Research on risk assessment method of subway driver driving fatigue based on AHP-FCE

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Abstract. Subway driver is one of the important factors in the "man-machine-environment" system of subway driving safety, which is of great significance to the safe operation of rail traffic. Based on the fatigue generation mechanism and previous experimental data, this paper establishes a risk assessment index system for subway driver driving fatigue including four elements: physiological, psychological, management and environmental factors based on systematic analysis of possible risks and influencing factors of driving fatigue. The Analytic Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation (FCE) were organically combined to establish a driving fatigue risk assessment model for subway drivers and obtain the driving fatigue risk level of subway drivers. Finally, through the case evaluation of a single driver on the main line of an existing operation line, it is found that the risk level of driving fatigue of the subway driver is general risk, and the AHP-FCE model has good adaptability and rationality, which has good application value for the study of driving fatigue of subway drivers.

Keywords: subway driver; risk of driving fatigue; analytic hierarchy process; fuzzy comprehensive evaluation.

1. Introduction

With strong transportation capacity and low anti-interference, the subway has become the main means of transportation in the city, and its driving safety is an important link and content to measure the management level of urban rail traffic [1]. As one of the important factors of subway driving safety, the driving status of subway drivers is directly related to the travel safety of passengers, the transportation capacity of rail traffic, transportation efficiency and safety [2]. However, the particularity of the work content, working hours and working environment of subway drivers determines that the work of subway drivers is monotonous and repetitive. Long-term and repetitive working mechanism is easy to cause driver fatigue, and fatigue will reduce the awareness of situational awareness, lead to a decline in judgment and operation ability, threaten driving safety, and directly threaten the safe operation of rail traffic.

In recent years, the domestic research on driving fatigue mainly focuses on two types of people: automobile drivers and locomotive drivers. The early stage mainly focuses on the research of fatigue generation mechanism. With the deepening of simulation technology, the later stage mainly focuses on fatigue detection technology research. However, due to the late start of subway drivers fatigue research, in recent years, it has mainly focused on the overview and analysis of the causes of subway driver fatigue [2, 3, 4, 5]. For fatigue monitoring, Jiang Xingyu [6] took the drivers of S Metro Company as the research object to carry out the main and objective monitoring research of driver fatigue. At the same time, there were few studies evaluating fatigue. At present, only Fang Weining, Zhang Yan [7, 8] and others propose to introduce the fatigue index method and the Ikeda formula model framework from the perspective of subway driver shift work, and apply the above two research methods to analyze the fatigue degree of subway shift drivers.

There are many factors related to fatigue and driving fatigue, so driving fatigue is generally uncertain. The current study explains the mechanism of subway driver fatigue, but does not establish multi-factor driving fatigue risk indicators, nor does it construct a mathematical model to demonstrate driving fatigue risk situation. Based on the systematic analysis of the possible risks and influencing factors of driving fatigue, this paper identifies the risks of driving fatigue from four aspects: physiological, psychological, management and environmental factors, and proposes a risk evaluation index system for subway driver driving fatigue. At the same time, the practical, concise and systematic characteristics of analytic hierarchy method are used to complete the weight division of each evaluation index. Using the fuzzy comprehensive evaluation method, the uncertainty is dealt with by considering the influence degree of various risk factor indicators on the system, and the driving fatigue risk assessment model of subway drivers is constructed, and the driving fatigue risk level of subway drivers is obtained. Finally, through the case evaluation of a single driver on a certain existing operation line, the evaluation results can basically reflect the actual situation.

2. Construction of metro drivers driving fatigue risk assessment index system

Based on the relevant literature research at home and abroad, combined with the existing research results, subway driver interview results and driving fatigue subjective and objective experimental data, this paper establishes a metro driver driving fatigue risk evaluation index system composed of physiological, psychological, management and environmental factors from the principles of systematic, scientific, practical and dynamic. Using the analytic hierarchy method [9], we set up 1 target layer, 4 criteria layers and 24 indicator layers, and the specific indicator system is shown in Table 1.

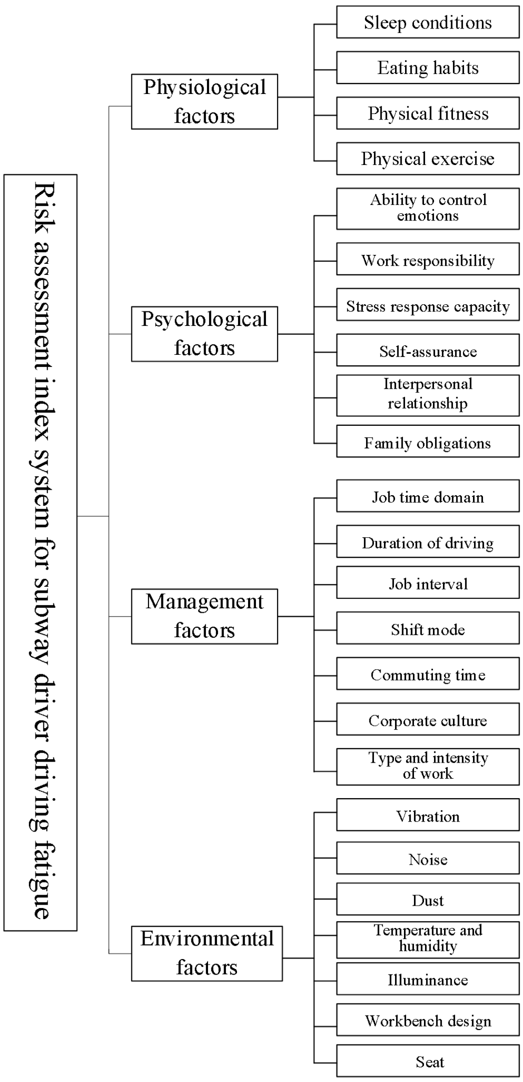

Fig. 1 Risk assessment index system of subway driver fatigue

3. Driving fatigue risk assessment for subway drivers

In this paper, the AHP-FCE model [10, 11, 12] is used to evaluate the fatigue risk of subway drivers. This method not only meets the hierarchical and quantitative needs of the decision-making process, but also considers the uncertainty of the analysis, and is suitable for the analysis of multiple causative factors such as fatigue. Its main steps consist of the following 6 modules.

（1）Establish a set of factors for comprehensive evaluation

The factor set is a general set composed of various factors as elements that affect the evaluation object, usually expressed by U ,namely: $\mathrm{U} = (U_1, U_2, U_3, \cdots, U_m)$, where element $U_i(i = 1,2,3,\cdots,m)$ represents the i-factor that affects the object of evaluation,$U_i = (U_{i1}, U_{i2}, U_{i3}, \cdots, U_{ij})$ represents its secondary set of indicators, which all have varying degrees of ambiguity.

（2）Determine factor weight vectors

In the evaluation work, the importance of each factor is different, so according to the steps of constructing the priority relationship judgment matrix, consistency test and calculating the weight, the weight $W_i(i = 1,2,3,\cdots,m)$ of each factor $U_i(i = 1,2,3,\cdots,m)$ and the fuzzy set of the weight set of each factor are represented by W: $\mathrm{W} = (W_1, W_2, \cdots, W_m)$.

（3）Establish an evaluation set for comprehensive evaluations

The evaluation set is a set of various possible outcomes that the evaluator may make to the evaluation object, usually denoted by V, namely: $\mathrm{V} = (V_1, V_2, \cdots V_n)$, Element $V_i(i = 1,2,3,\cdots,n)$ represents the evaluation result of i , which can be expressed by different levels, comments or numbers according to the needs of the actual situation. In the driving fatigue risk assessment of subway drivers, V is usually divided into 5 evaluation levels, which can be found in Table 1.

Table 1. Probability level of driving fatigue risk of subway drivers

Vn	Scoring band
Minimal	[90,100]
Law	[80,89]
Average	[70,79]
High	[60,69]

（4）Single-factor fuzzy evaluation was carried out to obtain the evaluation matrix

If the i element in factor set U is committed to the first element in evaluation set V r_{ij}, then the result of the single-factor evaluation of the i th element is expressed by the fuzzy set as: $R = (r_{i1}, r_{i2}, \cdots, r_{in})$. The matrix R is formed with m single-factor evaluation sets $\mathrm{R}_1, \mathrm{R}_2, \cdots, \mathrm{R}_m$ as rows, which is called the fuzzy comprehensive evaluation matrix.

（5）Establish a comprehensive evaluation model

After determining R and W , the fuzzy vector W on U is changed to the fuzzy vector B on V by means of a fuzzy transformation, i.e.

$$B = \mathrm{W} \circ R = (b_1, b_2, \cdots b_n) \tag{1}$$

where "∘" is the fuzzy operator.

（6）Determine the total risk score

After the comprehensive evaluation model is determined, the total risk score is determined. Based on the total risk score, the risk level can be assessed against the Driving Fatigue Risk Status Table 2.

$$F = \mathrm{B} \times S^T \tag{2}$$

where F is the total risk score and S^T is the score of the corresponding factor.

Table 2. Fatigue risk level of subway drivers

The total score of the system	90-100	80-89	70-79	60-69	40-59
Risk level	Minimal	Law	Average	High	Maximal

4. Case analysis

4.1 Overview of the instance situation

A single driver on the main line on an existing operation line adopts the working mode of four shifts and three operations. Day shifts are generally attended at fixed locations. The number of kilometers of work tasks is about 201.6km, the time is 8.5 hours, covering small breaks and lunch time, including 5-6 small breaks, the time is generally 8-15 minutes, and the lunch time is not fixed. The meal time is generally 45-65 minutes, and the place of attendance for the night shift and the next night is not fixed. The number of kilometers of work tasks is 220km as standard, up to 260km, and the night shift and the next night will rest in the nearest dormitory, 2-3 people per room, sleep time is about 4 hours.

4.2 Establish a weight set

Compile an expert questionnaire, according to the scale of 1-9, invite 10 experts who have been engaged in ergonomics and subway operation for many years according to the AHP method to establish the index system according to the above steps（2）. The relative weight of each index and the consistency test results are calculated, and the statistics of the calculation results are shown in Table 3.

Table 3. Calculation results of each index weight

One-level indicators	Weight	Two-level indicators	Itemized weight	Total weight
Physiological factors	0.1374	Sleep conditions	0.4930	0.0677
		Eating habits	0.1954	0.0269
		Physical fitness	0.1162	0.0160
		Physical exercise	0.1954	0.0269
Psychological factors	0.2791	Ability to control emotions	0.3172	0.0885
		Stress response capacity	0.1712	0.0478
		Work responsibility	0.2590	0.0723
		self-assurance	0.0880	0.0246
		Family obligations	0.0823	0.0230
		Interpersonal relationship	0.0823	0.0230
Management factors	0.3534	Job time domain	0.1794	0.0634
		Duration of driving	0.3494	0.1235
		Job interval	0.0603	0.0213
		Shift mode	0.1460	0.0516
		Commuting time	0.0766	0.0271
		Corporate culture	0.0694	0.0245
		Type of work, intensity	0.1188	0.0420
Environmental factors	0.2302	Dust	0.2356	0.0542
		Vibration	0.0919	0.0211
		Temperature and humidity	0.0785	0.0181
		Noise	0.2014	0.0463
		Illuminance	0.0785	0.0181
		Workbench design	0.1571	0.0362
		Seat	0.1571	0.0362

4.3 Establish a weight set

Experts engaged in ergonomic research and subway work for many years were organized to score 24 secondary evaluation indicators, and statistics were made by probability and mathematical expectation methods, and finally formed an evaluation matrix of each sub-factor R.

Physiological index evaluation matrix

$$R_1 = \begin{bmatrix} 0 & 0.2 & 0.3 & 0.4 & 0.1 \\ 0.1 & 0.2 & 0.2 & 0.3 & 0.1 \\ 0.1 & 0.5 & 0.3 & 0.1 & 0 \\ 0.1 & 0.5 & 0.3 & 0.1 & 0 \end{bmatrix}$$

Psychological indicator evaluation matrix

$$R_2 = \begin{bmatrix} 0 & 0.2 & 0.3 & 0.5 & 0 \\ 0.1 & 0.4 & 0.4 & 0.1 & 0 \\ 0.3 & 0.3 & 0.3 & 0.1 & 0 \\ 0.3 & 0.5 & 0.2 & 0 & 0 \\ 0.2 & 0.3 & 0.4 & 0.1 & 0 \\ 0 & 0.4 & 0.4 & 0.2 & 0 \end{bmatrix}$$

Management metrics evaluation matrix

$$R_3 = \begin{bmatrix} 0.1 & 0.1 & 0.2 & 0.4 & 0.2 \\ 0 & 0 & 0.1 & 0.4 & 0.5 \\ 0 & 0.3 & 0.4 & 0.2 & 0.1 \\ 0 & 0.1 & 0.2 & 0.4 & 0.3 \\ 0.1 & 0.1 & 0.4 & 0.3 & 0.1 \\ 0.2 & 0.4 & 0.3 & 0.1 & 0 \\ 0.2 & 0.2 & 0.4 & 0.2 & 0 \end{bmatrix}$$

Environmental indicator evaluation matrix

$$R_4 = \begin{bmatrix} 0 & 0 & 0.3 & 0.3 & 0.4 \\ 0.1 & 0.4 & 0.4 & 0.1 & 0 \\ 0.1 & 0.4 & 0.3 & 0.1 & 0.1 \\ 0.1 & 0.1 & 0.3 & 0.4 & 0.1 \\ 0.2 & 0.3 & 0.3 & 0.2 & 0 \\ 0.1 & 0.2 & 0.5 & 0.1 & 0.1 \\ 0.2 & 0.2 & 0.4 & 0.2 & 0 \end{bmatrix}$$

The two fuzzy subsets W_i and $R_i (i = 1,2,3,4)$ are synthesized by synthesizing the corresponding factor evaluation matrix B_i by the synthesis operator to obtain:

Physiological index evaluation matrix

$$B_1 = \mathrm{W}_1 {}^\circ R_1 = (0.0507 \quad 0.2935 \quad 0.3000 \quad 0.2870 \quad 0.0688)$$

Psychological indicator evaluation matrix

$$B_2 = \mathrm{W}_2 {}^\circ R_2 = (0.1377 \quad 0.3400 \quad 0.6900 \quad 0.3400 \quad 0)$$

Management metrics evaluation matrix

$$B_3 = \mathrm{W}_3 {}^\circ R_3 = (0.0632 \quad 0.1098 \quad 0.2231 \quad 0.3357 \quad 0.2681)$$

Environmental indicator evaluation matrix

$$B_4 = \mathrm{W}_4 {}^\circ R_4 = (0.1000 \quad 0.1747 \quad 0.3564 \quad 0.2311 \quad 0.1379)$$

After normalization, B_i establishes a total evaluation matrix

$B = [B_1 \quad B_2 \quad B_3 \quad B_4]^T$,

$$B = \begin{bmatrix} 0.0507 & 0.2935 & 0.3000 & 0.2870 & 0.0688 \\ 0.0910 & 0.2260 & 0.4580 & 0.2260 & 0 \\ 0.0632 & 0.1098 & 0.2231 & 0.3356 & 0.2681 \\ 0.1000 & 0.1747 & 0.3563 & 0.2311 & 0.1379 \end{bmatrix}$$

Driving fatigue risk assessment matrix of subway drivers $C = \mathrm{W}^\circ B$ After normalization treatment, we obtain:

$$C = \mathrm{W}^\circ B = (0.0778 \quad 0.1823 \quad 0.3298 \quad 0.2742 \quad 0.1359)$$

In the calculation, the evaluation set V of the five evaluation levels selects the median of each interval as the parameter of the scale, and the parameters corresponding to the five grades are: 95、84.5、74.5、64.5、49.5, its parameter column vector is $S^T = (95 \quad 84.5 \quad 74.5 \quad 64.5 \quad 49.5)$.

$$F = \mathrm{C} \times S^T = 71.7784$$

From the total score compared to the level of driving fatigue risk of subway drivers, it can be concluded that the quantitative evaluation of the driving fatigue risk of subway drivers is "average", indicating that subway drivers still have a certain fatigue risk, and the fatigue risk is within an acceptable level. According to the comprehensive analysis of the whole risk, the psychological factor score is the highest 76.372, the weight of driving duration is the highest, and its impact on driving fatigue is the largest, which is similar to the author's subjective and objective experimental data analysis results in the previous period, so the index system and model constructed by this study are reasonable and feasible.

4.4 Evaluation recommendations

（1）When conditions permit, the number of subway drivers can be appropriately increased, minimize or avoid drivers out of the group, reduce the driving time of drivers, and continuous driving time, form a normal shift mechanism, implement periodic shift schedules, ensure that working hours are relatively stable, and make drivers form a biological clock of work and life.

（2）Regularly provide psychological counseling and work guidance to subway drivers, adjust their emotional state, and reduce the work pressure of subway drivers by improving the working mechanism, environment or personnel adjustment.

（3）Carry out the training and measurement of the driving skills of subway drivers to ensure the ability of skilled driving operation and effectively alleviate the physical discomfort caused by unskilled operation.

（4）Relevant management departments and subway operators should increase health concerns for subway drivers, establish a health monitoring system, and conduct regular physical examinations of subway drivers. Quantitatively evaluate the risk of fatigue at regular intervals, and conduct relevant rapid fatigue detection tests before getting on the subway, so that the appearance of fatigue is directly killed in the cradle. At the same time, a fatigue monitoring system is established to carry out certain dynamic monitoring of subway drivers, and a wireless transmission device for driving status monitoring and monitoring data is developed to reduce the probability of accidents that may be caused by unsafe behavior. Ensure the occupational health of subway drivers and the safety of public transportation, and ultimately achieve the purpose of promoting the safe operation of the subway.

5. Conclusions

（1）In this paper, a risk assessment index system of subway driver driving fatigue based on fatigue generation mechanism and preliminary experimental data analysis is established, and the driving fatigue risk is analyzed from multiple dimensions of physiological, psychological, management and environment.

（2）Combining the advantages of analytic hierarchy and fuzzy comprehensive evaluation, the analysis hierarchy-fuzzy comprehensive evaluation method (AHP-FCE) is used to establish a driving fatigue risk assessment model for subway drivers, and the index weight is obtained by the analytic hierarchy method, the fuzzy consensus judgment matrix is introduced to ensure consistency, and fuzzy mathematical theory is introduced to deal with the uncertainty caused by driving fatigue risk more effectively.

（3）Through the case verification analysis, the driving fatigue risk of the subway company is general and consistent with the reality, indicating that this method can be used to analyze the driving fatigue risk of subway drivers and provide a scientific basis for the control of fatigue risk.

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