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Quality Function Deployment Application Based on Interval 2-Tuple Linguistic

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Abstract

The application of quality function deployment method can meet the customers' requirement, and optimize the enterprise product design. Based on the house of product design, the paper adopts the interval two-tuple linguistic model and possibility theory, and constructs the correlation matrix of product design and customer requirement for cars, then the important sequence of design elements: engineer oil consumption, vehicle size, fuel consumption design and transmission type are the main elements in the automobile design.

Keywords: *QFD, product design, interval two-tuple, IVTWA operator, possibility degree*

1. Introduction

Design of products belongs to multi-species and multi-dimensions, and the customers' requirements analysis is the base of product design, which is better for the enterprises to optimize the design and improve the products and quality [1]. Quality Function Development, as a method of improving quality to meet customer needs in product design process, which has been widely used in many industries [2].

Based on the QFD and global sensitivity analysis (Sobol's method), Yang etc.[3] analyzes the warning radar operation performance index value change's influence on the combat capability. Ma etc.[4] constructs the field vehicle repair equipment requirements of quality house through the QFD. Zhong etc. [5], according to the large software system, they put forward the object oriented equipments analysis method based on QFD. Xu etc. [6] proposed the QFD and ANP, and made the fuzzy military requirement mapping to quantitative operational performance. Based on the hierarchy analytic method and rough set theory, Wang etc. [7] took the hair dryer for example, and proposed a rough hierarchy analytic method to check the customer requirement importance in QFD. Zhang [8] applied the QFD to the design of automobile sun-shadingboard products. Phirouzabadi [9] measured the weight values of inventive principals based on QFD.

On the basis of the above study, the paper combines the QFD and interval two-tuple linguistic, and applies it to the products design, and optimizes the product performance index. The structure is as follows: in the second part, it introduces the QFD and interval two-tuple linguistic; in the third part, taking the automobile product design for instance, it determines the customer requirement weights; in the fourth part, it studies the application of QFD, and finally the importance sequence of automobile product design is figured out.

2. Preliminary Knowledge

2.1. QFD

QFD was proposed by Akao Yoji and Shigeru Mizuno in 1970s in Japan, then it was further developed by Japan, United States, Europe and other countries, it was introduced to China in 1990s. In the products design process, all activities are driven by customer requirement [10]. The core content of QFD is the customer transformation, according to the house of quality, it analyzes the customer requirement, customer property and so on, and picks

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out the product performance index in the customer requirement [11]. The house of quality model is as shown in Figure 1.

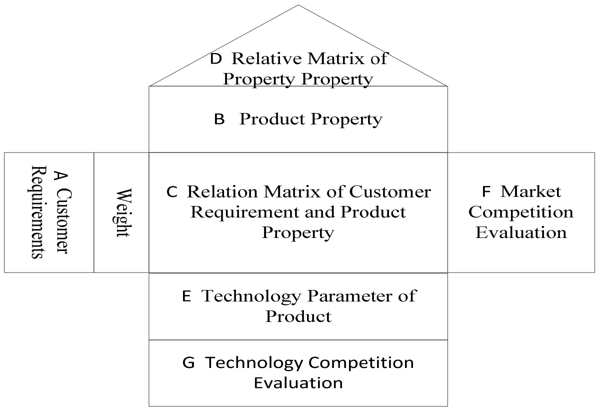

Figure 1. House of Quality Model

The product design adopts the form of house of quality, it is carried out according to the customer requirement, through the production design, parts development, technology deployment and production plan [12], as shown in Figure 2. House of quality can be constructed in each stage, and the intrinsic relation exists in each stage, the main ceiling project can be transferred to the left wall of next stage. During the deployment, the first stage-the construction of product design of quality house is the key stage, the paper mainly analyzes the stage.

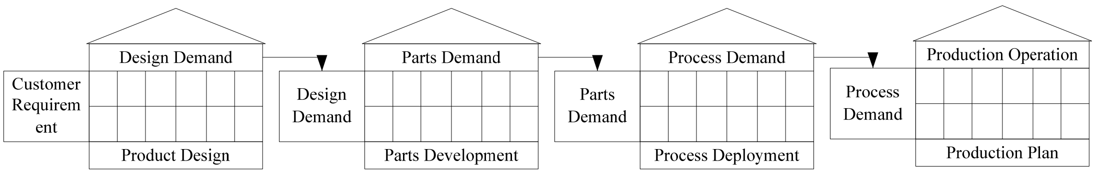

Figure 2. House of Quality Deployment in QFD

2.2. Interval 2-Tuple Linguistic

In QFD, the key stage is to determine the customer requirement. Different customers may propose lots of requirements and expectations of the same product, but it can not be exhaustive in the design and manufacturing, we should seize the main customer requirement and take the secondary requirement into consideration, it's necessary to determine the weights of customer requirements. Lots of scholars have adopted different methods to determine the customer requirement weights. Lai etc. [13] proposed a group decision-making technique to determine the customer requirement weights. Che etc. [14] adopted the artificial neural network (ANN) to determine the customer weights. Chan etc. [15] adopted the entropy method to calculate the customer requirement weights. Based on the hierarchy analysis and rough set theory, Kong etc. [16] proposed the rough hierarchy analysis of determining the customer requirement weights in OFD. Song etc. [17] adopted the available resources deviation between decision value and target value as the optimization objective integer programming model, so as to realize the mapping from customer requirements to technical characteristics. Wang etc. [18] adopted the relaxation coefficient method to ensure the optimal set of seeking and key demand to realize the priority. Gong etc. [19] put forward the fuzzy consistent matrix into the use of hierarchy analysis to determine the customer requirement weights in QFD.

During the process of determining weights, calculation values are not always clear, it is more suitable for fuzzy numbers. Many papers have used triangular fuzzy numbers and linguistic variables, but the use of these methods can reduce the accuracy of the information [20]. Therefore, Herrera and Martinez [21] proposed the use of 2-tuple linguistic method based on the symbol translation can turn preference information into 2-tuple linguistic information, and calculated. Wang [22] unified the different forms of hybrid decision data as the 2-tuple linguistic information, and evaluated the agile manufacturing. Wei [23] applied the 2-tuple linguistic information aggregation operators to the fuzzy multi-attribute group decision-making. Chang and Wen [24] made an important analysis of the factors leading to the product design failure based on the 2-tuple linguistic and ordered weighted averaging operator. Lin etc. [25] proposed the interval 2-tuple linguistic model and helped decision-makers express preference information better. However, the interval 2-tuple linguistic model is for the single linguistic valuation set conversation, and does not solve the different linguistic term set conversation. In view of this, the normalized interval 2-tuple linguistic model is adopted in this paper, through the interval 2-tuple linguistic aggregation operators, and different linguistic sets of 2-tuple will be aggregated.

Two-tuple linguistic (s_i,α) use 2-tuple to represent its calculation object. Among them, s_i is the language phrase of given linguistic term set $S=\{s_0,s_1,\cdots,s_g\}$, the number of terms is odd, g is even; $\alpha\in[-0.5,0.5)$ represents the symbolic translation, which represents the most close to the deviation of language phrases between the calculated language information $(s_i,\alpha)$and initial linguistic term set S.

Definition 1. Linguistic termset $S=\{s_0,s_1,\cdots,s_g\}$,$(s_i,\alpha)$is 2-tuple linguistic, the real number $\beta\in[0,g]$ is the result of aggregation operation, the following functionsΔ shows the 2-tuple linguistic information corresponding to β [21].

$$\Delta:[0,g]\rightarrow S\times[-0.5,0.5) \quad (1)$$

$$\Delta(\beta)=(s_i,\alpha),\begin{cases}s_i, & i=round(\beta)\\ \alpha=\beta-i, & \alpha\in[-0.5,0.5)\end{cases} \quad (2)$$

$round(\cdot)$expresses the integral operator through the rounding off, $i\in[0,g]$.

Conversely, the inverse functionΔ^{-1} can be converted to corresponding $\beta\in[0,g]$.

$$\Delta^{-1}:S\times[-0.5,0.5)\rightarrow[0,g] \quad (3)$$

$$\Delta^{-1}(s_i,\alpha)=i+\alpha=\beta \quad (4)$$

$$s_i\in S\Rightarrow(s_i.0) \quad (5)$$

Definition 2. Linguistic termset $S=\{s_0,s_1,\cdots,s_g\}$, (s_i,α) is 2-tuple linguistic, real number $\beta\in[0,1]$, through the following function Δ, it can be represented as the corresponding 2-tuple linguistic information [26].

$$\Delta(\beta)=(s_i,\alpha),\begin{cases}s_i, & i=round(\beta*g)\\ \alpha=\beta-i/g, & \alpha\in[-0.5/g,0.5/g)\end{cases} \quad (6)$$

Conversely, 2-tuple linguistic can be converted to corresponding β through the following inverse function Δ^{-1}.

$$\Delta^{-1}(s_i,\alpha)=i/g+\alpha=\beta \quad (7)$$

The differences lie in the value range, in definition 1, $\beta\in[0,g]$, in definition 2, β ranges $[0,1]$, the value range of β can be treated as standard, in this way it can tell the 2-tuple linguistic from different linguistic term set.

Definition 3. Set $r_{mn}=[s_i,s_j]_{mn},(i=1,2,\cdots,m;j=1,2,\cdots,n)$, as the complementary judgment matrix, $r_{nm}=[Neg(s_j),Neg(s_i)]_{nm}$, Neg is the inverse operation, $Neg(s_j)=s_i,i=g-j$.

Definition 4. Set linguistic termset $S=\{s_0,s_1,\cdots,s_g\}$,$[(s_i,\alpha_1),(s_j,\alpha_2)]$ is interval 2-tuple linguistic, s_i and s_j are the linguistic phrases in S, $i\leq j$, $\alpha_1$and$\alpha_2$represent symbolic translation.

Interval numbers$[\beta_1, \beta_2](\beta_1, \beta_2 \in [0,1], \beta_1 \leq \beta_2)$can be represented as the corresponding interval 2-tuple linguistic through the following function Δ [27].

$$\Delta([\beta_1,\beta_2]) = [(s_i,\alpha_1),(s_j,\alpha_2)], \begin{cases} s_i, & i = round(\beta_1 * g) \\ s_j, & j = round(\beta_2 * g) \\ \alpha_1 = \beta_1 - i/g, \alpha_1 \in [-0.5/g, 0.5/g) \\ \alpha_2 = \beta_2 - j/g, \alpha_2 \in [-0.5/g, 0.5/g) \end{cases} \quad (8)$$

Conversely, interval 2-tuple linguistic$[(s_i,\alpha_1),(s_j,\alpha_2)]$can be converted to corresponding interval number through the following inverse function Δ^{-1}.

$$\Delta^{-1}[(s_i,\alpha_1),(s_j,\alpha_2)] = [i/g + \alpha_1, j/g + \alpha_2] = [\beta_1,\beta_2] \quad (9)$$

Definition 5. Set $X = \{[(s_1,\alpha_1),(s_1{}',\alpha_1{}')],[(s_2,\alpha_2),(s_2{}',\alpha_2{}')],\cdots,[(s_n,\alpha_n),(s_n{}',\alpha_n{}')]\}$ as a group of 2-tuple linguistic, $w_i = (w_1, w_2, \cdots, w_n)$ is the weight vector and satisfies$w_i \in [0,1]$and $\sum_{i=1}^{n} w_i = 1$, the operators of 2-tuple linguistic IVTWA will be:

$$IVTWA([(s_1,\alpha_1),(s_1{}',\alpha_1{}')],[(s_2,\alpha_2),(s_2{}',\alpha_2{}')],\cdots,[(s_n,\alpha_n),(s_n{}',\alpha_n{}')]) \\ = \Delta[\textstyle\sum_{i=1}^{n} w_i\, \Delta^{-1}(s_i,\alpha_i), \sum_{i=1}^{n} w_i\, \Delta^{-1}(s_i{}',\alpha_i{}')] \quad (10)$$

Definition 6. Set $R = ([s_{ij}, s'_{ij}])_{m\times n}$ as the calculation matrix, $(i = 1,2,\cdots,m; j = 1,2,\cdots,n)$, the comprehensive weight range of some calculation object i will be:

$$\theta_i = [\gamma_i, \gamma'_i] = \left[(\textstyle\sum_{j=1}^{n} s_{ij})/n, (\sum_{j=1}^{n} s'_{ij})/n\right] \quad (11)$$

Definition 7. If the calculation object i is not inferior to the calculation object k, it can be represented as $\theta_i \geq \theta_k, (i,k = 1,2,\cdots,m)$, and compares with the comprehensive value in definition 5, the comparative numbers will be figured out [28]:

$$p_{ik} = p(\theta_i \geq \theta_k) = max\left\{1 - max\left\{\frac{\gamma'_k - \gamma_i}{(\gamma'_i - \gamma_i) + (\gamma'_k - \gamma_k)}, 0\right\}, 0\right\} \quad (12)$$

Possibility matrix can be worked out as follows:

$$P = (p_{ik})_{m\times m} = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1m} \\ p_{21} & p_{22} & \cdots & p_{2m} \\ \vdots & \vdots & \vdots & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mm} \end{bmatrix}$$

Ordering vectors of possibility matrix are:

$$\varphi_i = \frac{\sum_{k=1}^{m} p_{ik} + m/2 - 1}{m(m-1)} \quad (13)$$

3. Weights Determination of Customer Requirement

3.1. Algorithm

According to the basic knowledge and definitions above, the paper presents a kind of interval 2-tuple linguistic method to determine the customer requirement weights, specific processes are as follows.

Step 1: Identifying customer requirements indicator. In order to ensure the consistency of weight calculation, the number of calculation indicator should be controlled, for the complex products, we can divide the customer requirements into different levels.

Step 2: Set up the linguistic term set $S = \{s_0, s_1, \cdots, s_g\}$,Valuators $A_k(k = 1,2,\cdots,l)$,evaluate customer requirement i and j, the number of customers is n, and figure out the measure value$[u_{ij}^k, v_{ij}^k], (u_{ij}^k, v_{ij}^k \in S), (i,j = 1,2,\cdots,n)$, so as to obtain the linguistic complementary judgment matrix$R_k = ([u_{ij}^k, v_{ij}^k])_{n\times n}$, the weight vector of calculation is $w_k = (w_1, w_2, \cdots, w_l), \sum_{k=1}^{l} w_k = 1$.

Step 3: According to definition 1, linguistic complementary judgment matrix R_k can be converted to interval 2-tuple linguistic judgment matrix $R_k' = ([(u_{ij}^k, 0), (v_{ij}^k, 0)])_{n\times n}$.

Step 4: According to definition 4, through the inverse functionΔ^{-1}, the interval 2-tuple linguistic$[(u_{ij}^k, 0), (v_{ij}^k, 0)]$ is converted to the corresponding interval number$[{c_{ij}}^k, {d_{ij}}^k]$.

Step 5: To aggregate the interval measure number $[{c_{ij}}^k, {d_{ij}}^k]$. Through the IVTWA operator, the comprehensive calculation matrix $\tilde{R} = ([c_{ij}, d_{ij}])_{n\times n} = ([\sum w_k \cdot {c_{ij}}^k, \sum w_k \cdot$ $dijk])n\times n$of interval 2-tuple linguistic will be figured out.

Step 6: The formula (11) can be used to calculate the customer requirement weight $[\gamma_i, {\gamma'}_i]$ of interval 2-tuple linguistic group importance value θ_i for customer requirement i.

Step 7: The possibility ranking method of definition 7 can be used to find the ordering vector φ_i of possibility matrix P, sorted by their sizes, different customer requirement weights will be worked out.

3.2. Case Study

In order to verify the validity of the above algorithm, the paper takes the car as an example to study. It develops gradually based on the interval 2-tuple linguistic method.

Step 1: The paper has selected a group of customer requirement indicators for the car, a number of market management personnel from a car enterprise and part of car customers, ultimately five indicators are determined as the customer requirement indicators: CR_1 represents manipulability, CR_2 represents safety, CR_3represents comfort, CR_4represents power and CR_5 represents economy .

Step 2: In this research, three experts participate in the calculation of customer requirement importance, experts' weights$w_k = (0.3,0.4,0.3)$.Three experts adopt three kinds of linguistic term sets: nine elements linguistic termset $X = \{x_0, x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8\}$; seven elements linguistic term set$Y = \{y_0, y_1, y_2, y_3, y_4, y_5, y_6\}$and five elements linguistic term set $Z = \{z_0, z_1, z_2, z_3, z_4\}$. According to the experts' calculation results, the linguistic complementary judgment matrix$R_k$is constructed.

$$R_1 = \begin{bmatrix} [x_4,x_4] & [x_1,x_3] & [x_4,x_5] & [x_2,x_4] & [x_1,x_2] \\ [x_5,x_7] & [x_4,x_4] & [x_2,x_3] & [x_3,x_5] & [x_3,x_4] \\ [x_3,x_4] & [x_5,x_6] & [x_4,x_4] & [x_1,x_2] & [x_1,x_3] \\ [x_4,x_6] & [x_3,x_5] & [x_6,x_7] & [x_4,x_4] & [x_6,x_8] \\ [x_6,x_7] & [x_4,x_5] & [x_5,x_7] & [x_0,x_2] & [x_4,x_4] \end{bmatrix}$$

$$R_2 = \begin{bmatrix} [y_3,y_3] & [y_1,y_1] & [y_2,y_3] & [y_1,y_2] & [y_1,y_3] \\ [y_5,y_5] & [y_3,y_3] & [y_1,y_2] & [y_2,y_4] & [y_3,y_4] \\ [y_3,y_4] & [y_4,y_5] & [y_3,y_3] & [y_5,y_6] & [y_1,y_2] \\ [y_4,y_5] & [y_2,y_4] & [y_0,y_1] & [y_3,y_3] & [y_2,y_4] \\ [y_3,y_5] & [y_2,y_3] & [y_4,y_5] & [y_2,y_4] & [y_3,y_3] \end{bmatrix}$$

$$R_3 = \begin{bmatrix} [z_2,z_2] & [z_1,z_2] & [z_1,z_1] & [z_1,z_3] & [z_2,z_3] \\ [z_2,z_3] & [z_2,z_2] & [z_2,z_3] & [z_1,z_2] & [z_0,z_2] \\ [z_3,z_3] & [z_1,z_2] & [z_2,z_2] & [z_1,z_1] & [z_1,z_2] \\ [z_1,z_3] & [z_2,z_3] & [z_3,z_3] & [z_2,z_2] & [z_1,z_3] \\ [z_1,z_2] & [z_2,z_4] & [z_2,z_3] & [z_1,z_3] & [z_2,z_2] \end{bmatrix}$$

Step 3: According to definition 1, linguistic complementary matrix R_k can be converted to interval 2-tuple linguistic judgment matrix R_k'.

$$R_1' = \begin{bmatrix} [(x_4,0),(x_4,0)] & [(x_1,0),(x_3,0)] & [(x_4,0),(x_5,0)] & [(x_2,0),(x_4,0)] & [(x_1,0),(x_2,0)] \\ [(x_5,0),(x_7,0)] & [(x_4,0),(x_4,0)] & [(x_2,0),(x_3,0)] & [(x_3,0),(x_5,0)] & [(x_3,0),(x_4,0)] \\ [(x_3,0),(x_4,0)] & [(x_5,0),(x_6,0)] & [(x_4,0),(x_4,0)] & [(x_1,0),(x_2,0)] & [(x_1,0),(x_3,0)] \\ [(x_4,0),(x_6,0)] & [(x_3,0),(x_5,0)] & [(x_6,0),(x_7,0)] & [(x_4,0),(x_4,0)] & [(x_6,0),(x_8,0)] \\ [(x_6,0),(x_7,0)] & [(x_4,0),(x_5,0)] & [(x_5,0),(x_7,0)] & [(x_0,0),(x_2,0)] & [(x_4,0),(x_4,0)] \end{bmatrix}$$

$$R_2{}' = \begin{bmatrix} [(y_3,0),(y_3,0)] & [(y_1,0),(y_1,0)] & [(y_2,0),(y_3,0)] & [(y_1,0),(y_2,0)] & [(y_1,0),(y_3,0)] \\ [(y_5,0),(y_5,0)] & [(y_3,0),(y_3,0)] & [(y_1,0),(y_2,0)] & [(y_2,0),(y_4,0)] & [(y_3,0),(y_4,0)] \\ [(y_3,0),(y_4,0)] & [(y_4,0),(y_5,0)] & [(y_3,0),(y_3,0)] & [(y_5,0),(y_6,0)] & [(y_1,0),(y_2,0)] \\ [(y_4,0),(y_5,0)] & [(y_2,0),(y_4,0)] & [(y_0,0),(y_1,0)] & [(y_3,0),(y_3,0)] & [(y_2,0),(y_4,0)] \\ [(y_3,0),(y_5,0)] & [(y_2,0),(y_3,0)] & [(y_4,0),(y_5,0)] & [(y_2,0),(y_4,0)] & [(y_3,0),(y_3,0)] \end{bmatrix}$$

$$R_3{}' = \begin{bmatrix} [(z_2,0),(z_2,0)] & [(z_1,0),(z_2,0)] & [(z_1,0),(z_1,0)] & [(z_1,0),(z_3,0)] & [(z_2,0),(z_3,0)] \\ [(z_2,0),(z_3,0)] & [(z_2,0),(z_2,0)] & [(z_2,0),(z_3,0)] & [(z_1,0),(z_2,0)] & [(z_0,0),(z_2,0)] \\ [(z_3,0),(z_3,0)] & [(z_1,0),(z_2,0)] & [(z_2,0),(z_2,0)] & [(z_1,0),(z_1,0)] & [(z_1,0),(z_2,0)] \\ [(z_1,0),(z_3,0)] & [(z_2,0),(z_3,0)] & [(z_3,0),(z_3,0)] & [(z_2,0),(z_2,0)] & [(z_1,0),(z_3,0)] \\ [(z_1,0),(z_2,0)] & [(z_2,0),(z_4,0)] & [(z_2,0),(z_3,0)] & [(z_1,0),(z_3,0)] & [(z_2,0),(z_2,0)] \end{bmatrix}$$

Step 4: According to definition 3, through the inverse function Δ^{-1}, the interval 2-tuple linguistic judgment matrix $R_k{}'$ can be converted to corresponding interval number matrix $\tilde{R}_k$.

$$\tilde{R}_1 = \begin{bmatrix} [0.5,0.5] & [0.125,0.375] & [0.5,0.625] & [0.25,0.5] & [0.125,0.25] \\ [0.625,0.875] & [0.5,0.5] & [0.25,0.375] & [0.375,0.625] & [0.375,0.5] \\ [0.375,0.5] & [0.625,0.75] & [0.5,0.5] & [0.125,0.25] & [0.125,0.375] \\ [0.5,0.75] & [0.375,0.625] & [0.75,0.875] & [0.5,0.5] & [0.75,1] \\ [0.75,0.875] & [0.5,0.625] & [0.625,0.875] & [0,0.25] & [0.5,0.5] \end{bmatrix}$$

$$\tilde{R}_2 = \begin{bmatrix} [0.5,0.5] & [0.167,0.167] & [0.333,0.5] & [0.167,0.333] & [0.167,0.5] \\ [0.833,0.833] & [0.5,0.5] & [0.167,0.333] & [0.333,0.667] & [0.5,0.667] \\ [0.5,0.667] & [0.667,0.833] & [0.5,0.5] & [0.833,1] & [0.167,0.333] \\ [0.667,0.833] & [0.333,0.667] & [0,0.167] & [0.5,0.5] & [0.333,0.667] \\ [0.5,0.833] & [0.333,0.5] & [0.667,0.833] & [0.333,0.667] & [0.5,0.5] \end{bmatrix}$$

$$\tilde{R}_3 = \begin{bmatrix} [0.5,0.5] & [0.25,0.5] & [0.25,0.25] & [0.25,0.75] & [0.5,0.75] \\ [0.5,0.75] & [0.5,0.5] & [0.5,0.75] & [0.25,0.5] & [0,0.5] \\ [0.75,0.75] & [0.25,0.5] & [0.5,0.5] & [0.25,0.25] & [0.25,0.5] \\ [0.25,0.75] & [0.5,0.75] & [0.75,0.75] & [0.5,0.5] & [0.25,0.75] \\ [0.25,0.5] & [0.5,1] & [0.5,0.75] & [0.25,0.75] & [0.5,0.5] \end{bmatrix}$$

Step 5: To aggregate the interval measure matrix $\tilde{R}_k$ through IVTWA operator, the comprehensive calculation matrix $\tilde{R}$ of interval 2-tuple linguistic will be figured out.

$$\tilde{R} = \begin{bmatrix} [0.5,0.5] & [0.18,0.33] & [0.358,0.461] & [0.217,0.508] & [0.255,0.5] \\ [0.669,0.821] & [0.5,0.5] & [0.292,0.471] & [0.321,0.603] & [0.313,0.567] \\ [0.538,0.642] & [0.528,0.708] & [0.5,0.5] & [0.446,0.55] & [0.18,0.396] \\ [0.492,0.783] & [0.396,0.678] & [0.45,0.555] & [0.5,0.5] & [0.433,0.792] \\ [0.5,0.746] & [0.433,0.686] & [0.603,0.821] & [0.208,0.567] & [0.5,0.5] \end{bmatrix}$$

Step 6: The formula (11) can be used to calculate the customer requirement weight $[\gamma_i, \gamma'_i]$ of interval 2-tuple linguistic group importance value θ_i for customer requirement i.
$\theta_1 = [0.302,0.46]$, $\theta_2 = [0.419,0.592]$, $\theta_3 = [0.438,0.559]$, $\theta_4 = [0.454,0.662]$, $\theta_5 = [0.449,0.664]$.

Step 7: The possibility ranking method of definition 7 can be used to compare the above importance calculation value θ_i, the following possibility matrix can be worked out:

$$P = \begin{bmatrix} 0.5 & 0.124 & 0.079 & 0.016 & 0.029 \\ 0.876 & 0.5 & 0.524 & 0.362 & 0.369 \\ 0.921 & 0.476 & 0.5 & 0.319 & 0.327 \\ 0.984 & 0.638 & 0.681 & 0.5 & 0.504 \\ 0.971 & 0.631 & 0.673 & 0.496 & 0.5 \end{bmatrix}$$

Ordering vector φ_i of possibility matrix P can be figured out as follows:

$\varphi_1 = 0.112$, $\varphi_2 = 0.207$, $\varphi_3 = 0.202$, $\varphi_4 = 0.24$, $\varphi_5 = 0.239$.

Sorted by their sizes, importance ordering of different customer requirements will be worked out:

$$\varphi_4 > \varphi_5 > \varphi_2 > \varphi_3 > \varphi_1.$$

Namely, car customers' most important requirement is power, then the economy, safety and comfort, finally comes the manipulability.

4. QFD Application in Product Design

4.1. Construction of Quality House in Product Design

According to the above, ultimately five customer requirement indicators are determined: manipulation, safety, comfort, power and economy, their weights are separately (0.1, 0.2, 0.2, 0.3, 0.2)

CR_1Manipulation: simple operation, various facilities, etc..

CR_2Safety: reliable quality, low failure rate, long service life, etc..

CR_3Comfort: beautiful appearance, reasonable decoration, comfortable space, etc..

CR_4Power: powerful horsepower, turbocharging, etc..

CR_5Economy: price economy, low fuel consumption, low maintenance cost of repair, etc.

At the same time, the experts and management personnel from the automobile manufacturing design department, production department, marketing department and after service department are all invited. Finally, the following elements are as the output: DE_1: transmission type; DE_2: car reversing aid service; DE_3: control configuration; DE_4: design life; DE_5: fault alarm; DE_6: air bag; DE_7: vehicle size; DE_8: interior configuration; DE_9: engineer displacement; DE_{10}: fuel consumption design; DE_{11}: car price; DE_{12}: maintenance design.

The house of quality model of car product design stage is as shown in Figure 3.

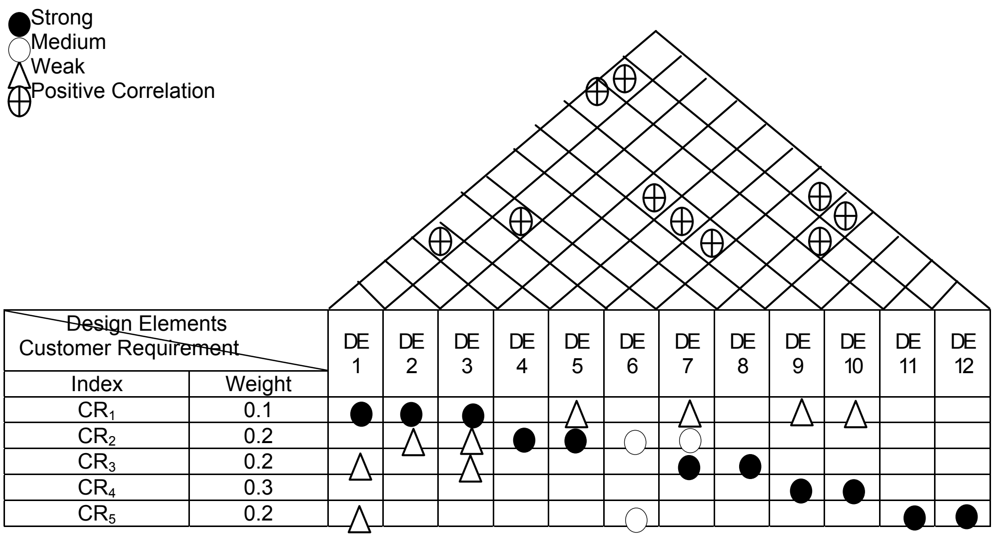

Figure 3. House of Quality Model of Car Product Design

4.2. Relative Matrix of Product Design and Customer Requirement

Relative experts and managers evaluate the product design elements' influence degree to the customer requirement, as shown in Table 1. In order to make the evaluator expresses better, the interval variables can be adopted, three linguistic assessment sets can be chosen, namely the 9 elements assessment set$X = \{x_0, x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8\}$, 7 elements assessment set $Y = \{y_0, y_1, y_2, y_3, y_4, y_5, y_6\}$, and 5 elements assessment set $Z = \{z_0, z_1, z_2, z_3, z_4\}$.

Table 1.Relative Matrix of Product Design and Customer Requirement

Design Element / Customer Requirement	Requirement Weight	DE_1	DE_2	DE_3	DE_4	DE_5	DE_6	DE_7	DE_8	DE_9	DE_{10}	DE_{11}	DE_{12}
CR_1	0.1	$[x_7,x_8]$	$[y_4,y_6]$	$[y_4,y_5]$		$[z_0,z_1]$		$[x_1,x_3]$		$[x_2,x_3]$	$[y_0,y_1]$		
CR_2	0.2		$[z_1,z_2]$	$[x_2,x_3]$	$[z_3,z_4]$	$[x_6,x_7]$	$[y_2,y_3]$	$[x_4,x_5]$					
CR_3	0.2	$[y_1,y_2]$		$[x_1,x_2]$				$[z_3,z_4]$	$[x_6,x_7]$				
CR_4	0.3									$[x_7,x_8]$	$[y_4,y_5]$		
CR_5	0.2	$[y_2,y_3]$					$[z_2,z_3]$					$[y_5,y_6]$	$[x_6,x_7]$
Design Element Weight													

4.3. Importance Degree of Product Design Element

According to definition 1 and definition 2, the weight range θ_j of product design element can be figured out.

$\theta_1 = [0.188,0.267]$, $\theta_2 = [0.117,0.11]$, $\theta_3 = [0.142,0.208]$, $\theta_4 = [0.15,0.2]$, $\theta_5 = [0.15,0.2]$, $\theta_6 = [0.167,0.25]$, $\theta_7 = [0.263,0.363]$, $\theta_8 = [0.15,0.175]$, $\theta_9 = [0.288,0.338]$, $\theta_{10} = [0.2,0.267]$, $\theta_{11} = [0.167,0.2]$, $\theta_{12} = [0.15,0.175]$.

According to definition 3 and weight range θ_j , the possibility matrix can be figured out.

$$P = \begin{bmatrix} 0.500 & 1.000 & 0.862 & 0.907 & 0.907 & 0.617 & 0.022 & 1.000 & 0.000 & 0.459 & 0.893 & 1.000 \\ 0.000 & 0.500 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 & 0.000 \\ 0.138 & 1.000 & 0.500 & 0.500 & 0.500 & 0.275 & 0.000 & 0.637 & 0.000 & 0.060 & 0.414 & 0.637 \\ 0.093 & 1.000 & 0.500 & 0.500 & 0.500 & 0.248 & 0.000 & 0.667 & 0.000 & 0.000 & 0.398 & 0.667 \\ 0.093 & 1.000 & 0.500 & 0.500 & 0.500 & 0.248 & 0.000 & 0.667 & 0.000 & 0.000 & 0.398 & 0.667 \\ 0.383 & 1.000 & 0.725 & 0.752 & 0.752 & 0.500 & 0.000 & 0.926 & 0.000 & 0.333 & 0.802 & 0.926 \\ 0.978 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.500 & 1.000 & 0.500 & 0.976 & 1.000 & 1.000 \\ 0.000 & 1.000 & 0.363 & 0.333 & 0.333 & 0.074 & 0.000 & 0.500 & 0.000 & 0.000 & 0.138 & 0.500 \\ 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 1.000 & 0.500 & 1.000 & 0.500 & 1.000 & 1.000 & 1.000 \\ 0.541 & 1.000 & 0.940 & 1.000 & 1.000 & 0.667 & 0.024 & 1.000 & 0.000 & 0.500 & 1.000 & 1.000 \\ 0.107 & 1.000 & 0.586 & 0.602 & 0.602 & 0.198 & 0.000 & 0.862 & 0.000 & 0.000 & 0.500 & 0.862 \\ 0.000 & 1.000 & 0.363 & 0.333 & 0.333 & 0.074 & 0.000 & 0.500 & 0.000 & 0.000 & 0.138 & 0.500 \end{bmatrix}$$

Ordering vector φ_i of P can be worked out as:

$\varphi_1 = 0.115$, $\varphi_2 = 0.005$, $\varphi_3 = 0.083$, $\varphi_4 = 0.082$, $\varphi_5 = 0.082$, $\varphi_6 = 0.105$, $\varphi_7 = 0.14$, $\varphi_8 = 0.07$, $\varphi_9 = 0.141$, $\varphi_{10} = 0.12$, $\varphi_{11} = 0.089$, $\varphi_{12} = 0.07$.

Sorted by size, the weight ordering of product design element can be figured out:

$$\varphi_9 > \varphi_7 > \varphi_{10} > \varphi_1 > \varphi_6 > \varphi_{11} > \varphi_3 > \varphi_4 = \varphi_5 > \varphi_{12} = \varphi_8 > \varphi_2.$$

In view of this, engineer displacement, vehicle size, fuel consumption design and transmission type are the main elements, the design staff should pay much attention these factors.

4.4. Comparison with Other Methods

Compared with 2-tuple linguistic based methods, the original decision information expressed by 2-tuple linguistic are always derived from a predefinedlinguistic term set. That is, all the experts are asked to give their judgments with only one linguistic term from the same linguistic term set. However, it is somehow unrealistic for each expert to give his or her opinion fully under such constraint. As a result, the cardinality of the term set may be too small to fully express the expert's opinion on a certain attribute, while may be so big that the evaluation on another attribute is out of his ability. Alternatively, if given the experts the right to freely choose their own linguistic term sets. That is, the decision information is present by linguistic term sets with different granularity. In such a case, it is needed to unify multi-granularity linguistic information before aggregation operation. For example, Herrera et al. [21] introduced a fusion approach of multi-granularity linguistic information with the basic linguistic term, which demands lots of calculation work. To avoid such issues, Lin et al. [25] proposed the definition of interval 2-tuple linguistic variable to better express decision information. Wang and Hao [29] presented the proportional 2-tuple fuzzy linguistic representation model and put forward some aggregation operators for proportional 2-tuples. But, in above models [25,29], all decision information provided by different experts is also derived from one same linguistic term set. On the contrary, the results of this paper indicate that the interval 2-tuple based quality function deployment method can expresses preferences of experts more fully than other linguistic methods.

5. Conclusion

The paper adopts the method of quality function deployment, and constructs the automobile design stage of house of quality, and analyzes the relationship between the elements of product design and customer requirement, on the basis of interval two-tuple linguistic model and possibility ordering, the importance degree of product design elements is figured out. The method starts from the perspective of customer requirement to the product design, and makes the design elements meet the customer requirement, the application is simple, which provides a new way and expands the application field of QFD.

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