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Research of Evaluation Method for Logistical Personnel Supportability Based on Attribute Hierarchical Model and Grey System

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Manpower and personnel is an important part of the support resources which can seriously influence the efficiency of the equipment support system. In order to effectively estimate、balance and optimize the support ability of logistical support staff, the paper created a hierarchical logistical staff support ability evaluating parameter system with multiple parameters and put forward a parameter analysis method based on AHM and Grey System Theory. Finally, an example of analysis and calculation for maintenance personnel was provided. The paper provided a scientific evaluation criterion which can improve the evaluation efficiency and provide an important basis for the support personnel optimization.

1. Introduction

Manpower and personnel is one of the basic elements of comprehensive security and an important part of the support system (Fabrizio G., 2012), which contributes to make sure that equipments can be normally used and supported in life period. Therefore, the supportability of the support personnel is one of the elements in determining the outcome of a war. It is necessary to evaluate the support capability of support personnel, in order to allocate human resources reasonably, give full play to the performance and improve utilization of the human resources.

The support capability of support personnel is affected by a variety of factors, including qualitative and quantitative factors, which are in fairly complicated relation to each other. In the past, support capability evaluations of support personnel were mostly ex-post evaluation and lack of a systematic and practical evaluation method.

This paper considers all kinds of factors synthetically that influence support capability of support personnel, puts forward a comprehensive support personnel ability evaluation index system according to the actual situation and establishes a support capability evaluation model of support personnel using attribute hierarchical model and grey system theory, thus provides a more general method for support personnel evaluation.

2. Logistical personnel supportability evaluation parameter system

The equipment support personnel is primarily responsible for the inspection and maintenance of equipment, in order to ensure they are in available state. The supportability of support personnel has many factor and there are many uncertainties exist, Therefore the index system should be systematic and comprehensive considerate instead of from any single aspect (Davide M., 2012). In order to establish a better practical index system, some principle s should be followed such as the unity of the systematic and hierarchy, the unity of comprehensiveness and emphasis, the unity of qualitative and quantitative. According to the characteristics of the equipment support personnel, analyse the various influence factors of security personnel, and then plan all sorts of parameters.

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The evaluating parameter system for supportability of support personnel has many aspects, and these aspects are both interacting and interrelated with each other (Luo L., 2012). This paper put the knowledge structure, innovation ability and practice experience, physical and psychological quality, and basic ability as top index, afterwards, put 13 more specific factors as secondary indicators including record of formal schooling, technical level, working years, and so on.
The knowledge structure includes record of formal schooling, graduate college, professional knowledge, technology level and training time per year, which make a comprehensive description of the support personnel's knowledge base and continuing education.
Innovation capabilities include articles and books published, patent applications and awards, covering both theoretical and technological innovations.
Practical experience is the core part of the parameter system, including support work completion rate, average support time, total amount of support work done and working years, which can be used to reflect the completion of their previous work and practical experience accumulated.
The physical and mental qualities measure the impersonal condition of the support personnel from the age, health, and psychological quality.
The basic ability includes command management ability, adaptability, communication ability, organization and coordination ability, learning ability, etc., which can be fully demonstrated by the personal qualities of the impact of support personnel.
The specific evaluation parameter system is shown in Figure 1.

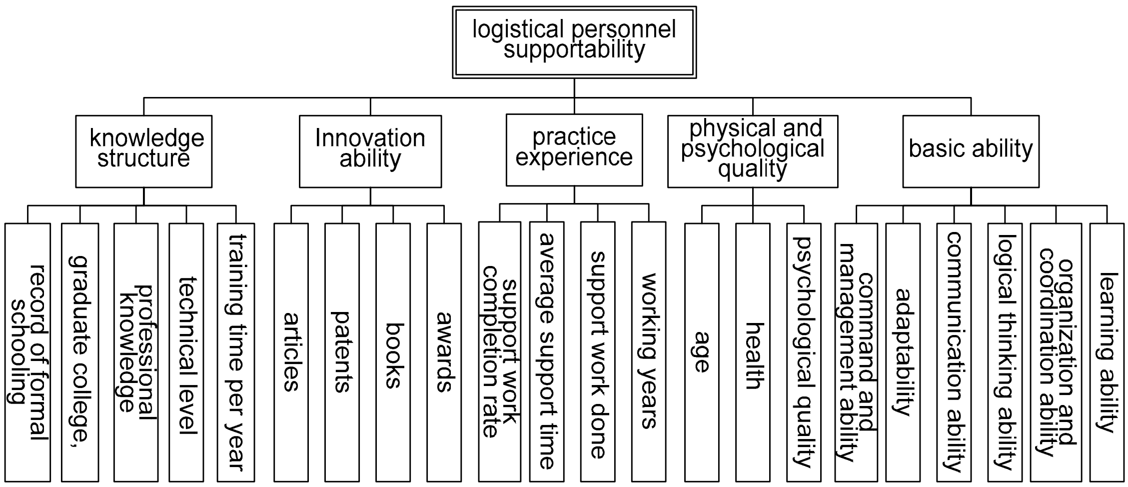


Figure 1: Logistical personnel supportability evaluation parameter system

3. Evaluation method based on AHM and grey system

3.1 Attribute hierarchical model

Attribute hierarchical model (AHM) is a method of unstructured decision making which is originated from analytic hierarchy process (AHP) (Cheng Q.S., 1997). Compared with the AHP, which based on the weight of the model, the biggest advantage of the game-based model of AHM is the matrix for comparison between every two indexes does not exist “consistency check problem", so there is no need for a large amount of calculation. The basic principle is described as follows:
Assume that C is a criterion, $\mu_1, \mu_2, \dots, \mu_n$ are n elements. For the criterion C, compare two different elements μ_i and μ_j ($i \neq j$), μ_{ij} is called the related attribute measure of μ_i and μ_j , $A = \left(\mu_{ij}\right)_{n \times n}$ is the attribute judgment matrix.
According to the requirements of the attribute measure, μ_{ij} and μ_{ji} should satisfy:

$$\begin{cases} \mu_{ij} \geq 0, \mu_{ji} \geq 0 \\ \mu_{ij} + \mu_{ji} = 1 \quad i \neq j \\ \mu_{ij} = 0 \quad i = j \end{cases} \tag{1}$$

If $\mu_{ij} > \mu_{ji}$, μ_i is stronger than μ_j ,we record as $\mu_i > \mu_j$ .If the judgment matrix A satisfy that when $\mu_i > \mu_j$ and $\mu_j > \mu_k$, $\mu_i > \mu_k$, then we say $A = (\mu_{ij})_{n \times n}$ is consistent.

The meaning of consistency matrix is all the game does not appear "woes". The so called "woes" is when $\mu_i > \mu_j$ and $\mu_j > \mu_k$, $\mu_i < \mu_k$. In this case, the consistency of the weight model is not satisfied, but the consistency of the game model can be satisfied, so the consistency requirement for the judgment matrix of the game type is much lower than that of weight model.

The matrix for comparison between every two parameter of AHM, $A = (\mu_{ij})_{n \times n}$, can be converted from the judgment matrix of AHP, $A = (a_{ij})_{n \times n}$. The conversion equation is

$$\mu_{ij} = \begin{cases} \dfrac{\beta k}{\beta k + 1} & a_{ij} = k \\ \dfrac{1}{\beta k + 1} & a_{ij} = \dfrac{1}{k} \\ 0.5 & a_{ij} = 1, i \neq j \\ 0 & a_{ij} = 1, i = j \end{cases} \tag{2}$$

Usually set β =2.

Table 1 : Ratio scale

k	1	3	5	7	9
μ_i vs μ_j	Equally	Moderately	Strongly	Very Strong	Extremely

Note: 2,4,6,8 are average values.

Relative attribute weight is

$$Wc_j = \frac{2}{J(J-1)} \sum_{i=1}^{J} \mu_{ij}, j = 1, 2, \ldots, J \tag{3}$$

Relative attribute weight matrix is

$$\mathbf{W}c = [Wc_1, Wc_2, \ldots, Wc_J] \tag{4}$$

3.2 Grey Hierarchy evaluation

The grey system is the system in which some information is defined and some undefined. Since grey theory was presented in 70s' 20 century by Deng J.L., it has been applied in many fields such as society, economy, science and technology, agriculture, and biology (Zhang S.H. et al.,2005;Liu W.J. et al.,2007). The personnel supportability evaluating parameter system is a grey system as there are many factors affecting the personnel support capability and most of them are gray and difficult to quantify. The evaluation based on the evaluator's level of knowledge and personal preferences is difficult to rule out human factors deviation. Gray system theory can make full use of the white information to reduce the error of judgement, provide an appropriate quantitative tool for the subjective assessment of the problem and help to improve the scientific and accuracy of the evaluation.

The grey hierarchy evaluation method put the discrete information offered by the evaluation experts into a weight vector which used to describe the different grey class level. On this basis, we can get the comprehensive evaluation value. The grey hierarchy evaluation method can help to improve the rationality and accuracy of evaluation.

3.2.1 Evaluation index value matrix

Calculate evaluation index value matrix,

$$D_i^{(C)} = \begin{bmatrix} d_1^{(C_1)} & d_2^{(C_1)} & \cdots & d_I^{(C_1)} \\ d_1^{(C_2)} & d_2^{(C_2)} & \cdots & d_I^{(C_2)} \\ \vdots & \vdots & \ddots & \vdots \\ d_1^{(C_J)} & d_2^{(C_J)} & \cdots & d_I^{(C_J)} \end{bmatrix} \tag{5}$$

$D_i^{(C)}$ is the evaluation index value matrix for factor j of criterion C offered by evaluator i.

For quantitative parameters, due to the dimension of each parameters is different It will be necessary to integrated into a unified dimensionless interval, so as to use the same method for comprehensive evaluation. First determine every index is positive index, negative index or interval index. Positive index means that, the personnel supportability increases with the index value increases, negative index is opposite. Interval index means when the index value falls in a certain interval, the personnel supportability is best. In this evaluation index system, the age and the work are interval index, the rest are positive index.

The transformation formulas are presented in Table 2.

Table 2 :Transformation formula

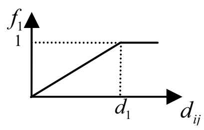
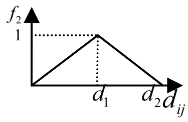
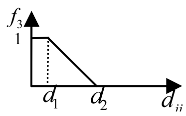
index	positive index	negative index	interval index
Transformation formula	$d_l=\begin{cases}0 & x_l<x_{\min}\\ \dfrac{x_l-x_{\min}}{x_{\max}-x_{\min}} & x_{\min}\le x_l\le x_{\max}\\ 1 & x_l\ge x_{\max}\end{cases}$	$d_l=\begin{cases}1 & x_l<x_{\min}\\ \dfrac{x_{\max}-x_l}{x_{\max}-x_{\min}} & x_{\min}\le x_l\le x_{\max}\\ 0 & x_l\ge x_{\max}\end{cases}$	$d_l=\begin{cases}0 & x_l<x_{\min}\vee x_l>x_{\max}\\ \dfrac{x_l-x_{\min}}{a-x_{\min}} & x_{\min}\le x_l<a\\ 1 & a\le x_l<b\\ \dfrac{x_{\max}-x_l}{x_{\max}-b} & b\le x_l<x_{\max}\end{cases}$

x_l is the actual value of the index , μ_l is the transformed value , $x_{\min}$ is the minimum of the actual value while $x_{\max}$ is the maximum, a is the lower bound of best interval while b is the upper bound.

3.2.2 Determine evaluation grey class

Determining evaluation grey class needs to determine the number of grey classes, the grey number and the grey whiten weight function. Commonly used whiten weight functions are the following three kinds.

Table 3 : Evaluation grey class

grey class	grey number	whiten weight function	whiten weight function image
First level	$\oplus\in[d_1,\infty)$	$f_1(d_i)=\begin{cases}\dfrac{d_i}{d_1} & (d_i\in[0,d_1])\\ 1 & (d_i\in[d_1,\infty])\\ 0 & (d_i\in[-\infty,0])\end{cases}$	
Second level	$\oplus\in[0,d_1,2d_1]$	$f_2(d_i)=\begin{cases}\dfrac{d_i}{d_1} & (d_i\in[0,d_1])\\ 2-\dfrac{d_i}{d_1} & (d_i\in[d_1,2d_1])\\ 0 & (d_i\notin[0,2d_1])\end{cases}$	
Third level	$\oplus\in[0,d_1,d_2]$	$f_3(d_i)=\begin{cases}1 & (d_i\in[0,d_1])\\ \dfrac{d_2-d_i}{d_2-d_1} & (d_i\in[d_1,d_2])\\ 0 & (d_i\notin[0,d_2])\end{cases}$	

Then assign the grey class, the matrix of assigned grey class is

$$\mathbf{B}=(b_1\quad b_2\quad\cdots\quad b_K) \tag{6}$$

3.2.2 Grey evaluation

According to $D_i^{(C_j)}$ and $f_k(d_i)$, the grey evaluation coefficient belonging to class k is $n_k^{(C_j)}=\sum_{i=1}^{I}f_k\left(d_i^{(C_j)}\right)$

The total coefficient of every grey class for index C_j is $n^{(C_j)}=\sum_{k=1}^{K}n_k^{(C_j)}$

According to $n_k^{(C_j)}$ and $n^{(C_j)}$, the weight for index C_j belonged to class k is $r_k^{(C_j)}=\dfrac{n_k^{(C_j)}}{n^{(C_j)}}$

The grey evaluation matrix for index C_j is

$$\mathbf{R}^{(C)}=\begin{bmatrix} r_1^{(C_1)} & r_2^{(C_1)} & \cdots & r_K^{(C_1)}\\ r_1^{(C_2)} & r_2^{(C_2)} & \cdots & r_K^{(C_2)}\\ \vdots & \vdots & \ddots & \vdots\\ r_1^{(C_J)} & r_2^{(C_J)} & \cdots & r_K^{(C_J)}\end{bmatrix} \tag{7}$$

3.3 Comprehensive Evaluation

By combining the AHM and the Grey Hierarchy evaluation, determine the comprehensive evaluation vector From the bottom to the top.

$$\mathbf{S} = \mathbf{W}_C \bullet \mathbf{R}^{(C)} \tag{8}$$

The result of the comprehensive evaluation is the class which the maximum value in the vector lies in. The comprehensive evaluation value can be determined by the following equation

$$E = \mathbf{B} \bullet \mathbf{S}^T \tag{9}$$

4. A case for personnel supportability evaluation

Take an equipment maintenance support personnel A for an example, do the support ability evaluation. The specific steps are as follows.

Step 1, set up the hierarchy system of maintenance personnel supportability which is similar to Figure 1.Assume that the first level indicators are named C_1, C_2,..., C_5 and the second level indicators are named C_{11}, C_{12},…, C_{56}.

Step 2, use AHM to calculate the value of the weight of each parameter. Build the matrix for comparison between every two parameter for C_1, C_2, C_3, C_4, C_5, according to the criterion C.

Table 4 :The comparison matrix

C	C_1	C_2	C_3	C_4	C_5
C_1	1	3	1/2	3	1
C_2	1/3	1	1/4	1	1/2
C_3	2	4	1	4	2
C_4	1/3	1	1/4	1	1/2
C_5	1	2	1/2	2	1

Table 5: The attribute judgment matrix

C	C_1	C_2	C_3	C_4	C_5	W_C
C_1	0	0.857	0.2	0.857	0.5	0.2414
C_2	0.143	0	0.111	0.5	0.2	0.0954
C_3	0.8	0.889	0	0.889	0.8	0.3378
C_4	0.143	0.5	0.111	0	0.2	0.0954
C_5	0.5	0.8	0.2	0.8	0	0.23

According to the conversion equation (2) and the relative attribute weight equation (3),we can get attribute judgment matrix for a single criterion C.

The relative attribute weight vector for criterion C is $\mathbf{W}c =$ (0.2414 0.0954 0.3378 0.0954 0.23). In the same way, the relative attribute weight vectors for criterion C_1, C_2, C_3, C_4, C_5 are $\mathbf{W}c_1 =$ (0.1757 0.2657 0.0577 0.3366 0.1643), $\mathbf{W}c_2 =$ (0.1905 0.3095 0.4243 0.0757), $\mathbf{W}c_3 =$ (0.3053 0.1818 0.4458 0.0671), $\mathbf{W}c_4 =$ (0.3143 0.5714 0.1143), $\mathbf{W}c_5 =$ (0.071 0.2564 0.1467 0.2564 0.0991 0.1704).

Step 3, give the evaluation index value matrix for maintenance personnel supportability. Suppose there are 5 evaluators that are $i = 1,2,3,4,5$. First evaluate the knowledge structure. To simplify the calculations, we set that the range of evaluation value is from 0 to 10 points.

In the five secondary index of knowledge structure, record of formal schooling and training time per year are quantitative indicators, which need to be taken in dimensionless process. Record of formal schooling is discrete value, which can get by the following table.

Table 6: Value for record of formal schooling

education	junior high school	senior high school	junior college	bachelor	master	doctor
value	4	6	7	8	9	10

Training time per year is quantitative indicators. In order to unify with the qualitative indicators, use the following processing formula:

$$d_l = \begin{cases} 0 & x_l < 10h \\ \dfrac{x_l - 10}{4} & 10h \le x_l \le 50h \\ 10 & x_l \ge 50h \end{cases} \tag{10}$$

We can get the knowledge structure evaluation index matrix according to the result score.

$$D_i^{(C_1)} = \begin{bmatrix} d_1^{(C_{11})} & d_2^{(C_{11})} & d_3^{(C_{11})} & d_4^{(C_{11})} & d_5^{(C_{11})} \\ d_1^{(C_{12})} & d_2^{(C_{12})} & d_3^{(C_{12})} & d_4^{(C_{12})} & d_5^{(C_{12})} \\ d_1^{(C_{13})} & d_2^{(C_{13})} & d_3^{(C_{13})} & d_4^{(C_{13})} & d_5^{(C_{13})} \\ d_1^{(C_{14})} & d_2^{(C_{14})} & d_3^{(C_{14})} & d_4^{(C_{14})} & d_5^{(C_{14})} \\ d_1^{(C_{15})} & d_2^{(C_{15})} & d_3^{(C_{15})} & d_4^{(C_{15})} & d_5^{(C_{15})} \end{bmatrix} = \begin{bmatrix} 7 & 7 & 6 & 7 & 7 \\ 6 & 4 & 5 & 7 & 6 \\ 4 & 4 & 4 & 4 & 4 \\ 8 & 6 & 5 & 6 & 6 \\ 5 & 5 & 5 & 5 & 5 \end{bmatrix} \tag{11}$$

Step 4, determine evaluation grey class. Suppose there are 4 evaluation grey classes, respectively as "optimal", "good", "medium", and "poor", that is $k = 1,2,3,4$. "Optimal" is the first lever, "good" and "medium" are the second lever, while "poor" is the third lever. Their grey numbers are $\oplus 1 \in [9, \infty)$, $\oplus 2 \in [0,8,16]$, $\oplus 3 \in [0,6,12]$ and $\oplus 4 \in [0,1,6]$.

Assign the grey class, namely take 4 for "optimal", 3 for "good", 2 for "medium", and 1 for "poor". So the matrix of assigned grey class is $\mathbf{B} = (4,3,2,1)$

Step 5, calculate the grey evaluation matrix. For index C_{11}, the grey evaluation coefficient belonged to each class are $n_1^{(11)} = f_1\left(d_1^{(11)} + d_2^{(11)} + d_3^{(11)} + d_4^{(11)} + d_5^{(11)}\right) = 3.778$, $n_2^{(11)} = 4.25$, $n_3^{(11)} = 4.333$, $n_4^{(11)} = 0$

So the total coefficient of every grey class for index C_{11} is $n^{(11)} = \sum_{k=1}^{4} n_k^{(11)} = 3.778 + 4.25 + 4.333 + 0 = 12.361$

The grey evaluation weight vector for index C_{11} is $\mathbf{r}^{(11)} = (0.306, 0.344, 0.350, 0)$

In the same way, we can get grey evaluation weight vector $\mathbf{r}^{(12)} \sim \mathbf{r}^{(15)}$ for indexes $C_{12} \sim C_{15}$, thus the grey evaluation matrix for index C_1 is

$$\mathbf{R}^{(1)} = \begin{bmatrix} 0.306 & 0.344 & 0.350 & 0 \\ 0.279 & 0.314 & 0.389 & 0.018 \\ 0.221 & 0.249 & 0.331 & 0.199 \\ 0.287 & 0.322 & 0.374 & 0.017 \\ 0.251 & 0.282 & 0.376 & 0.090 \end{bmatrix} \quad (12)$$

Similarly, the grey evaluation matrixes for indexes $C_2 \sim C_5$ can be obtained.

Step 6, evaluate the secondary indicators. The comprehensive evaluation vectors for the five secondary indicators are $\mathbf{S}^{(1)} = \mathbf{W}c_1 \bullet \mathbf{R}^{(1)}$ = (0.2785 0.3130 0.3716 0.0368), $\mathbf{S}^{(2)} = \mathbf{W}c_2 \bullet \mathbf{R}^{(2)}$ = (0.1563 0.1759 0.2246 0.4432), $\mathbf{S}^{(3)} = \mathbf{W}c_3 \bullet \mathbf{R}^{(3)}$ = (0.3122 0.3478 0.3389 0.0011), $\mathbf{S}^{(4)} = \mathbf{W}c_4 \bullet \mathbf{R}^{(4)}$ = (0.3472 0.3764 0.2764 0), $\mathbf{S}^{(5)} = \mathbf{W}c_5 \bullet \mathbf{R}^{(5)}$ = (0.3195 0.3565 0.3240 0).

Step 7, evaluate the top indicators. We can get the total grey evaluation matrix according to $\mathbf{S}^{(1)} \sim \mathbf{S}^{(5)}$.

$$\mathbf{R} = \begin{bmatrix} \mathbf{S}^{(1)} \\ \mathbf{S}^{(1)} \\ \mathbf{S}^{(1)} \\ \mathbf{S}^{(1)} \\ \mathbf{S}^{(1)} \end{bmatrix} = \begin{bmatrix} 0.2785 & 0.3130 & 0.3716 & 0.0368 \\ 0.1563 & 0.1759 & 0.2246 & 0.4432 \\ 0.3122 & 0.3478 & 0.3389 & 0.0011 \\ 0.3472 & 0.3764 & 0.2764 & 0 \\ 0.3195 & 0.3565 & 0.3240 & 0 \end{bmatrix} \quad (13)$$

The comprehensive evaluation vector is $\mathbf{S} = \mathbf{W}c \bullet \mathbf{R} = (0.2942 \quad 0.3277 \quad 0.3265 \quad 0.0515)$

Step 8, determine the comprehensive evaluation result and calculate the value. $max\{s_1, s_2, s_3, s_4\} = s2$,so the evaluation result for the support personnel supportability is “good”, and the evaluation value is $E = \mathbf{B} \bullet \mathbf{S}^T = 2.8644$ .Based on the value, we can not only evaluate the support personnel supportability but also order the support personnel by their supportability.

5. Conclusion

It is difficult to evaluate the support personnel supportability scientifically because the evaluation indexes are difficult to measure and the estimators are easy to be affected by their experience and preference. This paper established the support personnel supportability evaluation parameter system, determined the weight of each index using AHM, conclude the comprehensive evaluation using the theory of grey system.

The method combined the advantages of qualitative evaluation and quantitative evaluation, provided a more scientific evaluation criteria, to reduce the evaluation of objective factors compared with the commonly used fuzzy comprehensive evaluation and the weighted average method, improved the evaluation efficiency , provided an important basis for the support personnel optimization, and then improved the integrated equipment support performance.

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