Method to Evaluate Job Stress of High-Speed Train Drivers

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Abstract. In an overview of the high-speed railway systems in various countries, train drivers are the last line of rail safety. With the rapid increase in transportation demand, failure to promptly formulate appropriate coping strategies and implement adjustments imposes severe job stress on train drivers. Therefore, examining the job stress of train drivers has become a critical field of research. In the present study, 5 influential factors of total quality management (TQM), man, machine, material, method, and environment, and the SHELL model (i.e., software, hardware, environment, and liveware) were used to establish an evaluation system comprising 18 key indicators to measure the job stress of train drivers. Subsequently, extension engineering and the decision of an expert panel were used to determine the relative weight of each indicator and develop a rated classical domain model and an overall rated neighborhood domain model. By calculating the association between job stress indicators and their evaluation rating, the researchers confirmed the job stress ratings for individual train drivers. Finally, the feasibility of the evaluation method proposed in the present study was verified through testing.

Introduction

Train services are being rapidly reformed as part of the expeditious development of railways and the modernization of railway equipment in Eurasia Rail greatly changing the work environment, workload, and management systems to which locomotive drivers are accustomed. Railway safety awareness has increased in recent years because of the occurrence of numerous railway accidents. Therefore, measuring the job stress and mental health of high-speed train drivers presents practical implications for eliminating safety risks caused by human error and ensuring railway safety. Currently, the human resource management plans adopted by railway authorities primarily focus on examination, employment, remuneration, evaluation, and benefits, but fail to account for the job stress and mental health of high-speed train drivers.

Numerous European countries have adopted aviation safety standards to assess the risk of their high-speed railways, such as the SHELL model (i.e., software, hardware, environment, and live ware), a well-known conceptual model of human factors used for aviation safety management .

On the basis of live ware (human), software, hardware, and environment, this study invited numerous experts to collectively identify the physiological, psychological, and environmental factors influencing the job stress of train drivers. These factors were used to develop an evaluation system to measure the job stress of train drivers. Moreover, a rated classical domain and an overall rated neighborhood domain were developed to determine the differences between job stress indicators and their evaluation ratings, and to verify the job stress rating of individual train drivers. Finally, tests were performed to verify the feasibility of the proposed evaluation method.

Literature Review

Research concerning job stress began in World War II, and is divided into three distinct classifications: 1) determining job stress intensity by measuring various physiological conditions, such as the reaction of the skin to electricity, heart rate, electrocardiography, blood pressure, biological fluids, and behavioral symptoms; 2) examining the interactions between subjects, machines, systems, and environments, including operating procedures, unit time recording, and communication dialogues, and the influences that these interactions have on job stress; and 3) measuring the mental conditions of subjects. The majority of existing literature has employed qualitiative research approaches and focused on a specific aspect of job stress. This studied proposed a comprehensive qualitative-quantitative evaluation method based on extension engineering to assess the job stress of train drivers. The researchers individually reviewed literature relating to high-speed train operation, job stress, and evaluation methods based on extension theory. The findings are presented in the following section and the research framework is illustreated in Fig. 1.

High-Speed Train Operation

"High-speed trains" are defined differently in various countries. The Tokaido Shinkansen, a Japanese high-speed line between Tokyo and Shin-Osaka that began operation in 1964, was the world's first commerical train to reach a speed of 200 km/h. High-speed rail in context of wheel track (nonmaglev) trains are defined as 1) trains with a minimum speed of 250 km/h on lines specially built for high speed; or 2) of the order of 200 km/h on existing lines that have been specifically upgraded. According to the Railway Act of Taiwan, "high-speed railways" are defined as those with an operational speed above 200 km/h. The researchers adopted the definition proposed in the Railway Act

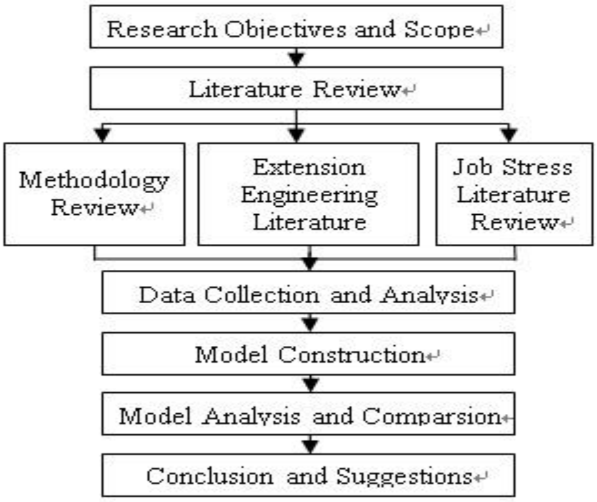

Fig.1 Research Framwork

According to the Regulations for Skills Training and Physical Examination of Railway Operation Staff, "operators" are defined as staff members that control the movement of locomotives. The Taiwan Railway Administration and Taiwan Rapid Transit Corporation define these operators as "drivers." Alternatively, the Regulations Governing the Certification of Public Train Operators define these operators as "train drivers." The Taiwan High Speed Rail Corporation defines "train drivers" as railway staff that are qualified to operate trains, check and monitor train conditions, and perform basic error correction. Therefore, in summary of the various defintions, this study adopted "train driver."

Job Stress

Selye introduced the "stress" into academia in 1956. Stress within an organization was first researched at the Institute of Sociology, University of Michigan, in 1962, in which the Institute for Social Research Model was developed. At present, stress research has expanded to encompass various fields.

Experts have extensively researched job stress. Cooper (1983)[1] researched the sources of job stress, developed relevant indicators to measure job stress, and identified 6 dimensions related to sources of job stress, namely, intrinsic to the job, management role, relationship with others, career and achievement, organizational structure and climate, and home/work interface. Robbins (1998)[2] proposed a generic model for stress management by characterizing the sources of job stress into environmental factors, organizational factors, and personal factors. Subsequently, stressful experiences are produced by using the mutual interactions between these 3 factor types and individual differences, which consequently cause physiological, psychological, and behavioral symptoms. Chang, Yang, and Wu (2005)[3] established a job stress measurement table for train drivers in Taiwan. Results indicated that job stress of train drivers primarily derived from physical operating conditions and environments, psychological feelings, career plans, organization structure and culture, job stress and work schedules, management systems, environment of work operation, physical environment of the control cab, interactions at work and at home, and the management methods of superiors. In addition, responses to stress comprise job dissatisfaction, poor mental health, and poor work performance and absenteeism. Based on previous studies relating to the sources of stress for train drivers, the present study adopted the job stress model proposed by Greenberg as a theoretical basis, and referenced the transtheoretical model for stress management proposed by Robbins, as well as the sources and indicators of job stress developed by Cooper to develop a job stress questionnaire and measurement table.

The information collection from the literature review was prepared and compiled into a pilot questionnaire to measure job stress. A pilot survey was conducted on numerous high-speed train drivers in May 2014. A total of 110 questionnaires were administered; 90 valid questionnaires were recovered. This study employed a critical ratio method and invited a panel of experts to assess the questionnaire items. The items in the pilot questionnaire were revised based on the results of the 2 assessment methods to produce the formal questionnaire.

Theoretical Bases of Extension Engineering

Extension engineering is the science of converting and resolving noncompatible problems, where elements are the basic unit of problems. Therefore, matter-element analysis is a combination of extension set theory and matter-element theory. Matter-element theory is used to determine the variability of objects; the conditions, approaches, and regulations of this variability; and conversion processes. Extension set theory is the mathematical aspect of matter-element analysis. Objects are characterized into extension sets based on their level of association. This association is determined by extending common closed interval [0, 1] continuous values into a $(-\infty,+\infty)$ real axis to measure the extension set association of the values. Extension set theory can express problems algebraically, thus quantifying noncompatible problems. To explain contradictory problems, problem models should be developed using matter-elements, where matter-element conversion can be employed to solve contradictory problems. Using extension set theory, correlation functions can then be established to explain the quantitative and qualitative changes of objects using quantifiable values (i.e., the quantitative and qualitative changes of objects examine extension domains and critical elements). Matter-element and extension set concepts explain the attributes and conversion processes of objects. Subsequently, these concepts enable the possibility for objects without specific attributes to be converted into objects containing these attributes.

Recent domestic and foreign studies concerning job stress models primarily focus on summarizing and revising conventional stress models and expanding or refining stress research, as well as simultaneously examining the influences that various variables (e.g., culture, personality, mentality, and organization management) have on stress.

Fried et al. (2008)[4] selected 113 independent samples from published and unpublished studies in the past 25 years, and separately incorporated these samples into a structural equation model and a substitution model to determine the associations between job stress and psychological adjustment, work performance, and resignation, and identified the theoretical factors influencing job stress. Subsequently, they established a job stress model corresponding to the influences that these factors have on individuals and organizations. Boyd et al. (2009) [5] surveyed the job stress of professional sales representatives. The researchers' findings provided an overall support to the majority of hypothesized associations between work-related stress factors, individual characteristics, and coping methods. Wallgren and Hanse (2007) [6] employed a structural equation model to determine the associations between job characteristics, incentives, and stress. The researchers employed an online survey targeting IT consultants in Sweden, and found that work demand and perceived stress showed a positive correlation, and that incentives at least partly moderate work control and perceived stress. The researchers also found a significant positive correlation between high work control and high incentive, and a negative correlation between incentive and perceived stress.

Pal and Saksvik (2008) [7] compared the job stress levels of 27 doctors and 328 nurses from Norway, and of 111 doctors and 136 nurses from India. The researchers found that in different cultural contexts and work environments, the influences that family conflict and psychological work environment played on workers varied significantly.

Review findings showed that the development of models for measuring job stress and theories concerning the mechanisms of job stress have gained substantial progress. However, research pertaining to the job stress of specific groups, such as high-speed train drivers, has not been scarce, and a structural model for measuring their job stress remains to be developed.

Definition of Matter-Element. Matter-elements are defined as follows. Rename the object (R) as N, where the object elements described by vector (v) of characteristic (c) and are as follows: select evaluation indicators from the accumulated analysis data and ensure these indicators corresponded to the variation range. Then, check the classical and neighborhood domains and the matter-element matrix of the test object.

$$R = (N,c,v) \tag{1}$$

Checking the Test Object. Regarding the test object (R), the recorded data or analysis results can be expressed as the following matter-element matrix:

$$R = \begin{bmatrix} N & C_1 & V_1 \\ & C_2 & V_2 \\ & \vdots & \vdots \\ & C_n & V_n \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} \tag{2}$$

where R represents the priority test matter-element, N represents item, and V_i represents the value of c_i, which are the physical values obtained from the test equipment.

Checking Classical and Neighborhood Domains. When N_j is the standard object and $V_i = \langle a_i \cdot b_i \rangle$ is the value range of c_i, then the classical domain of the matter-element can be expressed as follows:

$$R_j = (N_j, C_j, V_j) = \begin{bmatrix} N_j & C_1 & V_{j1} \\ & C_2 & V_{j2} \\ & \vdots & \vdots \\ & C_n & V_{jn} \end{bmatrix} = \begin{bmatrix} N_j & C_1 & \langle a_{j1} \cdot b_{j1} \rangle \\ & C_2 & \langle a_{j2} \cdot b_{j2} \rangle \\ & \vdots & \vdots \\ & C_n & \langle a_{jn} \cdot b_{jn} \rangle \end{bmatrix} \tag{3}$$

The neighborhood domain matter-element matrix can be expressed as follows:

$$R_P = (N_p, c_i, V_p) \begin{bmatrix} N_p & C_1 & V_{p1} \\ & C_2 & V_{p2} \\ & \vdots & \vdots \\ & C_n & V_{pn} \end{bmatrix} = \begin{bmatrix} N_p & C_1 & \langle a_{p1} \cdot b_{p1} \rangle \\ & C_2 & \langle a_{p2} \cdot b_{p2} \rangle \\ & \vdots & \vdots \\ & C_n & \langle a_{pn} \cdot b_{pn} \rangle \end{bmatrix} \tag{4}$$

where p represents the job stress load of train drivers and V_{pi} is the job stress value range of c_i in p (i.e., the neighborhood domain of p). Therefore, $v_{ji} \in v_{pi}$ must be determined.

Checking the Relative Weight of the Various Indicators. During evaluation, the level of influence of the various factors may vary. Therefore, various weight values must be appointed to each factor based on the magnitude of influence they impose on the surrounding environment. In the present study, relative weight was measured using a comparative method. Based on expert opinions, a pairwise comparison test was performed to score the influential significance of each indicator. The scores for each indicator were then summed and processed to determine relative weight. A 4-point scale was used to determine the relative weight of 18 indicators. The procedure is listed as follows:

1) The influential significance of the various indicators was determined through a pair-wise comparison test.

Matrix C = $(C_{ij})_{18\times18}$

As illustrated in Fig. 2, the equation used for calculating association was C_{ij} (i, j=l, 2, 3, …, 18), where C_{ij} represents the level of significance when comparing indicators i and j; C_{ij} =2 represents equal significance between i and j; C_{ij} >2 represents higher significance for i; and C_{ij} <2 represents higher significance for j.

2) Each row within the matrix was summed.

$$\sum_{j=1}^{18} C_{ij} \text{ (i = 1, 2, 3, …, n)}$$

3) The summed value of each row was normalized to determine the relative weight (ω_i) of each indicator.

$$\omega_i = \frac{\sum_{j=1}^{18} C_{ij}}{\sum_{j=1}^{18}\sum_{i=1}^{18} C_{ij}} \tag{5}$$

Checking Evaluation Levels and Their Associations. Correlation functions are defined as the level of compliance of a matter-element at a specific point on the real axis. The correlation function of an extension set can be expressed as an algebraic equation, which is beneficial for quantitatively solving noncompatible problems. For example, the correlation function of the ith job stress indicator of train drivers in the jth level can be expressed as follows:

$$\rho(v_i, V_{ji}) = \left| v_i - \frac{a_{ji} + b_{ji}}{2} \right| - \frac{(b_{ji} - a_{ji})}{2} \tag{6}$$

$$\rho(v_i, V_{pi}) = \left| v_i - \frac{a_{pi} + b_{pi}}{2} \right| - \frac{(b_{pi} - a_{pi})}{2} \tag{7}$$

Subsequently, correlation $K_j(v_i)$ can be defined as follows:

$$\left| v_{ji} \right| = \left| a_{ji} - b_{ji} \right| \tag{8}$$

$$K_j(v_i) = \begin{cases} \dfrac{\rho(v_i, V_{ji})}{\rho(v_i, V_{pi}) - \rho(v_i, V_{ji})} & x \notin V_{ji} \\ -\dfrac{\rho(v_i, V_{ji})}{\left| V_{ji} \right|} & x \in V_{ji} \end{cases} \tag{9}$$

where $\rho(v_i, V_{ji})$ represents the distance between point v and finite interval V_{ji} =[a, b]; $\rho(v_i, V_{pi})$ represents the distance between v and $V_p = [a_p, b_p]$; and v, V_{ji}, and V_{pi} respectively represent the value of the test matter-element, the value range of the classical domain of the matter-element, and the value range of the neighborhood domain of the matter-element. Subsequently, the ith characteristic (indicator) of $K_j(v_i)$ belongs to the overall correlation in the jth level. The value ω_i is adopted as the relative weight by c_i:

$$K_j(v_p) = \sum_{i=1}^{n} \omega_{ij} \; K_j(v_i) \tag{10}$$

Association indicates an object’s level of compliance to relevant standards, where the larger the value of association, the more compliant the object is to relevant standards.

$$K_j = \max K_j(v_p) \text{ (j=1,2,3,…,n)} \tag{11}$$

When the test item (v_i) is in the jth level, and the jth level is $K_j(v_p) \le 0$, then v_i is excluded for the evaluation level.

Methodology

To achieve system requirements, the set of indicators selected from the various output characteristics for the evaluation system is simplification of the complex real systems. Because of the complexity of high-speed rail operations, using a single indicator for evaluation is extremely difficult, and a multiangle, multiperspective evaluation method is preferred. In addition, the classical and neighborhood domains of job stress could only be confirmed through the collection and analysis of data. By combining the job stress model based on extension engineering and the SHELL model proposed by Edwards, a multi-interfaced SHELL model was developed, facilitating the comprehensive examination of the interactive influences and associations between liveware (humans) and other factors, and the systematic integration of these associations. The job stress of high-speed train drivers was characterized into 4 levels, as shown in Table 1.

Tab.1 Key Indicators Influencing the Job Stress of Train Drivers and Their Relative Weights

level 1 indicator	weight	level 2 indicator	weight
personal conditions (L~H) A1	0.38	work time (C1)	0.08
		physiological needs (C2)	0.06
		fatigue conditions (C3)	0.09
		ability to focus (C4)	0.05
		roster conditions (C5)	0.10
communication role between interfaces (L~L) A2	0.25	communicating with dispatch (C6)	0.08
		communicating with control (C7)	0.13
		communicating with superiors (C8)	0.04
individual and system (L~S) A3	0.27	personalized cabin design (C9)	0.03
		update of regulations and information (C10)	0.06
		handling emergencies (C11)	0.05
		security system functionality (C12)	0.03
		communication quality (C13)	0.03
		family interaction quality (C14)	0.03
		error tolerance and risk (C15)	0.04
operating environment (L~E) A4	0.10	cabin noise (C16)	0.04
		cabin comfort (C17)	0.03
		cabin lighting (C18)	0.03

The evaluation may vary depending on different problems and research objectives.

The job stress indicators (N_j) were characterize into 4 levels, namely, "heavy," "moderate," "light," and "normal." The information tabulated in Tables 1 and 2 were incorporated into MATLAB to create a mathematical model. LabVIEW was used to create a graphical representation of the model, and the following classical domain for the job stress of train drivers was produced:

$$R_1 = \begin{bmatrix} N_j & c_1 & \langle 0.75, 1 \rangle \\ & c_2 & \langle 0.75, 1 \rangle \\ & c_3 & \langle 0.75, 1 \rangle \\ & \vdots & \vdots \\ & c_{18} & \langle 0.75, 1 \rangle \end{bmatrix} \quad R_2 = \begin{bmatrix} N_j & c_1 & \langle 0.5, 0.75 \rangle \\ & c_2 & \langle 0.5, 0.75 \rangle \\ & c_3 & \langle 0.5, 0.75 \rangle \\ & \vdots & \vdots \\ & c_{18} & \langle 0.5, 0.75 \rangle \end{bmatrix}$$

$$R_3 = \begin{bmatrix} N_j & c_1 & \langle 0.25, 0.5 \rangle \\ & c_2 & \langle 0.25, 0.5 \rangle \\ & c_3 & \langle 0.25, 0.5 \rangle \\ & \vdots & \vdots \\ & c_{18} & \langle 0.25, 0.5 \rangle \end{bmatrix} \quad R_4 = \begin{bmatrix} N_j & c_1 & \langle 0, 0.5 \rangle \\ & c_2 & \langle 0, 0.5 \rangle \\ & c_3 & \langle 0, 0.5 \rangle \\ & \vdots & \vdots \\ & c_{18} & \langle 0, 0.5 \rangle \end{bmatrix}$$

Moreover, the neighborhood domain model for job stress was as follows:

$$R_P = [N_P, c_{18}, v_{18}] = \begin{bmatrix} N_j & c_1 & \langle 0,1 \rangle \\ & c_2 & \langle 0,1 \rangle \\ & c_3 & \langle 0,1 \rangle \\ & \vdots & \vdots \\ & c_{18} & \langle 0,1 \rangle \end{bmatrix}$$

Train drivers were instructed to self-evaluate the 18 key indicators for job stress. Equation (6) was used to confirm correlations of the various indicators, and the results were tabulated in Table2.

Tab.2 Association of the Various Indicators

Indicator	$k_1(v_i)$	$K_2(v_i)$	$K_3(v_i)$	$K_4(v_i)$
C1	.333	-.063	-.375	-.688
C2	-.171	.200	-.286	-.643
C3	.333	-.063	-.375	-.688
C4	.333	-.063	-.375	-.688
C5	.333	-.063	-.375	-.688
C6	-.171	.200	-.286	-.643
C7	-.171	.200	-.286	-.643
C8	-.171	.200	-.286	-.643
C9	-.171	.200	-.286	-.643
C10	.250	.333	-.167	-.583
C11	.250	.333	-.167	-.583
C12	.333	-.063	-.375	-.688
C13	.250	.333	-.167	-.583
C14	-.171	.200	-.286	-.643
C15	-.171	.200	-.286	-.643
C16	-.875	-.250	.333	-.375
C17	-.875	-.250	.333	-.375
C18	-.171	.200	-.286	-.643
$K_j(v_p)$	.015	0.93	-.240	-.631

According to (12), $K_j(v_p)$ train drivers experience considerable job stress in the "communication role between interfaces (L-L)" classification of daily operations.

Verification and Analysis

The SHELL model was used to evaluate the job stress of train drivers, which is a key evaluation model used in foreign aviation ergonomics research. It was first introduced in 1972 by Edwards, and later revised by Hawkins in 1975 [8]. In the present study, 110 questionnaires were administered to high-speed train drivers. A total of 96 questionnaires were recovered, of which 90 were valid questionnaires. The response and validity of the questionnaires were 87% and 94%, respectively. To organize the responses provided by all respondents and use the minimum number of influential factors to explain the associations of the responses, this study classified similar items into individual categories and selected one influential factor to represent each category. This approach reflected the majority of the information contained in the questionnaires by using the least amount of factors, and ultimately developed a job stress model.

The job stress model comprised 4 interfaces of liveware, hardware, software, and environment. The fitness of interfaces is of equal importance to the characteristics themselves, where unfit interfaces may result in human bias. In the examination of human factors, (L-H) commonly refers to the interaction between people and systems. However, this study defined the system aspect of this interface as the interaction between people and their job conditions. (L-L) refers to the interpersonal associations in a workplace. This interface is associated with the interactions of leadership, cooperation, collaboration, and personality. In general, the correlation between employees or that between employee and manager greatly influences capacity. Therefore, enterprise culture, atmosphere, and operating pressure also belong to this interface. (L-S) refers to the association between people and their support systems in the workplace, such as regulations, manuals, checklists, publications, SOPs, and software updates. This interface includes various "user-friendly" items, such as contemporaneity, accuracy, format, expression, vocabulary, clarity, and various symbolic system notations. (L-E) refers to the association between people and internal or external environments. The association between the various interfaces fluctuated, suggesting that the interfaces did not completely comply with each another. Therefore, caution should be maintained when considering the various system factors to prevent system error and collapse.

Matter-element features were sampled by identifying the evaluation indicators and levels in each construct and calculating these indicators and levels using a computer program. Findings verified the feasibility of using matter-element evaluation to establish complex job stress indicators. By examining the job stress items provided by the respondents, the researchers were able to preliminarily analyze their self-evaluation results, enabling train drivers and their relevant departments to engage in research and discussions based on real-time conditions. Analysis results are illustrated in Fig. 2, and the level of influence and evaluation results are illustrated in Fig. 3.

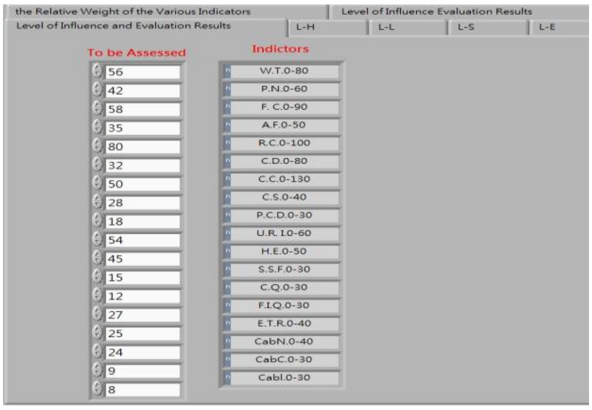

Fig.2 Level of Influence and Evaluation Results

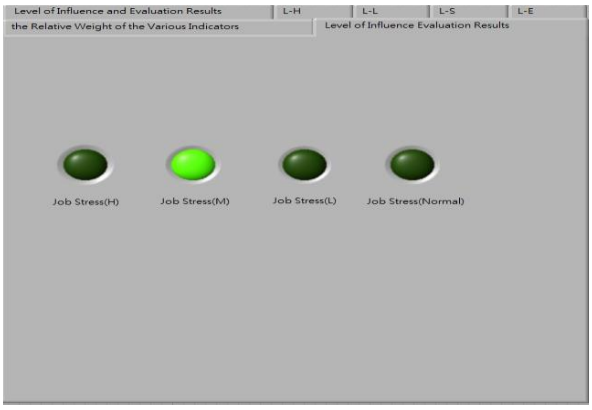

Fig.3 Level of Influence Evaluation Results

Conclusion

The job stress of high-speed train drivers directly influences transport safety, and has therefore gained considerable attention from transportation authorities. However, because of subjective and objective influences, a standardized evaluation method for the job stress of high-speed train drivers has not been proposed. The evaluation method for job stress developed in this study presented the following benefits:

(1) The evaluation model developed in this study was based on matter-element analyses. This is beneficial in that the job stress of train drivers can be measured quantitatively and qualitatively, and the evaluation results can be expressed with objective and quantifiable values.

(2) The results produced using the proposed evaluation method effectively reflected the behaviors and the physiological and psychological conditions that influence the job stress of train drivers.

(3) The proposed evaluation model requires only simple calculations, is highly adaptable, and uses user-friendly software. The model also demonstrates the potential to be incorporated into applications of broader scope, such as for work performance, roster planning, fatigue, and interface communication optimization.

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