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Application of aggregate analysis for product design quality using QFD model and TOPSIS

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1. Introduction

Design quality has a great influence on the success of a product. And the product design quality can be evaluated by various mature in product development phases [1]. On the other hand, the design quality should be consistently on product design target. More importantly, for the purpose of improving the level of product design quality, the suitable concept design is crucial [2]. In order to facilitate the process of transforming product design quality objectives into effective actions, product quality would be considered by many engineering design requirements (EDRs) [3]. In today's rapidly evolving world of manufacturing industry, design quality of mechanical and electrical products is more and more important [4]. Consequently, the aggregate analysis of product design optimization is a critical part for product quality during the design scheme decision processes [5].

An optimized design is the first step in product development, and many EDRs need to be considered. There are different product design quality models available in the present literature. Among lots of analysis techniques, Quality function deployment (QFD) model is particularly famous for its successful applications of transforming customer satisfaction into design stage. Technique for order preference by similarity to ideal solution (TOPSIS) method has been used to assist the decision making in many fields. In addition, the integration of QFD and TOPSIS can achieve good performance on many tasks. Moreover, product design quality researchers have become increasingly aware of the decision problems. The aim of this paper is to clarify the aggregate analysis by using QFD and TOPSIS and solve the problem of quantitative decision for product design quality.

The remainder of this paper is organized as follows. In Section 2, the proposed method for product design quality project selection problem is presented. Section 3 introduces the novel decision model based on QFD and TOPSIS. An application of aggregate analysis for design quality of a gas turbine is discussed in Section 4. The last section summarizes the findings of this research and closes with directions for further research.

2. The aggregate analysis method

In order to improve the product design quality, the customer needs should be accurately transformed into engineering technical requirements for the product design. The aggregate analysis model of this paper is established on the basis of QFD model and TOPSIS method. The proposed aggregate analysis model is illustrated in Fig. 1. The initial phase of the proposed model defines customer requirements (CRs) for the product design quality. Then, the house of quality (HoQ) has been integrated with QFD methodology in order to transformed CRs into EDRs. And the importance of EDRs can be accurately determined by using HoQ. Based on the data of EDRs provided by product design quality, the optimization design is easily identified based on TOPSIS method. So, the best concept design can be acquired with the max design quality.

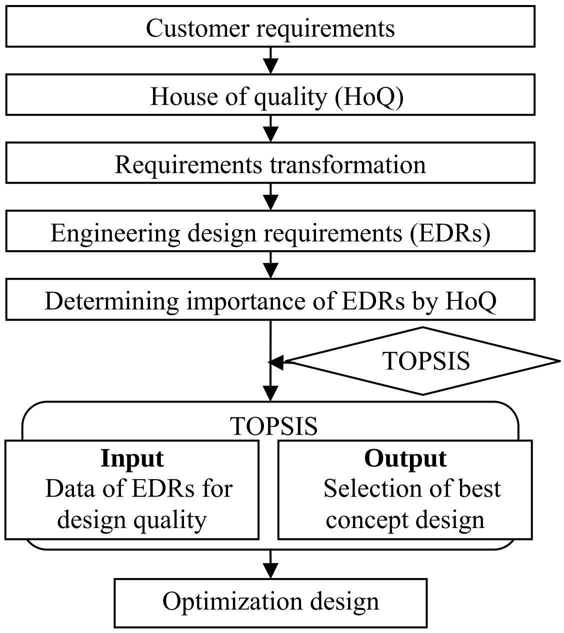

Fig. 1 Execution of proposed analysis model

3. Synthesis analysis model

Traditional design statistics data show some specifications and characteristics of a product structure, and only the product design quality that could be measured accurately is utilized. The systematic decision support approach integrates with QFD and TOPSIS for product design quality are described as follows.

3.1. QFD analysis model

The concept of QFD was first initiated by Akao in 1966, which is a customer-driven design method [6]. The QFD is a useful tool for product design, development and management. QFD meet the needs of customers and carries out a competitive analysis for design indicators.

In order to translate the voice of the customers through the various stages of product design, each translation matrix called house of quality (HoQ) is applied, as is shown in Fig. 2. The requirements relationships between customers needs and technical requirements are adjusted by HoQ. After obtaining what the customers want and need, the HoQ was applied to translate the customer needs into the measurable engineering characteristics. Recently, the initial structure and principles of QFD have been successfully used to manage design information and assist decision-making in product development process.

		Correlation between EDRs			
CRs	Weight	EDRs$_1$	EDRs$_2$	…	EDRs$_n$
CRs$_1$	W$_1$	R$_{11}$	R$_{12}$	…	R$_{1n}$
CRs$_2$	W$_2$	R$_{21}$	R$_{22}$	…	R$_{2n}$
…	…	…	…	…	…
CRs$_m$	W$_m$	R$_{m1}$	R$_{m2}$	…	R$_{mn}$
		The importance of EDRs			

Fig. 2 Standard house of quality

HoQ is an effective method to ensure attention for comfort in the product design process. The standard HoQ includes customer requirements (WHATs), engineering design requirements (HOWs) and relationship matrix of WHATs. Firstly, the customer requirements (CRs) are collected through market research by a design team. Next, the correlation between EDRs and CRs is calculated by expert practice advice. Finally, the importance of EDRs which affects CRs is indicated in the engineer language.

In practice, QFD is widely used as the most important technical tool to translate CRs into product technical requirements of new product development. QFD was applied to deal with product development for achieving the max product quality by meeting customer request [7]. With the purpose of gaining the best customer satisfaction, QFD was used to solve the correlation triangle problem of converting CRs into engineering characteristics (ECs) [8]. QFD integrated with robust design made a design solution for multiple optimization problems of product design [9].

3.2. TOPSIS decision method

The TOPSIS method is firstly proposed by Hwang and Lin in 1987 [10]. In general, TOPSIS has two major functions: the one is to calculate the longest distance from negative ideal solution; the other is to choose the optimization alternative which has the shortest distance from ideal solution. In case of analysis for decision problem, TOPSIS is an effective and practicable method used for rank ordering schemes by preference.

TOPSIS method has been successfully applied to solve multicriteria decision making problem in various industrial field. The multiattribute decision making model based on TOPSIS was arranged for the disposal of decision problem of logistic information technology [11]. TOPSIS was used to manage competitive benchmarking in product design process [12]. TOPSIS integrated with other methods were developed to deal with multipurpose reactive power compensation problem [13].

In this paper, the TOPSIS method was used to analysis decision process for product design quality because the concept is available and reasonable. The steps in the general TOPSIS process can be described as follows.

Step 1: Construct the normalized decision matrix. The vector combines the concepts of decision matrix in the following expression

$$A = \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1n} \\ g_{21} & g_{22} & \cdots & g_{2n} \\ \vdots & \cdots & \ddots & \vdots \\ g_{m1} & g_{m1} & \cdots & g_{mn} \end{bmatrix} \quad (1)$$

where g_{mk} represents the mth alternative for the nth attribute. And the normalized decision matrix can be calculated by

$$r_{mn} = g_{mn} \Big/ \left(\sum_{m=1}^{k} g_{mn}^{2} \right)^{1/2} \quad (2)$$

Step 2: Find the weighted normalized matrix. First, the set of importance weights of w_j are developed by QFD model. Then, the weighted normalized matrix can be constructed as follows

$$\tilde{V} = [v_{ij}]_{m \times n} \quad (3)$$

where $v_{ij} = r_{ij}(\cdot) w_j, \sum_{j=1}^{n} w_j = 1, i = 1,2,\ldots,m, j = 1,2,\ldots,n.$

Step 3: Identify ideal and antiideal solution. The ideal solution (V^*) is shown in the following

$$V^* = max\{v_1^*, v_2^*, \ldots, v_j^*\},\ j = 1,2,\ldots,n. \quad (4)$$

Similarly, antiideal solution V^- is determined as

$$V^- = min\{v_1^*, v_2^*, \ldots, v_j^*\},\ j = 1,2,\ldots,n. \quad (5)$$

Step 4: Develop the distances between each alternative. The distances of each alternative from ideal solution can be calculated by the equation given below

$$d_i^* = \left[\sum_{i=1}^{n} (v_{ij} - v_j^*)^2 \right]^{1/2} \quad (6)$$

The distances for antiideal solution are calculated as

$$d_i^- = \left[\sum_{i=1}^{n} (v_{ij} - v_j^*)^2 \right]^{1/2} \quad (7)$$

Step 5: Calculate the closeness coefficient. The ranking order of all alternatives by the sum of the distance to the ideal solution is

$$C_i^* = d_i^- / (d_i^* + d_i^-) \quad (8)$$

Step 6: Rank the alternatives. The preference order can be decided by Eq. (8), which is close to the ideal solution and far from the antiideal solution.

Step 7: Recommend the best alternative. The preferred alternative is the one with the maximum ratio of C_i^*.

4. An empirical application

The described methodology is applied to analysis product design quality by using QFD model and TOPSIS. The experiment was basically setup upon the decision of the design quality for a gas turbine. The number of *CRs* is heavily dependent on the consumer satisfaction. Here 5 *CRs* were selected: quality assurance (CRs_1), reliability (CRs_2), maintainability (CRs_3), indemnificatory (CRs_4), availability (CRs_5). In order to response to consumer requirements, *EDRs* are applied based on QFD model. In addition, the *EDRs* were consulted to construct relationship matrix based on Power ($EDRs_1$), Engine Speed ($EDRs_2$), Max Service Life ($EDRs_3$), Compression Ratio ($EDRs_4$), Noise ($EDRs_5$), Exhaust Pollution ($EDRs_6$, (NOx, COx)) and Combustion Efficiency ($EDRs_7$). The information and data for HoQ are depicted in Table 1.

Table 1

Original HoQ for design quality of gas turbine

	Weight	Power	Engine speed	Max service life	Compression ratio	Noise	Exhaust pollution	Combustion efficiency
Quality assurance	0.35	3	9	1	3	9	3	9
Reliability	0.15	9	3	9	1	3	1	3
Maintainability	0.10	1	1	3	3	1	3	9
Indemnificatory	0.25	3	9	3	1	1	3	1
Availability	0.15	9	3	1	9	3	9	1

The next step is to determine the *EDRs* of design quality for a gas turbine according to the *CRs*. For example, the importance value of $EDRs_1$ is calculated by using the correlation of HoQ as following

$$EDRs_1 = 0.35\times3 + 0.15\times9 + 0.10\times1 + 0.25\times3 + 0.15\times9 = 4.60.$$

Similarly, the other *EDRs* are determined as: $EDRs_2 = 6.40$, $EDRs_3 = 2.90$, $EDRs_4 = 3.10$, $EDRs_5 = 4.40$, $EDRs_6 = 3.60$, $EDRs_7 = 4.90$. Then, the importance can be obtained as: W = (0.1538, 0.2140, 0.0970, 0.1037, 0.1472, 0.1204, 0.1639). After translating *CRs* into *EDRs*, the data comparison of four solutions is completed in Table 2.

Table 2

Data for four solutions with seven *EDRs*

No.	Engineering design requirements (*EDRs*)						
	$EDRs_1$	$EDRs_2$	$EDRs_3$	$EDRs_4$	$EDRs_5$	$EDRs_6$	$EDRs_7$
	kW	rpm	hour	scale	dB	ppm	%
1	75	85000	55000	5.5	60	15	23.5
2	80	75000	45000	4.6	75	12	18.5
3	90	65500	42000	5.8	58	10	19.5
4	85	75500	53000	5.3	63	18	20.5

Then, by applying Eq. (2), the normalized decision matrix is calculated for each alternative. Next, we calculated weighted normalized decision matrix, and Eq. (3) is applied to calculate the total matrix. After that, the ideal solution is calculated by using the data of *EDRs* via Eq. (4). V^*= (0.0837, 0.1204, 0.0544, 0.0448, 0.0663, 0.0428, 0.0736). Similarly, the anti-ideal solution is computed as follows: V^-= (0.0698, 0.0928, 0.0415, 0.0565, 0.0858, 0.0770, 0.0935).

Next, using the data in Table 2 and Eq. (6), we can calculate the distances from the ideal solution as

$$d_1^* = 0.0336,\ d_2^* = 0.0289,\ d_3^* = 0.0329,\ d_4^* = 0.0390$$

The distances for antiideal solution can be obtained in the same way using Eq. (7)

$$d_1^- = 0.0374,\ d_2^- = 0.0374,\ d_3^- = 0.0447,\ d_4^- = 0.0276$$

In the next step, the closeness coefficient to the ideal solution is given. Finally, the aggregate analysis results for design quality are shown in Table 3. According to the analysis, solution No.3 is the best performer among four schemes. The final ranking obtained by the proposed method was totally in accordance with the intuitive preference of design quality for the gas turbine.

Table 3

Aggregate analysis results for design quality

Solution No.	d^*	d^-	C^*	Sort
1	0.0336	0.0374	0.5263	3
2	0.0289	0.0374	0.5643	2
3	0.0329	0.0447	0.5761	1
4	0.0390	0.0276	0.4143	4

5. Conclusions

The product design quality selection problem formulated as multiobjective optimization problem with competing amount of quality indicators. This paper has proposed a new integrated QFD model and TOPSIS method for product design quality in the manufacturing performance selection. In order to translate *CRs* into product technical requirements, the appropriate criteria weights of *EDRs* are obtained using QFD model. Then, we developed the HoQ model for dealing with various types of uncertain information of *CRs*.

In addition, the TOPSIS approach was fairly used to denote the level of design solution responding the performance difference. After the weights are obtained by QFD, the aggregate performance of each alternative is easier to achieve. The methodology solves the ambiguity of the comparison process by using the relative position of ideal and antiideal solution. For the comparison of all solution, we have selected the best alternative according to the aggregate analysis results.

The proposed aggregate analysis model has practical application as the empirical test showed in the case of design quality selection problem of a gas turbine. Furthermore, the proposed method is also used to solve other optimization problems in various industries. As a future step to this paper could be the comparison of the proposed approach to other multiple criteria group decision-making methods.

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Jihong Pang, Genbao Zhang, Guohua Chen

OFD MODELIO IR TOPSIS METODO KOMPLEKSINĖS ANALIZĖS TAIKYMAS GAMINIŲ PROJEKTAVIMO KOKYBEI GERINTI

R e z i u m ė

Klientai vis labiau vertina aukštą gaminių kokybę. Tinkamas gaminio kokybės parinkimas lemia naujo produkto sėkmę rinkoje. Kaip pasirinkti tinkamą analizės modelį pagerinant sprendimų tikslumą, tampa kompleksine problema. Straipsnyje pateikiamas sisteminis sprendimų palaikymo traktavimas naudojantis kokybės funkcijos išskaidymu ir pirmumo pasirinkimo metodika, esant idealiai panašiems gaminio kokybės projektavimo optimizavimo problemos sprendimams. Eksperimento rezultatai parodė, kad siūlomas kompleksinės analizės modelis gali labai padėti projektuojant dujų turbinas.

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APPLICATION OF AGGREGATE ANALYSIS FOR PRODUCT DESIGN QUALITY USING QFD MODEL AND TOPSIS

S u m m a r y

The high level of quality is becoming increasingly more important in manufacturing industry due to customer requirements. The selection of proper design quality is vital for the success of new product development. How to select the suitable analysis model to improve the decision accuracy has become a complex problem. This study presents a systematic decision support approach to solve the optimization design problems of product quality based on quality function deployment (QFD) and technique for order preference by similarity to ideal solution (TOPSIS). The experimental results showed that the proposed aggregate analysis model is expected to provide invaluable decision support for the design quality of a gas turbine.

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