Original Research Article

Research on psychology evaluation method of nuclear power plant operators

Abstract Nuclear power plant operators play more and more important part to plant safe operation. The paper analyzes and discusses the qualitative and quantitative evaluation methods to the operators. The comparing analysis to the scope and result of application has been done between method of outline figure fitted and method of fuzzy synthetic evaluation. The research can be referenced to the evaluation of operators.
Keywords nuclear power plant operator; fuzzy synthetic evaluation; psychology evaluation

1 Introduction

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

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

Psychology evaluation method can be proposed practically so as to supplying 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.

2 Qualitative evaluation method of operators

Outline figure matching method is used in qualitative evaluation method in the research. The theoretical hypothesis of outline figure matching method is that the outline figure of psychological characteristics of high performance operator is the optimal type.[5] During the selection and assignment of operators, the score various dimensions of high working performance operator can be drawn as standard outline figure firstly, then the performance of other operators can be got easily and directly through 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.

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

In Table 1: $z_1 \sim z_6$ 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.

Standard outline figure of successful operator and outline figure of operator A are shown in Figure1.

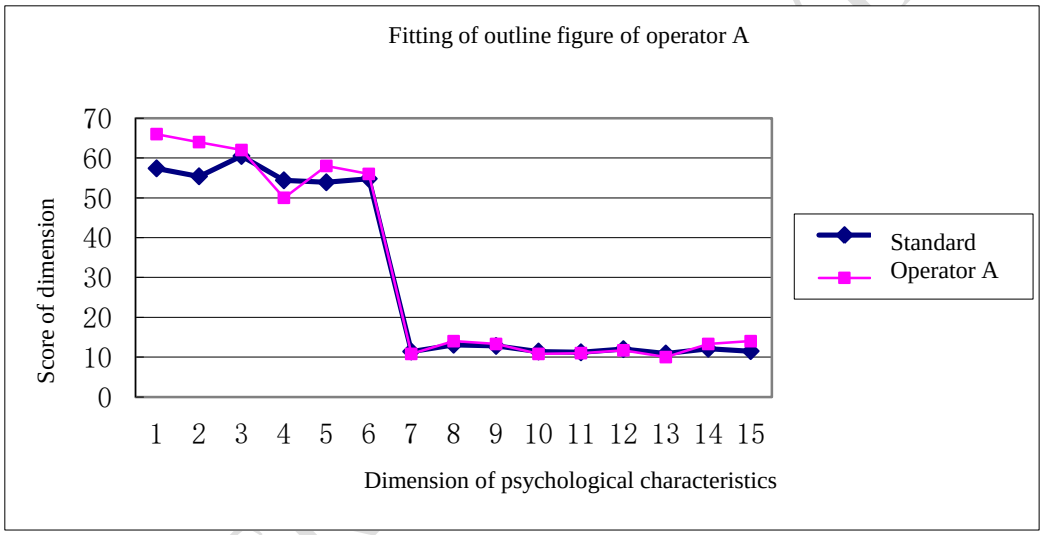

Fig. 1 Outline Figure Fitted of Operator A

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

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

Standard outline figure of successful operator and outline figure of operator B are shown in Figure2. The score of his $z_1 \sim z_6$ dimensions is generally lower than the score of standard outline figure. However, the score of his $S_1 \sim S_9$ dimensions is higher than the standard. It is difficult to fit the standard out figure. Operator B can be judged as low performance operator.

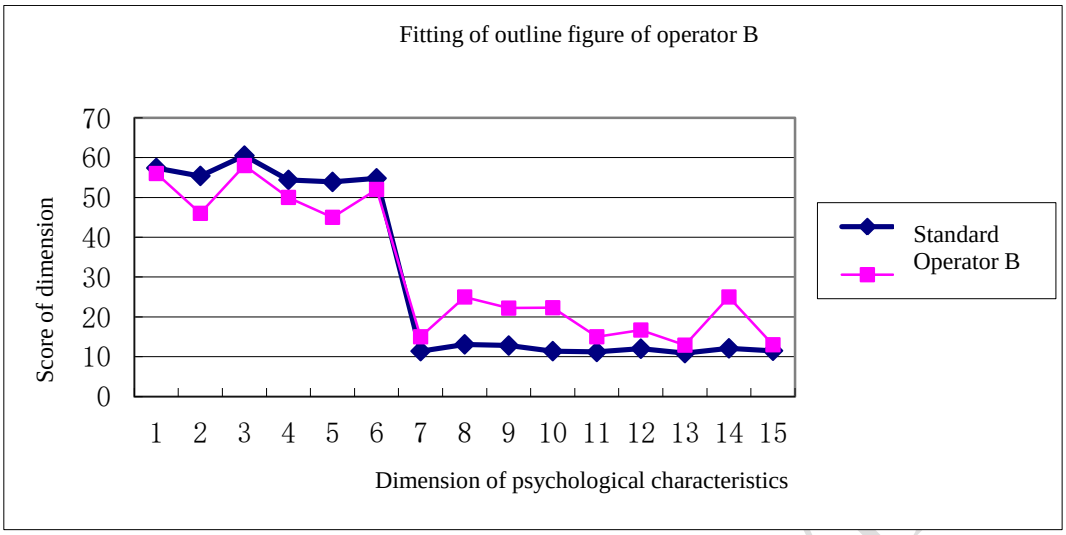

Fig.2 Outline Figure Fitted of Operator B

3 Quantitative evaluation method of operators

Though outline figure fitting method above can be used to evaluate operator figuratively, the quantitative data cannot be obtained in the method. So both multiple regression and fuzzy synthetic evaluation these two quantitative methods are tried to judge 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 one or more dependent variables are predicted by a set of independent variables.[6][7] Multiple psychological variables to the prediction result of performance of 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 regression model equation. The error of 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 above equation. The equations are formed. Then the value of parameters can be got.

The performance of 36 operators can be as dependent variable and 15 psychological variables is as independent variable. The dependent variables of regress equation can be confirmed through 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 stepwise regression algorithm of SPSS.[8] The strong prediction variables can be obtained. The calculation result is listed in Table 2.

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

Based on the calculation of SPSS program, gregariousness, depression, phobic anxiety and self-regulation are obvious variables to 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 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).

$$Y = 0.393z_1 - 0.637S_4 + 0.466S_7 + 0.247z_3 \tag{2}$$

Based on Formula (2), the estimated value of performance of 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 high or low comparing to the 2 average value Y above can be judged by the prediction performance calculation based on regress equation.

In 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 right judgment of high performance＋Number of right judgment of low performance）/Total operator number (3)

The effective value of operator evaluation based on 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.

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 $U=\{u_1, u_2, \ldots, u_n\}$, evaluation result can be expressed by different class, appraisal and data. Assuming there are m kind of evaluation class or appraisal, the relevant evaluation set is $V=\{v_1, v_2, \ldots, v_m\}$. 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 $A=\{a_1, a_2, \ldots, a_n\}$.

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.[9][10][11][12]

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 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 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 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 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 high performance group) Then

Ri=（0.2, 0.8）

End IF

The judgment matrix R is as below.

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

$$= \begin{vmatrix} 0.8 & 0.2 & 0.2 & 0.8 \\ 0.8 & 0.2 & 0.2 & 0.8 \\ 0.8 & 0.2 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.2 & 0.8 \\ 0.8 & 0.2 & 0.2 & 0.8 \\ 0.8 & 0.2 & 0.2 & 0.8 \\ 0.8 & 0.2 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.2 & 0.8 \\ 0.8 & 0.2 & 0.2 & 0.8 \\ 0.8 & 0.2 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.2 & 0.8 \\ 0.8 & 0.2 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.2 & 0.8 \end{vmatrix}$$

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

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

To operator B, the fuzzy synthetic evaluation calculation result is with high performance probability being 0.2 and 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 operator with high performance is as the standard of single factor judgment in above calculation. If the average psychological characteristics data of operator with low performance becomes the standard, the judgment process of each factor set with 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 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 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 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 low performance group) Then

R_i =(0.8, 0.2)

End IF

The judgment matrix R is as below.

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

$$= \begin{vmatrix} 0.2 & 0.8 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.2 & 0.8 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.2 & 0.8 & 0.8 & 0.2 \\ 0.8 & 0.2 & 0.8 & 0.2 \end{vmatrix}$$

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

The weight of each factor is the same as 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 low performance probability being 0.2 and high performance probability being 0.8.

To operator B, the fuzzy synthetic evaluation calculation result is with 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 maximum membership principle, the conclusion below can be obtained.

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

Table 3 The Fuzzy Synthetic Evaluation Result to Operator A and Operator B

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

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

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

Total 5 low performance operators can be selected correctly. Obviously fuzzy synthetic evaluation method is suitable to the quantitative psychology 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 multiple regression model, the variables including gregariousness, depression, phobic anxiety and self-regulation have obvious effect to performance prediction. These 4 variables can explain 51.5% variance of operators. Though the method has some certain predictability, the number of variables which are obvious to 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 result 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 standard respectively. Then both the high performance probability and the low performance probability of certain operator can be obtained through fuzzy synthetic evaluation method. The sum of the two kinds of probability may be not 1. The reason is that the two kinds of probability are got by different standards. The certain operator can be evaluated more comprehensively and scientifically by the results of two kinds of probability.

3 Summary and conlcusion

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

The fuzzy synthetic evaluation method can be used to the performance evaluation of

operators under small sample data through the comparison to two kinds of quantitative evaluation method. 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.

COMPETING INTERESTS DISCLAIMER:

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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