Pre-shift State Assessment of Air Traffic Controllers Based on Improved Grey Correlation Theory

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Abstract. In order to accurately assess the pre-shift competence of controllers, the thesis formulates eight assessment indicators affecting the pre-shift status of controllers based on the actual working conditions of controllers, the contents of pre-shift questioning and the existing research results. According to the partial correlation analysis, the rationality of the selected indicators is proved. The weights of the eight assessment indicators were determined by the entropy weight-CRITIC combination method, and the relative relevance of the indicators affecting the pre-shift status was further determined by applying the improved gray correlation theory, and the pre-shift status of the controllers was sorted according to the size of the relative relevance, and differentiated into three grades. Grade 1 controllers had the highest pre-shift status correlation, which indicated that they had the best pre-shift status and were able to carry out control work smoothly; Grade 2 controllers had medium pre-shift status correlation, which was affected by their age and long posting, and had average pre-shift status; Grade 3 controllers had the smallest pre-shift status correlation, which indicated that they were young and had short posting, and had average control ability and higher psychological pressure.

Keywords: Controller Pre-shift Competence · Entropy Weight-CRITIC Combination Method · Improved Gray Correlation Theory · Correlation Analysis

1 Introduction

At present, China's civil aviation is in the opening stage of the "14th Five-Year Plan" period, and one of the main tasks of civil aviation in the "14th Five-Year Plan" period is to adhere to the bottom line of flight safety and to build a perfect, safe and efficient production and operation guarantee system [1]. Air traffic management is an important part of civil aviation safety, with the increasing reliability of air traffic control equipment, the level of control ability of air traffic controllers (hereinafter referred to as controllers) is particularly important for the safety of the air traffic control system. Controllers complete the relevant training, post experience, license theory examination and skills assessment in order to obtain the civil aviation air traffic controller license [2]. Therefore, under normal circumstances, the control ability of each controller is in line with the requirements of the position.

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As the controller's work requires long-term day and night shifts, high mental concentration, and heavy workload, and at the same time, the 24/7 working conditions require that the controller may be on duty at any time [3], it is difficult to avoid the emergence of fatigue, nervousness, stress, impatience, negativity, and illness before going to work [4–6] and other undesirable conditions, these undesirable pre-shift states, which result in the lowering of the controller's work ability and performance, and bring the Therefore, it is very important to evaluate the pre-shift status of controllers.

In actual operation, the current ATC industry mainly relies on the pre-shift reporting system to determine whether the controller is now fit for duty, "whether he is physically unwell, whether he has invoked alcohol and drugs within the specified time [7]…" For the influencing factors of controllers' working ability, domestic and foreign scholars have conducted relatively in-depth studies. Sleep disorder [8, 9] is a common problem in the work of controllers, and little sleep and poor quality will lead to reduced alertness, cognitive decline, slow reaction, decision-making difficulties, and lack of concentration, resulting in giving instructions not fast enough and accurate enough, which induces control risks, and at the same time leads to controllers' moods of irritability and annoyance, which affects the communication between the shifts. Because the quality of sleep is closely related to the body's physiological age and biological clock. With the increase of age and the working mode of day and night shifts, the sleep quality of human body will gradually decrease [10], and there are individual differences in the duration of sleep demand. Therefore, adequate sleep duration and efficient sleep quality are prerequisites for ensuring the physical and mental health of controllers, as well as for achieving efficient work capacity [11].

In order to be able to minimize controller fatigue and maintain good working condition under the existing shift work pattern. Scholars have studied the effects of different shift systems on controller fatigue, and by comparing the shift systems of controllers working two on two off and one on two off, it is found that the shift pattern of working two on two off is more suitable for controllers [12], and the shift pattern of working two on two off is adopted by the majority of control units at present. In order to further verify the effect of shift system on controllers' pre-shift fatigue, scholars confirmed the significant effect of different shift systems on controllers' pre-shift fatigue by designing experimental protocols and conducting on-site surveys, and found that fatigue indirectly weakened controllers' basic reactive and judgmental decision-making abilities [13, 14]. In addition to the effects of sleep, shift system, psychological stress, physical health, and fatigue on controllers' work status, it was found that different ages and personality traits also had a greater effect on controllers' work performance [15], and younger controllers were found to be more prone to tension and anxiety and to have greater emotional fluctuations than their older counterparts. Older controllers were found to be more prone to fatigue and difficulty in recovering from it than younger controllers due to the gradual deterioration of their physical functions. Too high or too low a posting age also affects controllers' ability to control [16, 17].

In summary, most of the literature focuses on the fatigue of controllers and the impact of fatigue on controllers, but fatigue is only an important indicator, not the only one, for assessing pre-shift status. Therefore, this paper combines the content of the actual questioning of controllers' pre-shift status in frontline control units, and develops the assessment indexes of controllers' pre-shift status from the factors that diminish controllers' ability.

2 Model

Analysis of indicators for assessing the pre-shift status of controllers. Based on the current state of research on pre-shift status assessment indicators, the following eight assessment indicators were developed from the physiological and psychological perspectives of controllers, based on the nature of their work and the possible causes of their pre-shift maladies: fatigue [3, 4, 6–11], age [11, 15], length of shift [11, 15–17], quality of sleep [8, 10, 11], average duration of sleep [8. 10,11], number of shifts [10–14], psychological stress [3, 7, 10, 11, 15], and physical health [5, 6, 10, 11, 15], and the assessment indicators are explained in Table 1.

After reviewing the domestic and international literature and our regulations, we found that there is a mutual influence relationship between the controllers' pre-shift status assessment indicators, so we conducted a partial correlation analysis on the eight indicators, and the results of the analysis are shown in Table 2.

The closer the absolute value of the partial correlation coefficient is to 1, the greater the influence between the two, if the partial correlation coefficient is greater than 0, it means that there is a positive correlation between the two; if the partial correlation coefficient is less than 0, there is a negative correlation between the two. Combined with the results of partial correlation analysis in the above table, it can be seen that the older the age, the greater the fatigue, the worse the sleep quality, the shorter the average sleep time, and the more likely to have health problems. The relationship between shift age and psychological pressure is the closest, and controllers with longer shift age are more capable and experienced, and have less psychological pressure before going to work. The higher the number of shifts, the poorer the sleep quality and the greater the fatigue before the shift. The partial correlation analysis of the eight assessment indexes coincided with the conclusions of most of the related literatures, which proved that the results of the partial correlation analysis were accurate.

3 Method

3.1 Modeling Process Based on Improved Gray Correlation Theory

The basic idea of gray correlation theory is to determine the proximity of each indicator to the superior and inferior reference indicators from the similarity of the geometric shape of the sequence curves, i.e., the closer the shape, the closer the pattern of development and change, and the greater the degree of association [22]. Gray correlation analysis is suitable for measuring the degree of association between each evaluation object and the pre-existing state of the superior and inferior classes. In addition, gray correlation analysis can clearly show the specifics of the subjects themselves and the differences between them and other subjects.

Table 1. Explanation of controllers' pre-shift status assessment indicators

Controller pre-shift status assessment indicators	Descriptive
age	The physiological age of the controllers, the older they are, the more likely they are to be fatigued and difficult to recover from, indirectly leading to a poor pre-shift state [11, 15]
Length of experience in a job	The amount of time a controller has worked since being released from the order represents the controller's rank and work experience [11], with up to 10 years of service positively affecting pre-shift status, and more than 10 years of service negatively affecting pre-shift status [16]
Quality of sleep	The better the sleep quality, the better the pre-shift state of the controller achieved during the normal sleep time before work [11]. Larger values obtained from the Stanford Sleep Index Scale [18] indicate poorer sleep quality
Average sleep time	The shorter the average amount of time that controllers normally sleep during the week, the more severe the sleep deprivation and the more likely it is to cause a poor pre-shift state [19]
Number of shifts	The number of shifts a controller works during the week reflects circadian rhythmicity; the more shifts, the more disorganized the circadian rhythm is, the more likely it is to cause fatigue, indirectly leading to poor pre-shift status [9]
stress level	The extent to which controllers are in a state of physical and mental stress in the near future due to personal, family, and work problems that put the individual in a state of stress, the greater the psychological stress the more likely it is to stimulate undesirable emotions, which leads to a poorer pre-shift state [20]. The higher values measured by the Stress Perception Scale [21] indicate higher psychological stress

(*continued*)

Table 1. (*continued*)

Controller pre-shift status assessment indicators	Descriptive
fitness level	individual's physical health, the healthier the controller is the more beneficial the pre-shift status [19]. The physical fitness of the controllers who had taken drugs and alcohol during the pre-shift was recorded as 0, and those who had not were recorded as 1
fatigue	The more fatigued the controller is the worse the pre-shift condition is [19]. Larger values measured by the Samn-Perelli Crew Condition Check Scale [6] indicate more fatigued controllers

Table 2. Partial correlation analysis

relevant type		age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fitness level	fatigue
PCE	age	1.000	0.900	0.809	−0.468	0.084	−0.600	−0.624	0.801
	length of experience in a job	0.900	1.000	0.632	−0.410	−0.149	−0.893	−0.547	0.622
	Quality of sleep	0.809	0.632	1.000	−0.585	0.623	0.511	0.631	0.926
	Average sleep time	−0.468	−0.410	−0.585	1.000	0.273	0.045	0.191	−0.504
	Number of shifts	0.084	−0.149	0.623	0.273	1.000	−0.535	−0.582	0.740
	stress level	−0.600	−0.893	0.511	0.045	−0.535	1.000	0.076	0.552
	fitness level	−0.624	−0.547	0.631	0.191	−0.582	0.076	1.000	−0.390
	fatigue	0.801	0.622	0.926	−0.504	0.740	0.552	−0.390	1.000

There is no objective and scientific quantitative standard for the resolution coefficient of each indicator in the gray correlation theory, and the empirical value of 0.5 (when the number of indicators is 4) is mostly used, and many studies have shown that this method of assigning the value does not necessarily conform to the situation where the indicators have different degrees of influence on the whole at the same time and may lead to a low resolution of the results. Scholars such as Duan Zhisan [23] found that the value of the resolution coefficient should be dynamic rather than static. Therefore, it is necessary to redefine the assignment principle of the to improve the correlation resolving power, so that the correlation better reflects the wholeness of the system.

The value of the resolution coefficient determines the degree of influence of other series on the reference and comparison series, which in turn affects the size of the correlation distribution interval and ultimately affects the results of correlation analysis. The current methods of determining the resolution coefficient mainly include specifying its value according to whether the observed series is smooth or not [23], designing the dynamic resolution coefficient by using triangular fuzzy numbers [24], and assigning the value by using the information pairs of each indicator in the entropy weighting method [25], and so on.

In this chapter, the entropy weight-CRITIC combination method is used to assign values to the discrimination coefficients, and then the improved gray correlation theory is used to assess the controller's pre-shift status.

3.2 Weight Calculation Method Based on Entropy Weight-CRITIC Combination Method

The Basic Idea of Entropy Weight-CRITIC Combination Method. Entropy weight method is a kind of objective assignment that can be used for multiple evaluation programs and multiple evaluation indicators, and the weights are determined by the magnitude of the degree of change in the differences of the indicators [26]. The more useless the information provided by the indicators, the larger the entropy value and the smaller the entropy weight, and the smallest entropy weight is 0. However, when the entropy weights of all the indicators are close to 1, even small differences will affect the weight values to carry out exponential changes, which will lead to some unimportant indicators to be given mismatched weights.

The CRITIC weight method is an objective assignment method that integrates the weights of indicators based on the strength of the contrast of the evaluation indicators and the conflict between the indicators [27]. The more informative indicators provide a greater role in the whole evaluation index system, and the weight is correspondingly greater. Contrast strength is the size of the difference between the values provided by different evaluation objects for the same indicator, expressed in the form of standard deviation, the larger the standard deviation, the greater the variability, and consequently the greater the weight. Conflict between indicators is expressed in terms of correlation coefficient, if there is a strong positive correlation between two indicators, the smaller the conflict is, indicating that the information reflected by these two indicators in the evaluation of the strengths and weaknesses of the object has a greater similarity, and therefore the smaller the weight. However, this method cannot measure the degree of dispersion between indicators.

The combined weight coefficients are solved using the game theory aggregation model [27, 28], which is essentially a multi-player optimization problem that seeks consistency among different weights to minimize the gap between the combined weights and the weights obtained by the entropy weight method and the CRITIC weight method, respectively, as much as possible. The game theory aggregation model can determine the contribution rate of the above two assignment methods according to the nature of the indicator data, providing a more objective and accurate calculation method than the average distribution or artificial distribution of the contribution rate.

The evaluation object in this paper is the controller's pre-shift status data, so when calculating the weights of each indicator, in addition to the need to consider the degree of dispersion between the indicators, but also to take into account the comparative strength and conflict between the indicators, so the entropy weight-CRITIC combination method and the game theoretic aggregation model are chosen to calculate the combined weight coefficients, which more objectively reflect the weights of the indicators.

Entropy Weight-CRITIC Combination Method Calculation Steps. First of all, statistic raw data matrix. Assuming that there are m evaluation objects, each evaluation object has n indicators, construct the original data matrix R:

$$R = (r_{ij})_{m \times n} \tag{1}$$

Normalize the original matrix R to get a new matrix R':

$$R' = (r'_{ij})_{m \times n} \tag{2}$$

which $i = 1, 2, \cdots, m; j = 1, 2, \cdots, n$。 When the indicator is positive, $r'_{ij} = \frac{r_{ij} - r_{\min}}{r_{\max} - r_{\min}}$; When the indicator is inverse, $r'_{ij} = \frac{r_{\max} - r_i}{r_{\max} - r_{\min}}$。 The maximum $r_{\max}$ and minimum $r_{\min}$ values of the same indicator in different evaluation objects, respectively.

Define the entropy of evaluation indicators H_j。

$$H_j = -k \sum_{i=1}^{m} f_{ij} \times \ln f_{ij} \tag{3}$$

式中 $f_{ij} = \frac{r'_{ij}}{\sum_{i=1}^{m} r'_{ij}}, k = \frac{1}{\ln m}$, 且当 $f_{ij} = 0$时, $f_{ij} \times \ln f_{ij} = 0$。

Define entropy weights for evaluation indicators ω_j^1。

$$\omega_j^1 = \frac{1 - H_j}{n - \sum_{j=1}^{n} H_j} \tag{4}$$

where, $0 \leq \omega_j^1 \leq 1$, and it satisfies $\sum_{j=1}^{n} \omega_j^1 = 1$。

Define indicator variability S_j, expressed as standard deviation.

$$S_j = \sqrt{\frac{\sum_{i=1}^{n} (r'_{ij} - \overline{r'_j})^2}{n - 1}} \tag{5}$$

Where, $\overline{r'_j} = \frac{1}{m} \sum_{i=1}^{m} r'_{ij}$。

Define indicator conflictivity δ_j, expressed as a correlation coefficient.

$$\delta_j = \sum_{i=1}^{m} (1 - r'_{ij}) \tag{6}$$

Defining the amount of information C_j∘

$$C_j = S_j \times \delta_j \tag{7}$$

Defining objective weights ω_j^2∘

$$\omega_j^2 = \frac{C_j}{\sum_{j=1}^{n} C_j} \tag{8}$$

Denote the weight vector calculated by the entropy weight method as W_1^T, denote the weight vector computed by the CRITIC assignment method as W_2^T, W is defined as a linear combination of W_1^T and W_2^T.

3.3 Calculation Steps of the Improved Gray Correlation Theory

$$W = \sum_{p=1}^{2} \alpha_p \cdot W_p^T \tag{9}$$

where $p = 1, 2$, α_p is the portfolio weight coefficient, α_1 is the weight coefficient of the entropy weight method, and α_2 is the weight coefficient of the CRITIC weight method.

Define the objective function L based on the set modeling principle of game theory.

$$L : \min \left\| \sum_{p=1}^{2} \alpha_p \cdot W_p^T - W_i^T \right\| \tag{10}$$

where $i = 1, 2$∘

Define the objective function based on the set modeling principle of game theory.

$$\sum_{p=1}^{2} \alpha_p \cdot W_i \cdot W_p^T = W_i \cdot W_i^T \tag{11}$$

Define the system of linear equations to be solved α_p after optimization of the objective function.

$$\begin{pmatrix} W_1 \cdot W_1^T & W_1 \cdot W_2^T & \cdots & W_1 \cdot W_p^T \\ W_2 \cdot W_1^T & W_2 \cdot W_2^T & \cdots & W_2 \cdot W_p^T \\ \vdots & \vdots & \vdots & \vdots \\ W_i \cdot W_1^T & W_i \cdot W_2^T & \cdots & W_i \cdot W_p^T \end{pmatrix} \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_p \end{pmatrix} = \begin{pmatrix} W_1 \cdot W_1^T \\ W_2 \cdot W_2^T \\ \vdots \\ W_i \cdot W_i^T \end{pmatrix} \tag{12}$$

α_p is normalized to α_p' to obtain the final portfolio weights W'.

$$W' = \sum_{p=1}^{2} \alpha_p' W_p^T \tag{13}$$

3.4 Calculation Steps of the Improved Gray Correlation Theory

Let i be the serial number of the evaluation object, X_k be the kth assessment indicator, and $x_k(i)$ be the observed data of the factor in the ith object, then $\{X_k\} = (x_k(1), x_k(2), \cdots, x_k(i))$ is the behavioral sequence of the factor X_k. In this experimental scheme, 8 pre-shift status assessment indicators are identified as the behavioral characteristic data of the gray system, i.e., k = 8; 40 controllers are identified as the subject samples as the object sequence of the system, i.e., i = 40. Since each indicator has a different magnitude and order of magnitude, it is necessary to standardize the raw data according to Eq. (2).

Define the optimal reference sequence $\{Y_{sk}\}$ and the worst reference sequence $\{Y_{tk}\}$.The optimal reference sequence is the sequence composed of the maximum value of each evaluation index specification in all evaluation objects, which is the largest reference standard for measuring the pre-shift status of all subjects, and the closer the correlation coefficient of a subject is to the optimal reference sequence, the worse the pre-shift status of the subject is; while the worst reference sequence is the sequence composed of the minimum value of each evaluation index specification in all evaluation objects, which is the smallest reference standard for measuring the pre-shift status of all subjects, and the closer the correlation coefficient of a subject is to the worst reference sequence, the better the pre-shift status of the subject is.

$$\{Y_{sk}\} = \{\max(Y_1(i)), \max(Y_2(i)), \cdots, \max(Y_k(i))\} \tag{14}$$

$$\{Y_{tk}\} = \{\min(Y_1(i)), \min(Y_2(i)), \cdots, \min(Y_k(i))\} \tag{15}$$

Define the optimal difference sequence $\triangle\ Y_{sk}(i)$, the worst difference sequence $\triangle\ Y_{tk}(i)$. Calculate the difference between the comparison sequence $\{Y_k(i)\}$ and the optimal reference sequence and the worst reference sequence, respectively.

$$\triangle\ Y_{sk}(i) = (|Y_k(1) - Y_{sk}|, |Y_k(2) - Y_{sk}|, \cdots, |Y_k(i) - Y_{sk}|) \tag{16}$$

$$\triangle\ Y_{tk}(i) = (|Y_k(1) - Y_{tk}|, |Y_k(2) - Y_{tk}|, \cdots, |Y_k(i) - Y_{tk}|) \tag{17}$$

Define the correlation coefficient $\gamma^i_{k(s)}$ relative to the optimal reference sequence, i.e., the correlation coefficient of the points of the comparison series to the points of the optimal reference sequence.

$$\gamma^i_{k(s)} = \gamma(Y_{sk}, Y_k(i)) = \frac{\min\limits_k|\triangle\ Y_{sk}(i)| + \xi_k \max\limits_k|\triangle\ Y_{sk}(i)|}{|\triangle\ Y_{sk}(i)| + \xi_k \max\limits_k|\triangle\ Y_{sk}(i)|} \tag{18}$$

Where $\min\limits_k|\triangle\ Y_{sk}(i)|$ is the minimum value in the sequence of the optimal difference of each indicator in all evaluation objects, $\max\limits_k|\triangle\ Y_{sk}(i)|$ is the maximum value in the sequence of the optimal difference of each indicator in all evaluation objects, and ξ_k is the discrimination coefficient of the kth assessment indicator, defined by the combination weight ξ_k of each indicator to take the value.

Define the correlation coefficient $\gamma_{k(t)}^{i}$ relative to the worst reference sequence, i.e., the correlation coefficient of the points of the comparison series to the points of the worst reference sequence.

$$\gamma_{k(t)}^{i} = \gamma(Y_{tk}, Y_k(i)) = \frac{\min_k |\triangle Y_{tk}(i)| + \xi_k \max_k |\triangle Y_{tk}(i)|}{|\triangle Y_{tk}(i)| + \xi_k \max_k |\triangle Y_{tk}(i)|} \tag{19}$$

where $\min_k |\triangle Y_{tk}(i)|$ is the minimum value in the worst-case sequence for each indicator in all evaluation objects, and $\max_k |\triangle Y_{tk}(i)|$ is the maximum value in the worst-case sequence for each indicator in all evaluation objects.

Define the correlation $\gamma_{i(s)}$ relative to the optimal reference sequence, and the correlation $\gamma_{i(t)}$ relative to the worst reference sequence.

$$\gamma_{i(s)} = \frac{\sum_{k=1}^{n} \gamma_{k(s)}^{i}}{n} \tag{20}$$

$$\gamma_{i(t)} = \frac{\sum_{k=1}^{n} \gamma_{k(t)}^{i}}{n} \tag{21}$$

Define the relative relevance γ_i and rank the evaluation objects according to the magnitude of γ_i.

$$\gamma_i = \frac{\gamma_{i(s)}}{\gamma_{i(s)} + \gamma_{i(t)}} \tag{22}$$

4 Example Analysis

In order to truly evaluate the pre-shift status of the controllers, the subjects were all on-duty controllers in the approach control room of a terminal control center of an ATC unit, with a total of 40 subjects, all male and right-handed, aged 27–43 years old, with an average age of 32.7 years old. 40 subjects held a controller's license, and the age distribution of the subjects ranged from 3 to 21 years, with 4 of them ranging from 3 to 5 years old, and 36 ranging from 6 to 21 years old, as shown in Fig. 1. The age and post age distribution of the controllers is shown in Fig. 1.

In this experiment, the state of approach controllers was measured at the moment before the controllers went to work after a normal rest, and the physiological data of each controller were mainly obtained by subjective measurement, including age, post age, sleep quality of the previous night, the average sleep time of this week, the total number of shifts in this week, the psychological stress level of the recent period, the current fatigue level, and the health condition of the body. The sleep quality, psychological stress level and fatigue level were self-assessed by the Stanford Sleepiness Scale (Exhibit 1), the Stress Perception Scale (Exhibit 2), and the Samn-Perelli Crew State Examination Scale (Exhibit 3), respectively, and the results of the Stress Perception Scale are shown in Exhibit 4. A ten-point scale was also used to record the subject's overall evaluation of the current state, and the closer the score is to 10, the better the state the subject is in. The closer the score is to 10, the better the subject's state is.

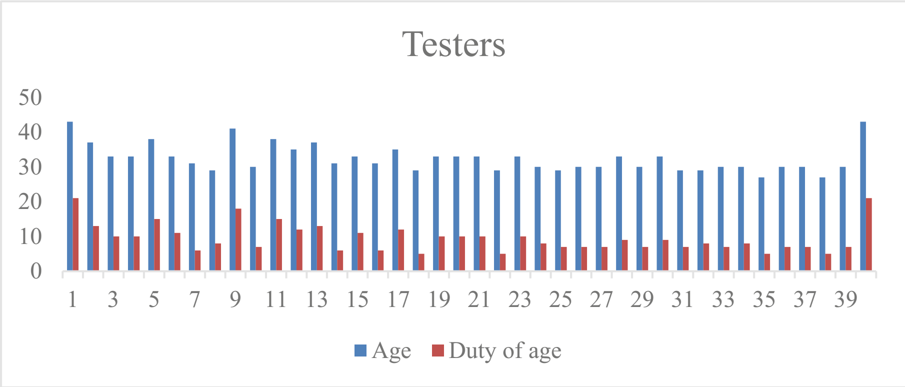

Fig. 1. Distribution of subjects' age and post age

4.1 Entropy Weight-CRITIC Combination Method to Calculate the Discrimination Coefficient

Based on the controller's pre-shift status research data, the original data matrix R is constructed as follows:

$$R = \begin{pmatrix} 43 & 21 & 2 & 7 & 2 & 1 & 3 & 1 \\ 37 & 13 & 3 & 4 & 4 & 2 & 3 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 43 & 21 & 3 & 7 & 4 & 1 & 3 & 1 \end{pmatrix}$$

Normalization was performed according to Eq. (2) to obtain the data matrix:

$$R' = \begin{pmatrix} 0.000 & 0.000 & 0.667 & 1.000 & 1.000 & 1.000 & 0.000 & 0.000 \\ 0.375 & 0.800 & 0.333 & 0.000 & 0.333 & 0.500 & 0.000 & 1.000 \\ \vdots & \vdots & \vdots & & & \vdots & \vdots & \vdots \\ 0.000 & 0.400 & 0.333 & 1.000 & 0.333 & 1.000 & 0.000 & 0.000 \end{pmatrix}$$

The entropy weight of each influencing factor is calculated according to Eqs. (3) and (4), as shown in Table 3.

Table 3. Entropy weights of each influencing factor of controllers' pre-shift state

entropy weight	age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fatigue	fitness level
ω_k^1	0.070	0.166	0.072	0.145	0.090	0.043	0.317	0.095

The correlation analysis of the influencing factors was performed using SPSS software and the results are shown in Table 4.

Table 4. Correlation matrix of factors influencing controllers' pre-shift status

	age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fatigue	fitness level
age	1.000	−0.234	0.070	0.010	−0.013	−0.326*	0.477**	0.420**
length of experience in a job	−0.234	1.000	0.372*	0.060	0.057	0.491**	0.131	0.354*
Quality of sleep	0.070	0.372*	1.000	0.656**	0.656**	0.738**	0.687**	0.493**
Average sleep time	0.010	0.060	0.656**	1.000	0.353*	0.568**	0.602**	0.176
Number of shifts	−0.013	0.057	0.656**	0.353*	1.000	0.454**	0.549**	0.226
stress level	−0.326*	0.491**	0.738**	0.568**	0.454**	1.000	0.479**	0.232
fatigue	0.477**	0.131	0.687**	0.602**	0.549**	0.479**	1.000	0.390
fitness level	0.420**	0.354*	0.493**	0.176	0.226	0.232	0.390*	1.000

Note: *Significantly correlated at the 0.05 level (bilateral); **Significantly correlated at the .01 level (bilateral)

The objective weights determined by the CRITIC method were then obtained according to Eqs. (5)–(8) and are shown in Table 5.

Table 5. Objective weights for each influencing factor of the controller's pre-shift status

entropy weight	age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fatigue	fitness level
ω_k^2	0.132	0.155	0.080	0.140	0.118	0.120	0.127	0.127

Since the weights calculated by entropy weighting method and CRITIC weighting method are inconsistent, the game set model is used to find the combination weights, and the final weights of each influencing factor are obtained according to Eqs. (9)–(13), which are shown in Table 6.

Table 6. Final weights for each influencing factor of the controller's pre-shift status

Portfolio weights	age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fatigue	fitness level
ω_k	0.072	0.166	0.073	0.145	0.091	0.046	0.311	0.096

This results in separate objective assignments of the discrimination coefficients ξ_k, where $\xi_1 = 0.072$, $\xi_2 = 0.166$, $\xi_3 = 0.073$, $\xi_4 = 0.145$, $\xi_5 = 0.091$, $\xi_6 = 0.046$, $\xi_7 = 0.311$, $\xi_8 = 0.096$。

4.2 Improvement of Gray Theory to Calculate the Correlation Coefficient

The correlation coefficient $\gamma_{k(s)}^{i}$ of each evaluation object relative to the optimal reference sequence is calculated according to Eqs. (14) (15) (16) and is shown in Table 7.

Table 7. Correlation coefficients of each evaluation object relative to the optimal reference sequence

	age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fatigue	fitness level
1	0.067	0.142	0.180	1.000	1.000	1.000	0.237	0.088
2	0.104	0.453	0.099	0.126	0.120	0.084	0.237	1.000
3	0.161	1.000	0.180	0.303	0.120	1.000	0.384	1.000
4	0.161	1.000	1.000	1.000	1.000	1.000	1.000	1.000
5	0.095	0.293	0.099	0.126	0.120	0.084	0.237	0.088
6	0.161	1.000	1.000	1.000	1.000	1.000	1.000	1.000
7	0.224	0.172	1.000	1.000	0.215	1.000	1.000	1.000
8	0.366	0.293	0.180	1.000	0.120	1.000	1.000	1.000
9	0.076	0.192	1.000	1.000	1.000	1.000	0.237	1.000
10	0.279	0.217	0.180	0.303	0.120	1.000	1.000	1.000
11	0.095	0.293	0.099	0.126	0.215	0.084	0.237	1.000

(*continued*)

Table 7. (*continued*)

	age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fatigue	fitness level
12	0.126	0.624	0.180	1.000	0.120	1.000	0.237	1.000
13	0.104	0.453	0.180	1.000	0.215	1.000	0.237	1.000
14	0.224	0.172	0.068	0.126	0.120	0.044	0.237	0.088
15	0.161	1.000	1.000	0.303	0.215	1.000	0.384	1.000
16	0.224	0.172	1.000	1.000	1.000	1.000	1.000	1.000
17	0.126	0.624	0.099	0.303	0.083	0.084	0.237	1.000
18	0.366	0.142	0.099	1.000	0.120	0.044	0.384	0.088
19	0.161	1.000	1.000	1.000	0.215	1.000	0.384	1.000
20	0.161	1.000	1.000	1.000	1.000	1.000	1.000	1.000
21	0.161	1.000	1.000	1.000	1.000	1.000	1.000	1.000
22	0.366	0.142	0.099	1.000	0.120	0.044	0.384	1.000
23	0.161	1.000	1.000	1.000	1.000	1.000	1.000	1.000
24	0.279	0.293	0.180	0.126	0.215	0.084	0.237	1.000
25	0.366	0.217	0.180	1.000	0.120	0.084	0.384	1.000
26	0.279	0.217	1.000	1.000	0.120	1.000	0.384	1.000
27	0.279	0.217	0.180	1.000	0.120	0.084	0.384	1.000
28	0.161	0.453	1.000	1.000	1.000	1.000	1.000	1.000
29	0.279	0.217	1.000	1.000	1.000	1.000	1.000	1.000
30	0.161	0.453	1.000	1.000	0.120	0.084	0.384	1.000
31	0.366	0.217	1.000	1.000	1.000	1.000	1.000	1.000
32	0.366	0.293	0.099	0.126	0.120	0.084	0.237	1.000
33	0.279	0.217	0.180	1.000	1.000	1.000	1.000	1.000
34	0.279	0.293	1.000	1.000	1.000	1.000	1.000	1.000
35	1.000	0.142	0.099	0.303	0.215	0.044	0.384	1.000
36	0.279	0.217	0.180	0.303	0.215	0.084	0.384	1.000
37	0.279	0.217	1.000	1.000	1.000	1.000	1.000	1.000
38	1.000	0.142	0.099	0.126	0.215	0.084	0.237	1.000
39	0.279	0.217	1.000	1.000	1.000	1.000	1.000	1.000
40	0.067	0.217	0.099	1.000	0.120	1.000	0.237	0.088

The correlation coefficient $\gamma_{k(t)}^{i}$ of each evaluation object relative to the worst reference sequence is calculated from Eqs. (15) (17) (19) and is shown in Table 8.

Table 8. Correlation coefficients of each evaluation object relative to the worst reference series

	age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fatigue	fitness level
1	1.000	1.000	0.099	0.126	0.083	0.044	1.000	1.000
2	0.161	0.172	0.180	1.000	0.215	0.084	1.000	0.088
3	0.104	0.142	0.099	0.178	0.215	0.044	0.384	0.088
4	0.104	0.142	0.068	0.126	0.083	0.044	0.237	0.088
5	0.187	0.217	0.180	1.000	0.215	0.084	1.000	1.000
6	0.104	0.142	0.068	0.126	0.083	0.044	0.237	0.088
7	0.088	0.453	0.068	0.126	0.120	0.044	0.237	0.088
8	0.076	0.217	0.099	0.126	0.215	0.044	0.237	0.088
9	0.366	0.356	0.068	0.126	0.083	0.044	1.000	0.088
10	0.082	0.293	0.099	0.178	0.215	0.044	0.237	0.088
11	0.187	0.217	0.180	1.000	0.120	0.084	1.000	0.088
12	0.126	0.156	0.099	0.126	0.215	0.044	1.000	0.088
13	0.161	0.172	0.099	0.126	0.120	0.044	1.000	0.088
14	0.088	0.453	1.000	1.000	0.215	1.000	1.000	1.000
15	0.104	0.142	0.068	0.178	0.120	0.044	0.384	0.088
16	0.088	0.453	0.068	0.126	0.083	0.044	0.237	0.088
17	0.126	0.156	0.180	0.178	1.000	0.084	1.000	0.088
18	0.076	1.000	0.180	0.126	0.215	1.000	0.384	1.000
19	0.104	0.142	0.068	0.126	0.120	0.044	0.384	0.088
20	0.104	0.142	0.068	0.126	0.083	0.044	0.237	0.088
21	0.104	0.142	0.068	0.126	0.083	0.044	0.237	0.088
22	0.076	1.000	0.180	0.126	0.215	1.000	0.384	0.088
23	0.104	0.142	0.068	0.126	0.083	0.044	0.237	0.088
24	0.082	0.217	0.099	1.000	0.120	0.084	1.000	0.088
25	0.076	0.293	0.099	0.126	0.215	0.084	0.384	0.088
26	0.082	0.293	0.068	0.126	0.215	0.044	0.384	0.088
27	0.082	0.293	0.099	0.126	0.215	0.084	0.384	0.088
28	0.104	0.172	0.068	0.126	0.083	0.044	0.237	0.088
29	0.082	0.293	0.068	0.126	0.083	0.044	0.237	0.088
30	0.104	0.172	0.068	0.126	0.215	0.084	0.384	0.088
31	0.076	0.293	0.068	0.126	0.083	0.044	0.237	0.088

(*continued*)

Table 8. (*continued*)

	age	length of experience in a job	Quality of sleep	Average sleep time	Number of shifts	stress level	fatigue	fitness level
32	0.076	0.217	0.180	1.000	0.215	0.084	1.000	0.088
33	0.082	0.293	0.099	0.126	0.083	0.044	0.237	0.088
34	0.082	0.217	0.068	0.126	0.083	0.044	0.237	0.088
35	0.067	1.000	0.180	0.178	0.120	1.000	0.384	0.088
36	0.082	0.293	0.099	0.178	0.120	0.084	0.384	0.088
37	0.082	0.293	0.068	0.126	0.083	0.044	0.237	0.088
38	0.067	1.000	0.180	1.000	0.120	0.084	1.000	0.088
39	0.082	0.293	0.068	0.126	0.083	0.044	0.237	0.088
40	1.000	0.293	0.180	0.126	0.215	0.044	1.000	1.000

The optimal correlation, the worst correlation and the relative correlation of each evaluating object are calculated by Eqs. (20)–(22) respectively, and the pre-shift status of each evaluating object is sorted according to the size of the relative correlation, and the results of the calculations and the sorting results are shown in Table 9.

Table 9. Relative relevance and pre-shift status ranking of each evaluation object

NO.	Best correlation	Worst correlation	Relative correlation	Sort	NO.	Best correlation	Worst correlation	Relative correlation	Sort
1	0.464	0.544	0.461	32	21	0.895	0.112	0.889	4
2	0.278	0.362	0.434	35	22	0.394	0.384	0.507	29
3	0.518	0.157	0.768	20	23	0.895	0.112	0.889	5
4	0.895	0.112	0.889	1	24	0.302	0.336	0.473	31
5	0.143	0.485	0.227	39	25	0.419	0.171	0.711	23
6	0.895	0.112	0.889	2	26	0.625	0.162	0.794	18
7	0.701	0.153	0.821	15	27	0.408	0.171	0.704	24
8	0.620	0.138	0.818	16	28	0.827	0.115	0.878	6
9	0.688	0.266	0.721	22	29	0.812	0.128	0.864	9
10	0.512	0.154	0.768	21	30	0.525	0.155	0.772	19
11	0.269	0.359	0.428	36	31	0.823	0.127	0.866	8

(*continued*)

Table 9. (*continued*)

NO.	Best correlation	Worst correlation	Relative correlation	Sort	NO.	Best correlation	Worst correlation	Relative correlation	Sort
12	0.536	0.232	0.698	25	32	0.291	0.357	0.449	34
13	0.524	0.226	0.698	26	33	0.709	0.132	0.844	12
14	0.135	0.719	0.158	40	34	0.821	0.118	0.874	7
15	0.633	0.141	0.818	17	35	0.398	0.377	0.514	28
16	0.799	0.149	0.843	13	36	0.332	0.166	0.667	27
17	0.320	0.351	0.476	30	37	0.812	0.128	0.864	10
18	0.280	0.498	0.360	38	38	0.363	0.442	0.451	33
19	0.720	0.134	0.843	14	39	0.812	0.128	0.864	11
20	0.895	0.112	0.889	3	40	0.354	0.482	0.423	37

4.3 Validation of Results

According to the relative correlation of each subject's pre-shift state in Table 9, correlation analysis was conducted with the subjects' self-measurement of the current overall state, and the results are shown in Table 10.

Table 10. Correlation matrix between subjects' pre-shift status correlations and self-assessment values

		Pre-shift state correlations	Subjects' self-assessed values
Pre-shift state correlations	Pearson correlation	1	0.740**
	Significance (bilateral)		0.000
	N	40	40
Subjects' self-assessed values	Pearson correlation	0.740**	1
	Significance (bilateral)	0.000	
	N	40	40

Note: ** indicates significant correlation at the 0.01 level (two-tailed)

The pre-shift status correlations calculated by the subjects through the modified gray correlation theory were significantly correlated with the subjects' self-rated pre-shift status values ($P < 0.01$), thus validating the feasibility of the present model.

5 Results and Discussion

1. In this study, the objective assignment of discriminant coefficient values based on the entropy weight-CRITIC combination method revealed that fatigue had the greatest weight, indicating that fatigue had the greatest influence on controllers' pre-shift status. Next in order of influence on controllers' pre-shift status are post age, average sleep time this week, physical health, number of shifts this week, sleep quality, age and psychological pressure.
2. A gray correlation theory pre-shift status assessment model was established to assess the controllers' pre-shift status. The relative correlation was comprehensively ranked by relative correlation, and it was found that the correlation of the controllers' pre-shift status relative to the optimal reference sequence ranged from 0.158 to 0.889, which indicated that there was a certain degree of difference in the pre-shift status among the controllers. The larger the relative correlation of the pre-shift status, the better the pre-shift status of the controller.
3. The relative correlation of the pre-shift status is categorized into three levels from large to small: 0.667–1 corresponds to the first level status, i.e., the controller's pre-shift status is good; 0.333–0.667 corresponds to the second level status, i.e., moderate; and 0–0.333 corresponds to the third level status, i.e., poor. The numbers and weights of controllers in different pre-shift status levels are shown in Fig. 2. It can be seen that the controllers under good pre-shift status account for a larger proportion, but there are still controllers with relatively poor pre-shift status.
4. Statistics on the distribution of personnel under each grade and the mean values of the eight assessment indicators are shown in Fig. 3, and the characteristics of each pre-shift status grade are described.

The age of controllers under the first level of status is mostly concentrated between 30–33 years old, which is the prime stage of control work. Sleep time generally satisfies 7 h, sleep quality is good, and they wake up full of vigor and vitality [18]. Low psychological pressure, low fatigue, good physical health, able to adapt to the shift work mode, able to meet the controller's pre-shift status requirements, and able to carry out the control and command work smoothly.

The age of the controllers in the secondary state is partly concentrated at 35 years old and above, with more than 10 years of posting experience. Due to their age, the decline in physical fitness is more likely to cause physiological fatigue and is not easy to recover, resulting in a higher fatigue level. However, because they have been engaged in control work for a long time, their psychological pressure is low, and they can still keep calm and not be nervous in the face of high-intensity work. This type of controller may have timely but not sensitive reaction ability, and is conscious but slightly slack.

The controllers in the third level are all 27 years old, with a lower posting age, which leads to higher psychological pressure due to the lack of control ability and experience. According to the interpretation of the Stress Perception Scale, it can be seen that the stress at this stage is persistent and cannot be calmed quickly, which has an impact on sleep and leads to insufficient sleep time and quality. However, the level of fatigue of the controllers in this state remained at a moderate level due to their young age, high energy level and good recovery ability.

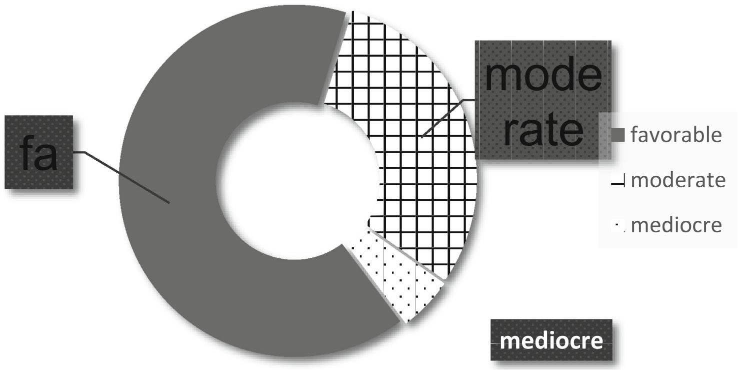

Fig. 2. Distribution of the number of people in different pre-shift status levels

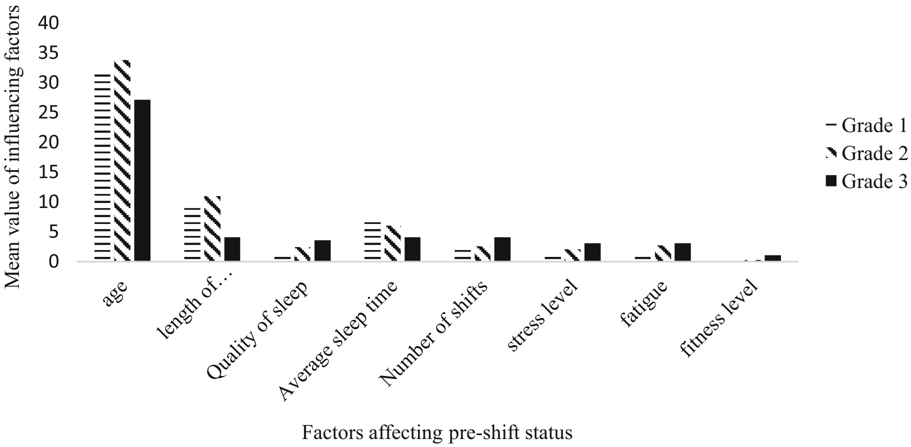

Fig. 3. Characteristic distribution of each influencing factor at different pre-shift status levels

6 Conclusion

1. In this thesis, eight indicators affecting the pre-shift status of controllers were formulated, and a gray correlation theory pre-shift status assessment model was established. And the entropy weight-CRITIC combination method was used to determine the influence weight of each factor of controller pre-shift state on controller pre-shift ability, and it was found that fatigue had the greatest influence on the control pre-shift state, followed by post age, the average sleep time of this week, and physical health.
2. The discriminating coefficient of the gray engineering theory was determined through the entropy weight-CRITIC combination method, which improved the reliability of the gray correlation theory. The relative correlation degree of each evaluation factor was determined through the gray correlation theory, and it was found that the correlation degree of the controller's pre-shift status relative to the optimal reference

sequence was in the range of 0.158–0.889, which indicated that there was a certain degree of difference in the pre-shift status among the controllers.

3. The controllers' pre-shift states were ranked according to the relative correlation of the pre-shift states, and three levels were distinguished. The greater the relative relevance of the pre-shift status, the better the controller's pre-shift status. Grade 1 controllers have the best pre-shift status and are able to carry out control work smoothly; Grade 2 controllers, due to their older age and longer years of service, have a greater impact on their pre-shift status; Grade 3 controllers, due to their younger age and shorter years of service, have higher psychological pressure and need regular psychological counseling and skill training to improve their control ability and reduce psychological pressure.
4. This thesis can provide a reference for ATC units to evaluate the pre-shift status of controllers, reduce the safety hazards arising from poor pre-shift status of controllers, and further improve the safety level of air traffic management work.

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