

Overall Assessment of Technical Conditions for Vessels

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Abstract. Overall assessment of technical conditions for a vessel is the major guarantees of ships' combat capability. They are created and completed based on data and information of vessel which are complicated and numerous, so the structure of the vessel system, the subsystems and equipment of the vessel should be investigated accurately and precisely. In this paper, three models, such as the key equipment, the subsystem and the vessel system are given to assess the technical conditions of the vessel by using D-S evidence theory, fuzzy theory and gray relative analysis. The basic probability assignment functions of the key equipment are obtained. The assessment matrix of the vessel for subsystem is given, and the relational degrees of the reference and comparison sequences of the vessel are derived in order to calculate the assessment value. Taking an equipment and a vessel for example, the numerical results show that multi-hierarchy assessment is a useful method for investigating the vessel technical conditions because it can take advantage of the assessment parameters to model and calculate effectively. The influence of the technical parameters of some key equipment for the vessel are considered in the assessment, the reliabilities of the procedures and the results of the assessment are promoted significantly based on D-S evidence theory. The present assessment methods are expected to be useful in the maintenance and management of the vessel and equipment.

1. Introduction

Assessment of technical conditions of a vessel plays a key role in navy equipment department. Many vessels have complicated structure so that the factors of the technical conditions are variable and interdependent [1, 2]. To assess the technical conditions accurately and precisely, the assessment procedures of the technical conditions should be created based on the data requirement of the technical condition, and the assessment methods and models of the technical conditions of the equipment, system and vessel should be investigated. The performance of key equipment, such as main engine and shafting, influence the vessel status, navigation safety and mission completion, and determine the overall level of the technical condition of the vessel [3].

However, the detection parameters of the key equipment are complicated and variable [4, 5], so it is difficult to find out a unified measurement for the key equipment assessment. Thus, the technical conditions of the key equipment should be studied and assessed to ensure the key equipment operation, reduce the vessel failure and improve the mission capability [6]. D-S evidence theory has no need for priori probability, and present fuzzy information in a better way. By using the parameters of the different equipment, it can transform the information of the variable parameter to the assessment



results in the same form, i.e., the probability of the equipment conditions, and develop a unified form for the assessment results. For the overall condition of the vessel, the mechatronic systems, hull and special equipment of the vessel play key roles in the assessment because all of them can influent the vessel condition independently [7]. Whereas grey system theory can process the limited data, so it is applicable to assess technical conditions when the detected data are limited. Thus, gray relative analysis (GRA) method is feasible to assess the vessel technical conditions.

In this paper, a vessel is decomposed of three hierarchies, i.e., vessel system, subsystem and equipment, from top to bottom by using hierarchical assessment. GRA method, fuzzy technology and D-S evidence theory are used to vessel system, subsystem and equipment respectively, and the technical conditions of a vessel are assessed.

2. Modeling

2.1. Key equipment modeling

Using D-S evidence theory, v_i is defined as a detected parameter of a key equipment. Rated value is represented as v_{ei} and corresponded the condition of the key equipment as excellent. Limited value is represented as v_{pi} and corresponded the condition of the key equipment as poor. The difference between the detected value and the rated value can be used as the criterion of the condition of the key equipment. The deviant of the detected value and the rated value is positive correlated to the possibility of the poor condition of the key equipment. As the deviant increases, the possibility of the failure also increases.

Generally, the detected parameters of the key equipment obey normal distribution due to system errors, i.e., $(v_i - v_{ei}) \sim (0, \sigma)$, and the interval is $[a, a]$. The detected parameter v_i is mapped to $[a, a]$ after normalization, x can be expressed as

$$x = a \left| \frac{v_i - v_{ei}}{v_{pi} - v_{ei}} \right| \quad (1)$$

The parameter x illustrates the technical condition of the key equipment. The less x , the nearer the detected parameter v_i approximates to rated value v_{ei} and the higher the possibility of the excellent condition of the key equipment, or vice versa.

The basic probability assignment function is represented as $A(x)$, and the excellent, fair and poor conditions of the key equipment are indicated as $A_e(x)$, $A_f(x)$ and $A_p(x)$ respectively, and the equations are written as

$$\begin{cases} A_e = 1 - \Phi(x_i - a/3) \\ A_f = \Phi(x_i - a/3) - \Phi(x_i - 2a/3) \\ A_p = \Phi(x_i - 2a/3) \end{cases} \quad (2)$$

2.2. Subsystem modeling

The subsystems of the vessel, such as the mechatronic system, the hull system and the special equipment system can be assessed by using fuzzy theory. Assessment standard vector of the technical conditions of the subsystems is defined as

$$\mathbf{G} = (g_1 \quad \cdots \quad g_s \quad \cdots \quad g_g)^T \quad (3)$$

Condition value vectors of the technical conditions of the m th subsystem for the n th assessment are defined as

$$\mathbf{B}_m^{(n)} = \begin{bmatrix} b_{m,1}^{(n)} & \cdots & b_{m,b}^{(n)} \end{bmatrix}^T, b_{m,b}^{(n)} = g_i \quad (4)$$

Assessment value vectors are defined as

$$\boldsymbol{\beta}_m^{(n)} = \begin{bmatrix} \beta_{m,1}^{(n)} & \cdots & \beta_{m,b}^{(n)} \end{bmatrix}^T, \beta_{m,i}^{(n)} = \begin{cases} 0 & b_{m,i}^{(n)} \leq g_s \\ 1 & b_{m,i}^{(n)} > g_s \end{cases} \quad (5)$$

The assessment value vectors of the m th subsystem for the vessel after N times assessment can be written as

$$\mathbf{s}_m = \sum_{n=1}^N \boldsymbol{\beta}_m^{(n)} = (s_{m,1} \quad \cdots \quad s_{m,b})^T \quad (6)$$

The element of the assessment value vector can be normalized as

$$\boldsymbol{\Psi}_m = \mathbf{s}_m / \sum_{i=1}^b s_{m,i} \quad (7)$$

It is the fuzzy value vectors of the technical condition for the m th subsystem, and assessment matrix of the vessel for M subsystems can be expressed as

$$\boldsymbol{\Psi} = (\boldsymbol{\Psi}_1 \quad \cdots \quad \boldsymbol{\Psi}_M) = \begin{bmatrix} \psi_{1,1} & \cdots & \psi_{M,1} \\ \vdots & \ddots & \vdots \\ \psi_{1,b} & \cdots & \psi_{M,b} \end{bmatrix} \quad (8)$$

2.3. Vessel system modeling

The subsystems of the vessel, such as the mechatronic system, the hull system and the special equipment system can be assessed by using gray relative analysis. Assessment standard vector of the technical conditions of the subsystems is defined as

The technical condition of the vessel can be assessed by gray relative analysis method. The mechatronic systems, hull and special equipment of the vessel play key roles in the assessment because all of them can influence the vessel condition independently. Thus, the assessment results of the subsystems and the key equipment can be used to analyze the technical condition of the vessel system.

Reference sequence of the technical condition of the vessel is defined as $V_0 = \{V_{0(k)}, k = 1, 2, 3, \dots\}$, and the natural number k represents the subsystems or the key equipment of the vessel. Comparison sequence of the technical condition of the vessel is defined as $V_i = \{V_{i(k)}, k = 1, 2, 3, \dots\}$. The least/most absolute value of the difference of the reference sequence V_0 and the comparison sequence V_i can be written as respectively.

$$\begin{cases} \delta_{\min} = \min_i \min_k |V_{0(k)} - V_{i(k)}| \\ \delta_{\max} = \max_i \max_k |V_{0(k)} - V_{i(k)}| \end{cases} \quad (9)$$

Then correlation coefficient of the reference sequence V_0 and the comparison sequence V_i can be expressed as

$$\xi_{i(k)} = \frac{\delta_{\min} + \rho\delta_{\max}}{|V_{0(k)} - V_{i(k)}| + \rho\delta_{\max}} \quad (10)$$

Where ρ is resolution ratio and its interval are $[0, 1]$.

The correlation coefficient is an index which represents the relationship between the reference sequence V_0 and the comparison sequence V_i . The data of the vessel assessment are too fragment because every subsystem or key equipment has a correlation coefficient. It is difficult to compare and assess, so relational degree of the reference sequence V_0 and the comparison sequence V_i is introduced.

$$r_i = \sum_{k=1}^K \xi_{i(k)} / K \quad (11)$$

The relational degree r_i can transforms the correlation coefficients of the vessel to a mean value, so as to calculate the data of the technical conditions and assess the relationship between the reference sequence V_0 and the comparison sequence V_i . However, the relational degree r_i cannot determine that the reference sequence V_0 and the comparison sequence V_i are positive correlation or negative correlation, so sign functions are defined as follow. When $\text{sign}(c_i / c_K) = \text{sign}(c_j / c_K)$, V_i and V_j are positive correlation. When $\text{sign}(c_i / c_K) = -\text{sign}(c_j / c_K)$, V_i and V_j are negative correlation.

$$\begin{cases} c_i = \sum_{k=1}^K k \xi_{i(k)} - \sum_{k=1}^K \xi_{i(k)} \sum_{k=1}^K (k/K) \\ c_K = \sum_{k=1}^K k^2 - \left(\sum_{k=1}^K k \right)^2 / K \end{cases} \quad (12)$$

2.4. CASE STUDY

This section studies the application of the methods and models above for a vessel. The invariable parameters used in a key equipment are given in Table. 1.

Table 1. Invariable parameters of a key equipment

| Detected parameters | Power (kW) | Speed (rpm) | Noise (db) | Working time (week) | Temperature (K) |
|---------------------|------------|-------------|------------|---------------------|-----------------|
| Excellent | 10 | 3000 | 100 | 10 | 200 |
| Poor | 6 | 2000 | 300 | 20 | 300 |
| Detected | 8 | 2600 | 220 | 16 | 270 |

For confidence is 0.99, the interval of x is $[2.576, 2.576]$, i.e., $a = 2.576$. According to (2), the excellent, fair and poor conditions of the key equipment are indicated as $A_e(x)$, $A_f(x)$ and $A_p(x)$ respectively, so the first boundary point is 0.8587 and the second boundary point is 1.7173. Thus, the basic probability assignment functions are obtained and shown in Table 2.

Probability assignment function Y_{PS} can be calculated by using D-S evidence theory and shown in Table 3.

The normalizing factor can be given as $f = 1 - (0.1443 + 0.1073 + 0.0818) = 0.3334$. The fusion results of the probability functions Y_P and Y_S are written as follow: $Y_{PS}(A_e) = A_e / (1 - f) = 0.1443 /$

$0.3334 = 0.4328$, $Y_{PS}(A_f) = A_f / (1 - f) = 0.1073 / 0.3334 = 0.3218$, $Y_{PS}(A_p) = A_p / (1 - f) = 0.0818 / 0.3334 = 0.2454$.

Similarly, the other fusion results of the probability functions can be given in Table 4, and the results shows that the probability of the excellent condition of the key equipment decreases from 43.28% to 11.63%. However, the probability of the poor condition of the key equipment increases from 24.54% to 63.36%, and the key equipment need repair and maintenance.

Table 2. The values of basic probability assignment functions

| Conditions | Power (Y_P) | Speed (Y_S) | Noise (Y_N) | Working time (Y_W) | Temperature (Y_T) |
|------------|--------------------|--------------------|--------------------|---------------------------|--------------------------|
| x_i | 1.288 | 1.0304 | 1.5456 | 1.5456 | 1.8032 |
| A_e | 0.3336 | 0.4325 | 0.2451 | 0.2451 | 0.1736 |
| A_f | 0.3328 | 0.3224 | 0.3224 | 0.3224 | 0.2905 |
| A_p | 0.3336 | 0.2451 | 0.4325 | 0.4325 | 0.5359 |

Table 3. The values of probability assignment function Y_{PS}

| probability assignment | Y_{PA_e} (0.3336) | Y_{PA_f} (0.3328) | Y_{PA_p} (0.3336) |
|---------------------------|------------------------|------------------------|------------------------|
| $Y_{SA_e}(0.4325)$ | 0.1443 | | |
| $Y_{SA_f}(0.3224)$ | | 0.1073 | |
| $Y_{SA_p}(0.2451)$ | | | 0.0818 |

Table 4. The fusion results of the probability functions

| Conditions | Y_{PS} | Y_{PSN} | Y_{PSNW} | Y_{PSNWT} |
|------------|----------|-----------|------------|-------------|
| A_e | 0.4328 | 0.3359 | 0.2449 | 0.1163 |
| A_f | 0.3218 | 0.3283 | 0.3148 | 0.2501 |
| A_p | 0.2454 | 0.3359 | 0.4320 | 0.6336 |

For the vessel valuation, the comparison sequence of the technical condition of the vessel V_i is (3.988, 4.264, 3.162), and the reference sequences of the technical condition of the vessel are given as follow: excellent condition(5, 5, 5), good condition(4, 4, 4), fair condition(3, 3, 3), poor condition(2, 2, 2), failure condition(1, 1, 1). In Table 5, the relational degrees r are calculated, and the results are given. The technical conditions of the vessel show that $r_{\text{good}} > r_{\text{fair}} > r_{\text{excellent}} > r_{\text{poor}} > r_{\text{failure}}$ and the condition is good.

3. Conclusions

Three models, such as the key equipment, the subsystem and the vessel system are given to assess the technical conditions of the vessel by using D-S evidence theory, fuzzy theory and gray relative analysis. Multi-hierarchy assessment is a useful method for investigating the vessel technical conditions because it can take advantage of the assessment parameters to model and calculate effectively. Moreover, the procedures of the assessments are more objective due to the lack of the human influence, so the results of the assessments are closer to the actual technical conditions of the assessed vessel. Based on D-S evidence theory, the influence of the technical parameters of some key equipment for the vessel are considered in the assessment, the reliabilities of the procedures and the results of the assessment are promoted significantly.

Considering of the data and information of tests and experiments of vessel models, the assessment methods and calculation procedures of a fleet have to be improved. For purpose further studies have to be performed.

Table 5. The results of the relational degrees r_i

| Conditions | Subsystem 1 | Subsystem 2 | Subsystem 3 | Relational degree |
|------------|-------------|-------------|-------------|-------------------|
| Excellent | 5 | 5 | 5 | 0.5966 |
| Good | 4 | 4 | 4 | 0.8442 |
| Fair | 3 | 3 | 3 | 0.7039 |
| Poor | 2 | 2 | 2 | 0.4882 |
| Failure | 1 | 1 | 1 | 0.3816 |
| Detected | 3.988 | 4.264 | 3.162 | Good condition |

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