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A Novel Fatigue Monitoring Evaluation System for Air Traffic Controllers

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Abstract. According to the domestic and foreign security agencies, at least 70% ATC' man-made incidents are directly or indirectly caused by fatigue, therefore ATC' fatigue has become a hot issue in the field of civil aviation safety management at home and abroad. In this paper, it firstly introduces the general situation of fatigue for ATCs and its related causes. Then, based on investigations and collected expert opinions, the evaluation system of fatigue monitoring for ATC is established. The weights of monitoring indicators are calculated by using the judgment matrix obtained by expert scoring method. Finally, a case study shows the feasibility and validity of the evaluation system.

Keywords: air traffic controller, fatigue, analytic hierarchy process (AHP), fuzzy math.

1. Introduction

With the rapid development of China's civil aviation, the air traffic flow continues to increase, and the problems faced by the civil aviation industry are also increasing. Air traffic controllers are the most direct guarantee link in the operation system of civil aviation air traffic control, and play an extremely important role in maintaining air traffic safety and smoothness.

The long-term reversal of shift scheduling mode and intense working rhythm can easily lead air traffic controllers to suffer from fatigue physically and mentally [1]. Fatigue will affect the physical, psychological, spiritual and emotional of controllers, and then cause controllers to make some errors that endanger aviation safety [2]. Man-made errors caused by controllers' physical and mental fatigue are one of the important hidden dangers affecting ATC safety [3]. The research data of British Aviation Safety Voluntary Reporting System show that 13% of air traffic errors are directly related to controllers' fatigue [4]. Because the controllers need to obtain important control information through the eyes, ears and other body organs, and then make analysis or judgment by synthesizing external information such as vision, hearing and accumulated work experience[5]. For example, in October 2008, two controllers in an area control room were asleep due to fatigue, resulting in flight conflicts [6]. The National Transportation Safety Board (NTSB) reports that about 75% of fatal accidents in commercial aviation operations involve human error [7]. Fatigue is inevitable but controllable. Monitoring fatigue and taking appropriate measures to control fatigue can reduce the impact of fatigue on controllers and maximize the safety of aviation operations.

This paper starts from the analysis of the causes of fatigue of controllers, according to the theory of civil aviation safety management and the current situation of domestic control. This study constructs a novel fatigue monitoring evaluation system, which provides theoretical guidance for the supervision and management of controllers' fatigue by control units. It will also further enrich the theory of ATC' fatigue management, while it may provide reference for fatigue assessment in other professional fields of civil aviation.

2. Causes of Controller Fatigue

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Human fatigue is a subjective discomfort, but it will objectively resulting in losing ability to complete the original normal activities or work under the same conditions. The International Civil Aviation Organization (ICAO) defines fatigue as a physiological state in which the ability to perform mental or physical activities decreases due to insufficient sleep, prolonged wakefulness, circadian rhythm or excessive workload (mental and/or physical activity), which impairs the alertness of crew members and their ability to safely operate aircraft or perform safety-related duties [8]. When a person experiences fatigue, it may show one or more behavioral changes. However, it is an important fact that it takes a very difficult time for individuals who are experiencing fatigue to recognize signs of fatigue. It's mainly because fatigue affects your decision-making ability and ability to cope with difficulties. The alertness of the body enables the brain to maintain good function and make good decisions when facing problems. Studies have shown that if the body concentrates for a long time, fatigue will weaken the alertness of the body. If a person's alertness is affected by fatigue, his physical function will be greatly reduced. Damage occurs in all parts of the body, such as physical, psychological and emotional aspects, specifically in response time, hand-eye coordination ability, judgment ability, decision-making ability and so on. Because the controllers themselves can't accurately and effectively judge whether they are tired or not and the degree of fatigue, they work under fatigue condition will directly threaten aviation safety.

Cause of controller fatigue can be divided into subjective factors and objective factors. Subjective factors mainly refer to the controller's own factors, such as staying up late, health problems, etc. The objective factors mainly include flight volume, duty time and other factors, which can be divided into facilities and equipment factors, operating environment factors, organizational management factors, duty scheduling factors and workload factors.

3. Algorithms and Simulation

In actual fatigue monitoring, because the influencing factors of controller fatigue often cover many aspects, and each factor may affect each other, if only considering a certain index or a certain kind of index to study the monitoring object, it will not be able to reflect the actual situation of the research object comprehensively and reasonably. Therefore, in view of the practical problems studied, we should start from the actual monitoring point of view, and consider systematically and comprehensively not only to reflect the fatigue of the controller, but also to facilitate the monitoring of multiple indicators. Of course, these indicators are not the more the better, we should screen out the most important indicators that can reflect the actual problems, and ultimately reflect the actual situation of controller fatigue in general.

Basing on the analysis of the causes of controller fatigue in Chapter 2, we can see that many indicators can reflect the fatigue problem of controller, ranging from sleeping status to the height of worktable and seat. In order to screen out the most important and easy to quantify indicators, and considering the current situation of domestic control work and the difficulty of monitoring indicators, we interviewed the first-line controllers in the process of field investigation of a regional air traffic control center, and sought the opinions of control experts. The fatigue indicators of controllers and their explanations are listed in Tab.1.

Table 1: Controller Fatigue Monitoring Indicators.

Indicators	Number	Explanation
Number of stays up late in the past week	U_{11}	The more recent stays up, the worse fatigue will be.
Age	U_{12}	The older the age, the worse the fatigue.
No meal time	U_{13}	The more hungry, the worse the fatigue.
Hourly flights	U_{21}	The larger the number of flights, the worse the fatigue situation.
Extreme weather	U_{22}	Heavy snow, fog, thunderstorms and other conditions will increase the load of controllers
Big event	U_{23}	Important gatherings, military exercises and other activities will increase the load of controllers
Shift mode	U_{31}	The time period in which the controller is currently on duty.
Working hours	U_{32}	The longer you have been on duty, the worse your fatigue will be.
Continuous working hours	U_{33}	The longer the continuous working hours, the worse the fatigue situation.

Basing on the analytic hierarchy process with the previously screened indicators, the evaluation system of monitoring indicators is established as shown in Fig.1.

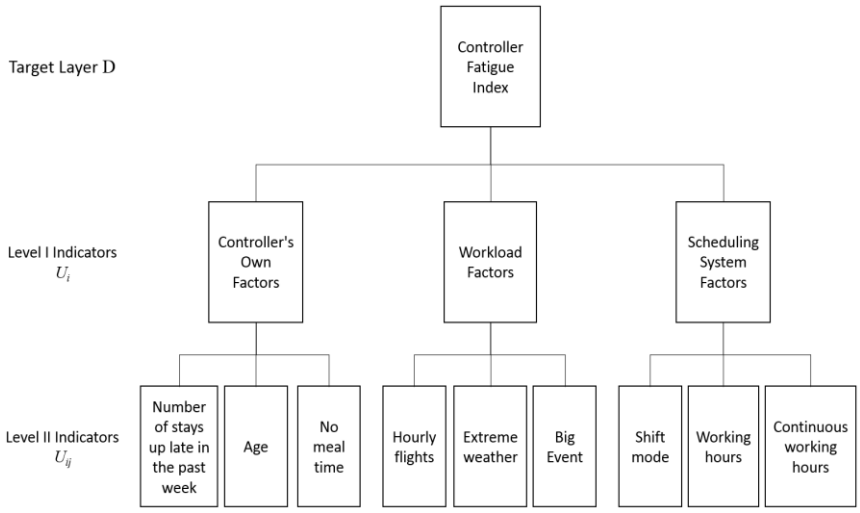

Fig.1: Evaluation System.

Referring to the data obtained from interviews with front-line controllers during field research and the opinions of control experts, the scoring criteria for each monitoring index are set out in Tab.2.

Table 2: Scoring Criteria for the Evaluation System of Controller Fatigue Monitoring Indicators.

U_{ij}	0	2	4	6	8	10
U_{11}	No	1	2	3	4-5	6-7
U_{12}	—	21-25	26-30	31-35	36-40	＞40
U_{13}	＜1	1-2	2-3	3-5	5-7	＞7
U_{21}	≤30	31-60	61-90	91-120	121-150	＞150
U_{22}	No	—	—	Yes	—	—
U_{23}	No	—	—	Yes	—	—
U_{31}	—	Day	—	Swing	—	Graveyard
U_{32}	—	＜2	2-4	4-6	6-8	＞8
U_{33}	—	—	＜0.5	0.5-1	1-1.5	1.5-2

Basing on the expert evaluation method, ten controllers of different control rooms were employed in investigation, including five area controllers and five terminal controllers. The age of the controllers selected ranged from 24 to 41 years old, and the grade of controllers ranged from trainee controllers to three-level controllers. The relative importance of each index in the analytic hierarchy process is analyzed. The judgement matrix of each index level is obtained by the expert scoring method. The weight results of each index are calculated by using the software of MATLAB. The judgment matrix of the first level indicator level, the controller's own factor judgment matrix, the workload factor judgment matrix and the scheduling system factor judgment matrix are obtained, respectively. In summary, it can be obtained by analytic hierarchy process that the weights of all levels of indicators in the fatigue monitoring index system of controllers as shown in Tab.3.

Table 3: Evaluation System and Weight of Controller Fatigue Monitoring Indicators.

Level I Indicators	Weight	Level II Indicators	Weight
U_1	0.1243	U_{11}	0.6250
		U_{12}	0.1365
		U_{13}	0.2385
U_2	0.5171	U_{21}	0.5936
		U_{22}	0.2493
		U_{23}	0.1571
U_3	0.3586	U_{31}	0.1047
		U_{32}	0.2583
		U_{33}	0.6370

In order to further verify the feasibility and validity of the established evaluation system of fatigue monitoring indicators for controllers, this paper selects three controllers as the monitoring objects, combines the fuzzy mathematics method introduced, and uses the established evaluation system of fatigue monitoring indicators for controllers to evaluate and analyze the monitored data.

According to the opinions of the control experts, combined with the scoring criteria, the final fatigue grade of the controllers can be judged by grading according to the judgment criteria in Tab.4.

Table 4: Standard Classification.

Index	Fatigue Degree
0-2	Extremely Low
2-4	Lower
4-6	Meidum
6-8	Higher
8-10	Extremely High

Then, we can establish object set A = (controller a1, controller a2, controller a3).

Controller a1 is a 28-year-old fourth-level controller with a monitoring time of 15:43, who guarantees important passengers to fly. Controller a2 is a 32-year-old third-level controller with a monitoring time of 21:17 and no special circumstances. Controller a3 is a 26-year-old fifth-level controller with a monitoring time of 00:56 and thunderstorms in the sector under control.

According to the scoring of the three monitored controllers in the evaluation system, the scoring is regarded as the membership degree of the evaluation, that is, the matrix Rij (the jth monitoring index of the ith monitored object).

$$\boldsymbol{R_{ij}} = \begin{matrix} 4 & 6 & 4 \\ 2 & 6 & 4 \\ 4 & 2 & 2 \\ 4 & 6 & 2 \\ 0 & 0 & 6 \\ 6 & 0 & 0 \\ 2 & 2 & 6 \\ 4 & 6 & 8 \\ 8 & 4 & 6 \end{matrix} \tag{1}$$

From the weight Wi and the evaluation decision matrix Ri (where Wi is the weight matrix of the second-level index under the ith first-level index and Ri is the membership matrix of the second-level index), the matrix calculation is carried out according to the synthetic operation rule Bi=WiRi, and the comprehensive evaluation results of the third subset of the three controllers' fatigue monitoring index system are obtained as follows:

$$\begin{gathered} \boldsymbol{B_1}=(3.7270,\ 5.0460,\ 3.5230) \\ \boldsymbol{B_2}=(3.3170,\ 3.5616,\ 2.6830) \\ \boldsymbol{B_3}=(6.3386,\ 4.3072,\ 6.5166) \end{gathered} \tag{2}$$

Basing on the fuzzy comprehensive evaluation result B of a single index, the comprehensive evaluation decision matrix $\boldsymbol{R}$ of each subset of U can be obtained.

According to the weight matrix W of the first index level and the value of the comprehensive evaluation decision matrix $\boldsymbol{R}$, the fuzzy transformation synthesis operation $\boldsymbol{B} = \sum \boldsymbol{W_i R}$ is carried out, and the comprehensive evaluation results of the three controllers' fatigue monitoring index system are obtained.

$$\boldsymbol{B}=(4.4515,\ 4.0135,\ 4.1622) \tag{3}$$

According to the results of the comprehensive evaluation and the classification of the criteria in Tab.9, the fatigue evaluation results of the three monitored controllers are all of medium grade. Combined with the specific situation of the three controllers and the real-time inquiry to the controllers, the evaluation results are reasonable and in line with the actual situation, which shows that the evaluation system of fatigue monitoring indicators for controllers is feasible.

4. Conclusion

In recent years, China's civil aviation industry has developed substantially and the number of flights has increased dramatically, which puts forward higher requirements for controllers. Firstly, this paper introduces

the research status of fatigue of controllers at home and abroad. Secondly, it introduces the general situation of fatigue of controllers and the related analysis of its causes, as well as the establishment of index evaluation system, the method of obtaining data and conducting evaluation analysis in field investigation. Thirdly, through field investigation and referring to expert opinions, it screens out the fatigue monitoring indicators of controllers, and establishes the fatigue monitoring indicators The evaluation system of fatigue monitoring indicators for controllers is established, and the weights of monitoring indicators are calculated by using the judgment matrix obtained by expert scoring method in MATLAB. Finally, the feasibility and validity of the evaluation system are verified by an example of control work. The research provides a theoretical guidance for Air Traffic Management Authority on monitoring ATC' fatigue, while it may provide reference for fatigue assessment in other professional fields of civil aviation.

5. Acknowledgements

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