Determining the Importance Ratings of Customer Requirements of Automotive Clutch Based on Quality Function Deployment

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Abstract. To obtain more comprehensive customer requirements and accurately determine the importance ratings of customer requirements in automotive clutch Quality Function Deployment (QFD), Affinity Diagram, expert evaluation method and rough Analytic Hierarchy Process (RAHP) were introduced in this paper. Firstly, fourteen requirements were identified for automotive clutch by using Affinity Diagram. Then rough numbers and rough boundary intervals were utilized to characterize vagueness and uncertainty of customer requirements, and constructed rough group decision matrices and rough pairwise comparison matrices. Finally, the importance ratings of customer requirements were determined by solving eigenvalues and eigenvectors of rough pairwise comparison matrices.

Introduction

Automotive clutch is installed between the engine and the transmission, is the component of cut off and transfer the power between engine and automotive transmission system. Automotive clutch cut off the power and power transmission by "separating" and "bonding", it can ensure the car start smooth, achieving a smooth shift of gears, preventing transmission from overload.

As the development trade of customer requirements becoming diversified and personalized, product updates fast, customer satisfaction has become one of the decisive factors in product design. Enterprises’ practices shows that the applications of QFD can greatly shorten the product development cycle, improve product quality, improve customer satisfaction, and finally obtain more good economic returns. The essence of QFD is to identify the real requirements of customers, and meet those requirements, the first stage of QFD is to build product planning house, it is the source of the waterfall decomposition process of QFD. Therefore, determining the importance ratings of customer requirements is a key step. As for determining the importance ratings of customer requirements, literature [1] utilized AHP method analysis the importance ratings of customer requirements, literature [2] put forward linear partial order method to analysis the importance ratings of customer requirements. But these methods all demand that the customer requirement information expression accurately, it does not conform to the language habits of customers. Evaluation of the importance ratings of
customer requirements inevitably contains a lot of vague and uncertain multi-semantic information, which is essentially ambiguous. To accurately describe the fuzziness of customer requirement, literature [3] used a special form of interval number of the fuzzy number to evaluated the importance ratings of customer requirements, and used the operation rule of interval number to analyze the importance ratings of customer requirements, determined the importance ratings of the basic priority of customer requirements, but there is a defect of the interval numbers in the fuzzy description customer requirements, it may lead to large deviation. Literature [4] introduced the fuzzy set theory in the research of QFD for the first time. Since then, a large number of researches explored using fuzzy theory and group decision-making method to determine the importance ratings of multi-granularity and multi-semantic customer requirements [5]. From the above analysis, there are mainly two questions of current researches: firstly, how to obtain comprehensive customer requirements; the second is how to determine the importance ratings of customer requirements accurately. An example of obtaining customer requirements more comprehensively and determine the importance ratings of customer requirements of automotive clutch accurately was introduced in this paper.

The method of expert evaluation and rough AHP

Expert evaluation

Because of the importance ratings of customer requirements in QFD determined the direction of product development, the decisions should be made according to the consensus of decision-making team, and policymakers should be a cross-functional team. So the first step of our work to set up a team of stakeholders, they have different perspectives and represent different roles. In actual survey, due to the limitations of customers’ understanding and some survey projects is not interested, it is usually difficult to obtain accurate information, so the customers we surveyed should had a deep understanding for the product. Therefore, customers should include many members, to describe convenience in this paper, our research chose "experts" within each stage to the whole life cycle of the automotive clutch product, including product designers, the users of the product, product maintenance personnel and industry experts, but does not affect the expression of ideas.

Rough Analytic Hierarchy Process

Rough set theory is a new mathematical tool for deal with ambiguity and uncertainty question. Compared with the probability statistics, fuzzy sets for dealing with vagueness and uncertainty question, rough set theory has the superiority of these theories do not have. Rough numbers and rough boundary intervals are two concepts that put forward on the basic principle of rough set, is a group of closed interval containing the upper and lower limits, which is calculated from the collected data. Compared with the traditional fuzzy number processing methods, rough number has two major advantages: the information of customer requirements get from rough numbers could reflect the true perception of customers much better, and maintain the objectivity of the original data; Rough numbers does not only consider the perception of a single customer, but also take the views of other customers into account, so the importance ratings of customer requirements draw from rough numbers are more holistic.

Put the concepts of rough numbers and rough intervals boundary based on rough set theory into the analysis process of analytic hierarchy process, restructure the investigation method and the steps of determining the importance of customer requirements in QFD according to the
theory of rough sets, forming rough analytic hierarchy process which fusion advantages of rough set and analytic hierarchy process.

The steps for determining the importance ratings of customer requirements of automotive clutch

Step 1: Acquiring the customer requirements of automotive clutch and classify them

Acquisition methods commonly used are: customer requirement inquiry, customer complaints and suggestions, questionnaire and brainstorming, the key is to obtain accurate customer requirements [6]. Considering the actual situation of the development of automotive clutch, car owners generally know only a little about automotive clutch. Therefore, it is difficult to obtain customer requirement by interviewing customer directly. In order to obtain customer requirements, we used Delphi method and sent the questionnaire to relevant experts. In addition, we also this study also looked up the common faults and causes of the clutch.

There will be some difference in the expression for original customer requirements obtained by the above method, but the actual meaning of them are the same or very similar, each requirements various cross each other mutually inclusive, so we must to classify and simplify the similar customer requirements. After obtaining the original customer requirements, affinity diagram, tree diagram and cluster analysis can be used to make customer requirements hierarchy. Garvin has proposed eight categories of quality: performance, features, reliability, conformance, durability, serviceability, aesthetics and perceived quality [7], which has become a guide for the design team to collect complete customer requirements data in product development process. In the classification of customer requirements, this study take it as a reference, according to the actual situation of the clutch product and combine Affinity Diagram to classify the requirements of customers. We built customer requirements hierarchy and determined 14 main customer requirements for the design and development of automotive clutch, divided then into five categories by clustering and affinity analysis, the hierarchy of customer requirements are shown in Fig.1.

![Figure 1. The hierarchy of customer requirements.](image-url)
Step 2: Determining the importance ratings of customer requirements, constructing pairwise comparison matrices of AHP

According to the expert evaluation method, 5 kinds of "experts" took part in the evaluation of the importance ratings of customer requirements in this study, they are: automobile drivers, professional designers of automobile, experts and scholars of automotive clutch industry, technical directors of automotive clutch factory and maintenance personnel of automobile. Then the evaluation results for each category of expert were integrated together, we got 5 kinds of evaluation results according to the 5 kinds of experts. For the first hierarchy of customer requirements, we created 5 AHP pairwise comparison matrices:

\[
A_{12} = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1
\end{bmatrix}
A_{13} = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1
\end{bmatrix}
A_{14} = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1
\end{bmatrix}
A_{15} = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1
\end{bmatrix}
A_{12} = \begin{bmatrix}
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1 & 1
\end{bmatrix}
\]

According to the consistency of the judgment equations \(C.I. = (\lambda_{\text{max}} - n)/(n-1)\) and \(C.R. = C.I. / R.I.[8]\), we can get the consistency ratios of the above 5 matrices: \(C.R._1 = 0.014, C.R._2 = 0.033, C.R._3 = 0.004, C.R._4 = 0.036, C.R._5 = 0.036\), All the \(C.R.\) values were less than 0.1, this indicates that these customer evaluation results are consistent.

Step 3: Building the rough group decision-making matrix, solving the rough numbers of the matrix elements

In this step, the five AHP matrices were represented with the form of rough group decision matrix.

\[
A_r = \begin{bmatrix}
1,1,1,1,1 & 1,1,1,1,2 & 4,4,5,4,4 & 3,3,3,2,2 & 2,3,2,3,3 \\
1,1,1,1,2 & 1,1,1,1,1 & 4,3,4,4,3 & 2,2,2,2,2 & 2,2,1,2,2 \\
4,4,5,4,4 & 4,3,4,4,3 & 1,1,1,1,1 & \frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2} & \frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2} \\
3,3,3,2,2 & 2,2,2,2,2 & \frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2} & 2,1,2,1,1 & 1,1,1,1,1 \\
2,3,2,3,3 & 2,2,1,2,2 & \frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2},\frac{1}{2} & 1,1,1,1,1 & 2,2,1,2,2
\end{bmatrix}
\]

According to the method introduced in literature [9], calculate the upper boundary and the lower boundary and average rough interval of each element in the matrix. Based on the above rough numbers and rough intervals, we constructed a pairwise comparison matrix of \(CR_1 \sim CR_5\) customer requirements.

\[
X_r = \begin{bmatrix}
[0.82,0.98] & [1,1] & [3.36,3.84] & [2,2] & [1.64,1.96] \\
[0.232,0.248] & [0.263,0.303] & [1,1] & [0.58,0.82] & [0.52,0.68] \\
[0.36,0.44] & [0.5,0.5] & [1.36,1.84] & [1,1] & [0.813,1.613] \\
[0.36,0.44] & [0.52,0.68] & [1.64,1.96] & [0.813,1.613] & [1,1]
\end{bmatrix}
\]

Step 4: Calculating the importance ratings of customer requirements for each hierarchy

Decompose the pairwise comparison matrix into a rough lower boundary matrix \(X^-\) and a rough upper boundary matrix \(X^+\):
Then we solved the eigenvalues and eigenvector of the boundary matrix, acquire the
importance ratings of customer requirements corresponding to this matrix. In general, the
eigenvalues of matrix $A$ can be obtained through the equation: $\det(A - \lambda I) = 0$. For the rough
lower boundary matrix $X^-$, we get the maximum eigenvalue $\lambda_{\text{max}} = 2.945$, and obtain the
 corresponding eigenvector by solving the equation $AX = \lambda X$, the eigenvector is
$X = (1.879, 1.553, 0.450, 0.724, 0.758)$. Similarly, we get the eigenvalues and eigenvector of the rough
upper boundary matrix is $\lambda_{\text{max}} = 2.945$ and $X = (2.167, 1.713, 0.530, 0.918, 0.989)$. Standardize them it is :

$$[g_1^-, g_2^-, g_3^-, g_4^-, g_5^-] = [0.350, 0.290, 0.084, 0.135, 0.141].$$

$$[g_1^+, g_2^+, g_3^+, g_4^+, g_5^+] = [0.343, 0.271, 0.084, 0.145, 0.157].$$

After getting the lower boundary and the upper boundary, calculate the average value of
them. Using the equation (1):

$$g_i = (g_i^- + g_i^+)/2$$

We get the eigenvector of the first hierarchy of customer requirements is:

$$[g_1, g_2, g_3, g_4, g_5] = [0.347, 0.280, 0.084, 0.140, 0.149].$$

Similarly to the above-described method can be used to determining the importance ratings
of customer requirements for the second hierarchy and the third hierarchy.

**Step 5: Synthesizing the value of the first hierarchy and the second hierarchy to calculate
the final importance ratings of customer requirements**

$$f_{ij}(CR_{ij}) = g_i(CR_i) \times g_{ij}(CR_{ij})$$

After calculating the importance ratings of customer requirements for each hierarchy, using
$f_{ij}(CR_i)$ to represent the final importance ratings of customer requirements. It can be calculated
by using the equation (2), and it is shown in Table 1. According to Table 1 we can set a figure
about the importance ranking of customer requirements for automotive clutch, as shown in
Fig.2.

In order to make the enterprise products to be successful in highly competitive market, the
QFD team must give more consideration and resources to the customer requirements which had
a greater value of final importance ratings, ensure those customer requirements could be satisfied at first.

Table 1. The importance ratings of customer requirements for automotive clutch.

<table>
<thead>
<tr>
<th>Customer requirements</th>
<th>$g_i(CR_i)$</th>
<th>Customer requirements</th>
<th>$g_{ij}(CR_{ij})$</th>
<th>$f_{ij}(CR_{ij})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good performance</td>
<td>0.347</td>
<td>Enough power, without slipping</td>
<td>0.413</td>
<td>0.143</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Separate thorough and prompt</td>
<td>0.370</td>
<td>0.128</td>
</tr>
<tr>
<td></td>
<td></td>
<td>High-speed stability</td>
<td>0.217</td>
<td>0.075</td>
</tr>
<tr>
<td>High reliability</td>
<td>0.280</td>
<td>Friction plates does not burn</td>
<td>0.357</td>
<td>0.100</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Parts not fracture</td>
<td>0.310</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Long life for use</td>
<td>0.333</td>
<td>0.093</td>
</tr>
<tr>
<td>Good service</td>
<td>0.084</td>
<td>Parts of good interchangeability</td>
<td>0.417</td>
<td>0.035</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Disassembly, adjustment and maintenance</td>
<td>0.583</td>
<td>0.049</td>
</tr>
<tr>
<td>Ergonomic design</td>
<td>0.140</td>
<td>Manipulation effortless and light</td>
<td>0.375</td>
<td>0.053</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Small vibration and noise</td>
<td>0.458</td>
<td>0.064</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Simple and compact structure</td>
<td>0.092</td>
<td>0.013</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Attractive appearance</td>
<td>0.075</td>
<td>0.011</td>
</tr>
<tr>
<td>Economic and environmental</td>
<td>0.149</td>
<td>Cheap price</td>
<td>0.417</td>
<td>0.062</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Meet environmental protection requirements</td>
<td>0.583</td>
<td>0.087</td>
</tr>
</tbody>
</table>
Summary

RAHP method was applied to determine the importance ratings of customer requirements of automotive clutch products in this paper. First of all, original data were obtained according to market surveys, and made the hierarchy of customer requirements; Secondly, the evaluation of the importance weights of customer requirements and the AHP pairwise comparison matrix were made by experts; Then, solving each element of the group decision matrix to obtain rough numbers and boundary intervals, get the pairwise comparison matrix, and get the importance ratings of customer requirements in each hierarchy by solving rough pairwise comparison matrix for eigenvalues and eigenvectors. RAHP method can effectively deal with the situations of more than one decision maker in group decision making, describe the uncertainty of customer perception and evaluate requirements more accurately, and get the priority of the final customer requirements, provides the reference for the enterprises to carry out a successful practice of QFD.

References


