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Research on Psychology Evaluation Method of Nuclear Power Plant Operators

Xiang Fang [a,b*] and Jingxuan Fang [c]

[a] Qinghu Rising Sunshine Data Technology (Beijing) Co., Ltd, Beijing 100074, China.
[b] Institute of Nuclear Energy and New Energy Technology of Tsinghua University, Beijing 100084, China.
[c] Hong Kong University of Science and Technology, Hong Kong, China.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Nuclear power plant operators play a more and more important part to plant safe operation. The paper analyzes and discusses the qualitative and quantitative evaluation methods for the operators. The comparison-analysis of the scope and result of application has been done between the method of outline figure fitted and the method of fuzzy synthetic evaluation. The research can be referenced in the evaluation of operators.

Keywords: Nuclear power plant operator; fuzzy synthetic evaluation; psychology evaluation; qualitative method; quantitative method.

1. INTRODUCTION

Nuclear power plant operator is the key factor to plant safe operation. Psychology factor places an important part in nuclear power plant operators. Based on the past research psychological characteristics and performance relativity are two important aspects of psychological research of nuclear power plant operators [1].

Some conclusions can be obtained through psychological characteristics and performance relativity research. The 6 personality characteristics dimensions (gregariousness,

**Corresponding author: Email: fxdirection@sina.com;*

venturesomeness, self-regulation, emotional stability, risk-taking, and achievement motivation) are positive relative to working performance. Gregariousness, self-regulation, and emotional stability are obviously positive relative to working performance. The 9 psychological health dimensions (somatization, obsessive-compulsive, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, and psychoticism) are negative relative to working performance. Obsessive compulsiveness, interpersonal sensitivity, and depression are obviously negative relative to working performance [2].

The psychology evaluation method can be proposed practically so as to supply scientific suggestions of evaluation to Chinese nuclear power plant operators based on past research results [3,4]. Furthermore, the evaluation of scientificness and reliability to operators can be improved so as to guarantee the safety and economy of nuclear power plant operation.

In this process, some auxiliary tools can be used to improve the safety and reliability of nuclear power plants. More and more changes like an auxiliary robot using etc. happen in the control room so as to operate nuclear power plant easily by operators [5,6].

2. QUALITATIVE EVALUATION METHODS OF OPERATORS

The outline figure matching method is used in the qualitative evaluation method in the research. The theoretical hypothesis of the outline figure matching method is that the outline figure of psychological characteristics of the high-performance operator is the optimal type [7]. During the selection and assignment of operators, the score of various dimensions of high working performance operator can be drawn as a standard outline figure firstly, then the performance of other operators can be got easily and directly by comparing with the standard outline figure. The psychological characteristics data of average high working performance operators(standard) is shown in Table 1. The data of operator A and operator B is also included.

In Table 1 : z_1 ~ z_6 are gregariousness, enturesomeness, self-regulation, emotional stability, risk-taking, and achievement motivation respectively; S_1~S_9 are somatization, obsessive-compulsive, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, and psychoticism respectively.

The standard outline figure of the successful operator and outline figure of operator A are shown in Fig. 1.

X zone （z_1 ~ z_6） includes 6 dimensions of personality characteristics. Based on the results of relativity analysis and T-test, the higher the dimension value, the higher performance got. The latter （S_1~S_9） includes 9 dimensions of psychological health. The value in the figure times 10 because of too small data. Also based on relativity analysis and T-test, the higher the dimension value, the lower performance got.

To operator A, his score of z_1~z_6 is higher than the score of the standard outline figure, and his score is S_1 ~ S_9 near to the standard. The conclusion that operator A is a high-performance operator can be obtained.

The standard outline figure of the successful operator and outline figure of operator B are shown in Fig. 2. The score of his z_1 ~ z_6 dimensions is generally lower than the score of the standard outline figure. However, the score of his S_1 ~ S_9 dimensions is higher than the standard. It is difficult to fit the standard figure. Operator B can be judged as a low-performance operator.

Table 1. The data of psychological characteristics

	z_1	z_2	z_3	z_4	z_5	z_6	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9
STD	57	55	61	54	54	55	1.1	1.3	1.3	1.1	1.1	1.2	1.1	1.2	1.2
A	66	64	62	50	58	56	1.1	1.4	1.3	1.1	1.1	1.2	1.0	1.3	1.4
B	56	46	58	50	45	52	1.5	2.5	2.2	2.2	1.5	1.7	1.3	2.5	1.3

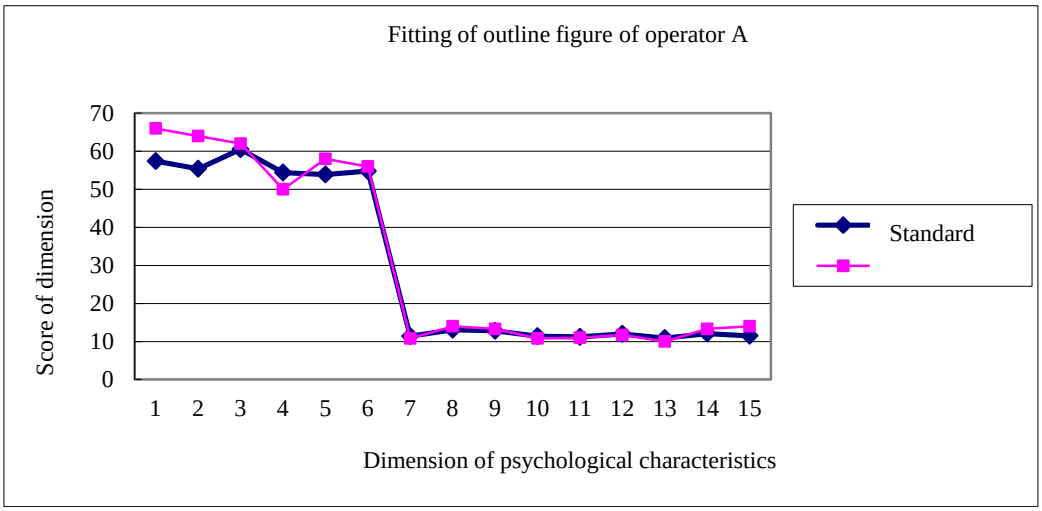

Fig. 1. Outline figure fitted of operator A

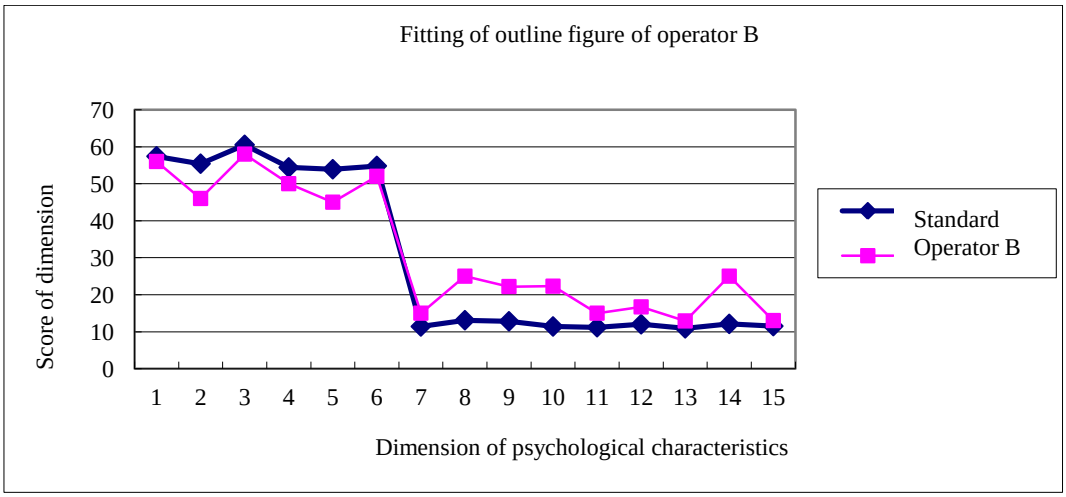

Fig. 2. Outline figure fitted of operator B

3. QUANTITATIVE EVALUATION METHOD OF OPERATORS

Though the outline figure-fitting method above can be used to evaluate the operator figuratively, quantitative data cannot be obtained in the method. So both multiple regression and fuzzy synthetic evaluation these two quantitative methods are tried to judge the psychological characteristics of operators.

3.1 Model of Multiple Regression Evaluation

3.1.1 Variable to synthetic prediction effect of performance

Multiple regression analysis is a kind of statistical method that which one or more dependent variables are predicted by a set of independent variables [8],9]. Multiple psychological variables to the prediction result of the performance of the operator can be analyzed through multiple regression. Standard linear and multiple linear regression model is used in the research. The formula is as below.

$$Y = \beta_0 + \beta_1 z_1 + \beta_2 z_2 + ... + \beta_6 z_6 + \beta_7 S_1 + \beta_8 S_2 + ... + \beta_{15} S_9 + \varepsilon \quad (1)$$

In Formula (1), Y is performance; z_1, z_2,… z_6 and S_1, S_2, …S_9 are 15 psychological characteristics dimensions respectively. The total 15 parameters β_1, β_2, …β_{15} are coefficients of the regression model equation. The error of the regression model equation is ε.

The research performance data comes from the experiment data of 36 Chinese certain nuclear power plant operators. The performance data and the relevant variable of psychology can be substituted into the above equation. The equations are formed. Then the value of the parameters can be got.

The performance of 36 operators can be the dependent variable and 15 psychological variables is as the independent variable. The dependent variables of the regress equation can be confirmed through the stepwise regression method. Here the performance of operators is the average of task performance and degree of satisfaction. The variables that are not obvious to the performance prediction can be removed one by one through the stepwise regression algorithm of SPSS [10]. The strong prediction variables can be obtained. The calculation result is listed in Table 2.

Based on the calculation of the SPSS program, gregariousness, depression, phobic anxiety and self-regulation are obvious variables in the performance prediction of operators. Among the 4 variables, the regression coefficient R to the performance prediction of operators is 0.718. R square value is 0.515. So these 4 variables can explain the 51.5% variance of operators.

3.1.2 Multiple regression equation of psychological evaluation

According to Formula (1) and the calculated value ofβ_1, β_2, …β_{15}, the regression equation of psychological evaluation of operators is as below Formula (2).

$$Y = 0.393z_1 - 0.637S_4 + 0.466S_7 + 0.247z_3 \quad (2)$$

Based on Formula (2), the estimated value of the performance of a certain operator can be obtained by the substituted value of gregariousness z_1, depression S_4, phobic anxiety S_7, and self-regulation z_3.

In the research Y average value of high performance (31 operators) is 37.22. Y average of low performance (5 operators) is 33.68. When the psychological characteristics data of a certain operator being got, the evaluation result of the operator whether performance is high or low compared to the 2 average values Y above can be judged by the prediction performance calculation based on the regress equation.

In an actual experiment based on multiple regression analysis, the right judgment number of high-performance is 28. The right judgment number of low-performance is 2. The 2 number can be substituted into effective calculation Formula (3) as below.

E＝（Number of the right judgment of high performance＋Number of the right judgment of low performance）/Total operator number (3)

The effective value of operator evaluation based on a multiple regression equation is as below.

E ＝ (2+28)/36 = 5/6

3.2 Model of Fuzzy Synthetic Evaluation

The standard of fuzzy synthetic evaluation in the research includes 2 parts. One is average psychological characteristics of high-performance operator. The other is average psychological characteristics of low-performance operator. Based on the 2 parts, the fuzzy probability of both high-performance operator and low-performance operator can be obtained.

Table 2. The result of regression analysis

Independent Variables	β	T	Significance	R	R Square
Gregariousness z_1	0.393	2.500	0.0179	0.503	0.253
Depression s_4	-0.637	-3.873	0.0005	0.578	0.334
Phobic anxiety s_7	0.466	2.735	0.0057	0.683	0.466
Self-regulation z_3	0.247	1.777	0.1697	0.718	0.515

3.2.1 Evaluation principle

Fuzzy synthetic evaluation supplies the method and tool of quantitative analysis to NPP operators. In this method, to the factor set U={u_1, u_2 , …, u_n }, the evaluation result can be expressed by a different class, appraisal and data. Assuming there are m kind of evaluation class or appraisal, the relevant evaluation set is V={ v_1 , v_2 , …, v_m }. Because of the different extent of different evaluation factor, evaluation factor u_i is arranged relevant weight factor a_i , and $\sum_{i=1}^{n} a_i = 1$. Different weight assignments can lead to different synthetic evaluation results. The weight assignment of various factors can be described as A={a_1, a_2 , …, a_n }.

It is necessary to make single factor judgment for each factor. Assuming the subordinate degree of factor i or U_i to evaluation V_j is r_{ij} , the evaluation set of U_i or R_i can be obtained.

Ri = (r_{i1} , r_{i2} ,…, r_{im}). Then the judgment matrix R can be got by n R_i. Furthermore the evaluation result can be obtained through fuzzy calculation after determining U, V, R and A [11,12,13,14].

3.2.2 Evaluation factor set

Based on the prior analysis, 15 dimensions of psychological characteristics of operator are related to working performance to some extent. So the value of 15 dimensions can be as an evaluation factor set.

Fuzzy synthetic evaluation factor set is U={ gregariousness z_1, venturesomeness z_2, self-regulation z_3, emotional stability z_4, risk-taking z_5, achievement motivation z_6, somatization S_1, obsessive-compulsive S_2, interpersonal sensitivity S_3, depression S_4, anxiety S_5, hostility S_6, phobic anxiety S_7, paranoid ideation S_8, psychoticism S_9}

3.2.3 Evaluation set

In the research m=2 and evaluation set V={High, Low}.

3.2.4 Single factor judgment

The average psychological characteristics data of operator with high performance can be as the standard of single factor judgment. Considering the error of psychological data testing and the 6 factors including gregariousness z_1, venturesomeness z_2, self-regulation z_3, emotional stability z_4, risk taking z_5 and achievement motivation z_6 being positive relative to working performance, the rule of judgment is as below.

If (score of factor U_i >average score of the factor whose operator belongs to the high-performance group) Then

Ri=（0.8, 0.2）

Else If (score of factor U_i < average score of the factor whose operator belongs to the high-performance group) Then

Ri=（0.2, 0.8）

End IF

To the factors including somatization S_1, obsessive-compulsive S_2, interpersonal sensitivity S_3, depression S_4, anxiety S_5, hostility S_6, phobic anxiety S_7, paranoid ideation S_8, and psychoticism S_9, the judgment rule is as below based on these factors being negative relative to working performance.

If (score of factor U_i < average score of the factor whose operator belongs to the high-performance group) Then

Ri=（0.8, 0.2）

Else If (score of factor U_i > average score of the factor whose operator belongs to the high-performance group) Then

Ri=（0.2, 0.8）

End IF

The judgment matrix R is as below.

$$R = \begin{vmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{vmatrix}$$

=

0.8	0.2	0.2	0.8
0.8	0.2	0.2	0.8
0.8	0.2	0.2	0.8
0.2	0.8	0.2	0.8
0.8	0.2	0.2	0.8
0.8	0.2	0.2	0.8
0.8	0.2	0.2	0.8
0.2	0.8	0.2	0.8
0.2	0.8	0.2	0.8
0.8	0.2	0.2	0.8
0.8	0.2	0.2	0.8
0.2	0.8	0.2	0.8
0.8	0.2	0.2	0.8
0.2	0.8	0.2	0.8
0.2	0.8	0.2	0.8

Here columns 1 and column 2 are the judgment matrix of operator A; columns 3 and column 4 are the judgment matrix of operator B.

3.2.5 Weight of factors

To the 15 factors of psychological characteristics, the weight value can be assigned based on the correlation to the working performance. The weight value can be decided by the normalization of the correlation value between these 15 factors of psychological characteristics and working performance. Thus the weight A can be calculated as below.

A＝（0.123，0.057，0.090，0.095，0.022，0.075，0.064，0.081，0.082，0.095，0.039，0.062，0.011，0.079，0.025）

3.2.6 Fuzzy synthetic evaluation result based on the standard of operators with high-performance

According to the prior judgment matrix R and weight A, the fuzzy psychological evaluation result of the certain operator can be obtained through the computer calculation based on Formula (4) below.

$$B = A \bullet R = (a_1, a_2, \ldots, a_n) \bullet \begin{vmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{vmatrix} = (b_1, b_2, \ldots, b_n) \quad (4)$$

The psychological characteristics data of operator A and operator B in Table 1 can be an example.

To operator A, the fuzzy synthetic evaluation calculation result is with the high-performance probability being 0.6 and the low-performance probability being 0.4.

To operator B, the fuzzy synthetic evaluation calculation result is with the high-performance probability being 0.2 and the low-performance probability being 0.8.

3.2.7 Fuzzy synthetic evaluation result based on the standard of operators with low-performance

The average psychological characteristics data of operators with high performance is the standard of single factor judgment in the above calculation. If the average psychological characteristics data of the operator with low performance becomes the standard, the judgment process of each factor set with a single factor is as below.

Considering the error of psychological data testing and the 6 factors including gregariousness z_1, venturesomeness z_2, self-regulation z_3, emotional stability z_4, risk-taking z_5, and achievement motivation z_6 being positive relative to working performance, the rule of judgment is as below.

If (score of factor U_i > average score of the factor whose operator belongs to the low-performance group) Then

R_i=(0.2, 0.8)

Else If (score of factor U_i < average score of the factor whose operator belongs to the low-performance group) Then

R_i=(0.8, 0.2)

End IF

To the factors including somatization S_1, obsessive-compulsive S_2, interpersonal sensitivity S_3, depression S_4, anxiety S_5, hostility S_6, phobic anxiety S_7, paranoid ideation S_8, and psychoticism S_9, the judgment rule is as below based on these factors being negative relative to working performance.

If (score of factor U_i < average score of the factor whose operator belongs to the low-performance group) Then

R_i =(0.2, 0.8)

Else If (score of factor U_i > average score of the factor whose operator belongs to the low-performance group) Then

R_i =(0.8, 0.2)

End IF

The judgment matrix R is as below.

$$R = \begin{vmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{vmatrix}$$

=

0.2	0.8	0.2	0.8
0.2	0.8	0.8	0.2
0.2	0.8	0.2	0.8
0.2	0.8	0.2	0.8
0.2	0.8	0.8	0.2
0.2	0.8	0.2	0.8
0.2	0.8	0.8	0.2
0.2	0.8	0.8	0.2
0.2	0.8	0.8	0.2
0.2	0.8	0.8	0.2
0.2	0.8	0.8	0.2
0.2	0.8	0.8	0.2
0.2	0.8	0.8	0.2
0.2	0.8	0.8	0.2
0.2	0.8	0.8	0.2
0.8	0.2	0.8	0.2

Here columns 1 and column 2 are the judgment matrix of operator A; columns 3 and column 4 are the judgment matrix of operator B.

The weight of each factor is the same as the prior calculation. Whether the operator belongs to low-performance fuzzy evaluation or not can be determined through Formula (4).

To operator A, the fuzzy synthetic evaluation calculation result is with the low-performance probability being 0.2 and the high-performance probability being 0.8.

To operator B, the fuzzy synthetic evaluation calculation result is with the low-performance probability being 0.6 and high-performance probability being 0.4

3.2.8 Result of fuzzy synthetic evaluation of operators

Table 3 shows the calculation result of operator A and operator B based on Formula (4). According to the maximum membership principle, the conclusion below can be obtained.

Operator A belongs to the high-performance operator(Probability 0.6). Operator A does not belong to the low-performance operator(Probability 0.2). Operator B does not belong to the high-performance operator(Probability 0.9). Operator B belongs to the low-performance operator(Probability 0.6).

6 unqualified operators are selected whose high-performance probability is below 0.5 and low-performance probability above 0.5 based on the fuzzy synthetic evaluation method for a total of 36 operators in the research. The result is shown in Table 4.

Total 5 low-performance operators can be selected correctly. Obviously, the fuzzy synthetic evaluation method is suitable for the quantitative psychological evaluation of operators.

From Formula (3), the effectiveness of fuzzy synthetic evaluation is as below.

E= (30+4)/36 = 12/13 = 0.92

3.3 Comparison between 2 Quantitative Evaluation Methods

In the multiple regression model, the variables including gregariousness, depression, phobic anxiety, and self-regulation have an obvious effect on performance prediction. These 4 variables can explain the 51.5% variance of

Table 3. The fuzzy synthetic evaluation result for operator A and operator B

Operator	High-performance probability(%)	Low-performance probability(%)
A	60	20
B	10	60

Table 4. The low-performance operators selected from fuzzy synthetic evaluation

Number	High-performance probability	Low-performance probability	Low-performance group (Y/N)
3	0.37	0.50	Y
9	0.27	0.50	Y
13	0.30	0.59	Y
17	0.20	0.57	Y
18	0.20	0.59	Y
23	0.30	0.53	Y

operators. Though the method has some certain predictability, the number of variables that are obvious to the prediction result is limited. It will affect the result of prediction to some extent. Because the performance of operators is relative to the factors of many aspects, the multiple regression evaluation results will be affected definitely by choosing the data of psychological characteristics as independent variables only in the research.

To fuzzy synthetic evaluation, the evaluation weight is decided by the relativity of dimension and performance. The average value of psychological characteristics of operators with high performance and the average value of psychological characteristics of operators with low performance are used as standards respectively. Then both the high-performance probability and the low-performance probability of certain operators can be obtained through the fuzzy synthetic evaluation method. The sum of the two kinds of probability maybe not be 1. The reason is that the two kinds of probability are got by different standards. A certain operator can be evaluated more comprehensively and scientifically by the results of two kinds of probability.

3. SUMMARY AND CONCLUSION

Both qualitative and quantitative evaluation methods for operators are discussed and analyzed in the paper. The methods include outline figure-fitting and fuzzy synthetic evaluation. The psychological characteristics of the operator can be evaluated by the outline figure-fitting method qualitatively. The visual evaluation method has an advantage in actual operation.

A nuclear power plant is a very complicated system. When operation tasks changed rapidly and continuously, the research about the relevant recognition model of operators should be set up so as to adapt to the corresponding rhythm [15].

In order to keep nuclear power plant operations safe, the research on human reliability will be more and more in-depth in the future [16]. The fuzzy synthetic evaluation method can be used for the performance evaluation of operators under small sample data through the comparison of two kinds of quantitative evaluation methods. From the evaluation effect of existing data, the effectiveness of fuzzy synthetic evaluation is already 92% currently. So it can provide an effective reference for operator evaluation.

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The authors declare that there is no conflict of interest regarding the publication of this paper.

COMPETING INTERESTS

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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