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The Process of Engine Reliability Fuzzy Prediction

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Abstract. Since reliability is one of the most important indicators of engines, reliability research has been increasing used in engines widely. These studies are based on the failure data which are obtained during working time, and the distribution can be summarized by using computer aided technology, hence improving the product reliability. With the help of computer aided technology, the reliability fuzzy prediction method of the engine system, for example, is used in supercharging system to verify the feasibility.

1. Introduction

Reliability issues came out at the occurrence of the Second World War. During the process when Germany research and develop the V-2 rocket, as well as the aircraft engine improvement in England, due to the complexity of the system structure and the harsh requirement for its usage, reliability requirement was come out in order to guarantee the functional feasibility of the system.

Generalizing reliability technology in automobile manufacturing industry is very significant because the development for both two are complementary. The incidents of recalling cars often happened before the launch of generalizing quality control and reliability index. The report of America automobile index has pointed out that the average value of faulted cars in each 1000 cars have been declined from 99 to 20 from the year of 1980 to 2000, and the reliability of engines have been improved distinctively. Reliability research started late in China compared with some other countries, and the early reliability research was applied to electronic products. Nevertheless, there are still gaps existing between China and some other countries who has already possessed advanced technology about it in the engine reliability field.

In order to study the system reliability, the system structure needs to be defined first. The system structure model should be set up first in the system reliability evaluation: The whole system is expressed in its parts; and then collect data for each part. Finally, the reliability of the system is evaluated with the value of the components and the reliability model of the system[1].The fault tree is a common system model, which is used for display critical event of system failures, the logical graph model between the causes of the parts malfunction. Building a fault tree is also a connection between the state of the system and the state of the parts[2].

After verifying the fuzzy prediction feasibility of universal confidence level, the related applications of reliability fuzzy prediction in failure associated problem can be found, following by selecting subsystem unite prediction, figuring out probability of subsystem unite faults by using triangular fuzzy numbers range, obtain and eventually obtaining the reliability prediction consequence.

2. The method of engine system reliability fuzzy prediction

2.1. Selecting the influence factors of subsystem reliability

The general system can be divided into multiple subsystems which contains multiple parts. The engine for example, the valve system and fuel feed system of which has numerous failure modes, and factors that influences its reliability vary as well. Without conducting the selection process, it will not only reflect no research value on main influence factors but also impact the rationality of the fuzzy prediction. Therefore, it is necessary to take the categories of influence factors as the reference when screening the factors, which can be done by dividing some factor into groups and constituting the factor compilations, following by refining into the sub-factors and constituting the factor subsets.

The inherent attributes of the subsystem can be neglected when selecting the factors since they have already been considered in the process of design and production.

2.2. The wight of influence factors

The ability of exerting influence for the factors need to be measured by the weight, which contains the weight of all kinds of factors, as well as the weight of the sub-factors within each of them. The degree of hazard needs to be identified by the hazard analysis when defining the weights of the factors in terms of vital, very important, important, unimportant, relatively unimportant, very unimportant and extreme unimportant in sequence. Considering that the fuzziness of the reliability information when it is designed, fuzzy numbers are used to express.

$$\widetilde{A}=\left\{\widetilde{1},\widetilde{2},\widetilde{3},\widetilde{4},\widetilde{5},\widetilde{6},\widetilde{7},\widetilde{8}\right\} \tag{1}$$

The stated factors weight and sub-factors weight respectively are:

$$\widetilde{Q}=\left(\mathrm{q}_1,q_2,q_3\right) \tag{2}$$

$$\begin{cases}\widetilde{Q}_1=\left(q_{11},q_{12,}q_{13}\right)\\ \widetilde{Q}_2=\left(q_{21},q_{22},q_{23}\right)\\ \widetilde{Q}_3=\left(q_{31},q_{32},q_{33},q_{34}\right)\end{cases} \tag{3}$$

2.3. Comprehensive assessment

The comprehensive assessment is a multi-objective decision actually. It is the comprehensive fuzzy assessment that evaluated the incidents and faults that influenced by multi-factor which include fuzzy factors or replaced by fuzzy factors. The fuzzy comprehensive evaluation has one and two grades, and generalized further could be multistage. All the sub-factors of each factor obtain the comprehensive assessment that is fuzzy comprehensive assessment. The degree of reliability of sub-system might achieved is impressed by alternative domain $Y=\left\{y_1,y_2,...,y_3\right\}$. Take the number j sub-factor x_{ij} in the sub-factor $X_i=\left(i=1,2,3\right)$ as an example, the fuzzy probability of fetching the alternative factor Y_k is $\widetilde{P}_{ijk}$, and the one grade fuzzy comprehensive assessment matrix is:

$$\widetilde{P}_{\mathrm{i}}=\begin{bmatrix}\widetilde{p}_{i11} & \widetilde{p}_{i12} & \cdots & \widetilde{p}_{i1m}\\ \widetilde{p}_{i21} & \widetilde{p}_{i22} & \cdots & \widetilde{p}_{i2m}\\ \cdots & \cdots & \cdots & \cdots\\ \widetilde{p}_{in1} & \widetilde{p}_{in2} & \cdots & \widetilde{p}_{inm}\end{bmatrix},\quad i=1,2,3 \tag{4}$$

Then the fuzzy comprehensive assessment each factor $X_{\mathrm{i}}\left(i=1,2,3\right)$ could obtain the judging aggregate

$$\widetilde{O}_i=\widetilde{Q}_{\mathrm{i}}\circ\widetilde{P}_{\mathrm{i}}=\left(\widetilde{o}_{i1},\widetilde{o}_{i2},\ldots,\widetilde{o}_{im}\right),i=1,2,3 \tag{5}$$

The "∘"means fuzzy operational symbol. If regard the $\widetilde{O}_i$ of the one grade fuzzy comprehensive assessment as comprehensive estimated matrix $\widetilde{P}$, reconsider the weight $\widetilde{Q}$ of each factor could obtain the judging aggregate of second grade fuzzy assessment:

$$\widetilde{R} = \widetilde{Q} \circ \widetilde{P} = (\widetilde{r}_1, \widetilde{r}_2, \ldots, \widetilde{r}_m) \tag{6}$$

Doing the weighted average when predict by using fuzzy assessment. And using the weight $\widetilde{R}_k$ to weighted average figure up the alternative factors, the predicted consequence is shown by fuzzy numbers:

$$\widetilde{P}_{ss} = \sum_{k=1}^{m} \widetilde{r}_k y_k / \sum_{k=1}^{m} \widetilde{r}_k \tag{7}$$

2.4. Fuzzy prediction

The consequence of fuzzy comprehensive assessment prediction is made up with the fuzzy numbers. The degree of reliability that figured out represents the interval named confidence interval of confidence level. According to the possible theory of the probability statistics, this interval in the fuzzy aggregate $\tilde{P}_{ss}$ has more possibility, and the higher confidence level λ， the littler ambiguity. Generally speaking, confidence level λ rather approaching to 1 than equate, because the fuzzy aggregate is determined value when confidence level is 1.

3. The Application of Engine Fuzzy Prediction

The malfunction assessment and reliability prediction of automobile engine system have been more complex due to the updating of engine materials, structure and technology. Applying the fuzzy reliability prediction is an efficient path. It is a gradual change process from the engine first been used to first break down, far from "entire" order changed into "entire" failure state. It would appear the failure symptom in the pilot process. Therefore, the malfunction and omen are fuzzy.

Take the pressurization system as application object, According to the setting initial each factor and sub-factor in the last section, the degree of reliability of pressurization system average fault-free period is 0.97 around by consulting the statistical data of references[3-4]. The design of pressurization system went wrong if the predicted value was divergent by using the aforesaid way. Increase the predicted range somewhat could get the alternative set:

$$Y = \{0.95, 0.96, 0.97, 0.98, 0.99\} \tag{8}$$

The weight of the each factor that was represented by triangular fuzzy numbers is shown in table 1. The first number of triangular fuzzy numbers represents the grade $\{\widetilde{1}, \widetilde{2}, \widetilde{3}, \widetilde{4}, \widetilde{5}, \widetilde{6}, \widetilde{7}, \widetilde{8}\}$ of weight that divided in above. And the other two numbers are lift and right distributed parameters of $\widetilde{A}$, that means greater than or less than the fuzziness of this grade , and bigger subtraction of the two numbers represent the bigger possibility.

Table 1. Weight of the each factor that was represented by triangular fuzzy

Each factor	Group one	Group two	Group three	Group four
Design	（7,0.5,0.5）	（8,0.4,0.4）	（8,0.6,0.2）	（8,0.7,0.1）
Usage	（6,0.4,0.7）	（7,0.6,0.6）	（7,0.5,0.3）	（6,0.2,0.8）
Production	（8,0.4,0.3）	（8,0.5,0.2）	（7,0.2,0.3）	（7,0.7,0.3）

During the counting process in last section could get the weight aggregate

$$\widetilde{Q} = (0.35, 0.31, 0.34) \tag{9}$$

And the weight aggregate of sub-factors

$$\begin{cases} \widetilde{Q}_1 = (0.334, 0.41, 0.256) \\ \widetilde{Q}_2 = (0.375, 0.301, 0.324) \\ \widetilde{Q}_3 = (0.296, 0.241, 0.272, 0.191) \end{cases} \tag{10}$$

The triangular fuzzy numbers are particularity in the one-level comprehensive fuzzy assessment prediction. That means the lift and right distributed parameters of $\widetilde{A}$ are equal. In order to simplified representation, using the letters replace the lift and right distributed parameters directly. And divide into three grades "very possible 0.04", "rather possible 0.08", "common possible 0.15", table 2 aims at

the fuzzy weight of design objective sub-factors. According to the sequencing computation consequence of alternative elements aggregation in the above, obtain the one-level fuzzy comprehensive assessment matrix.

Table 2. Sub-factors weight were represented by triangular fuzzy numbers

alternative elements	Group one	Group two	Group three	Group four
0.95	（0.30,0.08）	（0.25,0.08）	（0.20,0.04）	（0.20,0.15）
0.96	（0.85,0.04）	（0.80,0.08）	（0.75,0.08）	（0.70,0.08）
0.97	（1.00,0.08）	（0.95,0.04）	（0.90,0.08）	（0.95,0.08）
0.98	（0.90,0.08）	（1.00,0.08）	（1.00,0.15）	（1.00,0.15）
0.99	（0.70,0.15）	（0.75,0.08）	（0.60,0.08）	（0.90,0.15）

$$\widetilde{p}_{11}=\left[(0.24,0.09)\quad(0.78,0.07)\quad(0.95,0.07)\quad(0.98,0.12)\quad(0.74,0.12)\right] \tag{11}$$

Figure out the two-level comprehensive fuzzy assessment matrix according to the above next:

$$\widetilde{P}=\begin{bmatrix}(0.25,0.07) & (0.81,0.09) & (0.95,0.08) & (0.97,0.10) & (0.77,0.10)\\ (0.41,0.11) & (0.76,0.10) & (0.97,0.08) & (0.93,0.10) & (0.75,0.11)\\ (0.64,0.08) & (0.92,0.09) & (0.98,0.07) & (0.93,0.09) & (0.57,0.10)\end{bmatrix} \tag{12}$$

During the reliability prediction in the end the confidence level need to be ensured. The confidence level λ generally value 0.95 in the mathematical statistics, and approach to the initial predicted value 0.97 and all belong to the range of the alternative aggregation. So it is observed that the consequences are reasonable though figure out by reliability fuzzy prediction. Today, with the continuous improvement of human's thinking consciousness, we have gradually utilized this non quantitative model to break the shackles of traditional knowledge, and become a scientific theory with distinctive characteristics and complete system, and have been applied successfully in dozens of fields[5].

4. Conclusion

Using the ways of engine system reliability fuzzy prediction, briefly verify the feasibility of fuzzy prediction under the common confidence level by taking the pressurization system in the FAT as example. And come up with the malfunction relevance application of reliability fuzzy prediction. Proved the feasibility of reliability fuzzy prediction. It provides theoretical and data support for the test of automotive production design stage, and draws practical guidance. Starting from the product design stage, it improves reliability and prolongs the service life of products.But still need the optimized analysis.

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