method to the environmental and ecological factors to determine the relative weights of the related standards. Yang et al. [6] integrated the multi-objective decision model with DEMATEL and ANP so as to resolve some conflicting problems and tried to eliminate the risk of network engineering information being leaked. Their approach was verified to be able to reduce risks to an acceptable level.

Outline of the research model development process

This study proposed an approach which invites experts to assess products and establish the cluster relationship between products so as to acquire clusterised and modularised

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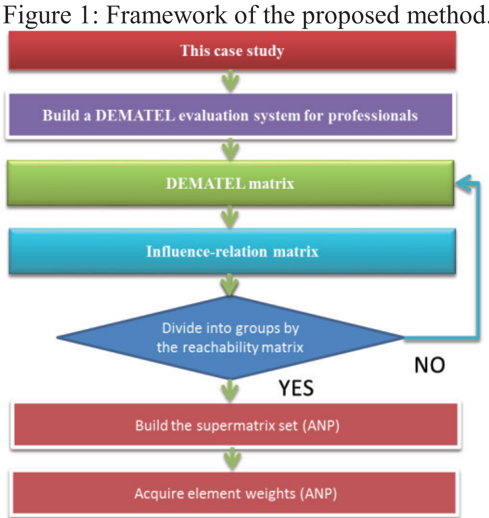
correlation matrices. The correlation matrices were further used for determining the optimal product module and the research process flowchart is shown in **Figure 1.** The DEMATEL method was then used to generate the correlation matrix from product descriptions. the ANP method is used to build the supermatrix and help acquire the weight of each element. Finally, the group modules were used as the evaluation criteria when conducting the market segmentation process. The implementation procedure is described as follows.

(1) Obtain the correlation matrix which is evaluated by experts
(2) Obtain the influence matrix by DEMATEL criteria
(3) Illustrate the hierarchical relationships between element modules
(4) Obtain the relationship distribution between each group module
(5) Generate the element distribution chart .

Figure 1: Framework of the proposed method.



Theoretical background

As shown in the above-mentioned research process flowchart, several different methods were utilized in this study for carrying out the analysis of each task. The details of how to implement those methods in this study are explained respectively as follows.

Decision making trial and evaluation laboratory (DEMATEL)

Gabus and Fontela [8] at the Battelle Memorial Institute in Geneva utilized the DEMATEL technique to resolve complex problems which were related to race, famine, environment, and energy issue and to obtain a type of self-feedback. They also built the network relationship between measurement guidelines and the causal relationships between elements. Based on their findings, Lin [13] carried out matrix operations to determine the degree of influence for evaluating the green supply chain management practices. In light of the studies by Fontela and Gabus [11,12], the procedure of the investigation in this study is divided into four steps as follows.

Step 1: Obtained the average influence matrix

By applying a pairwise judgment by specified criteria, each subject's perception of the degree of influence between indices can be assessed. The subjects were asked to mark the correlation degree of direct influence of index i on index j with an influence scale of 0, 1, 2, 3 to 4, which represents "without any influence (0)", "minor influence (1)", "moderate influence (2)", "major influence (3)", and "great influence (4)" respectively. A $n \times n$ direct influence matrix $\boldsymbol{A} = [a_{ij}]_{n \times n}$ can be acquired from the answers provided by the subjects.

Step 2: Transform the results into normalized direct influence matrix

The direct influence matrix $\boldsymbol{A}$ can be further normalized by Equations (1) and (2), and the direct influence matrix after normalization is $\boldsymbol{D} = [d_{ij}]_{n \times n}$, which is a matrix with zero diagonal.

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

$$k = \min\left\{1/\max_i \sum_{j=1}^{n} a_{ij}, 1/\max_j \sum_{i=1}^{n} a_{ij}\right\}, \quad i, j \in \{1, 2, \ldots, n\} \tag{2}$$

Step 3: Calculate total influence-relation matrix

After the normalized direct influence matrix was acquired, Equation (3) can be used to build the overall influence matrix $\boldsymbol{T}$ of the network relation chart, where $\boldsymbol{I}$ is an identity matrix.

$$\boldsymbol{T} = \boldsymbol{D} + \boldsymbol{D}^2 + \boldsymbol{D}^3 + \ldots + \boldsymbol{D}^k = \boldsymbol{D}(\boldsymbol{I} + \boldsymbol{D} + \boldsymbol{D}^2 + \ldots + \boldsymbol{D}^{k-1})$$

$$[(\boldsymbol{I} - \boldsymbol{D})(\boldsymbol{I} - \boldsymbol{D})^{-1}] = \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{D}^k)(\boldsymbol{I} - \boldsymbol{D})^{-1}$$

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

where $\boldsymbol{D} = [d_{ij}]_{n \times n}$, $0 \le d_{ij} < 1$,

$$0 < \sum_{j=1}^{n} d_{ij} \le 1, \ 0 < \sum_{i=1}^{n} d_{ij} \le 1$$

Step 4: Result analysis

The summation along columns ($\sum_{j=1}^{n} t_{ij} = t_i$) and the summation along rows ($\sum_{i=1}^{n} t_{ij} = t_j$) of the above-mentioned matrix were utilized to build the influence index vectors $\boldsymbol{r} = (r_1, \ldots, r_i, \ldots, r_n)'$ and $\boldsymbol{c} = (c_1, \ldots, c_j, \ldots, c_n)'$ which are defined by Equations (4) and (5), where *r* represents the ability to affect other indices and *c* represents being affected by other indices. The horizontal axis vector (*r*+*c*) could be obtained by adding ***r*** and ***c***. This value indicates the correlation degree

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between indices and is called prominence. Similarly, the vertical axis vector (*r*-*c*) is obtained by subtracting ***c*** from ***r***. This value represents the intensities of affecting or being affected by indices, and it is also called relation. Generally speaking, when (*r*-*c*) is positive, this indicates that the index is in the reason group. Contrarily, if (*r*-*c*) is negative, then this indicates that the index is in the effect group.

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

$$\boldsymbol{r} = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [t_{i\cdot}]_{n\times 1} = (r_1, \ldots, r_i, \ldots, r_n)' \qquad (4)$$

$$\boldsymbol{c} = \left[\sum_{i=1}^{n} t_{ij}\right]'_{1\times n} = [t_{\cdot j}]_{n\times 1} = (c_1, \ldots, c_j, \ldots, c_n)' \qquad (5)$$

where vector $\boldsymbol{r}$ and vector $\boldsymbol{c}$ represent the summations of rows or columns of the overall influence matrix $\boldsymbol{T} = [t_{ij}]_{n\times n}$ respectively.

Analytic network process (ANP)

Saaty [10] proposed the ANP method on the foundation of the earlier AHP method. He proposed adding a feedback mechanism to the conventional linear AHP so as to present it in a network form. Meanwhile, the ANP method also considers the interdependency which is generated between each factor [9] and provides a systematic approach so as to validate the targets for an organization and their priorities.

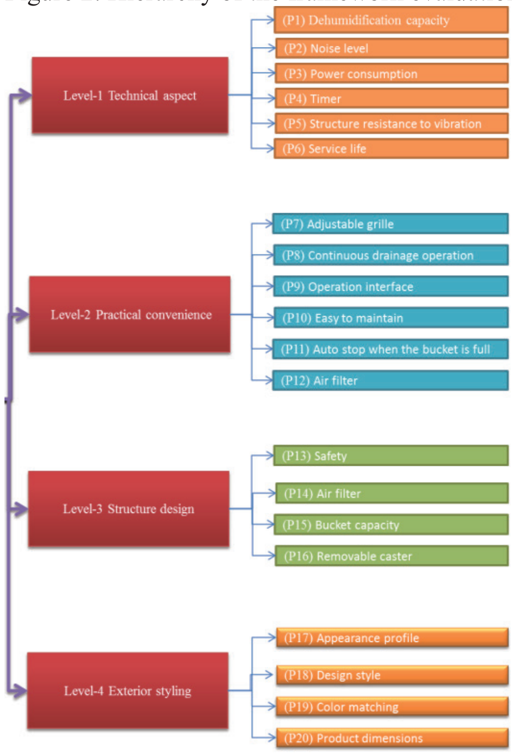
1. The first portion deals with the control hierarchy. The control hierarchy, which means the network relation between criteria and sub-criteria, affects the interior relations between systems.
2. The second portion deals with the network relation between elements and clusters.

The network relation can present the relevance between various criteria. The limiting influence between each control criteria can be calculated so as to form a supermatrix. Finally, each supermatrix will be assigned an adequate weight according to its own priority in the control hierarchy after a comprehensive assessment.

Case study and the verification of its application

This study began as an attempt to build the evaluation indices for the dehumidifier product by conducting a questionnaire survey. The design items of a dehumidifier were then graded for further classification. Experts in related fields were consulted for validating the relevance of preliminary evaluation indices. With the collected and organized dehumidifier indices, the experts conducted an assessment on the importance of each question based on their own expertise. The final evaluation indices were determined as shown in Figure 2. In this figure, the first level is the goal level and is the eventual goal for the dehumidifier evaluation. The second level is the objective level, which includes a total of four main dimensions: technique level, practical convenience, structure design, and appearance and styling. The third level covers twenty evaluation criteria. For conducting systematic evaluations and analyses, the related evaluation factors were derived on the index levels so as to establish a hierarchical framework.

Figure 2. Hierarchy of the framework evaluation.



DEMATEL calculations

The next step is to calculate and obtain the prominence and the relation, and vectors r and c can be obtained from the summation of each row and each column as shown in **Table 1**. The r vector represents the indices which affect other indices and the c vector represents the indices which are affected by other indices. The $(r+c)$ vector is called the prominence, which represents the intensity of the relation between indices. The $(r-c)$ vector is called the relation, which represents the intensity of indices affecting or being affected by others.

Table 1. Summations of the prominence and the relation values.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
r+c	2.78	2.53	2.80	2.89	2.96	3.30	3.11	3.09	3.05	3.05	2.93	2.85	2.96	2.95	2.90	2.99	3.05	3.08	3.11	3.08
r-c	1.54	1.60	1.34	1.19	1.13	0.85	1.39	1.37	1.32	1.32	1.20	1.13	1.23	1.22	1.17	1.26	1.32	1.35	1.38	1.35

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Based on the distribution of values in concern, the resulting optimal product distribution can be confirmed. The results indicate a sequence from small to large as: {0, 0.6, 1.3, 1.6, 2.3, 2.9}. This sequence was substituted into the calculation of each product. The products which better correspond to general-purpose product design can be obtained from **Table 2**.

Table 2. Analysis of clusterised markets after the modularization process.

	Module 1	Module 2	Module 3	Module 4	
0	M1-1	M2-1	M3-1	M4-1	◎
0.6	M1-2	M2-2	M3-2	M4-2	◎
1	M1-3	M2-3	M3-3	M4-3	◎
1.3	M1-4	M2-4	M3-4	M4-4	◎
1.6	M1-5	M2-5	M3-5	M4-5	◎
2.3	M1-6	N	M3-6	N	★
2.9	N	N	N	N	○

Based on the data shown in Table 2, i.e. the optimal product which satisfies the requirement of market segmentation was obtained when its value is {2.3}. To correspond respectively to the requirements for different segments, the optimal dehumidifier product is required to provide benefits such as a lower cost when developing assembly configurations. The clusterised markets which correspond to the modularization process as obtained in **Table 2** was further utilized for creating Modules 1 and 3. Those two groups obtained from the modularization analysis of the real case study can be used to create design drawings for two types of new dehumidifier products as shown in **Figure 3**.

Figure 3. Two types of new dehumidifier products.

Conclusions and suggestions

An approach which integrates different product assessment methods was proposed in this study. The main objective of this study is to make a complex product assessment system structuralized based on user demands. The design of a dehumidifier product was investigated in the study so as to build a new system for optimal product design.

The DEMATEL approach with a professional assessment was used for investigating the causal relationships between design elements and the extent of influence on the final product. the DEMATEL assessment contents After that, The optimal weight of each module can be obtained after the ANP method was utilized to build the group models.

The results of this case study successfully built the optimal product series based on different requirements by different groups and also resolved the modular configuration between product series. The systematic method for designing dehumidifier products can be implemented on similar product family designs so as to not only comply with consumer demands but also save cost by the realisation of modularization.

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