applied sciences

MDPI

Article

Application of a Fuzzy Decision Model to the Design of a Pillbox for Medical Treatment of Chronic Diseases

Hsin-Hung Lin [1,2]

[1] Department of Creative Product Design, Asia University, Taichung City 41354, Taiwan; hhlin@asia.edu.tw or a123lin0@gmail.com; Tel.: +886-04-2332-3456-1051

[2] Department of Medical Research, China Medical University Hospital, China Medical University, Taichung 404, Taiwan

Received: 14 September 2019; Accepted: 7 November 2019; Published: 15 November 2019

Abstract: It is critical for medical systems to reduce waste from medical resources. One of the reasons why patients with chronic diseases create waste is that they often forget to take their medicine. Patients pay attention to the time and amount of medicine to take to different degrees. This negligence often affects when they take medicine or preventive drugs. The amount of medicine is also different for different patients. The evaluation model in this study utilizes the fuzzy analytic hierarchy process (FAHP) to obtain the degree (weight) of each evaluation item that is determined by each patient. After that, a more objective overall shape can be determined depending on the individual's preference. In this study, the proposed package design serves as the case study. The results indicate that the evaluation model is feasible, and the research results of the case study are also valuable for follow-up designers. The design of a pillbox for patients with chronic diseases should consider the safety of taking the medicine; that is, the right person should take the right medicine at the right time at the right dose. Therefore, evaluating the feasibility of the pillbox for patients with chronic diseases is very important. The proposed evaluation model applies to products that have different compositions. Follow-up researchers or designers can apply this approach to different case designs.

Keywords: product design; layout strategy; design method

1. Introduction

The idea of a conceptual design phase was proposed by Pahl and Beitz in Germany and it has been viewed as the cornerstone of any conceptual design task. Their book has been used as the textbook for engineering design courses and implementation. Their approach was extended by introducing new technologies and tools. These technologies and tools can be embodied, and the extended design approach is called the integrated, customer driven, conceptual design method (ICDM). This approach can be applied to the entire conceptual design phase from defining demands to determining the optimal concept. Three out of the seven new ICDM tools can be used to enhance the task definition of quality function deployment (QFD), the conceptual failure mode analysis method (CFMA), and the design quality method (DQM) for assessing the satisfaction of the concepts that are generated. In addition to the Pahl and Beitz approach, ICDM also includes several steps that can contribute to the excellent design if they are fully implemented [1]. Gielisch proposed and evaluated four different product development approaches, which include the systematic approach of Pahl and Beitz (SAPB), theory of inventive problem solving (TRIZ), concurrent engineering (CE), and lean development (LD). These four approaches are specifically for the demand of micro-assembly and production on reconfigurable manufacturing systems (RMS). They feature clear structure, high integrated production, manufacturability, and time consumption. A new approach was proposed to successfully integrate the advantages of these four existing methods. The formal composition of an abstract product contains three data types. By using these attributes and a decision tree, the process that is required by RMS can be accomplished [2]. Fiorineschi proposed an approach to resolve the known deficiencies that can be contributed to systematic conceptual design (SCD). More precisely speaking, the well-known functional decomposition and morphology can be used to support creativity and to resolve the problem during the creation of innovative ideas during the activities of the SCD process. This approach is the problem–solution network that was developed in recent years. It provides a comprehensive guidance for the application of the TRIZ tool in SCD. In addition to their claim of resolving the deficiencies of functional decomposition and morphology (FDM), their study also considered PSN(Problem-Solution Network) for resolving problems and evolving into TRIZ integration. Their studies also proposed the application procedures to industrial case studies and carried out analyses in order to demonstrate their purpose [3]. Becattini applied general theory of powerful thinking (OTSM) and the theory of inventive problem solving to form an OTSM–TRIZ approach for students to resolve design problems within a problem network. This approach can be used to analyze design theories and design protocols. The purpose is to support the evaluation of students' overall achievement and to create systematic design courses for download learning. This approach also considered the process of generating new ideas and it allows people to carry out protocol studies during a limited amount of time and therefore it is very time-consuming [4]. During the Lorenzo integration process, the benefits of these three indicators can be utilized simultaneously. Innovative data can also be extracted from these three indicators during the evaluation process [5]. Jenab proposed a useful decision-making tooling for resolving the complexity of solutions during the conceptual design (CD) phase during the product development process. The purpose was to assess the potential new product investments so that the importance of the development strategy can be verified. The limit of the compatible information between design concepts still presents a challenge to the concept-selecting approaches. The layers within the decision standards can be aggregated to a chart, which can be used to determine the optimal alternative solution when evaluating the CD alternative [6]. The Erden universal framework can be used to understand functional modeling (FM). This approach highlights the characteristics of the FM-related classical methods so that the fundamental thinking can be classified [7]. Eckert proposed an approach for industrial designers, and it can be viewed as a portion of the quality function deployment (QFD) or failure mode and effect analysis (FMEA), which are suitable for functional modeling. This approach has been applied to the entire territory and has passed the formal process of an organization. Although both studies proposed the use of integrated design approaches, they were actually applied to the production demand and to form the structure rather than designing comprehensive tasks [8]. Ulrich proposed that the tasks that were related to design and manufacturing follow a plan that regulates the development stages, from the potential customer requesting a quotation to the final delivery of products. A product's functions can determine many related activities that should be designed to install in a specified region. A product also operates under the definite conditions so that the assembly manufacturer can work together with end users to enhance product quality and performance [9]. From the standpoint of creativity, Toh studied the conceptual selection process of engineering students in order to determine the factors that are helpful to the selection of creative concepts. A design team of students can carry out quantitative and qualitative analyses on the data that are acquired from controlled experiments. The results of similar studies indicated that the design team of students highlighted the technical feasibility of a design during the selection and discussion period. This is also highlighted in engineering education [10].

According to statistics, there is only a very small portion of people who can take the right medicine at the right time at the right dose. The chance for a patient who is more than 65 years old to take wrong medicine is seven times higher than those who are less than 65 years old. For the aged population in Taiwan, most of the elderly people who are more than 65 years old have developed more than one chronic disease. As a result, the safety issue of medicine is very important. At the moment, the pillboxes that are available on the market lack an important function of examining whether a patient has taken the same medicine repeatedly or has taken medicine with interfering effects. In order to allow a patient to take medicine regularly without worries, a new pillbox should be created for patients with chronic diseases as a solution to this type of problem. Moreover, the safety issue of taking medicine is considered in order to enhance the feasibility of a pillbox design for patients with chronic diseases so that they can take the right medicine at the right time at the right dose. As people are more concerned about environmental protection and are pursuing the goal of reducing the impact of a product on the environment to a minimum level, a new approach that integrates multi-criteria decision making (MCDM). This new approach is a fast and objective tool that is based on derivation from evidence. Earlier studies indicated that the proposed method can be applied to the evaluation of environmental functions of alternative design cases [11]. A comprehensive product evaluation method was proposed for students of industrial design so that they can carry out an effective design evaluation even when they encountered fuzzy information during the design evaluation stage. In this study, the fuzzy analytic hierarchy process (AHP) was used to evaluate product designs and to resolve the potential problems that might occur during the product evaluation process. The questionnaire with purposive selection was based on the judgment from experts so that different weights can be assigned to each evaluation criterion. The performance indicators of a fan were verified by CFD simulation and wind tunnel measurements. An optimal product can be created for evaluation of its optimized air flow rate. The integration of these methods is not only practical and objective, but also can help students make a decision between complicated and uncertain conditions. This approach also provides students with a good reference during the follow-up stage of product design and evaluation so that the learning competitiveness of students can be enhanced [12]. Similar to the technique for order of preference by similarity to ideal solution (TOPSIS), another framework was also proposed by integrating the analytical hierarchy process (AHP) with order priority technology. This approach can assist designers in identifying customer demands and design features. It is also helpful for determining the final design solution and for carrying out effective assessments. The proposed solution was first used in combination with the AHP for assessing customer demands and the overall relative importance of design features [13]. Fuzzy mathematics was proposed by the American control theory expert L.A. Zadeh in 1965 [14–16]. After years of development, the theoretical level is very comprehensive and this approach has been widely used in various areas, such as natural science and social science. Since fuzzy mathematics is used to handle objective and practical problems by its integration with precise mathematics, it is different from precise mathematics' characteristics of "one or the other" or "one and the other." Therefore, this approach finds a reason for its extensive applications. Moreover, the mathematical characteristics of the fuzzy approach also make it an emerging science within the design field. When assessing the quality of a lighting fixture design, for example, various factors must be considered. However, assessing the quality of a factor often includes human subjectivity and uncertainty, which leads to fuzziness. If an assessed result lacks objectivity, then reliability and validity will not be enhanced. Fuzzy mathematics can handle the condition of true and false and is also a feasible approach for measuring ideas. Whenever human thinking is involved, the fuzzy point-of-view could be a feasible approach for comprehensive assessment. Fuzzy theory can be applied to the selection of sites and studies, also indicating that the calculation of fuzzy numbers can also involve the ranking of several schemes based on their quality so that the quality of strategic analysis can be enhanced. In other studies, the fuzzy evaluation method is used to assess (computer-assisted instruction) the CAI curriculum. Fuzzy set theory is used to construct a multilevel fuzzy combined evaluation method for architecture colors. The goal is to determine the conclusion on the quality of the strategy of architectural color schemes. Kuo et al. [17] studied the selection of system operations of mobile value-added services by fuzzy theory. The results indicated that this model can effectively reduce human subjective awareness and enhance the precision of the selection so as to serve as the basis for the development of shape ideas. When a product design comes out, the fuzzy synthetic evaluation method can be used to assess product quality. The results indicate that building up this model can assist in the rationalization of the design process, reduce the misplay in the assessment, enhance the efficiency of the strategic decision, and increase the success rate of new product development [17].

Sun et al. [18] proposed applying triangular fuzzy numbers that cannot increase the reliability and authenticity of linear assessment by human sensory capture. Questionnaires are conducted in a qualitative manner to understand consumer preferences and needs through self-subjective judgments, matching collected terms, and screening consumers' shapes and functions for self-framed image vocabulary and expectation psychology. Then, using the quantization method, triangulation is used to calculate the ideal preference for the vocabulary closest to the consumer in different self-species. In their research, Hu and Liao studied 18-to-38-year-old individuals at colleges and universities, and then discussed various lifestyle attitudes and emotional consumption patterns of consumer groups. Consumer groups and frame styles have different factors to consider facets by evaluating various attributes of the vocabulary. By grouping consumers, they can understand the consumer groups and the consumption concepts they belong to and clearly understand their own positioning. Through the guidance of emotional imagery, consumers can find a path that suits them [19,20].

Fuzzy theory is a science used to study and deal with fuzzy phenomena. It was originally proposed by the computer scientist L.A. Zadeh of the University of California in 1965. It has been around for more than 40 years. It is used to process inaccurate and fuzzy data and operates through rigorous mathematical methods to solve decision problems in a fuzzy environment [21–23]. There are many objectives in the design evaluation, such as aesthetics (overall effect, shape, color, decoration, etc.), pleasure, safety, processability, etc., which are difficult to achieve by traditional quantitative analysis methods. To this end, it is necessary to introduce linguistic variables to describe and solve problems, and then use fuzzy mathematics to quantify the fuzzy information for quantitative evaluation [16].

Hsiao used fuzzy theory and analytic hierarchy analysis to make product decisions [14,24], and used fuzzy theory to perform monochrome color matching in the automotive design phase for related evaluations. In addition, he used fuzzy semantics to make automotive design decisions and lexical transformation product design descriptions to evaluate computer-aided industrial designs and images.

In addition, some scholars have proposed computer-aided systems to help design engineers reduce development and file processing time. Moskowitz and Kim proposed an optimal product design decision-support system in 1997 [15]. Developing an annual reasoning structure can infer the relationship between customer demand (CR) and design requirements (DR) [25]. However, developing these systems requires expertise and experience to build the rules while facing issues such as whether the system is performing well. According to fuzzy set theory, Kim et al. used supplier competition analysis to construct a relationship function between CR and DR and proposed a fuzzy multi-objective model. However, constructing these relationship functions has its difficulties, especially when developing a brand-new product. Data from competitors can be used for analysis [18]. Other scholars apply fuzzy sets, fuzzy operations, or defuzzification techniques to deal with complex and inaccurate quality functional problems; however, these methods do not consider the relationships between engineering design requirements [12,26]. Other scholars have emphasized that in addition to determining the degree of DR implementation based on customer satisfaction, we should also consider organizational conditions such as cost factors and technical difficulties to make economic, customer-friendly best decisions.

2. Theoretical Background

2.1. Fuzzy Theory

Fuzzy theory is a subject of science that deals with the study and processing of fuzzy phenomena. It was proposed in 1965 by L.A. Zadeh, an expert in control theory at the University of California, Berkeley, USA. It has been a subject for more than 40 years and has been used for processing imprecise data with vagueness. With rigorous mathematical methods for calculation, the strategic problems under a fuzzy environment can be resolved by this approach [14]. During design assessment, there are many targets, such as aesthetics (overall effect, shape, color, decoration, etc.), amenity, safety, machinability, etc. These targets are difficult to determine by conventional quantitative analysis. Therefore, linguistic variables must be introduced for description in order to acquire a solution. After that, the fuzzy mathematical approach can be used to numerate the fuzzy information for quantitative evaluation.

Hsiao utilized fuzzy theory and hierarchical analysis to carry out strategic decisions [25] and utilized fuzzy theory to evaluate monochromatic color schemes during the car appearance design phase [27,28]. In addition, he also applied fuzzy semantics to the strategic decision of automobile shape designs [21,22]. Moreover, the semantic transformation from adjectives was applied to the design of product forms in order to carry out computer-aided industrial design and assess form images [29,30].

In addition, a number of scholars have also proposed different computer-aided systems to assist designers and engineers in reducing the time for research and development and document processing. In 1997, Moskowitz and Kim proposed a decision support system with optimal product designs [31]. Temponi et al. proposed a deduction framework in 1999 in order to deduce the relationship between customer requirements (CRs) and design requirements (DRs) [32]. However, the knowledge and experience of experts are required to construct the rules when developing this type of system. At the same time, designers also encounter problems whether a system is in good operation or not. According to fuzzy set theory, Kim et al. utilized data, such as the analysis of the competitiveness of companies, to construct a correlation function between CRs and DRs. They proposed a fuzzy multi-objective model. However, it is difficult to build this correlation function. This is especially true when developing a brand-new product without any data from competitors for analysis [33]. Other scholars have applied fuzzy sets, fuzzy algorithms, or defuzzification techniques to process complex and imprecise quality function deployment problems. However, these methods do not take into account the relationships between engineering design demands. Other scholars have emphasized that the quality function deployment needs to not only determine the performance based on customer satisfaction but also consider organizational criteria such as cost factors and technical difficulties so as to determine the optimal decision that is economical and satisfactory for customers.

Among various targets of a design, some required concepts are definite while others are vague. It is also required to consider several targets and comprehensively consider various relevant factors and carry out comprehensive assessments. This is the so-called fuzzy comprehensive assessment. The process of implementing fuzzy assessment includes constructing the affecting factor set, determining the factor weight set, determining the parameter evaluation set, creating the single-factor assessment matrix, and conducting the fuzzy evaluation. These procedures are described as follows:

2.1.1. Constructing the Affecting Factor Set

When conducting a fuzzy evaluation, first confirm the factors affecting the values of the evaluation parameters. If it is known that the affecting factors are $u_1, u_2, \ldots, u_\mathrm{m}$, the factor set that is composed of these parameters is $U = \{u_1, u_2, \ldots, u_\mathrm{m}\}$. This factor set is a common set.

2.1.2. Determining the Factor Weight Set

The degree of influence and importance of each parameter for the factors are different; that is, the weight of each parameter is different for each factor. The factor weight set is the set that is composed of the degree of influence of each parameter for each factor and can be expressed as $A = \{a_1, a_2, \ldots, a_n\}$. If $\mathrm{a_i}$ indicates the ith factor weight, the weights of all of the factors need to satisfy Equation (1). A weight set is a fuzzy subset of the factor set and can be expressed as Equation (2):

$$\sum_{i=1}^{n} a_i = 1,\ a_i \geq 0\ (\mathrm{i} = 1,2,3,\ldots,a_n), \quad (1)$$

$$\begin{aligned} A &= \frac{a_1}{u_1} + \frac{a_2}{u_2} + \frac{a_3}{u_3} + \ldots + \frac{a_n}{u_n} \\ &= \{a_1, a_2, a_3, \ldots, a_n\} \end{aligned} \quad (2)$$

The weight of each factor can be determined by the weight coefficient method, analytic hierarchical process, paired comparison method, Likert scale, or any subjective determination according to the practical problem. It does not matter which approach is used, and human factors are involved, with the only difference being in credibility. Here, A is the fuzzy set of each factor weight. For the same factor, if different data are taken, the assessment result is different. The method of the determinant table is to carry out pairwise comparison of the importance of these evaluation targets. Scores are given after further calculation and are entered into the table. The equation for calculating a_i is as follows:

$$a_i = k_i / \sum_{i=1}^{n} k_i, \tag{3}$$

where k_i is the total score of each evaluation target and n is the number of evaluation targets.

$$\sum_{i=1}^{n} k_i = \frac{n^2 - n}{2} \times 4 = 2(n^2 - n). \tag{4}$$

2.1.3. Determining the Parameter Evaluation Set

The evaluation set is composed of the various evaluation results that an assessor might obtain for the evaluation target. It is represented as V, and $V = \{v_1, v_2, \ldots, v_{\mathrm{n}}\}$ and v_i ($i = 1, 2, 3, \ldots, n$) represent the possible total evaluation results. The purpose of fuzzy evaluation is to comprehensively consider all of the affecting factors and obtain an optimal evaluation result from the evaluation set. The relationship between v_i and V is also a common set relationship. Therefore, the evaluation set is also a common set. For the evaluation in this study, the evaluation set is V = {*very satisfied, satisfied, neither satisfied nor dissatisfied, dissatisfied, very dissatisfied*}.

2.1.4. Creating the Single-Factor Assessment Matrix

A single-factor fuzzy evaluation is conducted to judge one factor separately and confirm the degree of membership for the target of evaluation toward evaluation-set elements. The evaluation target is carried out by the *i*th factor $\mathrm{U_i}$ and the membership grade of the *j*th element V_i in the evaluation set is r_{ij}. Therefore, the evaluation result of the *i*th factor U_i can be determined as follows:

$$R_i = \frac{r_{i1}}{V_1} + \frac{r_{i2}}{V_2} + \ldots + \frac{r_{in}}{V_n} \tag{5}$$

where *Ri* is called the single factor evaluation set, which is the fuzzy subset of the evaluation set. It can be expressed as $R_i = (\mathrm{r_{i1}}, \mathrm{r_{i2}}, \ldots, \mathrm{r_{in}})$. Similarly, the single factor evaluation set of each factor can be determined as follows:

$$\begin{gathered} R_1 = (r_{11}, r_{12}, \ldots, r_{1n}) \\ R_2 = (r_{21}, r_{22}, \ldots, r_{2n}) \\ \vdots \\ R_m = (r_{m1}, r_{m2}, \ldots, r_{mn}) \end{gathered} \tag{6}$$

The fuzzy matrix that is composed of the membership grade of each single factor evaluation set is called the single-factor assessment matrix, R, as shown in Equation (7). R is a fuzzy matrix and can also be viewed as the fuzzy relational matrix from U to V, or so-called fuzzy mapping.

$$R = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_i \\ \vdots \\ R_n \end{bmatrix} = \begin{bmatrix} r_{11} & r_{12} & \ldots & r_{1j} & \ldots & r_{1m} \\ r_{21} & r_{22} & \ldots & r_{2j} & \ldots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{i1} & r_{i2} & \ldots & r_{ij} & \ldots & r_{im} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \ldots & r_{nj} & \ldots & r_{nm} \end{bmatrix}. \quad (7)$$

However, in this study, there are numerous factors to be considered and each factor can have different levels. It is difficult to resolve a problem by using single-factor fuzzy evaluation. It is also difficult to obtain reasonable assessment results. As a result, this study is based on fuzzy comprehensive evaluation, and then the fuzzy comprehensive evaluation is implemented. This is because there are too many factors to consider when making a selection from complicated schemes. There are levels between factors, therefore we must adopt the multifactor assessment matrix. The procedure is to divide the factor set into several levels according to its characteristics, carry out comprehensive assessment on each level, and then conduct in-depth combined evaluations on the evaluation results.

2.1.5. Conducting the Fuzzy Evaluation

If the fuzzy evaluation matrix of a certain scheme on the evaluation target is the R in Equation (7), the weighted comprehensive fuzzy evaluation and the product of fuzzy matrices to be considered is as follows:

$$B = A \bullet R = \left[b_1, b_2, \ldots b_j, \ldots b_m \right] \quad (8)$$

where • indicates the fuzzy synthetic operation.

There are several synthetic approaches of fuzzy weight matrix A and factor judgment matrix R. In this study, four synthetic approaches were implemented for the analysis and comparison of the evaluation results. These four models are described as follows:

Model 1: M $(\wedge, \vee)$ synthetic operation, in which

$$b_j = \mathop{\vee}_{i=1}^{m} (a_i \wedge r_{ij}); j = 1, 2, \ldots, n, \quad (9)$$

where $\vee$ and $\wedge$ indicate taking the maximum or minimum. When taking the minimum, the r_{ij} of all $r_{ij} > w_{ij}$ is not taken into consideration. Therefore, when there are various factors, the values are bound to be large after the weighted coefficients are normalized. As a result, a lot of the single-factor evaluation information will be lost. When there are fewer factors, w_{ij} might be larger and therefore the w_{ij} of all $w_{ij} > r_{ij}$ will not be taken into consideration. The influence of the main factors might be lost.

Model 2: M $(\bullet, \vee)$ synthetic operation, in which

$$b_j = \mathop{\vee}_{i=1}^{m} (a_i r_{ij}); j = 1, 2, \ldots, n. \quad (10)$$

The feature of this model deals with no loss of any useful information. However, the operation of taking the maximum $\vee$ could possibly lose a lot of useful information. It can still reflect the single-factor evaluation result and the degree of importance of each factor.

Model 3: M $(\wedge, +^{\circ})$ synthetic operation, in which

$$b_j = \min\{1, \sum_{i=1}^{m} (a_i \wedge r_{ij})\}; j = 1, 2, \ldots, n, \quad (11)$$

where $+^{\circ}$ takes the summation with an upper limit of 1. The feature of this model deals with the loss of a lot of valuable information during the operation of taking the minimum. Therefore, it might not achieve the expected evaluation result. When the values of w_i and r_{ij} are larger, the resulting b_j could be equal to the upper limit of 1. When the values of w_i and r_{ij} are smaller, the resulting b_j could be equal to the summation of all w_i As a result, it could be more difficult to obtain the expected evaluation result.

Model 4: M (•, +) synthetic operation, in which

$$b_j = \min\{1, \sum_{i=1}^{m} a_i r_{ij}\}; j = 1, 2, \ldots, n. \tag{12}$$

This model is also called the weighted-average model and it deals with the situation when w_i is equipped with normalization, i.e., $\sum_{i=1}^{m} a_i = 1$, $\sum_{i=1}^{m} a_i r_{ij} << 1$.This model can be restructured as M (•, +), in which

$$b_j = \sum_{i=1}^{m} a_i r_{ij}; j = 1, 2, \ldots, n; \sum_{i=1}^{m} a_i = 1, \tag{13}$$

where $\sum_{i=1}^{m} a_i = 1$. This model not only considers the influence of all factors, but also keeps all the information of the single-factor evaluation. During its operation, it does not apply the upper limit to a_i and r_{ij} $(i = 1, 2, \cdots, \mathrm{m}; j = 1, 2, \cdots, n)$. However, a_i should be normalized. These are the significant characteristics and advantages of this model. When carrying out the fuzzy comprehensive evaluation and fuzzy optimization design on engineering design parameters, this model is implemented, since typically it can obtain better effects. This model not only considers the influence of all factors, but also keeps all information of the single-factor evaluation. During the operation, there is no upper limit on w_i and r_{ij}. It is only required to carry out normalization on w_i. This is the distinguishing feature and the main advantage of this model.

The goal of Models 1–3 is to obtain individual evaluation results based on certain limitations and by taking the extreme value. Therefore, a lot of useful information could be lost to various degrees during the evaluation process. As a result, these three models are applied to the scenarios that only care about the extreme values of objects in order to highlight certain main factors. Based on this, Model 4 is used for the synthetic operation in this study.

2.1.6. Processing the Evaluation Indices

After the evaluation indices b_j (j = 1, 2, … , n) are determined, the results of the evaluation target can be determined by the methods of maximum degree of membership and weighted average, as follows.

(a) Maximum degree of membership

Based on the principle of maximum degree of membership, the evaluation element v_i corresponding to the maximum evaluation index b_j is selected. This approach considers only the contribution of the maximum evaluation index; information supplied by other indices is neglected. Moreover, when there are more than one maximum evaluation indices, it will be difficult for maximum degree of membership to determine a concrete result. In this case, weighted average is usually used.

(b) Weighted average

By taking b_j as the weight, the weighted average of each evaluation element v_j is determined to obtain the evaluation result; that is,

$$D = \frac{\sum_{j=1}^{n} b_j v_j}{\sum_{j=1}^{n} b_j}. \tag{14}$$

When the evaluation index b_j is normalized, then

$$D = \sum_{j=1}^{n} b_j v_j. \tag{15}$$

If the evaluation target is quantitative, Equation (14) can be used to determine the D value, which is the result of the fuzzy comprehensive evaluation for the evaluation target. If the target is not quantitative and the evaluation set is {superior, good, neither good nor bad, bad}, quantification of the nonquantitative targets of superior, good, neither good nor bad, and bad should be carried out. Otherwise, maximum degree of membership should be used. Based on these evaluation criteria, the distribution of various characteristics of the evaluation target can be determined. This method provides a deeper understanding of the evaluation target in order to determine the most appropriate processing approach to evaluate the data.

2.2. Analytic Hierarchy Process (AHP)

The analytic hierarchy process is a decision method proposed by Saaty (1980). It mainly applies to uncertain situations and multicriteria decision-making problems [34,35]. The AHP systemizes complicated multicriteria problems with a concise hierarchical framework. A decision maker carries out pairwise comparison between two criteria on their relative importance within a level. After that, a pairwise comparison matrix is constructed in order to determine the relative importance between the criteria. The overall prioritized vector of the entire level can be calculated by making the levels serially connected, leading to the weight of each evaluation criterion. The quantized result assists decision-makers in making comprehensive evaluations of alternative schemes in order to determine their priority and reduce the risk of making a wrong decision. Liu et al. proposed a new approach of calculating weights to replace the pairwise comparison of the analytic hierarchy process (AHP), called the voting analytic hierarchy process. This approach is simpler than AHP and can calculate weights systematically. It can also determine the priority of various suppliers by determining each one's score.

The procedure of the analytic hierarchy process includes five steps:

Step 1: Delimit the decision-making problem.

Step 2: Build the hierarchical framework.

Step 3: Construct the pairwise comparison matrix, as shown in Table 1, which is the assessment scale and relative comparison of the hierarchy analysis.

Table 1. Assessment scale and relative definitions of hierarchy analysis.

Scale	Definition
1	Equally important
3	Slightly important
5	Important
7	Very important
9	Absolutely important
2, 4, 6, 8	Intermediate values

Step 4: Calculate the eigenvalues.

Step 5: Examine the consistency.

When calculating the eigenvectors in Step 4, the following algorithms can be used:

(1) Theoretical analysis of eigenvalues and eigenvectors.

(2) Four approximate solutions that were proposed by Saaty: Normalization of the means of row vectors, also called normalization of the row average; normalization of the means of column vectors, also called the means of normalized columns; normalization of the geometric means of

row vectors, also called normalization of the geometric mean of the rows; and the average of the inverse of the normalized rows.

The consistency examination in Step 5 determines whether the evaluation results obtained from the pairwise comparison are consistent. In other words, it determines whether the experts' preference satisfies the transitivity. Saaty proposed the use of the consistency index (Consistency Index, *C.I.*) and consistency ratio (Consistency Ratio, *C.R.*) to carry out the examination. If both *C.I.* and *C.R.* are less than 0.1, it indicates that the pairwise matrix has consistency. The equations of *C.I.* and *C.R.* are as follows:

$$\text{C.I.} = \frac{\lambda_{\max} - n}{n-1} \tag{16}$$

where $\lambda_{\max}$ is the maximum eigenvalue of the matrix, and n is the order of the matrix (number of parameters); and

$$C.R. = \frac{C.I.}{R.I.} \quad \begin{array}{c} C.R. < 0.1 \Rightarrow \text{OK} \\ C.R. = \ Consistency ratio \\ C.I. = \ Consistency index \\ R.I. = \ \text{Random } index \end{array} \tag{17}$$

where n is the number of evaluation criteria, and *R.I.* is the random index, and its value increases with the number of criteria, as shown in Table 2.

Table 2. Stochastic indicator table.

Order N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.44	1.45	1.49	1.51	1.48	1.56	1.57	1.58

3. Case Design

The objective of this study is to build an evaluation index for the design of a pillbox for patients with chronic diseases. The first step is to classify and determine the items to be scored for product design. In order to identify the relevance of the preliminary evaluation indices, semi-structured interviews were conducted. The researchers surveyed professionals in related fields for their opinions, aiming at collecting an organized evaluation indicator based on their capacity to make professional judgments, assessing the importance of each question, and applying corrections or supplements to these evaluation indices. In addition to the drafted evaluation indices, the interview contents and questions were prepared so that the interviewees were asked questions such as "Any other factors to be included as the evaluation indices?" and "What are the criteria for a pillbox for patients with chronic diseases?". The interview procedure included preparing for the interview, drafting interview contents and an outline, determining the interviewees, questioning and making records, ending the interview, and collecting and analyzing the data. After interviewing the experts, the appraisal process for a pillbox for patients with chronic diseases could be determined. In addition, assessing the professional literacy of the interviewees, the conditions of the pillbox are among the critical factors during the evaluation process. Therefore, the evaluation indices can be determined, and include the first level, i.e., the goal level, which is the eventual goal of appraising product designs. The second level is the objective level, which includes five constituent elements: functionality, structure, aesthetics, creativeness, and economy. The third level covers 19 evaluation criteria. In order to carry out systematic evaluation and analysis, the evaluation factors and constituent elements were chosen to build the hierarchical structure, as shown in Figure 1. Since numerous factors could affect the selection of interviewees, quantification of the degree of influence of each factor had to be carried out. After that, the degrees of influence of various factors were combined and calculated by utilizing a systematic approach in order to obtain quantization results. The definitions of the assessment items are as follows.

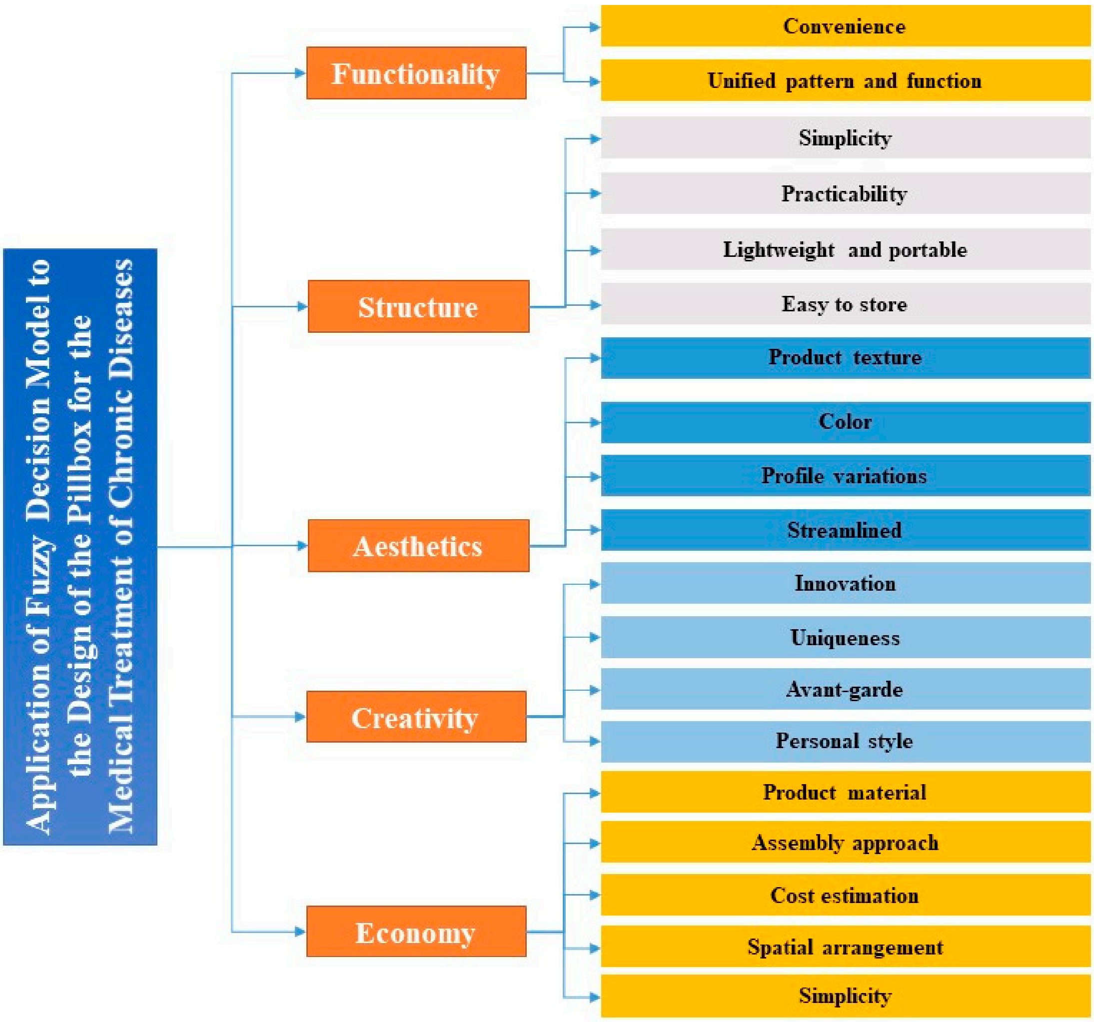


Figure 1. Hierarchical framework of evaluation indices of a pillbox for patients with chronic diseases.

First, the functionality part indicates the functionality of the pillbox for patients with chronic diseases. It covers two criteria, a product's "convenience" and its "unified pattern and function." Structure comprises "simplicity, "practicability,", "lightweight and portable," and "easy to store." Aesthetics comprises "product texture," "color," "shape variation," and "streamlined." Creativeness comprises "innovation," "uniqueness," "avant-garde," and "personal style." Economy comprises "product material," "assembly approach," "cost estimation," "spatial arrangement," and "simplicity."

In addition, the interviewees were mainly experts who could provide answers to the questions. Through the investigation and questionnaire, the resulting data were processed by the quantization approach. A total of 24 experts participated in this study, including 14 who run a business in an industry related to the pillbox and 10 workers in this industry. The information on their backgrounds is shown in Table 1. The participants were asked to consider the evaluation factors of the design of a pillbox for patients with chronic diseases. Answers, including the implementation of the AHP method and the fuzzy comprehensive evaluation, were checked. The goal was to obtain objective results from the questionnaire survey. After the relative weight of each factor was obtained by the AHP method and the consistency examination was carried out, Model 4 of the fuzzy synthetic method was used to apply the evaluation indices to obtain the final evaluation results.

Fuzzy multicriteria decision-making was used in this study to determine the evaluation indices of a pillbox design for patients with chronic diseases. Based on the above-mentioned analysis and construction of the evaluation factors for the pillbox, a total of 5 constituent elements and 19 evaluation criteria were obtained. They were classified into upper-level and lower-level factors as follows:

Upper-level factors: U = {Functionality ($U1$), Structure ($U2$), Aesthetics ($U3$), Creativity (U_4), Economy (U_5)}

Lower-level factors: U_1 = {Convenience (u_{11}), Unified pattern and function (u_{12})}

U_2 = {Simplicity (u_{21}), Practicability (u_{22}), Lightweight and portable (u_{23}), Easy to store (u_{24})}

U_3 = {Product texture (u_{31}), Color (u_{32}), Shape variation (u_{33}), Streamlined (u_{34})}

U_4 = {Innovation (u_{41}), Uniqueness (u_{42}), Avant-garde (u_{43}), Personal style (u_{44})}

U_5 = {Product material (u_{51}), Assembly approach (u_{52}), Cost estimation (u_{53}), Spatial arrangement (u_{54}), Simplicity (u_{54})}

In order to reflect the importance of each factor, the AHP was implemented to obtain the relative weights determined by the experts in this study. The questionnaire contents included a letter of instruction, instructions for filling out the questionnaire and examples, the standards of the intensity of importance, the hierarchical framework of indices, explanations, and questions. The importance of two factors in each subsystem was compared. The evaluation scale basically can be divided into five levels: equally important, slightly important, considerably important, very important, and absolutely important. They were assigned weights of 1, 3, 5, 7, and 9. An additional four levels between these five levels were assigned weights of 2, 4, 6, and 8. Left-aligned scales indicated that the factors on the left were more important than the factors on the right. On the other hand, right-aligned scales indicated that the factors on the right were more important than the factors on the left. The experts were asked to tick adequate assessment items, and the results are shown in Tables 3 and 4.

Table 3. Weight set of upper-level factors of evaluation indices for a pillbox design for patients with chronic diseases.

Ranking	Upper-level Factor	Weight	*CR*
1	Aesthetics (U_3)	0.40	
2	Structure (U_2)	0.29	
3	Creativity (U_4)	0.15	0.01
4	Functionality (U_1)	0.10	
5	Economy (U_5)	0.07	

Table 4. Weight set of lower-level factors of evaluation indices for pillbox design for patients with chronic diseases.

Upper-level Factor	Lower-level Factor	Weight	*CR*
Functionality (U_1)	Convenience (u_{11})	0.532	0.01
	Unified pattern and function (u_{12})	0.468	
Structure (U_2)	Simplicity (u_{21})	0.424	0.03
	Practicability (u_{22})	0.232	
	Lightweight and portable (u_{23})	0.312	
	Easy to store (u_{24})	0.032	
Aesthetics (U_3)	Product texture (u_{31})	0.153	0.03
	Color (u_{32})	0.241	
	Shape variation (u_{33})	0.194	
	Streamlined (u_{34})	0.412	

Table 4. *Cont.*

Upper-level Factor	Lower-level Factor	Weight	CR
Creativity (U_4)	Innovation (u_{41})	0.22	0.02
	Uniqueness (u_{42})	0.229	
	Avant-garde (u_{43})	0.352	
	Personal style (u_{44})	0.199	
Economy (U_5)	Product material (u_{51})	0.164	0.01
	Assembly approach (u_{52})	0.201	
	Cost estimation (u_{53})	0.167	
	Spatial arrangement (u_{54})	0.178	
	Simplicity (u_{55})	0.29	

In addition, it is known from the AHP method that when $C.R. \leq 0.1$, it can be determined that the judgment matrix has satisfactory consistency. It also demonstrated that the weight distribution is reasonable, and the results are shown in Tables 3 and 4.

Based on the results in Tables 2 and 3 and from Equation (2), the weight set of each factor can be obtained as follows:

$$\widetilde{W}_1 = [0.532, 0.468], \quad \widetilde{W}_2 = [0.424, 0.232, 0.312, 0.032],$$
$$\widetilde{W}_3 = [0.153, 0.241, 0.194, 0.412], \quad \widetilde{W}_4 = [0.22, 0.229, 0.352, 0.199],$$
$$\widetilde{W}_5 = [0.164, 0.201, 0.167, 0.178, 0.29], \quad \widetilde{W} = [0.135, 0.286, 0.297, 0.159, 0.123].$$

Moreover, the set of evaluation results obtained from the participants' judgment of the evaluation target can be classified into five levels: V = {completely agree, agree, neither agree nor disagree, disagree, completely disagree}. Based on the factor set and evaluation set, the questionnaire for comprehensive evaluation of the designs allowed experts to fill in their answers to evaluate each factor. After the researchers collected the questionnaires for further statistical analysis, the membership grade of the evaluation of each factor was determined in order to obtain their fuzzy evaluation matrices. The fuzzy set is summarized as follows:

$$\widetilde{R}_1 = \begin{bmatrix} 0.32 & 0.48 & 0.16 & 0.04 & 0.00 \\ 0.19 & 0.29 & 0.48 & 0.05 & 0.00 \end{bmatrix},$$

$$\widetilde{R}_2 = \begin{bmatrix} 0.33 & 0.38 & 0.25 & 0.04 & 0.00 \\ 0.20 & 0.30 & 0.40 & 0.10 & 0.00 \\ 0.46 & 0.23 & 0.31 & 0.00 & 0.00 \\ 0.35 & 0.26 & 0.35 & 0.04 & 0.00 \end{bmatrix},$$

$$\widetilde{R}_3 = \begin{bmatrix} 0.20 & 0.30 & 0.40 & 0.10 & 0.00 \\ 0.21 & 0.16 & 0.53 & 0.11 & 0.00 \\ 0.21 & 0.32 & 0.32 & 0.16 & 0.00 \\ 0.35 & 0.39 & 0.17 & 0.09 & 0.00 \end{bmatrix},$$

$$\widetilde{R}_4 = \begin{bmatrix} 0.18 & 0.41 & 0.36 & 0.05 & 0.00 \\ 0.19 & 0.43 & 0.29 & 0.10 & 0.00 \\ 0.35 & 0.39 & 0.17 & 0.09 & 0.00 \\ 0.21 & 0.47 & 0.11 & 0.21 & 0.00 \end{bmatrix},$$

$$\widetilde{R}_5 = \begin{bmatrix} 0.33 & 0.50 & 0.08 & 0.08 & 0.00 \\ 0.18 & 0.41 & 0.36 & 0.05 & 0.00 \\ 0.33 & 0.38 & 0.25 & 0.04 & 0.00 \\ 0.21 & 0.32 & 0.32 & 0.16 & 0.00 \\ 0.38 & 0.29 & 0.19 & 0.14 & 0.00 \end{bmatrix}.$$

The fuzzy evaluation matrix can be obtained from the above-mentioned procedures. The comprehensive evaluation and operation were carried out by implementing Model 4 of the fuzzy synthetic method. This synthetic method only requires carrying out normalization of w_i. Therefore, there is no need to normalize the results obtained from the fuzzy comprehensive evaluation. The operations are as follows for the low-level evaluation:

$$\text{Functionality factor}: \widetilde{B}_1 = \widetilde{W}_1 \bullet \widetilde{R}_1 = \begin{bmatrix} 0.263 & 0.397 & 0.300 & 0.044 & 0.00 \end{bmatrix},$$

$$\text{Structure factor}: \widetilde{B}_2 = \widetilde{W}_2 \bullet \widetilde{R}_2 = \begin{bmatrix} 0.341 & 0.311 & 0.307 & 0.041 & 0.00 \end{bmatrix},$$

$$\text{Aesthetics factor}: \widetilde{B}_3 = \widetilde{W}_3 \bullet \widetilde{R}_3 = \begin{bmatrix} 0.266 & 0.307 & 0.321 & 0.110 & 0.00 \end{bmatrix},$$

$$\text{Creativity factor}: \widetilde{B}_4 = \widetilde{W}_4 \bullet \widetilde{R}_4 = \begin{bmatrix} 0.248 & 0.419 & 0.227 & 0.045 & 0.107 \end{bmatrix},$$

$$\text{Economy factor}: \widetilde{B}_5 = \widetilde{W}_5 \bullet \widetilde{R}_5 = \begin{bmatrix} 0.293 & 0.369 & 0.239 & 0.099 & 0.00 \end{bmatrix}.$$

It is known from Table 2 that the weights of the high-level factors can be determined, and the high-level judgment matrix is as follows:

$$\widetilde{R}^* = \begin{bmatrix} \widetilde{B}_1 \\ \widetilde{B}_2 \\ \widetilde{B}_3 \\ \widetilde{B}_4 \\ \widetilde{B}_5 \end{bmatrix} = \begin{bmatrix} 0.263 & 0.397 & 0.300 & 0.044 & 0.00 \\ 0.341 & 0.311 & 0.307 & 0.041 & 0.00 \\ 0.266 & 0.307 & 0.321 & 0.110 & 0.00 \\ 0.248 & 0.419 & 0.227 & 0.107 & 0.00 \\ 0.293 & 0.369 & 0.239 & 0.099 & 0.00 \end{bmatrix}.$$

Therefore, the result of the high-level fuzzy comprehensive evaluation is

$$\widetilde{C} = \widetilde{W} \bullet \widetilde{R}^* = \begin{bmatrix} 0.288 & 0.346 & 0.289 & 0.080 & 0.00 \end{bmatrix}.$$

As for the processing of evaluation indices, typical methods in common use are maximum degree of membership and weighted averaging. Weighted averaging can turn vague values into definite values. This is the so-called defuzzification effect. The purpose of defuzzification is to transform the final data or results with vague properties into definite values and data. If vague values are used in the operations, the result is also a vague value. Defuzzification of vague values must be done so that they can turn into definite values with their own representativeness for the benefit of follow-up comparison and ranking operations. Therefore, by calculating with the weighted-average method in this study, the concept of a hierarchy of values is applied to the results (Kuo and Chen, 2006). Assigning V = {completely agree, agree, neither agree nor disagree, disagree, completely disagree} = {1, 0.75, 0.50, 0.25, 0}, the researchers calculated defuzzified values of evaluation results D, shown in Tables 5 and 6.

Table 5. Degrees of conformity of various factors determined by interviewees.

Evaluation Factor	Completely Agree	Agree	Neither Agree nor Disagree	Disagree	Completely Disagree	Defuzzification
Functionality	0.259	0.391	0.304	0.046	0.00	0.716
Structure	0.319	0.391	0.300	0.063	0.00	0.723
Aesthetics	0.300	0.297	0.251	0.152	0.00	0.686
Creativity	0.298	0.324	0.236	0.142	0.00	0.694
Economy	0.300	0.306	0.250	0.144	0.00	0.691

Table 6. Degrees of conformity of index framework for evaluation by interviewees.

Constituent Elements of Evaluation Indices of Pillbox Design for Patients with Chronic Diseases	Completely Agree	Agree	Neither Agree nor Disagree	Disagree	Completely Disagree	Defuzzification
	0.288	0.346	0.289	0.080	0.00	0.711

In this study, the evaluation of pillbox designs for patients with chronic diseases was carried out by the fuzzy theory. The research results are shown in Tables 5 and 6. The degrees of conformity of various factors determined by the interviewees are shown in Table 5. The degrees of conformity of the index framework for evaluation by the interviewees are shown in Table 6. If the principle of maximum membership serves for the processing of evaluation indices, for the Structure factor, the evaluation items include "simplicity" (u_{21}), "practicability" (u_{22}), "lightweight and portable" (u_{23}), and "easy to store" (u_{24}). The evaluation result indicates that using the factors as constituent elements of the pillbox design is at the level

If the values obtained after defuzzification serve as evaluation indices for processing, it is known from the comprehensive evaluation that the result of the Functionality factor is 0.716, which indicates a level of "Completely agree" for the pillbox design, followed by Structure at 0.713, Aesthetics at 0.686, Creativity at 0.694, and Economy at 0.691. Since the design of a pillbox for patients with chronic diseases should follow regulated dimensions and patterns, according to the AHP, the factor weights are as shown in Tables 3 and 4. The weight of the Structure factor is 0.319, which corresponds to the ranking from the fuzzy comprehensive evaluation. However, the pairwise comparison matrix in the AHP has the problems of subjectivity, inaccuracy, and vagueness. In order to resolve this problem, the AHP approach must be extended to the vague environment in order to compensate for the deficiency of the vagueness problems that the AHP cannot resolve. After that, the fuzzy comprehensive evaluation is implemented to select the evaluation items in order to obtain their fuzzy values. Therefore, the result can be viewed as a dual verification, which indicates a certain degree of commonality between two factors in order to enhance the accuracy of the research. Moreover, the resulting values in Table 5 indicate that the overall index of the evaluation of the pillbox design is 0.723, which is between the levels "Completely agree" and "Agree." This indicates that the framework of the evaluation indices is acceptable. The result serves as a good reference for the process of designing a pillbox for patients with chronic diseases, as shown in Figure 2.

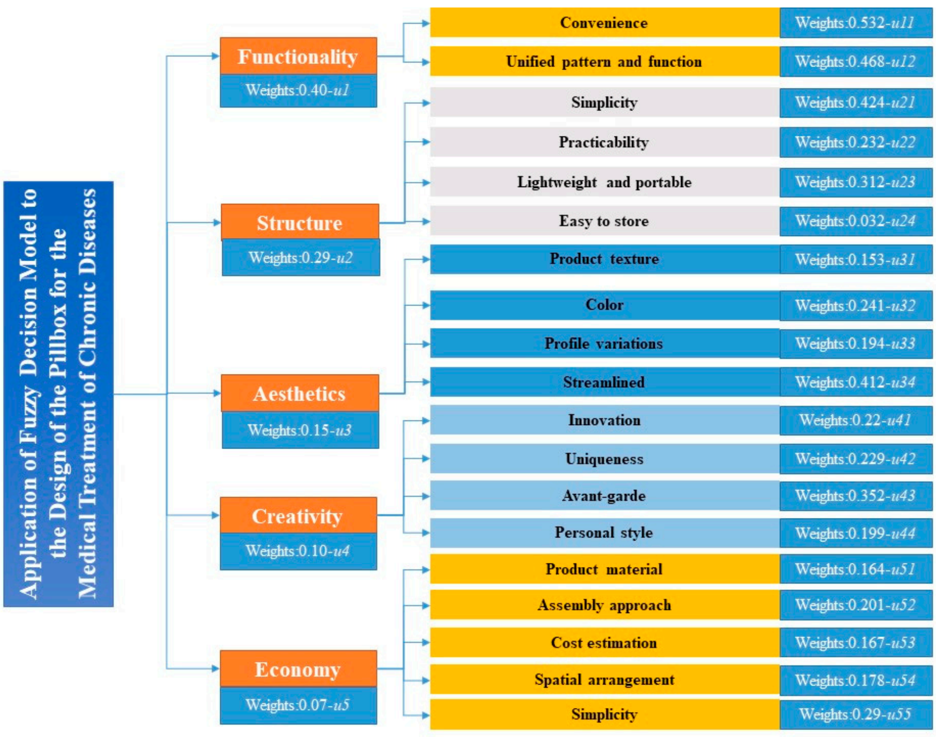


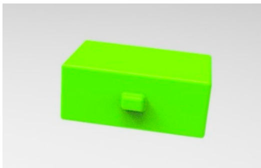
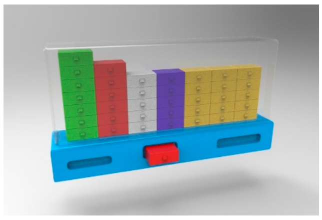
Figure 2. Weight set of the lower factors of the trolley selection indicator.

3.1. Design Case Comparison

Finally, three pillbox designs with different forms and styles are shown in Table 7. Case 1 presents a timed pillbox design as the main body and its contents show a simple and convenient design. This design provides a simple and convenient way of reminding users of the time and function of taking a pill. Case 2 presents a concept of a pillbox composed of a button-type storage compartment. This design is simple and easy to use. Case 3 features a rotating pillbox. The main idea is to implement a rotating shape in an attempt to increase the storage space. Each of these three designs has a different style.

For the evaluation of the overall schemes, it is known from Figure 3 that the defuzzified values of Case 3 is 0.74, which is at the "Satisfied" level, followed by Case 1, which has a defuzzified value of 0.62, at the "Neither satisfied nor dissatisfied" level. Therefore, Case 1 is one the most favored by subjects who made the decision. This scheme is not only full of functionality and economical, but it also performs well considering the coordination between humans, machines, and the environment. The advantage of this scheme lies in its creativity and aesthetics. Follow-up studies are advised to highlight the consideration of aesthetics. The results also indicate that Case 2 is inferior in terms of aesthetics. On the other hand, the economic aspect of Case 1 should be further enhanced as well.

Table 7. Three types of new pillbox designs with different shapes for patients with chronic diseases.

	Case 1	**Case 2**	**Case 3**
Design case			
Design name	Modularization and barcode applications	Button-type pillbox	Smart barcode application with rotatable pillbox
Design case description	Application of barcodes. Each pillbox package has a QR code. Before taking a pill, the user scans the QR code and is made aware of the contents, including side effects and directions for use. The container can link to the pillbox. The weight of each pill is shown on the front panel. Users know the weight of the pillbox and the remaining pills so they know whether they forgot to take a pill and on which day.	Composed in the shape of a button-type storage compartment. The main design is simple and easy to use.	Each kit has a QR code. Before taking the pill, the user scans the QR code and knows the drug content, including side effects and instructions for use. The container can be linked to the kit. The addition of color and LED display provides the correct medication for the user, and the weight of each pill is displayed on the front panel. Users know the weight of the pillbox and the remaining pills so they know if they forgot to take the medicine and on which day.

The pillbox design of Case 3 provides the function of a favorable performance design with portable pill cells. Since patients are not professional medical personnel (Figure 4), they might take the wrong medicine by mistake or by misunderstanding the information. In order to create an intelligent pillbox that can recognize prescriptions and scheduling, a new type of portable cell is created. It is similar to the design of hospital medicine bags that can prevent cross-contamination of different medicines. Each cell is loaded with only one type of medicine and there is a barcode for the medicine information on the top. The information includes patient name, medicine name, and dose, as well as medication instructions. Based on doctors' prescriptions, pharmacists load the medicines into the portable cells and seal them for patients.

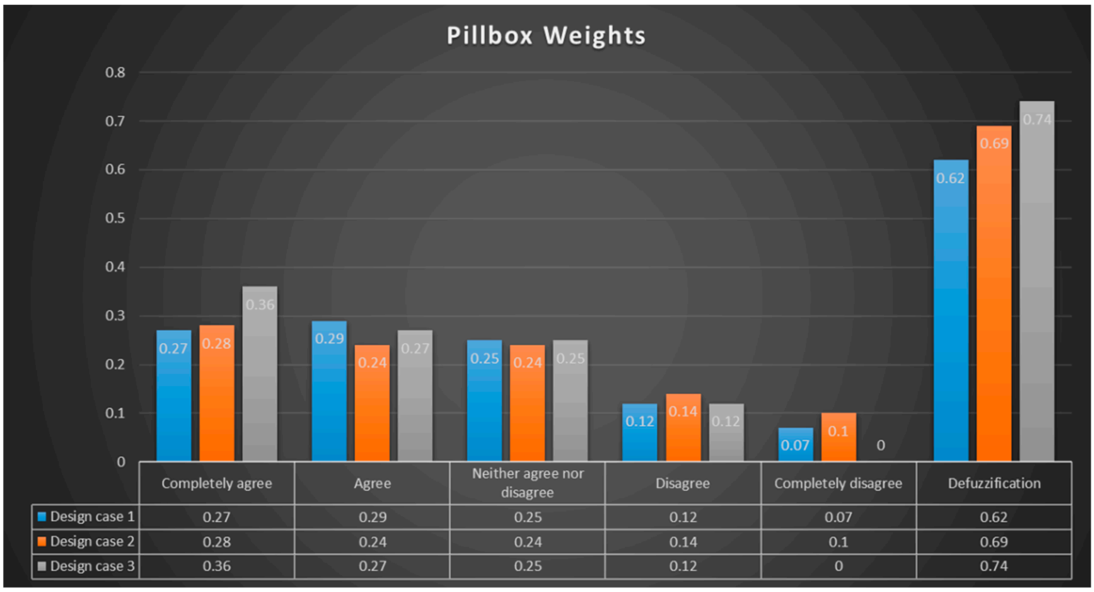


Figure 3. Subjects' satisfaction degree and defuzzification values for the three design cases. satisfaction degree value, the highest score of each program.

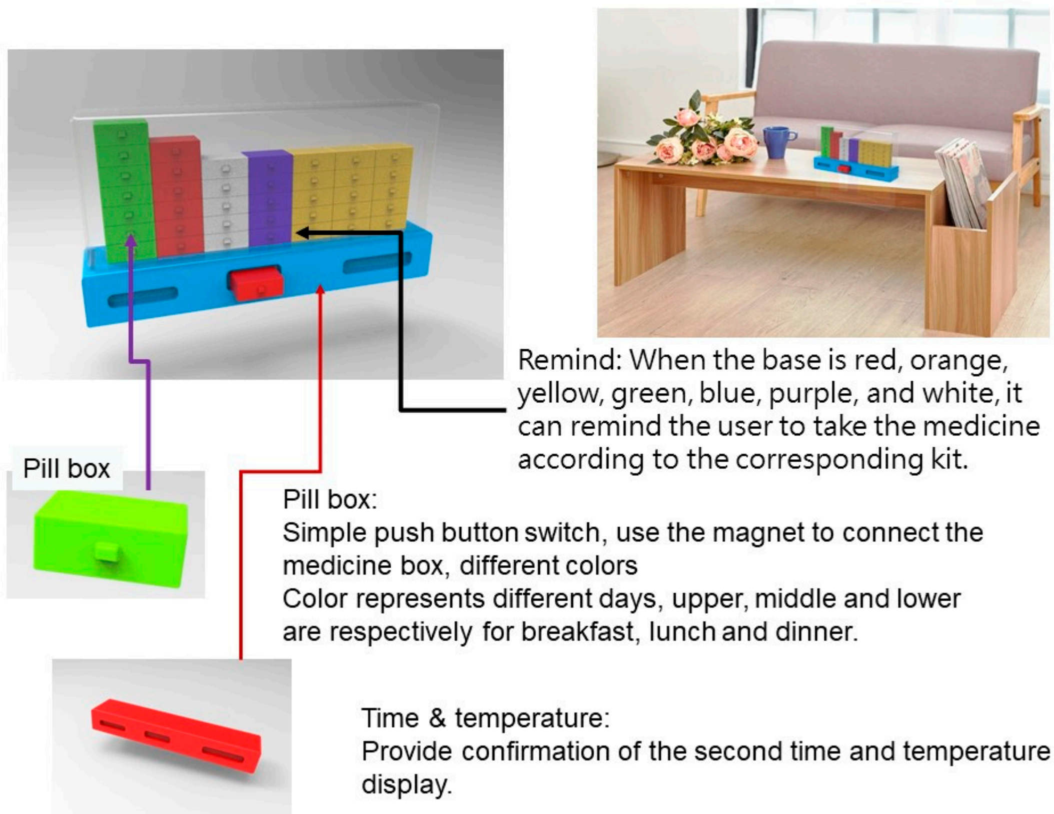


Figure 4. Pillbox control module mock-up.

In addition, the design of the pillbox control module is to house the portable medicine cells. The top cover is opened to display the barcodes of the cells so that patients can scan for prescriptions. Moreover, in order to effectively avoid medication errors, the pillbox control module is equipped with a mechanical device that includes an electronic lock, sensors, and LEDs for controlling and managing the cells. The functions of the control module include detecting whether the portable medicine cell is loaded and the top cover is sealed, locking the pillbox, and indicating medicine locations by LEDs, etc.

4. Conclusions

From the case study and verification of its applications, the results in Table 2 indicate the design of a pillbox for patients with chronic diseases, which is part of the aesthetics study of the entire evaluation of items. Not only were some of the designs chosen, but their aesthetics were improved. Finally, some satisfactory designs were determined by the participants. The score of Case 3 after defuzzification is 0.74, which is at the satisfactory level, followed by 0.69 for Case 2, which is at the common level. Therefore, the overall evaluation result is favored by the decision-making group in Item 1. This design scheme not only provides functionality, aesthetics, and economy, but the functions of the pillbox design for patients with chronic diseases show favorable performance. That is to say, the procedure is to determine the optimal design that can be realized. In this study, a new AHP method was proposed, featuring the integration of fuzzy theory and numerical analysis. First, the AHP is used to calculate the weight of factors affecting the importance of performance parameters. The next step is to satisfy various parameters. The defuzzification procedure is implemented to obtain the results of fuzzy weights, which indicated good consistency of the numerical results. The fuzzy decision-making method can realize any engineering evaluation that is required for the overall product design of a pillbox for patients with chronic diseases. The emphasis of this method is on the overall evaluation of the design and the new performance evaluation. In other words, not only the design of the product set of chronic medicine, but also the entire evaluation method is improved. The results can serve as a basis for an overall evaluation model of the product set for chronic medicines based on the new aesthetic design.

Funding: This work was supported by the Ministry of Science and Technology of the Republic of China under grant MOST-108-2221-E-468-003.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Menachem, P.W. Amihud Hari, Extension of the Pahl & Beitz systematic method for conceptual design of a new product. *Procedia CIRP* **2015**, *36*, 254–260.
2. Gielisch, C.; Fritz, K.P.; Noack, A.; Zimmermann, A. A Product Development Approach in The Field of Micro-Assembly with Emphasis on Conceptual Design. *Appl. Sci.* **2019**, *9*, 1920. [CrossRef]
3. Fiorineschi, L.; Frillici, F.S.; Rotini, F.; Tomassini, M. Exploiting TRIZ Tools for enhancing systematic conceptual design activities. *J. Eng. Des.* **2018**, *29*, 259–290. [CrossRef]
4. Becattinia, N.; Cascinia, G.; Rotinib, F. OTSM-TRIZ Network of Problems for evaluating the design skills. *Procedia Eng.* **2015**, *131*, 689–700. [CrossRef]
5. Fiorineschi, L.; Frillici, F.S.; Rotini, F. Three-dimensional approach for assessing uncommonness of ideas. *Proc. Des. Soc. Int. Conf. Eng. Des.* **2019**, *1*, 229–238. [CrossRef]
6. Jenab, K.; Sarfaraz, A.; Ameli, M.T. A conceptual design selection model considering. *J. Eng. Des.* **2013**, *24*, 293–304. [CrossRef]
7. Erden, M.S.; Komoto, H.; van Beek, T.J.; D'Amelio, V.; Echavarria, E.; Tomiyama, T. A review of function modeling: Approaches and applications. *Articial Intell. Eng. Des. Anal. Manuf.* **2008**, *22*, 147–169. [CrossRef]
8. Eckert, C. That which is not form: The practical challenges in using functional concepts in design. *Articial Intell. Eng. Des. Anal. Manuf.* **2013**, *27*, 217–231. [CrossRef]
9. Ulrich, K.T.; Eppinger, S.D. *Product Design and Development*, 5th ed.; Mc Graw Hill Irwin: New York, NY, USA, 2012.
10. Toh, C.A.; Miller, S.R. How engineering teams select design concepts: A view through the lens of creativity. *Des. Studies.* **2015**, *38*, 111–138. [CrossRef]
11. Ng, C.Y. Evidential reasoning-based Fuzzy AHP approach for the evaluation ofdesign alternatives' environmental performances. *Appl. Soft Comput.* **2016**, *46*, 381–397. [CrossRef]
12. Lin, H.H.; Hsiao, S.W. A Study of the Evaluation of Products by Industrial Design Students. *EURASIA J. Math. Sci. Technol. Educ.* **2018**, *14*, 239–254. [CrossRef]
13. Lin, M.C.; Wang, C.C.; Chen, M.S.; Chang, C.A. Using AHP and TOPSIS approaches in customer-driven product design process. *Comput. Ind.* **2008**, *59*, 17–31. [CrossRef]

14. Hsiao, S.W. Fuzzy logic based decision model for product design. *Int. J. Ind. Ergon.* **1998**, *21*, 103–116. [CrossRef]
15. Moskowitz, H.; Kim, K.J. QFD optimizer: A novice friendly quality function deployment decision support system for optimizing product designs. *Comput. Ind. Eng.* **1997**, *32*, 641–655. [CrossRef]
16. Jin, Y.; Cao, W.; Wu, M.; Yuan, Y. Accurate fuzzy predictive models through complexity reduction based on decision of needed fuzzy rules. *Neurocomputing* **2019**, *323*, 344–351. [CrossRef]
17. Kuo, Y.F.; Chen, P.C. Selection of mobile value—Added services for system operators using fuzzy synthetic evaluation. *Expert Syst. Appl.* **2006**, *30*, 612–620. [CrossRef]
18. Sun, J.H.; Tsai, H.C.; Chen, S.I. Using triangles to blur the preferences of different types of consumers. In Proceedings of the 17th National Conference on Fuzzy Theory and Its Applications, Kaohsiung, Taiwan, 18–19 December 2009; pp. 396–401.
19. Hu, T.W.; Liao, Y.T. The Effects of Consumer's Visual Cognition on the Feature Composition of Bicycle Frames. *J. Chaoyang Univ. Technol.* **2010**, *15*, 283–300.
20. Hajek, P.; Froelich, W. Integrating TOPSIS with interval-valued intuitionistic fuzzy cognitive maps for effective group decision making. *Inf. Sci.* **2019**, *485*, 394–412. [CrossRef]
21. Zadeh, L.A. Fuzzy sets. *Inf. Control* **1965**, *8*, 338–353. [CrossRef]
22. Zadeh, L.A. The concept of a linguistic variable and its application to approximate reasoning I. *Inf. Sci.* **1975**, *8*, 199–249. [CrossRef]
23. Depeng, K.; Tianqing, C.; Jiali, P.; Na, H.; GuoZhen, Y. A decision variable-based combinatorial optimization approach for interval-valued intuitionistic fuzzy MAGDM. *Inf. Sci.* **2019**, *484*, 197–218.
24. Nazemi, A.; Pour, F.F.; Heidenreich, K.; Fabozzi, F.J. Fuzzy decision fusion approach for loss-given-default modelling. *Eur. J. Oper. Res.* **2017**, *262*, 780–791. [CrossRef]
25. Temponi, C.; Yen, J.; Tian, W.A. House of quality: A fuzzy logic—Based requirements analysis. *Eur. J. Oper. Res.* **1999**, *117*, 340–354. [CrossRef]
26. Fang, X.; Yang, Q.; Dong, W. Fuzzy decision based energy dispatch in offshore industrial microgrid with desalination process and multi-type DGs. *Energy* **2018**, *148*, 744–755. [CrossRef]
27. Kim, J.K.; Han, C.H.; Choi, S.H. A knowledge-base approach to the quality function deployment. *Comput. Ind. Eng.* **1998**, *35*, 233–236. [CrossRef]
28. Saaty, T.L. *The Analytic Hierarchy Process*; McGraw-Hill New York: New York, NY, USA, 1980.
29. Hsiao, S.W.; Tsai, H.C. Fuzzy set theory on car-color design. *Color Res. Appl.* **1994**, *19*, 202–213. [CrossRef]
30. Hsiao, S.W. A systematic method for color planning in product design. *Color Res. Appl.* **1995**, *20*, 191–205. [CrossRef]
31. Hsiao, S.W.; Chen, C.H. A semantic and shape grammar based approach for product design. *Des. Stud.* **1997**, *18*, 275–296. [CrossRef]
32. Hsiao, S.W.; Chang, M.S. A semantic recognition-based approach for car's concept design. *Int. J. Veh. Des.* **1997**, *18*, 53–82.
33. Hsiao, S.W. Fuzzy set theory applied to car style design. *Int. J. Veh. Des.* **1994**, *15*, 255–278.
34. Hsiao, S.W.; Fan, C.W. Integrated FSM, STM and DFA method to faucet design. *J. Chin. Inst. Ind. Eng.* **1996**, *13*, 225–235.
35. Lin, H.H. A systematic approach of predicting color preference on the basis of gray relational grade. *Color Res. Appl.* **2019**, *44*, 194–204. [CrossRef]