Research on Reliability Evaluation of Engine Crankshaft Flexible Production Line Based on AHP Fuzzy Comprehensive Evaluation Method

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Abstract: According to the reliability evaluation system of production line and the Petri net model of production line availability, the relationship between reliability index and reliability index correlation is analyzed by statistically calculating reliability data. According to the relationship between the actual production situation and the correlation between the reliability index and the reliability index, the analytic hierarchy process based on interval judgment is used to give the weight of each reliability indicator to the reliability of the production line, and according to the reliability index, the membership function of the evaluation grade is evaluated by the fuzzy comprehensive evaluation method for the reliability of the engine crankshaft flexible production line.

Key words: production line; interval judgment; reliability evaluation; comprehensive evaluation

1. Introduction

A production line is a complex manufacturing system consisting of multiple pieces of equipment, but the reliability assessment of a production line cannot simply assess the reliability of its constituent equipment. The reliability indicators of the evaluation equipment mainly include Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR) and availability [1]. If the equipment fails, it must be repaired, otherwise the equipment will not continue to operate. Compared to equipment, the production line has its own unique operating characteristics. There is a buffer area between each device. When the device fails, the operation of the production line can last for a period due to the existence of the buffer cache product. If the device returns to normal during this time, the production line is in normal operation; Or when the equipment fails, due to the parallel layout of the faulty equipment, the operation of the entire line can be realized. Therefore, the evaluation of production line reliability requires a comprehensive consideration of multiple elements, and considering the hierarchical relationship and ambiguity between elements, the author combines interval number analysis theory, analytic hierarchy process, and fuzzy theory to ensure the reliability of the engine crankshaft flexible production line. Evaluation.
2. Production line reliability evaluation system

According to the operating characteristics of the flexible production line of the crankshaft and the specific requirements for the reliability evaluation index of the flexible production line of the crankshaft, the equipment availability, the availability of the production line and the cost are determined by considering the equipment factors, cache factors and usage factors of the flexible production line of the crankshaft. The reliability index, which establishes the reliability evaluation system for the flexible production line of the crankshaft, is shown in Table 1.

### Table 1. Crankshaft flexible production line reliability evaluation system

| Reliability Factors | Reliability Indices | Reliability Indicator Correlation |
|--------------------|-------------------|----------------------------------|
| Equipment factor   | Equipment availability | Equipment productivity |
| Cache factor       | Production line availability | Equipment maintenance rate |
| Use factor         | Cost               | Equipment failure rate |
|                    |                    | Cache allowed capacity |

3. Analysis of the relationship between the reliability t-mark and the reliability index

3.1. Reliability Data Analysis of Crankshaft Flexible Production Lin

According to the production record, fault record, maintenance record, operation record and production line layout of a certain engine crankshaft flexible production line in 2014, the correlation between the reliability indicators of each equipment is calculated as shown in Table 2.

### Table 2. Correlation quantity of reliability index of each equipment of flexible production line of crankshaft

| Equipment  | Equipment productivity | Equipment maintenance rate | Equipment failure rate | Cache allowed capacity |
|------------|------------------------|---------------------------|------------------------|-----------------------|
| OP10-140   | 12.67                  | 2                         | 2.62*10^-3             | 10                    |
| OP150, 200 | 25.35                  | 0.69                      | 5.9*10^-3              | 40                    |
| OP160      | 25.35                  | 0.36                      | 3.43*10^-3             | 60                    |
| OP170      | 25.35                  | 0.33                      | 1.08*10^-3             | 30                    |
| OP180      | 8.45                   | 2                         | 2.62*10^-3             | 20                    |
| OP190      | 25.35                  | 0.63                      | 0.56*10^-3             | 10                    |
| OP210      | 25.35                  | 1.61                      | 3.31*10^-3             | 50                    |

3.2. Relationship between equipment availability and reliability indicators

The reliability level of the flexible production line of the crankshaft has a great relationship with the availability of the equipment. If the availability of the equipment is low, the reliability of the production line can only depend on the complexity of the layout. Therefore, the reliability of the production line must first be determined on the production line. Perform reliability assessment and obtain equipment availability[2] according to formula (1).

\[
EA = \frac{MTBF}{MTBF + MTTR}
\] (1)

Considering the operating characteristics of the flexible production line of the crankshaft, in the event of equipment failure, the production line is considered to be in a normal state as long as it does not affect the production cycle before the equipment failure, that is, the equipment is repaired to a normal state...
within the allowable capacity range of the buffer area. Therefore, when the availability of the device is the same, the smaller the MTTR, the higher the reliability level of the production line.

### 3.3. Relationship between availability of production lines and correlations between reliability indicators

Analysis of the availability of the production line needs to consider the equipment failure rate, equipment maintenance rate, buffer capacity and equipment productivity, take the equipment OP10-40 and the buffer area between them, establish the flexible production line availability of the crankshaft Petri net[3]. Model shown in Figure 1. The description of the library and the changes are shown in Table 3.

The Petri net model of the flexible production line of the crankshaft was simulated to change the equipment productivity, equipment maintenance rate, equipment failure rate and buffer allowable capacity, and the available capacity of the buffer area to the flexible production line of the crankshaft was obtained.

![Figure 1. Production line availability Petri net model](image)

The greatest impact, equipment maintenance rate, equipment failure rate and equipment productivity are the second; the availability of the flexible production line of the crankshaft increases with the equipment maintenance rate and the allowable capacity of the buffer area, with the decrease of equipment productivity and equipment failure rate raise.

**Table 3.** Description of the library and transition of the production line availability Petri net model

| Library / Change | Interpretation |
|------------------|----------------|
| P₁, P₃, P₅, P₇  | The equipment OP10, OP20, OP30, OP40 in normal state |
| P₂, P₄, P₆, P₈  | The equipment OP10, OP20, OP30, OP40 in a fault state |
| P₋₁, P₋₂, P₋₃  | Number of products staying in the front buffer area of OP20, OP30, and OP40 |
| T₁, T₃, T₅, T₇  | The equipment OP10, OP20, OP30, OP40 malfunction |
| T₂, T₄, T₆, T₈  | The service equipment OP10, OP20, OP30, OP40 |
| T₋₁, T₋₂, T₋₃, T₋₄ | The equipment OP10, OP20, OP30, OP40 working |
3.4. Relationship between cost and reliability indicator correlation

The relationship between the cost and the reliability indicator is as shown in equation (2).

\[ E = E_1 + E_2 + E_3 - E_4 \]  \hspace{1cm} (2)

Among them: E is the total cost of improving the reliability level of the flexible production line of the crankshaft; E1 is the cost to improve the equipment maintenance rate; E2 is the cost to reduce the equipment failure rate; E3 is the cost to increase the capacity of the buffer area; E4 is the cost to reduce the equipment productivity.

4. Reliability evaluation of crankshaft flexible production line

According to the relationship between the elements of the production line reliability evaluation system, the hierarchical structure of the production line reliability evaluation system is shown in Figure 2[4].

![Figure 2. Production line reliability evaluation system hierarchy](image)

According to the analytic hierarchy process[5] based on interval judgment, combined with the actual production situation, the T-C interval judgment matrix of the elements in the criterion layer C to the elements in the target layer T is established as:

\[
A = \left[ A^-, A^+ \right] = \left[ \begin{array}{ccc}
(1,1) & (2.5,3.2) & (3,3.3) \\
(1,1) & (0.9,1.3) & (1,1)
\end{array} \right]
\]

Judging matrix \( A = \left[ A^-, A^+ \right] \) according to T-C interval, The maximum feature quantity of \( A^-, A^+ \) is \( \lambda^- = 2.781, \lambda^+ = 3.256 \), Corresponding normalized feature vectors are \( x^- = \begin{bmatrix} 0.606 \\ 0.203 \\ 0.191 \end{bmatrix}, x^+ = \begin{bmatrix} 0.590 \\ 0.216 \\ 0.194 \end{bmatrix} \). And according to formulas (3), (4), \( p = 0.944, q = 1.057 \), It can be seen from 0 < p < 1 < q that the consistency test of the T-C interval judgment matrix is passed[7], so that the weight vector of the element in the criterion layer C to the element in the target layer T is:

\[
C = [p x^-, q x^+] = [(0.572, 0.624), (0.192, 0.229), (0.182, 0.205)]
\]

\[
p = \frac{\sum_{j=q}^{p} 1}{\sum_{j=q}^{p} d_j}
\]  \hspace{1cm} (3)
\[ q = \sqrt{\sum_{j=1}^{n} \frac{1}{a_{ij}}} \tag{4} \]

In the same way, according to the relationship between the reliability index of the flexible production line of the crankshaft and the correlation quantity of the reliability index, the weight vector of the element in the S layer of the plan layer to the element in the criterion layer C is obtained as:

\[
S = \begin{bmatrix}
(0.054, 0.239, 0.139) \\
(0, 0.675, 0.263) \\
(0.495, 0.230, 0.079)
\end{bmatrix}
\]

Finally, the weight vector of the element in the solution layer S to the element in the target layer T is obtained as:

\[
T = C \times S = [(0.120, 0.308, 0.144, 0.312), (0.145, 0.394, 0.181, 0.385)]
\]

According to formula (5), take \( \alpha = 0.8 \), and obtain the normalized weight vector:

\[
T_j = \frac{K_j + (2\alpha - 1)J_j}{2}
\tag{5}
\]

Among them: \( K_j = T_j + T_j^\top \), \( J_j = T_j^\top - T_j \); \( 0 \leq \alpha \leq 1 \), \( 1 \leq j \leq n \).

In order to comprehensively consider all the reliability indicator correlations, the reliability index correlation amount is used as the evaluation index, and the hierarchical structure of the evaluation index and the evaluation level is as shown in Fig. 3. In order to quantitatively describe the evaluation results, the "level 1", "level 2", "level 3", and "level 4" in the evaluation level are assigned[8], and the evaluation level set is assigned.

\[
G = [G_1, G_2, G_3, G_4]^T = [9, 7, 5, 3]^T
\]

Figure 3. Hierarchical structure of evaluation indicators and evaluation levels

According to the relationship between the reliability index of the flexible production line of the crankshaft and the correlation quantity of the reliability index, the membership function[9] of the evaluation index to the evaluation level is established. The main value interval of each equipment productivity is shown in Table 4, wherein the membership function of the OP10 productivity versus the evaluation level set is as shown in Figure 4.
The membership functions of the equipment maintenance rate and equipment failure rate for the evaluation level set are shown in Figures 5 and 6.

### Table 4. Main value interval for each equipment productivity

|        | OP10-140 | OP180 | others |
|--------|----------|-------|--------|
| Level 1| 13       | 9     | 26     |
| Level 2| 14       | 10    | 27     |
| Level 3| 15       | 11    | 28     |
| Level 4| 16       | 12    | 29     |

**Figure 4.** OP10 Productivity to membership function of evaluation level set

**Figure 5.** Maintenance rate versus membership function of the evaluation level set

**Figure 6.** Failure rate versus membership function of the evaluation level set

According to formula (6)[10], the equipment maintenance degree is 90%, the optimal buffer capacity allowed between the devices is obtained, and the main value interval is determined as shown in Table 5,
wherein the OP10 buffer allows the capacity to be attached to the evaluation level set. The function is shown in Figure 7.

\[ B_i = \frac{\left( \ln \frac{1}{1-P} \right) r_i}{\mu_i} \]  

(6)

Among them: \( B_i \) is the optimal buffer capacity allowed between devices; \( P \) is the equipment maintenance degree; \( \mu_i \) is the equipment maintenance rate; \( r_i \) is the equipment productivity.

Table 5. Allowable capacity value interval for each device buffer

|          | Level 1 | Level 2 | Level 3 | Level 4 |
|----------|---------|---------|---------|---------|
| OP10-140 | 15      | 12      | 8       | 5       |
| OP140-150| 30      | 25      | 15      | 10      |
| OP150-160| 85      | 70      | 45      | 30      |
| OP160-170| 160     | 130     | 80      | 55      |
| OP170-180| 175     | 140     | 85      | 60      |
| OP180-190| 30      | 25      | 25      | 10      |
| OP190-200| 90      | 75      | 50      | 30      |
| OP200-210| 85      | 70      | 45      | 30      |

Figure 7. OP10 Cache area allows capacity to evaluate the membership function of the level set

According to the membership function of each reliability index, taking the device OP10 as an example, the membership matrix[11] of the evaluation index to the evaluation level set is:

\[ M_{10} = \begin{bmatrix} 
1 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0.5 & 0.5 & 0 
\end{bmatrix} \]

The weight vector of the evaluation level is:

\[ D_{10} = T \times M_{10} = [0.487, 0.339, 0.174, 0] \]

Device rating is:

\[ H_{10} = D_{10} \times G = 7.625 \]

Similarly, the scores of other devices are:

\[ H_{20-140} = 7.625, \ H_{150} = 6.596, \ H_{160} = 5.736, \ H_{170} = 5.003, \ H_{180} = 6.578, \ H_{190} = 5.486, \ H_{200} = 4.851, \ H_{210} = 6.76 \]

Since the OP10-140 includes 28 devices in the flexible production line of the crankshaft, the OP180 includes 3 devices, and according to the equipment rating, the score of the crankshaft flexible production line is:

\[ H = \frac{28 \times 7.625 + 6.596 + 5.736 + 5.003 + 3 \times 6.578 + 5.486 + 4.851 + 6.76}{37} = 7.23 \]

After the above analysis, the crankshaft flexible production line scored 7.23, which is in a relatively good operating state.
5. Conclusion

(1) According to the data record of the flexible production line of the crankshaft and the layout of the production line, the degree of influence of the reliability index on the availability of the equipment is the order of equipment maintenance rate and equipment failure rate. The degree of influence of the reliability index on the availability of the production line is large. The order to the small order is the buffer allowed capacity, the equipment maintenance rate, the equipment failure rate, and the equipment productivity; the optimal buffer allowed capacity between the devices is 15, 30, 85, 162, 177, 30, 93, 85, respectively.

(2) Using the AHP fuzzy comprehensive evaluation method based on interval judgment, comprehensively considering the reliability index and the reliability index correlation amount to evaluate the flexible production line of the crankshaft, and classifying the equipment of the flexible production line of the crankshaft through the quantitative evaluation level set, thereby realizing Evaluation of the reliability of a flexible production line for crankshafts.

(3) The crankshaft flexible production line studied in this paper is in a relatively good operating state. The degree of influence of the reliability index correlation on the reliability of the flexible production line of the crankshaft is the order of equipment maintenance rate, buffer capacity, equipment failure rate, equipment. Productivity, the degree of influence of equipment on the reliability of the flexible production line of the crankshaft is from OP200, OP170, OP190, OP160, OP180, OP150, OP120, OP10-140.

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