A Study on Modelling Methods to Assess and Evaluate Simulation based Training of Ship Power Systems

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Abstract - **In simulation based training of ship power systems, personnel operations need to be evaluated. Aiming at the problem that traditional evaluation methods cannot meet the demand of the staff examination, some factors on the operation ability are studied. By the method of quantifying the evaluation factors, mathematical models of operational capability evaluation factors are established. Practical applications shows that these models can improve the assessment and evaluation rationality and fairness for the power system operators, and the training efficiency and quality can be enhanced.**

Keywords-simulation training; evaluation; modeling

I. INTRODUCTION

With the rapid development of weapons and equipment, marine power simulation training system is constantly increasing [1]. The evaluation of their ability level is getting higher and higher. The traditional training and evaluation methods are difficult to meet the demand. Now, most operation evaluation methods are subjective. It is not conducive to enhancing the training efficiency and teaching quality. A lot of factors are involved in carrying out training and evaluation. It must be systematically and comprehensively considered and researched so that the evaluation can be automatic by the modeling and simulation [2,3].

In this paper, a mathematical model for operating capability evaluation is established by construction of evaluation system and quantifying evaluation factors. The effect of its application in a certain type of power training system is studied. The foundation for the realization of the automated assessment is established [4,5].

II. THE PRINCIPLES OF THE ESTABLISHMENT OF EVALUATION SYSTEM

The evaluation system of operating ability in ship power system is established in the criterion of objectivity and impartiality. The following principles should be followed in the construction of evaluation system [6,7,8]:

A. *The objectivity of evaluation factors.*

The evaluation factors should be objective and remove the influence of personal subjective assumption. They are determined by the mode of coordinated decision-making. The choice of evaluation factors have to reflect the actual operation ability of power system operator.

B. *The operability of evaluation factors.*

The evaluation factors must to be simple, clear, strongly operable, and easy to understand. They should be in accord with the objectivity, stable in data source, and easy to be programmed.

C. *The integrity of evaluation system.*

The true ability and level of the operator should be described in training evaluation system. The factors are interacted with each other. So the comprehensiveness and reliability of evaluation can be ensured.

D. *The representative of evaluation factors.*

A factor of evaluation should be able to reflect personnel operation ability. The difference of operator ability level can be reflected by evaluation factors. And the factors must maintain relative independent.

III. THE BASIC PROCESS OF ESTABLISHING EVALUATION SYSTEM

Generally, the assessment and evaluation system is the basis of power simulation training system. The efficiency and effect of crew training can be improved in an objective and reasonable evaluation system. Multiple factors must be considered in the establishment of evaluation system of operation training. An evaluation index system can be got in order to reflect the situation of evaluation objects [9,10,11]. The general process of establishment of reasonable evaluation system is: various aspects that reflect the operating level are analyzed, the quantization method is put forward, and a set of appropriate factors are selected as evaluation standard. The basic process of establishing evaluation system can be shown in Fig. 1.

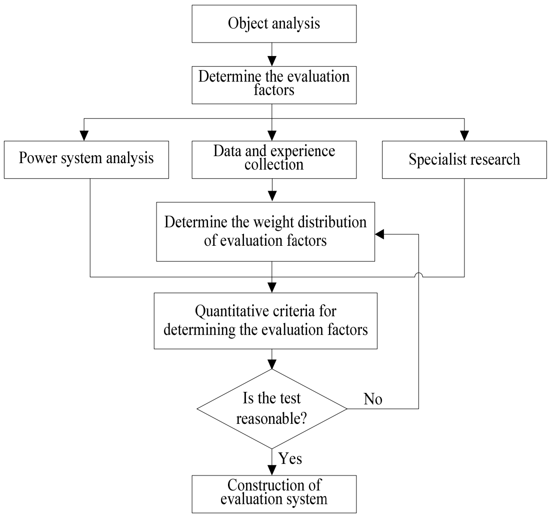

Figure 1. The basic process of establishing evaluation system

IV. ESTABLISHMENT OF THE EVALUATION MODEL

A. The evaluation model of power system operation management. The evaluation model of operation accuracy.

There are a lot of operation steps in the drills of power system. The process is also complicated. In the study of complex process, it can be decomposed into a series of simple and independent subprocess until the process can not be divided any more.

According to this method, the operation management steps of power system can be decomposed into the post operation management, the department cooperation management, the system operation management and the department cooperation operation. They are first-order class subsystems. These first-order subsystems can be further decomposed into second-order subsystems. For example, the post operation management can be divided into the diesel engine system, the generator system and the auxiliary system. The second-order subsystems can be continually decomposed into third-order subsystem. So the whole system will be decomposed into a series of subsystems finally.

For example, the operation management model is shown in Fig. 2 based on the above principle.

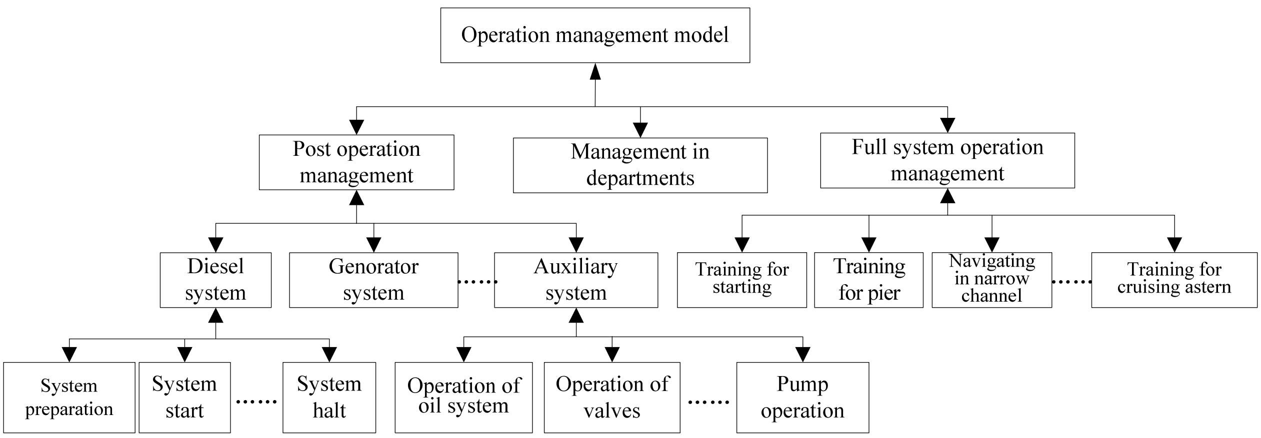

Figure 2. The operation management model

According to the operation management model, the steps of operation accuracy evaluation can be decomposed into some basic units. The operation errors have four situations which evaluation model can be analyzed as following method.

In accordance with the operation rules, the right operation step is $A \to B \to C \to D \to E$. The A~E represents operating actions such as pressing a button or turning a switch. By the standard of right steps, the wrong operating action can be classified as following: missing operation, excessive operation, wrong sequence operation and repetitive operation.

The first type is that the operator misses some steps in the training. For example, if the operation process is $A \to B \to D \to E$, The step of C has not been done. For this type of evaluation, all steps are searched firstly to find that whether operation step A is done according to the correct sequence. If step A is not done, the operation steps are matched with the evaluation rules. The type of operation error is recorded. And then the step B is done. At last, all missing operation steps can be recorded by the above method.

The second type is that the excessive steps or equipments are done by operators. For example, if the operation process is $\mathrm{X} \rightarrow \mathrm{A} \rightarrow \mathrm{B} \rightarrow C \rightarrow Y \rightarrow \mathrm{D} \rightarrow \mathrm{E} \rightarrow Z$. In this process, $\mathrm{X}, \mathrm{Y}, Z$ are excessive steps. The evaluation method is that: Firstly, the steps are numbered. The right steps are numbered by $\frac{\mathrm{A}}{1} \rightarrow \frac{\mathrm{B}}{2} \rightarrow \frac{\mathrm{C}}{3} \rightarrow \frac{\mathrm{D}}{4} \rightarrow \frac{\mathrm{E}}{5}$. After the operation assessment is completed, the wrong steps are numbered by $\frac{\mathrm{X}}{1} \rightarrow \frac{\mathrm{A}}{2} \rightarrow \frac{\mathrm{B}}{3} \rightarrow \frac{C}{4} \rightarrow \frac{\mathrm{Y}}{5} \rightarrow \frac{\mathrm{D}}{6} \rightarrow \frac{\mathrm{E}}{7} \rightarrow \frac{\mathrm{Z}}{8}$. Secondly, the wrong steps are recorded after they are matched with operation rules. The number of wrong steps can be recorded by comparison with the right operation number. The position and the number of wrong operation can be recorded by the number difference of adjacent correct steps. For example, the position and number of wrong operation can be calculated by the expression $\mathrm{B}-\mathrm{A}, \mathrm{C}-\mathrm{B}, \mathrm{D}-\mathrm{C}, \mathrm{E}-\mathrm{D}$. By the comparison of the number of step Z and E, it is can be determined whether there is an error before the operation is completed.

The third type is that the sequence of operation steps is wrong. For example, the operation steps are $\mathrm{A} \rightarrow C \rightarrow \mathrm{B} \rightarrow \mathrm{D} \rightarrow \mathrm{E}$. So the evaluation method is that, firstly, the operation steps are numbered such as the numbers of steps are $\frac{\mathrm{A}}{1} \rightarrow \frac{\mathrm{C}}{2} \rightarrow \frac{\mathrm{B}}{3} \rightarrow \frac{\mathrm{D}}{4} \rightarrow \frac{\mathrm{E}}{5}$. Then every step number is subtracted by its adjacent step such as $\mathrm{B}-\mathrm{A}, \mathrm{C}-\mathrm{B}, \mathrm{D}-\mathrm{C}, \mathrm{E}-\mathrm{D}$. If the result is negative, it means that the operation sequence is wrong. By matching with the evaluation rules, the operation type is recorded. The numbers of wrong sequence operation can be also recorded by the numbers of the negative results.

The fourth type is that the repetitive steps are existed in the operation processes such as an operation sequence $\mathrm{A} \rightarrow \mathrm{B} \rightarrow C \rightarrow C \rightarrow \mathrm{D} \rightarrow C \rightarrow \mathrm{E}$. The operation steps are numbered in this type of evaluation method by $\frac{\mathrm{A}}{1} \rightarrow \frac{\mathrm{B}}{2} \rightarrow \frac{\mathrm{C}}{3} \rightarrow \frac{\mathrm{C}}{4} \rightarrow \frac{\mathrm{D}}{5} \rightarrow \frac{\mathrm{C}}{6} \rightarrow \frac{\mathrm{E}}{7}$.The first step C between B and D is remained and the repetitive step C is removed. And the wrong operation steps are recorded by matching with the evaluation rules. If there are no operation steps between B and D, the first operation C is remained. Finally the analysis of the results are renumbered by $\frac{\mathrm{A}}{1} \rightarrow \frac{\mathrm{B}}{2} \rightarrow \frac{\mathrm{C}}{3} \rightarrow \frac{\mathrm{D}}{4} \rightarrow \frac{\mathrm{E}}{5}$. The evaluation method can be determined by the operation type.

B. Evaluation model of parameter control level.

In the operation process of ship power system, the main operation parameters are required by running range. The engine speed, the main motor excitation current, the armature voltage and other parameters are changed in some range. As shown in Fig. 3, the evaluation of parameter control level is based on the deviation and the deviation degree between actual and standard operation curves. The control ability of parameters can be calculated by accumulated deviation and deviation degree.

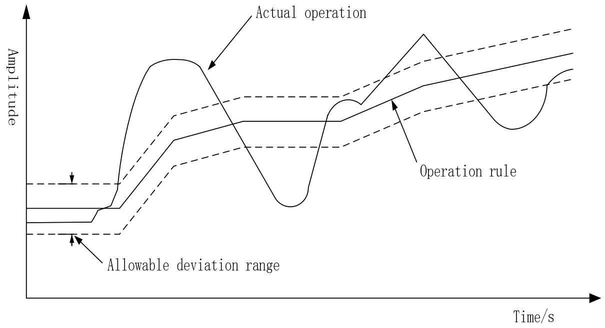

Figure 3. Parameter control curves

For operation evaluation of different parameter control, such as diesel speed and excitation current of main propulsion motor, the evaluation model can be established by the modification of standard operation curves.

In the evaluation of parameter control level, the deviation area can be calculated in real-time by the deviation of actual and standard operation curve. The evaluation model can be written as

$$CK_s = \sum_{i=1}^{n} v_i x_i \int_0^T \left| \left(X_k - \bar{X}_k \right) \text{-e}_t \right| dt \qquad (1)$$

where, *i* is parameter control type. There are *n* types;

v_i is the weight coefficient;

x_i is the number of times that operation *i* occurred in the whole process;

t is the assessment time;

X_k is the actual value of the operation parameter *k* at the time *t*;

$\overline{X}_k$ is the standard value of the operation parameter *k*;

e_t is the deviation allowed for standard curve at the time *t*;

In order to prevent the calculated value is too large, X_k is equal to X_{kmax} when $X > X_{k\max}$.

C. Evaluation model of parameters alarm.

In the operation of the power equipments, the improper operation will cause the system alarm. For example, a diesel engine body temperature will rises rapidly if a cooling pump stops working in the running of diesel generator. Then the system will be alarmed for the high fresh water temperature. If this process continues for too long, the system will be alarmed by the sound and light which indicates that the system should be deal with promptly.

When the system alarms, it must be taken measures immediately to make the parameter value back to the standard scope. Parameters alarm lasts more longer, the ability level of operation are more poor. The evaluation model of parameter alarm is mainly related with the alarm number and time. It can be written as

$$CB_s = \sum_{i=1}^{n} w_i x_i L_i(t) \tag{2}$$

where, i is the type of system parameter alarm, there are n types;

w_i is the weight coefficient of the deduction score;

x_i is the occurred times of alarm type i during the operation;

$L_i(t)$ is a function of time. $L_i(t) = t_i / T_i$. In the normal subjects operation training of ship power simulation training system, t_i is the duration time of alarm. T_i is the recovery reference time of alarm i. The parameter alarm is not due to human error in the failure course training of ship power, the time of trouble shooting should be considered. So, $L_i(t) = (t_i - T_i)/T_i$. When $t_i \le T_i$, it can be indicated that the faults have been ruled out within the given time. So, $L_i(t) = 0$. When $t_i > T_i$, it can be indicated that the faults have not been ruled out within the given time. The score of the operator should be deducted.

D. Evaluation model of the operation opportunity.

The judgment of operation opportunity is based on the correct operation. For example, there are operation steps as follows in the start and speed governing of the main motor operation: When the Excitation Hand Wheel is in the position of minimum excitation current, Reversing Switch should be turned to Forward or Backward. And when the armature current gradually decreased and stabilized, the Running Switch should be immediately turned to the Second Forward position. The correct operation opportunity is needed in these steps.

Firstly, the switch or button needed to be operated is determined, such as Reversing Switch and Forward Switch. The steps is related to operation time as $\frac{\mathrm{A}}{\mathrm{t}_1} \to \frac{\mathrm{B}}{\mathrm{t}_2} \to \frac{\mathrm{C}}{\mathrm{t}_3} \to \frac{\mathrm{D}}{\mathrm{t}_4} \to \frac{\mathrm{E}}{\mathrm{t}_5}$.

Secondly, the excitation current and armature current are compared with the theoretical values after the switch or button is operated. If the maximum excitation current is I_m in the correct operation, the bias value $ES = \frac{abs(I_m - I)}{I_m} * 100\%$. Then the bias value is matched with evaluation rules, the wrong operation steps are recorded.

E. Evaluation model of trouble shooting.

The evaluation of trouble shooting is based on the results of the operation, the correct rate of trouble shooting, proficiency and explanatory ability. Firstly, the handling results and proficiency need to be quantified, then all possible types are classified and the evaluation model can be determined.

The trouble shooting time can be calculated by

$$f(i) = \begin{cases} ER_i & 0 < T_i < T_{i\max} \\ 0 & T_i \ge T_{i\max} \end{cases} \tag{3}$$

$$GC_s = \sum_{i=1}^{n} a_i f(i) X_i \tag{4}$$

where, $f(i)$ is the result of trouble shooting;

ER_i is the evaluation result;

T_i is actual handling time of the fault i;

$T_{i\max}$ is the maximum limit of trouble shooting time;

a_i is weight coefficient of score deducting;

X_i represents the fault i has been occurred.

The trouble shooting time can be calculated by

$$GS_s = \begin{cases} ERT_i \dfrac{T_{i\max} - T_i}{T_{i\max}} & 0 < T_i < T_{i\max} \\ 0 & T_i \ge T_{i\max} \end{cases} \tag{5}$$

where, ERT_i is the evaluation result of trouble shooting time;

T_i is the actual shooting time of fault i;

$T_{i\max}$ is the maximum given shooting time of fault i.

The model of explain ability can be wirtten as

$$GJ_s = FS\frac{N_r}{N_a} \quad (6)$$

where, FS is full score, N_r is the actual number of keywords matched with the standard answer, N_a is the number of all keywords.

F. Evaluation of psychological quality.

The evaluation of psychological quality is mainly depend on the teacher. These abilities are hard to be recorded by computer. The outlook of operator, the quality of trouble shooting is vital in the evaluation. For example, before the start of power equipment, the equipments needed to be checked whether there is sundry, which can not be recorded by computer. These information can only be obtained by the teacher's observation. The evaluation results can be graded by the weight coefficients set by the teacher.

G. The method to determine evaluation weights.

In the evaluation system of post operation ability for ship power system, multiple factors is adopted to evaluate the skills of power system staff. The factors reflecting various personnel quality are not equally important. In order to reflect the role and importance of each evaluation factor in the evaluation index system, the evaluation weight is introduced. Weight is a quantitative form and a measure of the relative importance of various factors in the overall evaluation. So, the weight of an evaluation factor is usually referred to the relative importance of this factor in the overall evaluation.

The determination method of weight can be divided into two kinds, the subjective and the objective method.

In the subjective weighting method, the evaluation index weight can be determined or judged of by the expert in some field with practical experience. The weight of each index can be got by comprehensive evaluation. In the subjective weighting method, there are mainly methods such as the expert investigation method, the adjacent comparison method, the mutual assignment method, the two coefficient method, the analytic hierarchy process and so on. The determination of weight in the subjective weighting method is based on the experience and knowledge of experts in their fields. The choice of different experts can cause different results of the weight determination, which makes the weight determined by the subjective randomness.

In the objective weighting method, the evaluation index weight can be comprehensively determined by the historical index data and the relationship between the index and the evaluation results. In the objective weighting method, there are mainly methods such as the least square method, the eigenvector method, the maximum entropy technology method, the principal component analysis method, the multi-objective programming method and so on. The determination of weight in the subjective weighting method is based on the data in actual decision-making, which has strong theory basis. But the index weights may deviate from the actual situation because the subjective judgment of decision-makers is not considered.

V. APPLICATION EXAMPLES

In the operation of training simulator of a certain type of ship power system, the model is simulated in the computer. For example, responsibilities in a post include

a. the management of right diesel engine and its auxiliary system, carriage clock;

b. stopping right diesel engine, closing intake and exhaust valves, opening the fuel system valves in a navigation state,c. recovery diesel engine and its auxiliary system to a specified state, checking watertight of starboard engine control room.

The comprehensive evaluation system can be modeled by the hierarchy of the operation ability evaluation which is shown in Fig. 4. The highest level is comprehensive evaluation parameter, the intermediate level is divided from the operation ability and quality of department chief. The next level is divided from the above level which like as a hierarchy. The parameter level is in the bottom and is the base of operation ability evaluation.

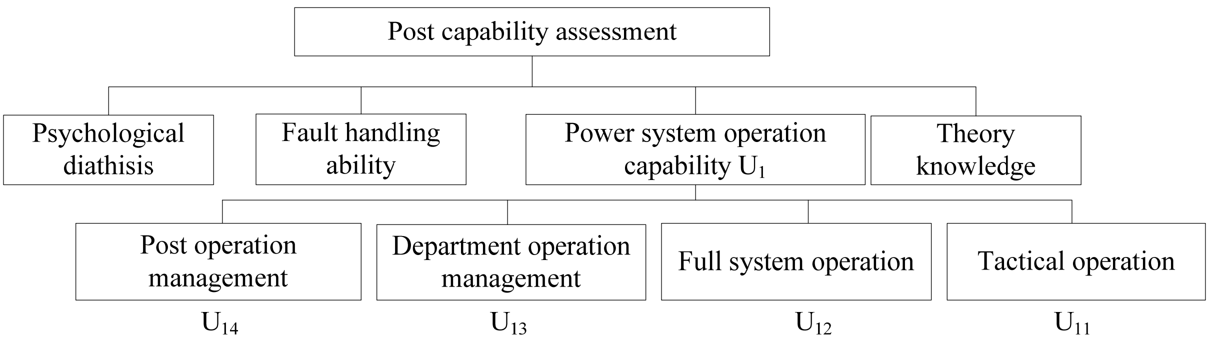

Figure 4. Comprehensive evaluation model of post operation capability

A. The weight of evaluation.

According to the study above, a number of experts in mechanical and electrical department will be invited to assess the elements of operating ability of ship power system. The weight of evaluation can be calculated by the method of combining weight.

In the evaluation of power system operation and management level, the calculation results are given as follows:

The weight of tactical operation

$$w_1 = (0.2352, 0.2060, 0.1981, 0.3607)$$

The weight of system-wide operation

$$w_2 = (0.2603, 0.2280, 0.2193, 0.2924)$$

The weight of department operation

$$w_3 = (0.2723, 0.2383, 0.2291, 0.2602)$$

The weight of post operation management

$$w_4 = (0.3095, 0.2442, 0.2348, 0.2116)$$

The weight of secondary comprehensive evaluation

$$W = (0.1754 , 0.2129, 0.2296, 0.3821)$$

B. Comprehensive evaluation of post operation capability.

Based on above analysis, the set of comprehensive evaluation of the post operation capability in power system operation and management can be written as follows:

$$U_1 = \{U_{11}, U_{12}, U_{13}, U_{14}\}$$

$$U_{11} = \{u_{11}, u_{12}, u_{13}, u_{14}\}$$

$$U_{12} = \{u_{21}, u_{22}, u_{23}, u_{24}\}$$

$$U_{13} = \{u_{31}, u_{32}, u_{33}, u_{33}\}$$

$$U_{14} = \{u_{41}, u_{42}, u_{43}, u_{44}\}$$

The set of evaluation

$$V = \{v_1, v_2, v_3, v_4\} = \{\text{Excellence, Good, Passed, Average}\}$$

In the factors set U of constituting post skills evaluation system, the degree of importance of each factor is different in the evaluation. According to the previous calculation, the weight of post operation capability in power system operation management can be obtained.

In accordance with the evaluation of the post operation capability, each evaluation factors are considered and the degree of membership of the evaluation set elements is determined.

In an evaluation process of operation capability, the matrix of single factor comprehensive evaluation can be written as:

$$R_{11} = \begin{Bmatrix} 0.6, 0.4, \ 0, \ 0 \\ 0.1, 0.8, 0.1, 0 \\ 0.3, 0.6, 0.1, 0 \\ 0.5, 0.3, 0.2, 0 \end{Bmatrix}$$

$$R_{12} = \begin{Bmatrix} 0.3, 0.2, 0.5, \ 0 \\ 0.3, 0.4, 0.2, 0.1 \\ 0.7, 0.2, 0.1, 0 \\ 0.8, 0.1, 0.1, 0 \end{Bmatrix}$$

$$R_{13} = \begin{Bmatrix} 0.7, 0.3, \ 0, \ 0 \\ 0.6, 0.4, \ 0, \ 0 \\ 0.3, 0.7, \ 0, \ 0 \\ 0.3, 0.4, 0.3, 0 \end{Bmatrix}$$

$$R_{14} = \begin{Bmatrix} 0.2, 0.2, 0.5, 0.1 \\ 0.3, 0.4, 0.2, 0.1 \\ 0.5, 0.2, 0.1, 0.2 \\ 0.6, 0.3, 0.1, 0 \end{Bmatrix}$$

According to first and second class comprehensive evaluation matrix, single factor evaluation matrix $B_i = m_i \circ R_i$. Based on the weighted fuzzy average, the fuzzy subset

$$b_j = \sum_{k=1}^{n} (m_i \cdot r_{ij}) \quad (j = 1, 2, \cdots, m) \qquad (7)$$

So the comprehensive evaluation of results are as follows:

$$B_1 = w_1 \circ R_1 = (0.4750, 0.5000, 0.0250, 0)$$

$$B_2 = w_2 \circ R_2 = (0.2207, 0.0385, 0.1477, 0.0169)$$

$$B_3 = w_3 \circ R_3 = (0.1048, 0.0495, 0.1250, 0.0372)$$

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$$B_4 = w_4 \circ R_4 = (0.5550, 0.3300, 0, 0)$$

The overall evaluation matrix can be calculated by:

$$R = \begin{pmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{pmatrix} = \begin{pmatrix} 0.4750, & 0.5000, & 0.0250, & 0 \\ 0.2207, & 0.0385, & 0.1477, & 0.0169 \\ 0.1048, & 0.0495, & 0.1250, & 0.0372 \\ 0.5550, & 0.3300, & 0 \quad , & 0 \end{pmatrix}$$

According to the equation $B = W \circ R$, the evaluation matrix of post operation management can be written by

$$B = W \circ R = (0.1305,\ 0.0700,\ 0.0348,\ 0.0780)$$

To be normalized, the matrix

$$B' = \left(\frac{b_1}{b},\ \frac{b_2}{b},\ \frac{b_3}{b},\ \frac{b_4}{b}\right) = (0.4165,\ 0.2234,\ 0.1111,\ 0.2490)$$

According to operational capability evaluation index system, the results is quantified by the fuzzy theory examination and evaluation matrix analysis. So the scores can be obtained. Various levels scoring system is commonly used in the method of quantization, such as the "five scale" or "100 scale." The operation level is reflected by the evaluation results. And it meets the requirement of automatic evaluation.

VI. CONCLUSIONS

The comprehensive evaluation of operation ability of electromechanical personnel method is presented. The multi-level comprehensive evaluation model is established, and the evaluation example for operation ability is analyzed. Based on the factors of operation ability for power system, the evaluation method and principle for the power simulation training system is established and studied. And the hierarchy of evaluation for ship power system and evaluation factor of operation ability is modeled. The results show that the model can improve the fairness and rationality of operation evaluation which can improve the training efficiency and quality.

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