Applied Ergonomics 62 (2017) 131–141

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Fatigue of Chinese railway employees and its influential factors: Structural equation modelling

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ARTICLE INFO

Article history:
Received 1 July 2016
Received in revised form
18 February 2017
Accepted 28 February 2017

Keywords:
Railway safety
Fatigue
Structural equation modelling

ABSTRACT

Fatigue is an identifiable and preventable cause of accidents in transport operations. Regarding the railway sector, incident logs and simulation studies show that employee fatigue leads to lack of alertness, impaired performance, and occurrence of incidents. China has one of the largest rail systems in the world, and Chinese railway employees work under high fatigue risks; therefore, it is important to assess their fatigue level and find the major factors leading to fatigue. We designed a questionnaire that uses Multidimensional Fatigue Instrument (MFI-20), NASA-TLX and subjective rating of work overtime feelings to assess employee fatigue. The contribution of each influential factor of fatigue was analysed using structural equation modelling. In total, 297 employees from the rail maintenance department and 227 employees from the locomotive department returned valid responses. The average scores and standard deviations for the five subscales of MFI-20, namely General Fatigue, Physical Fatigue, Reduced Activity, Reduced Motivation, and Mental Fatigue, were 2.9 (0.8), 2.8 (0.8), 2.5 (0.8), 2.5 (0.7), and 2.4 (0.8) among the rail maintenance employees and 3.5 (0.8), 3.5 (0.7), 3.3 (0.7), 3.0 (0.6), and 3.1 (0.7), respectively, among the locomotive employees. The fatigue of the locomotive employees was influenced by feelings related to working overtime (standardized $r = 0.22$) and workload (standardized $r = 0.27$). The work overtime control and physical working environment significantly influenced subjective feelings (standardized $r = -0.25$ and 0.47, respectively), while improper work/rest rhythms and an adverse physical working environment significantly increased the workload (standardized $r = 0.48$ and 0.33, respectively).

1. Introduction

Fatigue is the largest identifiable and preventable cause of accidents in transport operations (Åkerstedt, 2000). In all transportation sectors, fatigue has been attributed as the cause of incidents and accidents (Caldwell, 2001; Hill and Rothblum, 1994; Phillips, 2014). In the railway sector, incidents associated with fatigue occur at a substantial rate around the world (e.g. 1.5 cases per 100 trips determined from a review of 2270 trips in Japan during 1972 (Kogi and Ohta, 1975)). Fatigue can lead to impairment of operator safety performance, which contributes to real-world fatal accidents (Australian Transport Safety Bureau, 2015; Dorrian et al., 2007a; Rail Safety and Standards Board, 2015). In a laboratory setting, simulated trials demonstrate the relationship between fatigue and specific performance measures to confirm that fatigue leads to decrements in alertness and impairments of performance among railway employees (Dorrian et al., 2006, 2007b; Roach et al., 2001; Thomas et al., 1997).

Considering the adverse effects of fatigue, fatigue risk management is critical in railway systems to ensure the safety of the operators, passengers, and cargo. China has one of the largest railway systems in the world. There were 121,000 km of revenue generating rail tracks in the Chinese railway system by the end of 2015. By 2015, the volume of passenger transportation reached 1.2×10^{12} person · kilometres/year, the volume of cargo transportation reached 2.2×10^{12} ton · kilometres/year, and over 2 million employees were working in the railway transportation sector directly in China's railway system (National Railway Administration of People's Republic of China, 2015). Given the size of the Chinese railway system, the employees in the Chinese railway system, particularly those in the rail maintenance and locomotive departments, are generally required to work over vast regions and for long shifts. Rail maintenance employees throughout all the 18 railway bureaus in China need to repair rails, bridges, and

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http://dx.doi.org/10.1016/j.apergo.2017.02.021
0003-6870/

tunnels over vast regions (e.g. employees in Shenyang rail maintenance department are responsible for the maintenance of 9500 km of revenue generating rail tracks (Shenyang Railway Bureau, 2010)). Employees in locomotive department need to drive trains for extended trips (e.g. several lines travel from the far north of China to the south, requiring more than 50 h of travel time (Zuo, 2013)). The heavy work might bring about high fatigue risks among the railway employees, which challenges safe operations in the rail industry. Shi et al. (1995) reported that accidents in the Chinese railway system were related to the fatigue levels of railway employees. Therefore, it is necessary to assess the fatigue level of employees within the Chinese railway system and to understand how fatigue-related factors influence the fatigue level of these employees so that managerial strategies can be developed and implemented to reduce the risk of rail accidents. However, few studies focus on fatigue-related factors and their impact on the Chinese railway system.

In this study, we conducted a survey of employees from two railway departments within the Chinese railway system (i.e. rail maintenance and locomotive serving in cargo transportation) to assess the subjective fatigue level among railway employees in China. We then quantitatively specified the contribution of each influential factor to fatigue using structural equation modelling. Countermeasures to control the fatigue of Chinese railway employees were described according to the findings of the structural model.

2. Method

2.1. Literature review and survey construction

To study the fatigue of Chinese railway employees, we designed a survey to collect their fatigue-related information. A questionnaire comprising two parts was designed. The first part aimed at understanding the current fatigue status of Chinese railway employees, adapting the methods used in previous fatigue evaluations. The second part was designed to identify influential factors of fatigue and to describe how these factors influenced employee fatigue.

2.1.1. Questionnaire part I: fatigue status

To evaluate the fatigue status of Chinese railway employees, we measured their subjective assessments of fatigue state. Additionally, we collected data on task load and feelings related to working overtime as indirect measures of fatigue. The fatigue level was investigated using the Multidimensional Fatigue Inventory (MFI-20) developed by Smets et al. (1995). This 20-item self-report instrument was originally designed to measure the fatigue of patients, but it has been successfully adapted to other contexts (Boter et al., 2014). Each of the items in the MFI-20 was a statement on the recent feelings of the participant. The scoring of each item was ranked from 1 (yes, it is true) to 5 (no, that is not true), and after recoding of the scores, a higher score would indicate higher fatigue. The 20 items were organised into five subscales, with four items in each of the following subscales: General Fatigue, Physical Fatigue, Mental Fatigue, Reduced Motivation, and Reduced Activity. The average score of the four items indicated the fatigue level in each subscale. Participants' workload was measured using NASA-TLX (Task Load Index; Hart and Staveland, 1988), which reflects subjective task load in six dimensions: Mental Demand, Physical Demand, Temporal Demand, Performance, Physical Effort, and Frustration. In each dimension, a 1 (low task load) to 21 (high task load) scale was used to collect the perceived load level of the participants. The NASA-TLX score was obtained by converting the 1 to 21-point scale to a 0 to 100-point scale (Dadashi et al., 2013; Fallahi et al., 2016). Five-point Likert scales ranging from 1 (optimistic) to 5 (pessimistic) were used to collect the feelings (joy, effort, and stress) of employees regarding working overtime.

2.1.2. Questionnaire part II: fatigue-related factors

The factors proven to influence fatigue in previous studies were categorized into groups (see Table 1 for the summary). Items were designed along each fatigue-related factor group to describe how these factors performed in the Chinese railway system. We also conducted a focus group interview with the front-line employees and managers in each of the two target departments (rail maintenance and locomotive) to explore the specific conditions in the Chinese railway system; we subsequently modified the item/factor design of the questionnaire to reflect the specific fatigue problems in the Chinese railway system.

As described by the interviewees, there were three types of overtime work in the Chinese railway system: overload, overwork, and on-call, hereafter abbreviated as 'OL,' 'OW,' and 'OC,' respectively. 'Overload' referred to the cases in which the actual duration of a specific task was longer than the suggested working period. 'Overwork' referred to the instances in which the employees were required to work overtime. This type of overtime was not included in the employee contract, and the duration for a specific task was not longer than the suggested working period. 'On-call' referred to the situations in which the employees were off-duty but they had to keep alertness for emergency tasks. For the rail maintenance employees, their shifts were categorized as 'ordinary work day' shifts and 'holiday' shifts. They may encounter all three cases of overtime work, i.e. overload (OL), overwork (OW), and on-call (OC). For the locomotive employees, their shifts were categorized as either 'day shift' or 'night shift,' and they only had overload cases (OL) and on-call cases (OC). In addition to the problems of working overtime, commute was also a problem mentioned by the employees. The long distances between home and the working spots made the commute very inconvenient. Instead of travelling between home and work by bus or by trains, the employees sometimes rested at working places.

Generally, we found that work schedules and job demands were commonly mentioned work-related factors leading to fatigue among railway employees. Furthermore, personal factors also significantly influenced fatigue (e.g. demographic characteristics, health status, working conditions, physical exercise, occupational factors, and life outside work). Based on the findings, six factor groups were designed: 1) personal information; 2) physical working environment; 3) work demand and job control; 4) work overtime reward; 5) rest quality; and 6) commute. The items in each factor group and literature verifying the relationship between these factors and fatigue are listed in Table 1.

2.2. Data analysis

Considering the differences in job demands and work schedules between the rail maintenance and locomotive departments, we analysed the data for these two departments separately with similar procedures. We evaluated the fatigue status, task load, and feelings related to working overtime by the mean scores of the items. The correlations of each item and fatigue-related measures were calculated. After screening out the items that were not significantly related to MFI-20 and NASA-TLX, we assessed the appropriateness of factor analysis on the remaining items using the Kaiser-Meyer-Olkin test and Bartlett's test. An overall Measure of Sample Adequacy (MSA) greater than 0.70 and a Bartlett's p-value less than 0.01 indicated that the items could be used in subsequent factor analysis. We conducted exploratory factor analysis (EFA) with orthogonal rotation to modify the original structure of the