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博士論文

鐵路司機員對工作壓力之感認及持續駕駛對事故風險影響之研究

Exploring the Perception of Job Stress and the Effect of Consecutive Driving on Accident Risk for Train Drivers

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摘要

本研究主要是探討鐵路司機員在駕駛中面臨的不同壓力源時，對這些壓力源的難易度的感認，及持續駕駛對事故風險影響的研究。

本研究第一部份是發展一套鐵路司機員面臨不同壓力源的量表，再經過模式的分析，而量測出司機員對不同壓力源感受不同難度順序。研究程序是收集鐵路司機員不同的壓力源，經由與鐵路員工進行焦點團體法的討論及鐵路專家質與量的分析，產生本研究的問卷即是司機員覺得較難克服的壓力源，再將此問卷對台鐵局的司機員進行普查，將回收資料進行檢定後，再利用 Rasch 模式進行分析，經信、效度檢定，而得到司機員面臨駕駛中不同壓力源時，感受的不同難度。從本研究中，發現台鐵司機員覺得外在環境的壓力源最難克服，本研究也提供了減輕司機員壓力的策略，協助鐵路安全的管理。

第二部份是檢視駕駛時間與司機員責任事故的關係，進而分析持續駕駛與事故風險的關係。首先收集 1996 到 2006 年司機員駕駛時間及責任事故的資料，然後分別算出客

車及貨車不同時段的事故率。本研究結果發現不論客車或貨車，事故風險隨著時駕駛時間的增加而增加，且駕駛時間在 4 小時後，其事故率為開始駕駛第 1 小時的 2 倍，且發現貨物列車有額外的事故風險，可能的原因是第 1 小時貨車在調車場從事調車工作，因調車場路線配置較複雜且僅是半自動聯鎖控制，所以較容易發生事故。從研究中也發現，火車駕駛比公路駕駛的事故風險隨著駕駛時間的增加上升較快，可能原因為火車駕駛的工作壓力較大且較單調的駕駛環境所致。為了降低人為的事故風險，建議採取加強安全設備及司機員訓練和建立嚴謹的稽核制度。

關鍵詞：壓力源、曝光量、事故率、持續駕駛、鐵路安全、Rasch 模式

Exploring the Perception of Job Stress and the Effect of Consecutive Driving on Accident Risk for Train Drivers

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ABSTRACT

This study explores the difficulties of various stressors for train drivers, as well as to identify the relationship between hours of consecutive driving and train accident risk.

The first step was to develop an approach to measure the difficulties of various stressors for train drivers. Through focus group discussions and experts' judgments, a questionnaire was designed to explore the stressors confronted by train drivers while driving. A census survey was used to collect responses of train drivers from the Taiwan Railway Administration (TRA), and the Rasch model, which can estimate values on an interval scale from ordinal responses, was then applied to explore the perceived difficulties of various stressors to be confronted while driving. The study results showed that most of the critical stressors come from the external driving environment. The study results provide valuable information about the stressors confronted by train drivers, and provide consultation assistance on railway safety management.

The second part of the study examined the relationship between driver responsible accidents and on-board driving hours to determine the effect of consecutive driving hours on accident risk. The data collected from the Taiwan Railway Administration for the period 1996-2006 was used to compute accident rates for varied accumulated driving hours for passenger and freight trains. The results showed that accident risk grew with increased consecutive driving hours for both passenger and freight trains, and doubled that of the first hour after four consecutive hours of driving. Additional accident risk was found for freight trains during the first hour due to required shunting in the marshalling yards where there are complex track layouts and semi-automatic traffic controls. Also, accident risk for train driving increased more quickly over consecutive driving hours than for automobile driving, and accumulated fatigue caused by high working pressure and monotony of the working environment are considered to be part of the reason. To prevent human error accidents, enhancing safety equipment, driver training programs, and establishing a sound auditing system are suggested and discussed.

Key words: Stressor, Exposure, Accident Rate, Consecutive Driving, Railway Safety, Rasch Model

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CHAPTER 1 INTRODUCTION

Train driving is a job that entails many demands and responsibilities. A train driver is responsible for both the safety and punctuality of train operations; a job that requires a high level of concentration and alertness to react to oncoming signals, information, switches, and the immediate environment (Kecklund et al., 1999). Train driving relies heavily on numerous cognitive functions, including sustained attention, object detection and recognition, memory, planning, decision-making, and workload management (Reinach and Raslear, 2001). Although driving the train on an exclusive track, a train driver is required to maintain a high degree of vigilance, often over a prolonged period of time, while responding to stimuli throughout the entire journey. Interpreting signs is a constant requirement in order to recognize malfunctions, conflicts, or the need for clarification. Moreover, because of the low coefficient of friction between wheels and rails, and also the delay in braking response, trains cannot stop quickly when encountering obstacles or dangerous signs. An error in any area may have serious consequences for the safety of passengers and train crews. Given this, reducing possible errors of train drivers is an urgent topic for railway safety.

1.1 Research Motivation

Train drivers are exposed to a demanding psychosocial working environment, which includes solitary work, limited opportunities for socializing with colleagues, and a heavy responsibility for operation of the train. Those factors give rise to an enormous workload and restrict a driver's ability to decide how the job should be done. Hence, train drivers have a high risk of accidents and driver error. The empirical data shows that driver-responsible accidents made up 31 % of the total from 1996 to 2004. Those accidents were determined by the Accident Investigation Prevention Committee of the Taiwan Railway Administration (TRA) to be caused by driver error. Similarly, train driver-error accidents totaled 38% of all accidents that occurred during the period of 1970-1998 in Norway (Jernbaneverket, 1999). The extremely serious problem of driver error should not only be noticed but also explored for possible causes.

The relevant research on driver error is categorized as a field of driver human-factors analysis. There is still a dearth of human factors studies in the train driver sector, particularly in comparison with research on safety used in aviation, road transportation, and process industries. There is a great need to perform more scientific studies of human factors for railway safety (Kecklund et. al., 2001; Wilson, 2006). According to previous human factor studies of train drivers, there are many factors that cause train driver error. Those include irregular working hours (Akerstedt et al., 1980); physical working environment (Netterstom et al., 1981); fatigue (Beruskens, 2000; Kristal-Boneh, 1996); stress (Gaillard, 1993); consecutive driving (Gouin et al, 2001) and mental workload (Meijman, 1997). Moreover, Kecklund et al. (1999) studied eighty accident reports from the period 1980-1997 in Sweden and found that in about one-third of the accidents stress and fatigue seem to have been contributing factors. These finding are consistent with other previous studies that found stress and fatigue to be important traffic accidents risk factor (e.g., Connor et al., 2002, Hanowski et al., 2003; Helmereich et al., 1990; Horne and Reyner, 1995; Hudoklin, 1996, Philip et al., 2001). But fatigue have direct relation with the consecutive driving, driving behavior is exemplified as information management (Shinar, 1978), driving and working for a sustained period of time can generate fatigue (Okogbaa et al., 1994; Smiley, 1998; Sussman and Coplen, 2000) so drivers would not be able to maintain the level of driving safety under conditions of continuous driving (Dinges, 1995; Horne and Reyner, 1995).

Efficient railway management needs to find train drivers' stressors and ways to reduce them, as well as fatigue happen. Hence, this study will try to identify the critical human factors associated with various stressors for train driver during driving, and identify the relationship between consecutive driving and train accident risk. Then, suggestions will be offered to reduce stress and to arrange reasonable working shift in order to increase railway safety.

1.2 Research Objectives

A railway traffic system is a complex man-machine system. Human unreliability can seriously affect system functioning; therefore, an investigation of possible human errors in the system is worthwhile. This study develops an effective approach to exploring drivers' job stressors, and explores the relationship between hours of consecutive driving and accident risk.

The first purpose of this study was to develop an approach to measure various train drivers' job stressors difficulty for safe driving. Variables can be 'manifest' or 'latent'. Manifest variables can be observed and measured publicly. Most physical variables (e.g., length, weight, force, etc.) are manifest. Latent variables, on the other hand, are inferred from judgments. Most psychological variables are latent; they are inferred from subjects' reports or observer judgments of subjects' behavior. The job stressors in this study are all latent variables, which are inferred subjective judgments by the respondents. This study will first identify possible train driver job stressors, and then develop an approach to measure the different difficulties of various stressors for train drivers. Based on the findings of the study, various problem areas serving as job stressors for train drivers will be understood. It offers valuable information about the stressors confronting train drivers, and provides the consultative assistance regarding railway safety management. The results will also provide guidance in how to distribute limit resources in accordance with the different conditions. The optimal benefit of safety policy is suggested.

This study's other purpose is to explore the effect of consecutive driving on accident risk, as well as to examine the difference in accident rates over time between passenger and freight train driving. This helps to identify the relationship between consecutive driving and accident risk for train drivers. Since, different work requirements exist between passenger and freight train driving, the results may also reveal some important insights regarding accident risk in these two areas. For example, freight train drivers usually have irregular work schedules, boredom during operations (Sussman and Coplen, 2000), and a higher proportion of night operation problems (Jackson, 2005). Hence, passenger and freight train accident risks were analyzed separately. In undertaking a study of this type, *exposure* should be operationally defined and data collected. In the context of this type of study, Chapman (1973) defined the concept of *exposure* as the amount of opportunity to be involved in an accident that a driver or traffic system experienced. The purpose of using exposure as an independent variable is to equalize differences in "intensity of use" so as to make reasonable safety comparisons between different entities or time periods. Then, the accidents caused by train drivers' errors should also be defined and collected during study period as a dependent variable. Based on the collected data, accident rates for each time slot could be measured by dividing the number of accidents that occurred in one time slot by its exposure, indicating the accident risk for each time slot. The results of the study will be beneficial in making decisions regarding what constitutes a reasonable and safe working shift, as well as contributing to suggestions regarding strategies to improve railway safety.

1.3 Overview of thesis

This thesis contains six chapters, which are organized as follows. Chapter 1 introduces our research motivations, objectives, and contributions. Chapter 2 presents the results of a literature review on previous human factors analyses of train drivers, the relationship between human factors and railway accidents, the relationship between stress and railway safety, and examines consecutive driving as a contributing risk factor in train accidents. Chapter 3 illustrates our methodology to explore perceived stressors for train drivers and calculates accident risk of driving in different time slots. Chapter 4 empirical study demonstrates the different difficulties of various stressors' during train driving. And, we discuss our findings and draw conclusions. Chapter 5 empirical study demonstrates the accident rates for different numbers of hours of consecutive driving of passenger and freight trains. And, we discuss our results and draw conclusions. At the end of the thesis, in chapter 6, we provide suggestions regarding strategies to improve railway safety and propose suggestions for future study. A flowchart of the research project is shown in Figure 1-1.

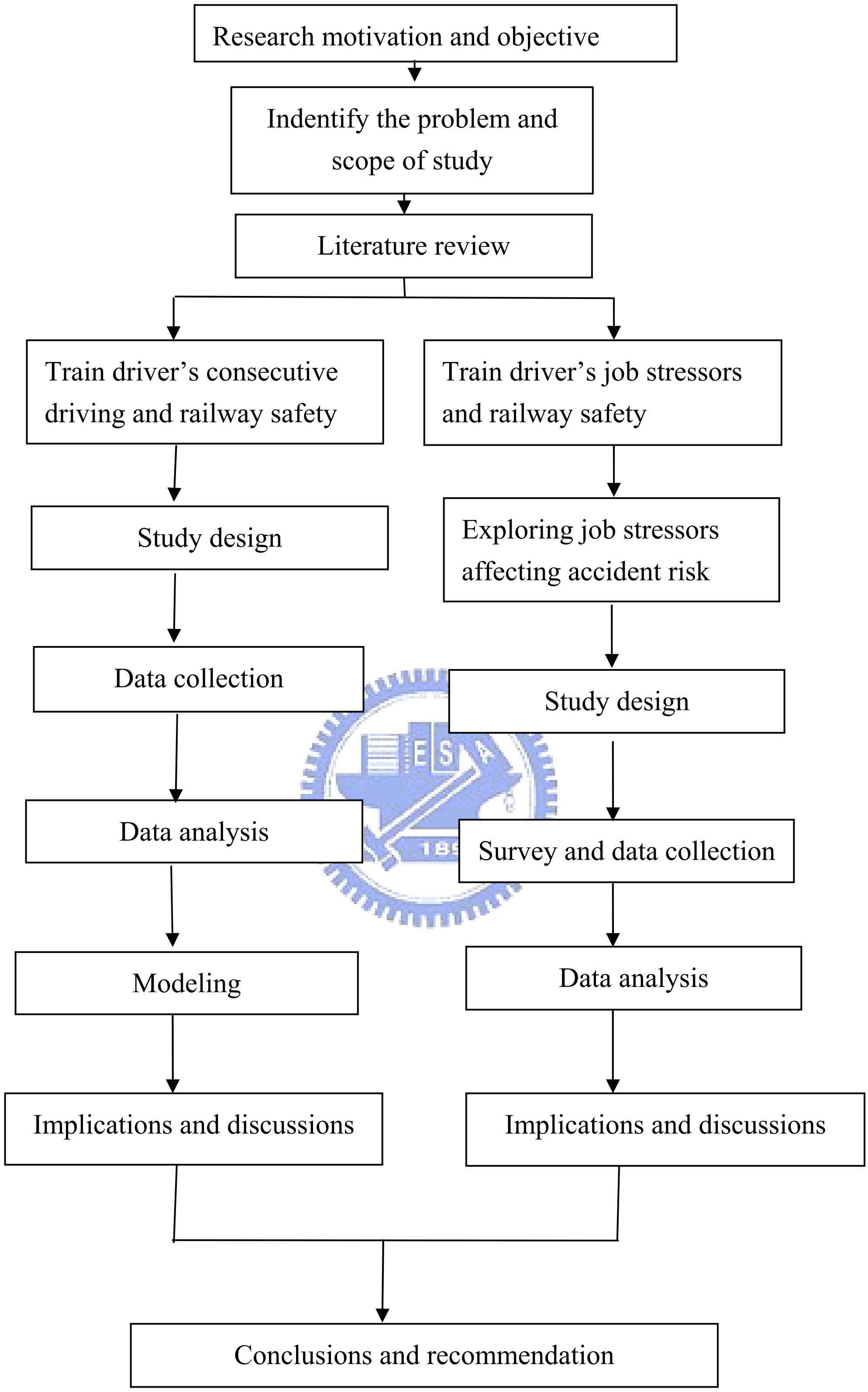

Fig. 1-1 The flow chart of research

CHAPTER 2 LITERATURE REVIEW

2.1 Human factor for railway safety

In every country with a rail network of any importance, the relevant operational, regulatory, and government bodies are trying to achieve something similar. This is, to move more people and goods, on time and safely, to satisfaction of their customers. Rail human factors is not limited in its contribution in terms of providing dimensional and performance information for design of equipment, interfaces, and workspaces (e.g., train cab design), working environments (e.g., signal boxes), minimization of risk from manual handling (e.g., track working), and design of information display systems (e.g., lineside signage or train movement displays). Rail human factors is increasingly working at a systems level, being central to systems engineering. The drive behind this comes from contributions such as better understanding of organizational failure in accidents (Reason, 1997), acceptance that cognitive task performance is situated in a setting that it strongly influences (Nardi, 1993), and is spread across people, places, and time (Hutchins, 1995).

Elms' (2001) research certified that 1/3 of railway accidents and personnel casualties are caused by human factors, which is a greater effect than for technical factor. Approximate 60%

to 90% of accidents are caused by human factors, and the most important factor in railway operation safety is human reliability (Dickens, 1992). The focus of rail human factors research includes signalers and controllers; drivers; station and on-train staff; planners, engineers, and managers; track (maintenance) workers; passengers and the general public. However, the drivers are in a critical role for railway safety.

Treat's (1977) study stated that more than 90% of human factor-related accidents are related to drivers, which is also the leading cause of accidents. Ugajin (1999) investigated the total number of railway accidents that occurred in Japan in 1997 and found that 40% of these accidents were due to human factors on the part of drivers. According to Hall (1997), driver errors accounted for approximately 46% (N = 18) of the registered accidents during period 1970-1997 in the U.K. During the period 1970-1998 in Norway, train drivers error accidents accounted for 38% of all accidents that occurred (Jernbaneverket, 1999). In addition, driver responsible accidents made up 31% of the total accidents in Taiwan Railway Administration (TRA, 2006). It is our crucial on-going mission to keep accidents like these caused by human factors of train drivers from occurring, and to contribute to establishing methods for preventing them.

2.2 Human factors research for train drivers

The current research addresses the fundamental elements of the train driver's role and performance, including route knowledge and the underlying psychological components of train driving (Farring-Darby et al., 2005; Jansson et al., 2006; McLeod et al., 2005). Much research in this area has investigated the potential causes of human error (Reason et al., 1994) and the extent to which the in-cab environment supports the driver's ability to maintain situational awareness (Endsley et al., 2003). A part of reducing the potential for driver error and increasing effective (on-time) performance lies in the design of jobs and job aids (Kecklund et al., 2001) as well as understanding and optimizing – neither too high nor too low–workloads.

There has been, in particular, a broad and relatively well-studied research field in the area of train driver vigilance and perception, in terms of their recognition of and acting upon signs and signals. This includes investigations into signals passed at danger (SPAD) and the appropriate design of signage and signaling systems. Recently in the UK, motivated by the Ladbroke Grove rail crash and by reports of incidents not leading to injury, there have been various studies of SPADs (Pasquini et al., 2004; Turner et al., 2003), predictive tools (Wright et al., 2007), and development of tools to identify the risk of SPADs at different signals (Holywell, 2005; Lowe and Turner, 2005). Because of the desire to find a technological fix to such incidents, there has been related research into the use of vigilance devices and reminder appliances (McLeod et al., 2005; Whitlock et al., 2005). Modern observation techniques, such as the measurement of eye movements and of direction of gaze, allow interpretation of drivers' behavior and of the possible reasons for it (Luke, 2006; Merat et al., 2002).

One use of eye tracking is as a technique to investigate the onset, manifestation, and consequences of fatigue (e.g., dwell or fixation times will become longer as people get fatigued). Studies have also examined the prevalence of sleep apnea (Hack et al., 2007). Research related to fatigue has also examined the effects of driver work shift (Hawarth and Tapas, 2001), used observation and self-report to study the effects of long (>6 h) journey times (Gouin et al., 2001), run simulator studies (Dorrian et al., 2005), and developed checklist tools such as the Fatigue Index (Cotterill and Jones, 2005), as well as prototypical preferred roster patterns (Ashton and Fowler, 2005). Related to impairment through fatigue is the incidence and effects of drugs and alcohol use on performance (Ervasti et al., 2007).

2.3 The major factors affecting accident risk by train drivers

Prolonged attention is the most significant factor influencing the occurrence of accidents in human factors, especially errors related to railway traffic signals (Grahan, 1997). Factors that result in the reduction of prolonged attention are fatigue, noise (Hancock, 1990), particularly cold or hot temperatures (Davies and Parasuraman, 1981), time of day (Folkard and Monk, 1997); alcohol effects (Horne and Gibbons, 1991), stress (Kecklund, 1999) and differences in experience (Bisseret, 1988). It has been found that railway drivers' negligence of traffic signals is due to distraction, which is also the major cause of reductions in prolonged attention (Haga, 1984). In addition, temperature, humidity, and noise within the driver's cabin are environment factors influencing prolonged attention (Smiley, 1990). Finally, most of the evidence indicates that decreasing prolonged attention has an adverse effect on performance and safety for train drivers.

Previous studies are confirmed that consecutive driving (Dinges, 1995; Horne and Reyncr, 1995) and stress (Hockey and Hamilton, 1993; Kecklund et al., 1999; Zakay, 1993) decrease prolonged attention. For improving railway safety, it is important to identify the most critical human factors influencing job stressors while train driving. In so doing, it is hoped the results will aid in mitigating job stress for train drivers. At the same time, it is also important to understand the relationship between consecutive driving and train accident risk.

2.3.1 Stress and railway safety

The concept of stress is built upon three principle components: the environment or the demands of the situational context (the environment here is identified as the work situation); the capacity and resources the individual has for dealing with these demands; the individual's physiological, psychological and behavioral reactions (Kalimo et al., 1998). Stress in its negative sense implies an imbalance between the demands of the environment and the capacity of the individual to cope, or that the individual's expectations exceed what is offered by the environment. If a stress situation cannot be controlled, negative reactions arise (e.g., discontent, worry, fear, frustration, and a lack of pleasure or motivation at work (Brown, 1980), or endocrine or physiological responses such as increased heart rate (Robertson, 1988)).

There are numerous factors and situations that can cause stress at work and some of the most common are difficult social relationships, problems with the organization, poor career opportunities, strenuous physical conditions, excessive workloads and time pressure, demands are too low, little decision-making opportunity, no stimulation, lack of control and an inability to exert influence on the job. But, stress conditions experienced by humans affect performance and reliability (Dhillon, 1986). Zakay (1993) stated that increased stress can lead to reduced productivity and performance, and performance is generally shown to deteriorate under some sources of load (e.g., noise, vibrations and heat) (Hockey and Hamilton, 1993).

One reason why performance is often impaired by stress is that, under favorable conditions, many people are able to deal with moderate levels of stress by mobilizing extra (mental) resources and focusing themselves on the task (Hockey and Wastell, 1998; Schonflug, 1983; Meijman, 1997). There have been a number of studies that link highly aroused stress states with impaired decision making capabilities (Baddeley, 1972), decreased situational awareness (Vidulich et al., 1994), and degraded performance which impaired driving ability (Helmereich et al., 1990). Hudoklin (1996) mentioned that stress levels above a moderate level cause a decrease in human reliability, and lower driver reliability can cause lower driver performance, which increases accident rates for railways. In order to improve railway safety, it is necessary to measure train drivers' conceptualization of stressors during the driving process. However, very little is known about the strategies people use for coping with stress and, in real situations, those coping mechanisms influence performance and safety.

Previous studies have explored different job stressor for train drivers. For example, Chang (2005) applied Cooper's Occupational Stress Indicator to explore job stress in train drivers, and Yu (1998) examined the factors in job stress and strain using the National Industry Safety and Healthy Research Institute's generic job stress questionnaire. It should be noted, those studies utilized only a general industry job stress questionnaire. Because the railway is a specialized field, a specific questionnaire needs to be designed for measuring job stress in train drivers.

Table 2-1 Stressors that influence driving safety

Dimension	Latent stressor
Equipment	Fixed equipment: route equipment (including railroad ties, bridges, track or overhead power lines), safety equipment (including ATW/ATS), communication equipment, signal system, signal device position, signing site for construction
	Mobile equipment: train type, train length, train fault, train equipment, train emergency device
Environment	Internal environment: control cabin space, noise, vibration, temperature
	External environment: weather conditions (including raining, temperature or visibility), night driving, road signal confusion, route slope, effect of buildings and trees, passing attended (unattended) grade crossing, trespassing by people or animals
Management	Work shift: mixed shifts, length of duty time, duty break
	Management measures: training (including simple troubleshooting, operating different types of trains, operating skill, learning operation rules), monotonous tasks, work assurance, promotional channel, performance evaluation, single-driver or two-driver duty service, supervisor communication and management style, work requirements (including safety rule examination, call-response evaluation, physical examination specification)

As a first step in that direction, we apply rail system safety theory as proposed by Zhao et al. (2003), which includes equipment, environment, management and driver as the four dimensions of a railway safety system. Furthermore, based on relevant literature (e.g., Chang et al., 2005; Cooper et al., 1988; Dorrian 2006, Yu et al., 1998), those variables fit particularly well in Taiwan. The general key stressors that influence train driver safety are shown in Table 2-1.

Stressors related to equipment problems in railway systems during operation can be divided into fixed equipment and mobile equipment. Stressors related to fixed equipment include whether the railroad ties, track, and overhead power lines are functioning normally, and whether the signal devices are mounted and functioning properly. Ohlsson (1990) pointed out that, as drivers rely more on driving safety equipment, such as automatic train warning (ATW) or automatic train stop (ATS), the availability of such safety equipment would affect a driver's response, thus causing huge work stress for a driver. The potential problems with mobile equipment include locomotive or passenger car conditions. Since the train is operated via many electronic devices, any malfunctioning equipment would affect the safety of the train and drivers. Moreover, due to limited control cabin space and lack of toilets, drivers' physiological needs cannot be met while on duty, thus bringing added stress to driving.

Apart from stress related to equipment, the environment inside and outside the locomotive can also bring stress to drivers on duty. Internal environment refers to the work environment in the control cabin. Akerstedt (1980) indicated that the space, noise, temperature, and vibration of the control cabin could make drivers uncomfortable, and monotonous train driving distracted drivers' attention; all these factors resulted in stress on drivers, and further jeopardized their driving safety (Edkins and Pollock, 1997). The external environmental factors that bring driving safety stress include: (1) too cold, too hot, foggy, and snowy days that hamper drivers' responses and driving safety (Park, 1987); (2) weather or environmental changes (e.g., growing trees along the railway) make it hard for drivers to identify fixed signals, thus affecting their response speed; and (3) when a train is passing a railway grade crossing and there are cars or pedestrians intruding. The external environment poses a serious threat to train driving safety, and involves unexpected risks that are out of the control of train drivers, which results in additional sources of stress for train drivers.

Besides tangible driving stressors, such as equipment and environment factors, drivers also face intangible stress from management. Kolmodin-Hedman (1975), Akerstedt (1980), and Netterstom (1981) suggested that mixed work shifts and irregular work timed are main factors contributing to drivers' work stress and affect their driving safety. Due to limitations in work time and shift switch sites, train drivers often have to serve prolonged shifts, thus facing more stress. In addition, as pointed out by Edkins (1997), without enough motivation or aspiration, train drivers would be stressed about personal uncertainty of the future. Yu (1998) also mentioned that uncertainty about work is an important source of stress for train drivers. Therefore, reasonable supervision and promotional channels could cause stress on drivers to a variable extent. Tsang and Wilson (1997) pointed out that, if work demand is beyond one's capability, then higher work stress would be brought to drivers, leading to more errors. Therefore, the availability of sufficient training so that drivers can drive various types of locomotives, execute simple locomotive troubleshooting procedures, and master operating skills to respond to driving needs, could also cause considerable work stress for drivers. Finally, as drivers have to make immediate responses to various situations when driving (such as signal identification or responding to obstacles), work stress for drivers in "single-driver duty" service is naturally higher than for those in "two-driver duty" due to lack of warning and aids.

2.3.2 Consecutive driving and railway safety

Driving behavior is exemplified as information management; the efficiency of information management is closely related to the conscious status of driver. Driving and working for a sustained period of time can generate fatigue (Okogbaa et al., 1994; Smiley, 1998; Sussman and Coplen, 2000) so drivers would not be able to maintain the level of driving safety under conditions of continuous driving (Dinges, 1995; Horne and Reyncr, 1995). Consecutive driving can decrease vigilance, which is a major factor accounting for driver error. Moreover, consecutive driving is one of the greatest causes of traffic accidents (Harris, 1977; Hermann, 2004; Li et al., 2005). The accident rate goes up significantly as the number of consecutive driving hour increases for highway truck operations (Chang and Hwang, 1991). According to a National Transportation Safety Board (NTSB) analysis of railway accident research from 1990 to 1999 in America, it also shows that consecutive driving is the major cause of train collisions and accident (Sussman and Coplen, 2000). Therefore, the risk of being involved in a railway accident is expected to increase as the number of hours of consecutive driving increases.

Few studies have examined the risk of train drivers' accidents as a function of consecutive driving time. Wharf (1993) analyzed the frequency of signals passed at danger (SPAD) per million driving hours for British Rail train drivers and found a distinct peak during the second and third hours of duty, followed by a relatively low level, which then subsequently increased again. Based on an investigation of accident records from the Swedish National Rail Administration during the period 1980–1997, Kecklund et al. (1999) also indicated that a risk peak existed at the third hour of the shift, followed by a period of low risk, which then showed an exponential increase in risk over hours on duty. Additionally, a Dutch study (van der Flier and Schoonman, 1988) explored the relationship between driver errors (missed signals) and working hours and found that the probability of error is at its peak during the second and third hours of the shift. Kecklund (2001) and van der Flier (1988) also discussed possible reasons for the findings and speculated that such mistakes are due to fatigue accumulated from previous shifts or that drivers might relax too much during the start of a shift.

However, little has been said about the definition of working time and types of train drivers in the previous studies. Actually, given the work tasks and missions assigned to TRA train drivers, a work shift can usually be divided into three sequential stages: pre-starting, on-board driving, and post-arrival stages (Figure 2-1). Using the start and end times of shifts, including the static pre-driving and post-arrival times mostly collected for payroll or other reasons as the input, in most studies (Fletcher et al., 2001) may confound the time effect on risk of accidents for actual on-board driving.

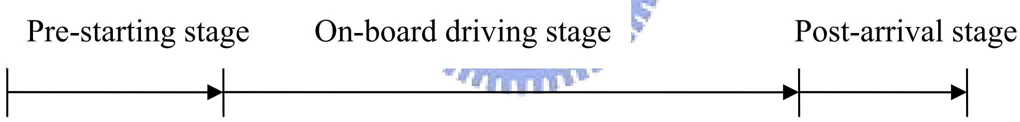

Figure 2-1 Three stages of one driver's work shift under TRA operation.

In addition, ignoring differences between passenger and freight train drivers in accident risk may result in the loss of some important implications due to their different working environments and requirements. Freight train drivers usually have irregular work schedules, boredom during operations (Sussman and Coplen, 2000), and a higher proportion of night operation problems (Jackson, 2005). It is well-documented that irregular shift workers suffer from restless sleep while undertaking early morning and night-time work (Akerstedt and

Folkard, 1996; Pollard, 1996). Furthermore, shunting in marshalling yards by the starting station is exclusively required for freight trains. Shunting is a notoriously unsafe activity (Elms, 2001); therefore, freight train driving is expected to have more accident risk than passenger train driving because it has more wearying and complex work requirements.

CHAPTER 3 METHODOLOGY

3.1 The train driver's stressors

This study applied rail system safety theory proposed by Zhao et al. (2003) and designed variables that fit particularly well in Taiwan. The different stressors for train driver as shown Table 2-1 are all latent variables, which are inferred from subjective judgments by the respondents. Researchers in transportation have directed their attention to the relationship between one's latent consideration and his/her response. After multiple related studies were conducted, one was left to question: Were convincible and comparable measures on the related latent constructs obtained? Such a challenge in the measurement is critical, especially for those latent variables that have no normalized scales (the norms) to serve as a reference of measurement. In practice, researchers usually measure such latent constructs by collecting respondents' opinions, and those opinions are mostly represented by items with ordinal scales (e.g. the Likert-type scale) in questionnaires. If these ordinal categories in the items are naively assigned some incremental integers, such integers can only represent the rank among categories in a single item, which has limitations in statistical inference. For this reason, one of the aims of the study is to demonstrate approaches in how to measure a newly-specified latent construct; especially for ensuring the results on the trait level can serve as reasonable and effective factors for further statistical inference.

3.2 Methods for measuring a latent trait

To provide an objective and valid rating scales for solving such a problem, the item response model has been developed and improved. Item response theory (IRT), which is a model-based measurement in which trait level estimates depend on both persons' responses and on the properties of the item that were administered, has become the mainstream of psychological measurement (Hambleton and Swaminathan, 1978). Among the various models of IRT, the Rasch model is one that is widely applied for exploring psychological constructs. A review of IRT and the Rasch model are provided in the following parts of this chapter.

3.2.1 Review of Item Response Theory

Psychological constructs are usually conceptualized as latent variables that underlie behavior. Latent variables are assumed as unobservable entities that influence the manifest variables (e.g., test scores or item responses). Thus the observation of these manifest variables can only serve as indicators of a person's standing on the latent variables. As a result, measurements of psychological constructs are usually indirect; that is, latent variables are measured by observing behavior on relevant tasks or items. A measurement theory in psychology must provide a rationale that both persons and items on a psychological dimension should be inferred from behavior. Based on such a rationale, item response theory has been elaborated to serve as a methodology in developing or executing a psychological test.

Item response models are designed to estimate the values of latent variables on an interval scale from item scores that form an ordinal scale. Items scores, or linear combinations of item scores, are called "raw scores". If the raw scores form a unidimensional ordinal scale, then when the data are displayed with the items ordered according to item raw scores (the sum of each subject's responses to each item) and with the subjects ordered according to individual raw scores (the sum of each subject's responses across all items), the data matrix will conform to a Guttman scale (Guttman, 1950).

A Guttman scale means that item raw scores are monotonic with item difficulty, and test scores are monotonic with the subject's ability. The sum of scores across items for each person is the person's raw score and the sum of scores across people for each item is item's raw scores. If the raw scores form a Guttman scale, then when people are rank-ordered by person raw score and items are rank-ordered by item raw scores, the person rankings will be the same for each item and item rankings will be the same for each person. There are likely to be inconsistencies with this rigid rule, but the overall statistical pattern of responses should agree with these expectations. The more closely the data agree with the Guttman scale, the more likely it is that the raw scores represent at least an ordinal scale.

Item response theory begins with an explicit definition of the latent variable that the instrument is supposed to measure, θ. This variable is an attribute of the respondent and will have a unique value for each respondent n, θ_n. Each item of the instrument requires a specific value (threshold) of θ to elicit a particular response from the respondent 50% (or some other criterion percentage) of the time. The response threshold for item i, b_i, is in the same units as θ. The probability that respondent n will give a particular response to item i can be modeled with Birnbaum's logistic:

$$P(\theta_{ni}) = c + \frac{d-c}{1+e^{-a_i(\theta_n - b_i)}} \quad (1)$$

where c is the lower performance asymptote ($0 \le c < 1$), d is the upper performance asymptote ($0 < d \le 1$), and a_i controls the slope of item response function. The parameter c usually refers to chance performance, d is controlled by the rate of careless response errors, and a is the discriminability of the item. In the case of our study, there is no "right" or "wrong" answer. Therefore, c is equal to 0 and d is equal to 1 in Eq. (1). If θ and

b are in the same units, then item-dependent variations in the slope of the item-response function must indicate different levels of measurement noise for different items. Measurement noise could be due to instability in θ, instability in b, or instability in both. It also can be attributed to variables not under study. The parameter of discriminability, a, soaks up the variability and creates the illusion of precise estimation of person and item values. Furthermore, an item-dependent slope parameter is inconsistent to measurement theory because it implies that the measurement units vary across items (Wright, 1977). Thus we define $a = 1$, even the imprecise estimation might be made, however, the estimates of the items can be interpreted as measurements of a single variable.

The simplified item response model (d = 1, c = 0, and a_i = 1) in our case is identical to the probabilistic measurement model developed by Georg Rasch (Rasch, 1960). He deduced his model from item response theory, and proved that the person and item parameters (θ_n and b_i) are separable, and that item and person raw scores are sufficient statistics to estimate the values of the item and person parameters. Since the 1980s, Rasch models have been intensively used to estimate values on an interval scale from raw scores in psychometric studies.

3.2.2 Introduction to the Rasch Model

From 1980s, Rasch models have been widely applied in analyzing data from assessing instruments in rehabilitation medicine (Fisher, et al., 1995).To apply item response theory to our assessment of the conceptualization of job stress ability for train drivers, we begin with an explicit definition of the variable we hope to measure. Generally, the main interest of this study is to explore the ability of train driving to overcome job stress for safe driving, θ. In our hypothesis, this latent variable is constructed by the occupational stress indicators of the train drivers. Each train drivers, n, has a unique ability, θ_n, that we try to measure (the person parameter).

Depending on the conceptualization of the job stressors related to train driving, some items (stressors) will seem easy to overcome and others will be perceived as more difficult. It is reasonable to hypothesize then that train drivers with more ability will be able to overcome a greater number of items (stressors) with ease than those with less the ability. Thus, we can consider each item as requiring a specific level of ability of train driving in order to overcome the stressor and be able to drive safely. The threshold value for overcoming a job stressor is the ability required to perform item i with ease, and is, thus, the item parameter b_i.

To simplify the review of the Rasch model, consider only dichotomous responses. If train drivers respond that they can overcome an item with ease, we assign a score of 1 to that item; otherwise, we assign a score of 0. The probability that train driver n will report that he can overcome item i with ease is:

$$P(1|\theta_n, b_i) = \frac{e^{\theta_n - b_i}}{1 + e^{\theta_n - b_i}} \tag{2}$$

The probability that train drivers n will report that he cannot overcome item i with ease is:

$$P(0|\theta_n, b_i) = 1 - P(1|\theta_n, b_i) = \frac{1}{1 + e^{\theta_n - b_i}} \tag{3}$$

The odds that train driver n will report that he overcame item i with ease is:

$$\frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = e^{\theta_n - b_i} \tag{4}$$

and the log of the odds ratio, or "logit", is:

$$\ln \frac{P(1|\theta_n, b_i)}{P(0|\theta_n, b_i)} = \theta_n - b_i \tag{5}$$

which isolates the parameters of interest.

The person and item parameters can be estimated from response odds ratios in the data set using a constrained form of Eq. (5). Because there are no free model parameters, the Rasch model is prescriptive rather than descriptive. That is, the data have to fit the model, or the assumptions of the model must be rejected for the data set. The model assumptions are: (1) the subjects used to test the model differ in their abilities to overcome job stressors related to safe train driving, (2) the subjects' responses to items depends only on their ability to overcome the job stressors, (3) subjects' response are probabilistic and conditional on their ability to overcome the job stressors, and (4) the odds of performance on an item increases monotonically with the difference between the subjects' ability θ_n and the perceived item difficulty b_i.

In addition to dichotomous responses, the Rasch model is modified to be applicable in polytomous rating scale instruments, such as the five point Likert scale used in our questionnaire (Andrich, 1978; Masters, 1982). The modified Rasch model assumes b_{ix} as the parameter of difficulty in rating category x to item i, and assumes that Eq. (2) refers to the probability of subject n responding with rating category x rather than rating category $x-1$ to item i. In other words, we can model the log odds of the probability a person response in category x of item i compared to category $x-1$ as a linear function of latent ability θ_n, and the relative difficulty of category b_{ix}:

$$\ln\left(\frac{P_{nix}}{P_{ni(x-1)}}\right)=\theta_n-b_{ix} \qquad (6)$$

Following Andrich's modification on polytomous responses in the Rasch model, there are two types of formulations that are widely applied in assessing the value of item difficulty and person ability, which are "Rating Scales Model" and "Partial Credit Model". The Rating Scales Model is used only for instruments in which the definition of the rating scale is the same for all items and, in general, the Partial Credit Model should be used when the definition of the rating scale differs from one item to the next. In sum, the Partial Credit Model is similar to the Rating Scales Model except that each item i has its own threshold parameters, F_{ix}, for each category x (Wright and Masters, 1982). This is achieved by a re-parameterization from Eq. (6):

$$b_{ix} = b_i + F_{ix} \tag{7}$$

and the Partial Credit Model becomes:

$$\ln\left(\frac{P_{nix}}{P_{ni(x-1)}}\right) = \theta_n - b_i - F_{ix} \tag{8}$$

The Partial Credit Model addresses items where: (1) credit is given for partially correct answers, (2) there is a hierarchy of cognitive demands on respondents in each item, (3) each item requires a sequence of tasks to be completed, or (4) there is a batch of ordered response items with individual thresholds for each item (Wright and Masters, 1982). In assessing the perceived physical ability of the elderly travelers, we lose the limitation of the same rating scale for all items, and adopt the Partial Credit Model for our measuring method.

The Rasch model provides estimates of the variable of interest on an interval scale, and allows us to test the validity of any psychometric instrument with an objective set of criteria. The tests of construct validity are the fit of person measures to the model, and the correlations of person and item parameter values with other variables, compared with expected correlations. The tests of content validity are the fit of individual items to the model, the estimation errors of item parameter values, and the spacing and range of item parameter values, relative to the distribution of person values.

3.2.3 Parameter estimation of the Rasch model

Based on different statistical assumptions, there are several approaches for estimating the parameters of the Rasch model. Among them, the joint maximum likelihood (JML) estimation is a relatively simple and effective way, which is also the core technique of the related computer programs: WINSTEPS and FACETS (Linacre and Wright, 1997). A simple introduction of JML estimation is given as follows.

In JML estimation, unknown construct levels are handled by using provisional trait level estimates as known values. The provisional trait level estimates themselves are improved by using subsequently estimated item parameters, which are successively improved. In other words, JML estimation is an iterative procedure which typically involves sequential estimates of person and item parameters. In the initial stage, person parameters are estimated.

The first iteration of the two-stage procedure involves specifying starting values for the item parameters so that the maximum likelihood estimates of person parameters can be obtained. Then the item parameters are estimated using the first person-parameter estimates. In the following iterations, person and item parameters are iteratively estimated using the improved person or item parameters respectively. The iterations continue until the item parameters change very little between the successive iterations (the convergence status).

JML has been extensively applied in the estimation of many IRT models. It has several advantages in applications. First, this algorithm is easily programmable. Second, JML is applicable to many IRT models. Both the 1PL IRT (e.g. the Rasch model) and 2PL IRT (e.g. the Multi-Facet Rasch Model) can be estimated with JML. Third, JML is efficient on computation. One thing has to be noted in applying the JML estimation that there is a strong limitation in applying the JML algorithm. In JML estimation, the items or persons with perfect scores (all passed or all failed) provides no information about the parameters because there are no constraints are placed on the solution.

Therefore, estimates of such items or persons with perfect scores are not available in the JML estimation. In fact, such measures of items or persons with perfect scores mostly occur in the data of educational tests but rarely in psychological exploration. the psychological exploration, items with perfect scores are regarded as inappropriate items because they provide no information on evaluating construct levels of the respondents; person with perfect scores can be also considered as an ineffective observation for their construct levels are not comparable. It is generally suggested to exclude these items or persons from the original data, or to withdraw the data and redesign the whole investigation program.

3.2.4 Reliability and validity statistics in the Rasch model

If any of items are sensitive to more than one variable distributed in the train driver sample, then the pattern of responses to those items will appear noisy or outlying relative to model expectations. Noise is assessed with the information-weighted fit statistic ('infit') which is the ratio of the mean (across train drivers) squared response residuals (relative to response expected by the model) to the mean squared residuals expected by the model. Outlying items are detected with the outlier-sensitive fit statistic ('outfit'), which is the mean ratio of the squared train driver response residuals to the expected squared train driver response residuals. These two weighted mean-squared fit statistics can be normalized and expressed in model standard deviation units (Smith, 1991; Wright and Masters, 1982). The expected values are 0, with a tolerance of ±2 standard deviation units. Positive zstd values indicate that response residuals exceed the expectations of the model, which means that the responses to the item are inconsistent with the assumptions of the model. Negative values indicate that response residuals are less than the expectations of the model, which implies some strong source of covariance that is shepherding item responses toward the expected value.

3.3 Accident rates for different timeslots of consecutive train driving hours

3.3.1 Exposure data collection

Chapman (1973) defined the concept of exposure as the amount of opportunity to be involved in an accident that a driver or traffic system experiences. In practice, exposure is the denominator when the accident rate is calculated. Dividing the accident frequency by exposure serves an important purpose; that is, equalizing differences in "intensity of use" so as to make reasonable safety comparisons between different entities or time periods. Different exposure measures have been used depending on the type of accident under investigation. Examples include vehicle miles of travel, ton-miles, passenger miles, vehicle registrations, driving hours, and number of vehicles passed. Applications of exposure vary with discussed subjects, and the good or bad of exposure design and collection usually are the decisive factors of research success. How to define exposure is critical step to find reasonable accident risk.

Throughout the literature, “distance traveled” and “time traveled” are the two most widely used measures of driving exposure to accident risk. Since different types of trains (e.g., passenger train and freight train) have different traveling speeds, distance-based exposure may not provide a fair basis for assessing the effect of fatigue generated by consecutive driving on accident risk. As such, driving hours is commonly recognized as an appropriate measure to gauge its effect on fatigue, which might influence accident risk. Therefore, “time traveled” is selected as the exposure measure in this study.

According to the jobs assigned to TRA drivers, a work shift can be divided into three sequential stages: pre-starting, on-board driving, and post-arrival (Fig. 2-1). At the pre-starting stage, a driver is required to pass an alcohol test, receive shift instructions, conduct a carriage check (e.g., brake tests, automatic train protection system, etc.), and drive the train from the origin depot to the starting station. Generally, completing all of the tasks at this stage takes about 40-60 minutes depending on different types of work shift patterns.

Trains are usually required to run to the depot at the destination station after finishing the mission. Also, drivers must go to the destination dispatching units and complete reports before going off duty. Tasks completed by drivers from destination station to destination depot, as well as back to the destination dispatching unit, are classified into the post-arrival stage, which takes about 30-40 minutes depending on the type of shift pattern.

Only, the on-board driving stage is the operating duration from the starting station to the ending station. The driving task at this stage is relatively continuous and a driver needs more concentration and alertness to operate safely. Therefore, fatigue caused by consecutive driving is expected to develop gradually and significantly influence accident risk. Shunting is exclusive to freight train driving before leaving the starting station and, since it requires continuous driving, that period is included in the on-board driving time in this study.

In addition, a complete train trip starts at the origin depot and ends at the destination depot. Hence, a shift can be classified into one of four types based on starting and ending points and different work tasks (see Table 3-1). A Type I shift means the driver departs from the origin depot and completes the shift midway in the train trip. In a Type II shift a driver initiates the shift midway in a train trip and finishes at the destination depot. In Type III, a driver initiates and completes the shift at a midpoint owing to a long train trip. When a trip is short, a driver completes the trip and is classified into the Type IV shift.

For these four shift patterns, we can identify the pre-starting instructions, trunk line driving (including shunting for freight trains), and job reporting, which are the three common tasks required for each pattern. "Trunk line driving and shunting" at the on-board driving stage is a relatively continuous job for drivers, that influences operations, occupies the main tracks, and yields available driving records. Therefore, the time spent doing on-board driving for each driver's shift can be calculated by combining train operation data with shift records, which provides valuable information to explore the effect of consecutive driving on the risk of being involved in an accident.

Table 3-1 Working items for different types of driver work shift pattern

Driver work shift pattern	Pre-starting stage			On-board driving stage	Post-arrival stage	
	Pre-starting instruction	Pre-starting check	Driving from depot to starting station	Trunk line driving (including shunting for freight train)	Driving from ending station to depot	Job reporting
Type I	V	V	V	V		V
Type II	V			V	V	V
Type III	V			V		V
Type IV	V	V	V	V	V	V

3.3.2 Collection driver responsible accidents

According to the TRA's operation rules, a train accident is defined as an event that causes more than 10 minutes delay in operation, and the related personnel are responsible for reporting the accident to the Accident Investigation Prevention Committee (AIPC). Thereafter, the accidents will be further classified into human error or non-human error accidents based on APIC's judgment. Based on this study's purpose, only the driver-responsible accidents are counted.

3.3.3 Finding accident rates for different time slots of consecutive train driving hours

Since TRA regulations limit the hours of a work shift, almost all on-board driving time is shorter than 4.5 hours. Therefore, a maximum of 4.5 hours of consecutive driving was observed in this study. To determine whether the accident rate rises as driving hours increase, the study's length of on-board driving time was further divided into several time slots; 15 minutes for each slot and 18 time slots total. According to the length of on-board driving for different shifts, they could be distributed into the 18 different time slots. A longer shift would cover more consecutive slots compared with a shorter shift. Taking 3 hours and 10 minutes of on-board driving as an example, the 3 hours were assigned to the first 12 time slots (i.e., 4 (15-minute slots per hour) × 3 = 12 slots) and the last 10 minutes were assigned to the 13th time slot. Finally, the accumulated on-board driving hours within each time slot could then be calculated.

Based on the collected data, the accident rates for each time slot could be measured by dividing the number of accidents that occurred in one time slot by its corresponding driving exposure (i.e., the on-board driving hours in the same time slot), indicating the accident risk for that time slot. That is, the accident rate for the i^{th} time slot can be expressed as

$$AR_i = A_i / H_i \tag{1}$$

where AR_i is the accident rate for the i^{th} time slot, A_i is the number of accidents that occurred in the i^{th} time slot, and H_i is the accumulated driving hours in the i^{th} time slot.

According to the above definition, the accident rates for different time slots for the consecutive driving of all trains, passenger trains and freight trains, are computed and found.

CHAPTER 4 EMPIRICAL STUDY OF THE STRESSORS FOR TRAIN DRIVERS

As was noted earlier, drivers' perceptions of stressors are all latent variables. As such, designing a questionnaire that could effectively assess the drivers' perceptions regarding those stressors was a very important step in the study.

4.1 Questionnaire design

Based on the framework of rail system safety theory (Zhao et al., 2003), as was discussed above, 43 stressors that could possibly effects driving safety were identified. After three focus group discussions with drivers at the Taipei, Changhua, and Hsinchu dispatching units, the initial list of 43 stressors was narrowed down to 28. Since this study gathered self-report data from drivers, subject matter experts (SMEs) in the areas of qualitative and quantitative research methodologies were used to ensure the questionnaire would reflect the respondents' perceptions. The qualitative method asked the SMEs to modify the items so drivers could better understand their meaning. In the quantitative method 30 SMEs from the dispatching units were asked to respond to the items, and those results were examined to ensure questionnaire fitness, as was proposed by Aiken (1996). A total of 18 stressors were finally selected as the ones most likely to impact drivers. Those items are shown in Table 4-1.

Of those items, five concerned the equipment dimension, five concerned the environment dimension, and eight concerned the management dimension.

In order for drivers to express their personal feelings fully, this questionnaire utilized a 5-point Likert-type scale, with (1) Strongly disagree; (2) Disagree; (3) Fair; (4) Agree; and (5) Strongly agree, representing the variation in drivers' perceptive difficulty of each driving stressor. A choice of "Strongly agree" indicates the driver feels this stressor is very easy to overcome, while "Strongly disagree" indicates the driver feels the stressor is very difficulty to overcome. The survey also collected data regarding age, educational level, driving experience, position, and occurrence of driver-responsible accidents. Age and driving experience are to be filled out in numbers; educational level and position are classified in 4-point categorical scales; and occurrence of driver-responsible accident has a dichotomous "Yes" or "No" response option. This study also explores whether the competency of drivers of various years of experience, ages, educational levels, job grades, and occurrence of driver-responsible accidents would vary, so as to facilitate future planning and implementation of driving safety strategies.

Table 4-1 Content of the questionnaire for train driver stressor

Item	Type	dimension
01: I feel that the vehicle acoustic warning signal device performs well and will not influence my driving safety	5-point scale	Equipment
02: I feel that railroad ties, tracks, and overhead power lines are in good condition, and will not influence my driving safety	5-point scale	Equipment
03: I feel that the ATW/ATS safety equipment functions well, and will not influence my driving safety	5-point scale	Equipment
04: I feel that temporary signals are properly positioned at route construction sites, so I can respond in time and control driving speed, and will not influence my driving safety	5-point scale	Equipment
05: I can solve physiological problems well during duty, and will not influence my driving safety	5-point scale	Equipment
06: I feel that control cabin space will not stress me and, thus, influence my driving safety	5-point scale	Environment
07: I feel that noise in the control cabin will not influence my attention to driving and influence my driving safety	5-point scale	Environment
08: During night operations, signals along the road will not influence my identification of railway signals and thus affect my driving safety	5-point scale	Environment
09: I feel that railway ramps change properly, and will not influence my driving safety due to greater slope	5-point scale	Environment
10: I feel that trees or buildings along the railway will not influence my identification of railway signals and affect my driving safety	5-point scale	Environment
11: I can arrange meal time while on duty, and that will not influence my driving safety	5-point scale	Management
12: I feel I can adapt to mixed shifts, and that will not influence my driving safety	5-point scale	Management
13: I feel that duty driving time is well arranged, and will not affect my driving safety due to excessive fatigue	5-point scale	Management
14: I feel that I am competent for a single-driver duty work schedule, and meet driving safety demands	5-point scale	Management
15: I feel that I am familiar with all locomotives and vehicles to drive, and that will not influence my driving safety	5-point scale	Management
16: I feel I am competent to handle simple locomotive faults during operation to meet driving safety demands	5-point scale	Management
17: I feel I have undergone enough training on operating skills and rules, to be sufficient to compete for driver work to meet driving safety demands	5-point scale	Management
18: I feel I can execute a "call-response" system design smoothly, and it will not influence my driving safety	5-point scale	Management
Age	Numeric response	
Education level (junior high school, high school or vocational school, college or university)	4-point scale	
Experience driving	Numeric response	
Position (assistant, learning driver, driver, senior driver)	4-point scale	
Have you been involved in a responsible accident (Yes, No)	Binary response	

4.2 Data collection

After designing the questionnaire it was administered to 1250 drivers at monthly training sessions held at five dispatching units of the Taiwan Railway Administration, from October to December of 2005. The questionnaire was explained by trained personnel, and then filled out anonymously by the drivers. A total of 934 (74.72%) questionnaires were returned. After deleting invalid questionnaires, 840 (68.2%) valid questionnaires were retained for analyses. The results of the demographic data are shown in Table 4-2. Most drivers are between 40 and 49 year of age (48%) and 50 and 59 years of age (36%),while the remaining 16% is scattered across the remaining three categories. In terms of educational level, the majority of drivers (67%) have senior high or vocational school. As to position, the majority of the respondents are drivers (79%), while learning drivers and assistant drivers make up about 9% of the sample. In terms of service experience, drivers with 15 or more years of experience account for 67% of the respondents. Not unexpectedly, the results also show that drivers who are older generally hold higher positions, drivers with no accidents have longer service experience, and drivers with higher educational level have less service experience. Interestingly, education level is inversely related to accident rate.

Table 4-2 The data analysis of survey

Item		No	%
Age	20-29 years	9	1
	30-39 years	119	14
	40-49 years	401	48
	50-59 years	304	36
	Above 60 years	7	1
Education degree	Junior high school	50	6
	High school Vocational school	559	67
	College or University	231	27
Position	Assistant driver	49	6
	Learning driver	28	3
	Driver	666	79
	Senior driver	97	12
Happened responsible accident	Yes	159	17
	No	681	83
Experience	1-14 Years	275	33
	Above 15 Years	565	67

The average age of of the respondents was 46.30 years, which is very close to the average age of the target population (i.e., 46.36 Years). As for driver experience, the average work experience of the sample was 16.84 years, which is close to 17.42 years, for the population. To verify whether the sample appropriately represents the population, the drivers were divided into three groups based on gae age; namely, below 39, 40~49 and above 50, and then subdivided into two groups according to experience (i.e., < 15 years and ≥ 15 years). The groupings were compared with the population as a differential test. The results indicated that age and experience distributions in the sample were not significantly different than the population. As such, the sample adequately represents all drivers of the Taiwan Railway Administration.

4.3 Application of Rasch analysis

Depending on the perceptions of train drivers about overcoming job stress in order to drive safely, some items will seem easy to overcome and others will be perceived as difficult. The Rasch measurement model provides a means for constructing interval measures from raw ordinal category data. On the basis of the Rasch model, a value on an interval scale was estimated for each item (i.e., the item parameter) and for each respondent (i.e., the personal parameter). The responses of the 840 train drivers for 18 items analyzed with WINSTEPS (Linacre and Wright, 1997), an iterative computer program that estimated the perceptive difficulty of confronting stressors by train drivers in logit units. WINSTEPS helps to deal with polytomous responses by applying the Masters-Andrich modification (Masters, 1982) of the Rasch model. The estimated parameters and model fit statistics could therefore be calibrated via a joint maximum unconditional-likelihood estimating procedure (Wright, 1997).

The estimated parameters and fit statistics of our whole Rasch model are shown in Table 4-3. The Rasch assessment fixed the average measure of all item parameters at zero logits to be a comparative basis for the relative interval scale; the average value of the ability to overcome job stressors across all of the drivers was 0.31 logits. Such a positive value indicates that these drivers generally have high adaptability to a driving safety stressor. Before we start detailed discussion and interpretation of the estimated item and person parameters, the reliability and validity of this Rasch model must first be discussed.

Table 4-3 Model estimation and fit statistics obtained from Rasch analysis

Items: 18 input, 18 measured						
	Raw score	Number of observations	Measure (logit)	Standard error	Infit Zstd	Outfit Zstd
Mean	2718.4	840	0.00	0.05	-0.1	-0.1
Item reliability: 1.0						
Persons: 840 input, 840 measured						
	Raw score	Number of observations	Measure (logit)	Standard error	Infit Zstd	Outfit Zstd
Mean	58.3	18	0.31	0.37	0	0
Person reliability: 0.88						

Reliability is commonly defined as the consistency of responses to a set of items or the consistency of scores from the same instrument. It is also defined as the degree to which scores are free from measurement errors. The WINSTEPS program provided reliability information for both items and persons, as shown in Table 4-3. The person and item reliability coefficients can be interpreted similarly to a Cronbach alpha reliability coefficient for the internal consistency of responses to items (Wright, 1997). The personal reliability index of 0.88 and item reliability index of 1.0 indicate the data are consistent with the assumptions of the Rasch model from the viewpoints of both items and persons.

Validity refers to the creation or selection of items to measure the same construct in performing a measurement of a latent characteristic. The validity information is expressed by the fit statistics in a Rasch measurement. With the help of a comparison of the expected and the observed patterns, the fit statistics aid in quality control and in identification of data that do not meet the requirements of the model. Two fit statistics were estimated by WINSTEPS, namely an information-weighted fit ("infit") and outlier-sensitive fit ("outfit") (Smith, 1991). The infit and outfit are expressed as normalized residuals in Table 4-3. The *Z*-standardized fit statistic (Zstd) has previously been used to select items at the 0.05 significance level and according to ± 2. In our model, the infit and outfit statistics of the estimated parameters for both persons and items are all close to zero, which implies the overall validity of our model, is acceptable.

4.4 Findings and Interpretation

After confirming the high reliability of questionnaire items and results, this study further interpreted the deeper meaning of model estimation result. Basically, the Rasch model can effectively isolate the difficulty of each item and check whether each item has deviated from the basic hypothesis of the model. Table 4-4 lists the difficulty and fit of each item estimated by WINSTEPS. The content of each item is shown in Table 4-1. Questions in Table 4-4 are sequenced in descending order according to the estimated difficulty for further comparison and analysis. Column 2 shows the difficulty estimation of each item. Since the Rasch model anchors the average mean of the difficulty levels of all items to 0 logits, the difficulty of estimated items would be positive or negative. The difficulties are relative values, and convenient for cross comparison. Among the 18 items designed in this study, the highest difficulty is 1.89 logits, and the lowest is -1.41 logits. Positive values mean it is more difficult for a driver to adapt to a stressor; higher difficulty indicates greater stress to drivers induced by the stressor. Column 4 and Column 5 in Table 4-4 are Infit mean Z-standardized fit statistic and Outfit mean Z-standardized fit statistic, both mean squares of the 18 items are between 0.88 and 1.13, indicating a good fit for the 18 items, and the questionnaire is reliable as a test tool. Column 6 shows the dimension of each item, including equipment, environment, and management.

Table 4-4 Estimates of item measures and fit statistics from Rasch analysis

Item	Difficulty (logit)	Standard deviation (logit)	Infit Zstd	Outfit Zstd	Dimension
10	1.89	0.05	1.02	1.02	Environment
07	1.82	0.05	1.08	1.10	Environment
08	1.07	0.04	1.02	1.04	Environment
05	0.83	0.04	0.97	0.98	Equipment
06	0.74	0.05	1.05	1.05	Environment
04	0.36	0.05	1.11	1.11	Equipment
13	0.33	0.05	0.93	0.93	Management
09	0.20	0.05	1.02	1.02	Environment
14	0.17	0.05	0.93	0.93	Management
11	0.08	0.05	1.04	1.05	Management
12	-0.39	0.05	0.91	0.91	Management
15	-0.40	0.05	0.89	0.89	Management
02	-0.91	0.05	1.12	1.13	Equipment
18	-0.97	0.06	0.98	0.96	Management
17	-0.98	0.06	0.91	0.89	Management
03	-1.05	0.05	1.03	1.02	Equipment
01	-1.37	0.05	1.06	1.05	Equipment
16	-1.41	0.06	0.89	0.88	Management

Among the 18 driving safety stressors in this questionnaire, Item 10, "Trees or buildings along railway cause signal identification difficulty," is rated the highest (1.89 logits); followed by Item 7, "Control cabin noise is so loud that it affects drivers' attention while driving" (1.82 logits); while the third highest is Item 8, "Road signals along railway affect identification of railway signals at night" (1.07 logits). Item 5 "Solve physiological problem well during duty (0.83 logit)" and item 6 "Control cabin space pressure (0.74 logit)" are rated the fourth and fifth, respectively.

As to low stressors, Item 16 “Handle simple locomotive faults in operation” is the lowest (-1.41 logits), followed by Item 1 “Vehicle acoustic warning signals device performance” (-1.37 logits), and Item 3 “ATW/ATS safety equipment functionality” (-1.05 logits) is the third lowest. While Item 17 “Undergone enough training on operating skills and rules” (-0.98 logits), Item 18 “Call-response system execution” (-0.97 logits), and Item 2 “Condition of railway ties, track or overhead power lines” (-0.91 logits) are ranked the fourth, fifth, and sixth, respectively.

When further classifying the 18 stressors according to dimensions, it was found that the “environment” dimension had the highest difficulty, with an average difficulty reaching 1.14 logits. The average difficulty of the “equipment” dimension was the second most difficult (-0.43 logits), and the average difficulty of the “management” dimension is the lowest (-0.45 logits). A detailed discussion of status and causes follows.

4.5 Discussion

Although the “environment” dimension only has five stressors in the questionnaire, the top three driving safety stressors recognized by TRA drivers as being most difficult to adapt to are included in that group. Those three, in descending order of difficulty, are “Trees or buildings along railway cause identification difficulty,” “Control cabin noise is so loud that it affects drivers' attention on driving," and "Road signals along the railway affect identification of railway signals at night". Because cities in Taiwan developed along the railway in early days, there are more buildings along the railways, and subtropical trees grow rapidly in Taiwan, thus hindering drivers' identification of railway signals, and causing work stressors that are difficult to adapt to. As for control cabin noise, the operating mechanism and electronic equipment are installed in the control cabin, and without proper sound-proofing, equipment noise could seriously affect drivers' attention, resulting in discomfort and stress for the driver. In addition, Taiwan railways are often built parallel to highways and, with the similarity of highway and railway signal displays, nighttime driving easily causes identification difficulty, and leads stress. Furthermore, pressure from the narrow control cabin and great changes in railway grade due to the terrain of the island nation also brings driving safety stress. These last two are ranked fifth and eighth, respectively, as difficult-to-overcome stressors.

The main stressors in the "equipment" dimension include inability to meet physiological needs immediately, such as using toilet, thus causing serious stress to drivers. There is no toilet in the control cabin, and the stopover time at each station is very short, hence, if a driver wants to use the toilet, he needs to wait until after work. Moreover, temporary signal devices that are installed at improper locations at railway construction sites would also make it hard for drivers to identify the signal which could result in accidents due to negligence, thus causing stress for drivers. However, the functional quality of basic equipment, such as routes, overhead power lines, tracks, railway ties, and safety devices, including Automatic Train Warning (ATW), Automatic Train Stop (ATS), or acoustic warning signal devices, bring less stress to drivers. Because the TRA conducts routine inspections, repairs, maintenance, and replacement of equipment, once defects are found, they would be fixed immediately; in particular, the maintenance and management of safety equipment are especially important. Therefore, drivers are confident in equipment performance safety, and feel much less stress, thus, the difficulty of adapting to these stressors is relatively low.

In terms of the stressors in the "management" dimension, although drivers commonly feel it is less difficult to adapt to stressors in this dimension, they still feel some level of stress in driving safety and difficulty in adaptation concerning driving fatigue due to prolonged duty time, single-driver duty, inability to arrange the meal time properly when on duty , and mixed work shifts. Besides paying attention to signals, drivers also need to react to road conditions and intruding objects, and make proper responses. In addition, drivers need to operate in monotonous environment; hence, they are likely to feel tired. During single-driver duty service, without the aid of an assistant driver and confirmation of signals, all the work noted above depends on one individual's attention, thus drivers have difficulty in adapting to single-driver duty. Also, mixed shifts may lead to difficulty in adapting their circadian rhythms.

Drivers generally feel skilled in driving various types of locomotives, and regard the knowledge of operating skills and rules, as well as simple locomotive troubleshooting, as stressors that are easy to overcome. This is primarily because the TRA follows strict processes to be a driver. From being a trainee to being able to drive independently, the process usually takes at least two years, and the drivers need to pass numerous tests in order to become a railway driver. Also, there is on-job training each month. Therefore, the stress from these potential stressors is less difficult to overcome. In particular, although there are many operation rules to be followed for driving safety, the drivers are aware the operation rules are critical in ensuring driving safety, as well as the safety of drivers and passengers; thus, management puts very stringent demands on drivers' knowledge of the operation rules. As a result, drivers feel less stressed to learn the procedures. The "call-response" management system may bring an extra burden to drivers, but after a period of time, drivers would adapt to the system, and feel less stressed.

CHAPTER 5 EMPIRICAL STUDY FOR THE EFFECT OF CONSECUTIVE DRIVING ON ACCIDENT RISK FOR TRAIN DRIVING

5.1 Train operations and work shift regulations of the TRA

The TRA is the only institution in Taiwan providing 24 hour service for both passenger and freight railway operations with 219 stations and 1,097.2 kilometers of track. The TRA has 1,250 drivers who alternately drive both passenger and freight trains, and each is assigned to one of five dispatching units (Taiwan Railways Annual Report, 2006). Drivers are assigned to freight trains for at least two consecutive weeks after finishing a specific number of work shifts driving passenger trains. A driver's work schedule is arranged and strictly controlled under regulations issued by TRA. The work shift regulations include:

(1) driving distance for each shift must be less than 300 kilometers;

(2) each shift must not exceed 6 hours from 6 a.m. to 10 p.m.;

(3) each shift must not exceed 5 hours from 10 p.m. to 6 a.m.;

(4) drivers' rest duration between consecutive shifts must be longer than 6 hours; and

(5) drivers must have at least one off-duty day a week (duration must exceed 24 hours).

5.2 Data collection

5.2.1 Driver responsible accidents

According to the TRA's operation rules, a train accident is defined as an event causing more than 10 minutes delay in operations, and the related personnel are responsible for reporting it to the Accident Investigation Prevention Committee (AIPC). Details of the accident report include, among other things, the characteristics of train driver(s) and his/their corresponding work shift information. The AIPC then investigates possible causes of the accident and determines whether the personnel are responsible for its occurrence; thus, they are further classified into human- or non-human-error accidents. Given this, a driver's consecutive driving hours before the accident can be determined by combining his work shift record with the accident report.

The records of accidents that occurred during 1996-2006 were collected and used in this study. Among the total of 10,990 TRA accidents, 10,371 were reported as non-human errors and 619 were human error accidents. Furthermore, among those human error accidents, 193 accidents were attributed to train driver errors, which accounted for 31% of all human error accidents. Based on the study purpose, only the driver-responsible accidents are counted in the study. According to the statistics of accident occurrence time, 172 driver-responsible accidents occurred at the on-board driving stage, 12 at the pre-starting stage, and only 9 at the post-arrival stage. For the purpose of studying the effect of consecutive driving on accident risk, a total of 172 on-board driving accidents were examined in this study, which included 122 passenger train accidents and 50 freight train accidents.

5.2.2 Driving exposure to the risk of accident

As mentioned in Chapter 2.3.2, the on-board driving stage is defined as the operating duration from the starting station to the ending station for each train driver. The driving task for a train driver at this stage is relatively continuous and a driver needs more concentration and alertness to operate safely. In addition, "trunk line driving and shunting" at the on-board driving stage is a relatively continuous job for train drivers during their work shifts, and usually influences train operations, occupies the main tracks, and leaves available driving records for train drivers. Therefore, only the on-board driving time was calculated and was selected as the exposure measure in this study.

On average, there were 1,072 working shifts per day and approximately 4.3 million working shifts were collected to calculate the on-board driving hours during 1996-2006. A passenger train driver had a mean of 2 hours and 45 minutes of on-board driving, while a freight train driver had a higher average of 3 hours and 20 minutes. In addition, the variation in on-board driving time for passenger train drivers (SD = 89 min) was larger than that for freight train drivers (SD = 42 min). This demonstrated that the length of on-board driving for freight train drivers was longer but more consistent than for passenger train drivers.

Distributing all drivers' work shifts from the eleven observed years into different time slots, the accumulated on-board driving hours in each time slot for both types of train driving are shown in Figure 5-1. The total on-board driving hours for passenger trains was 9.88 million hours while the total on-board driving hours for freight trains was 2.57 million hours, which comprised only 20.6% of total on-board driving hours. The distribution of driving exposures for different time slots also showed that passenger train drivers had greater variability in their on-board driving hours as the pattern deviates more from a uniform distribution than that of freight train drivers.

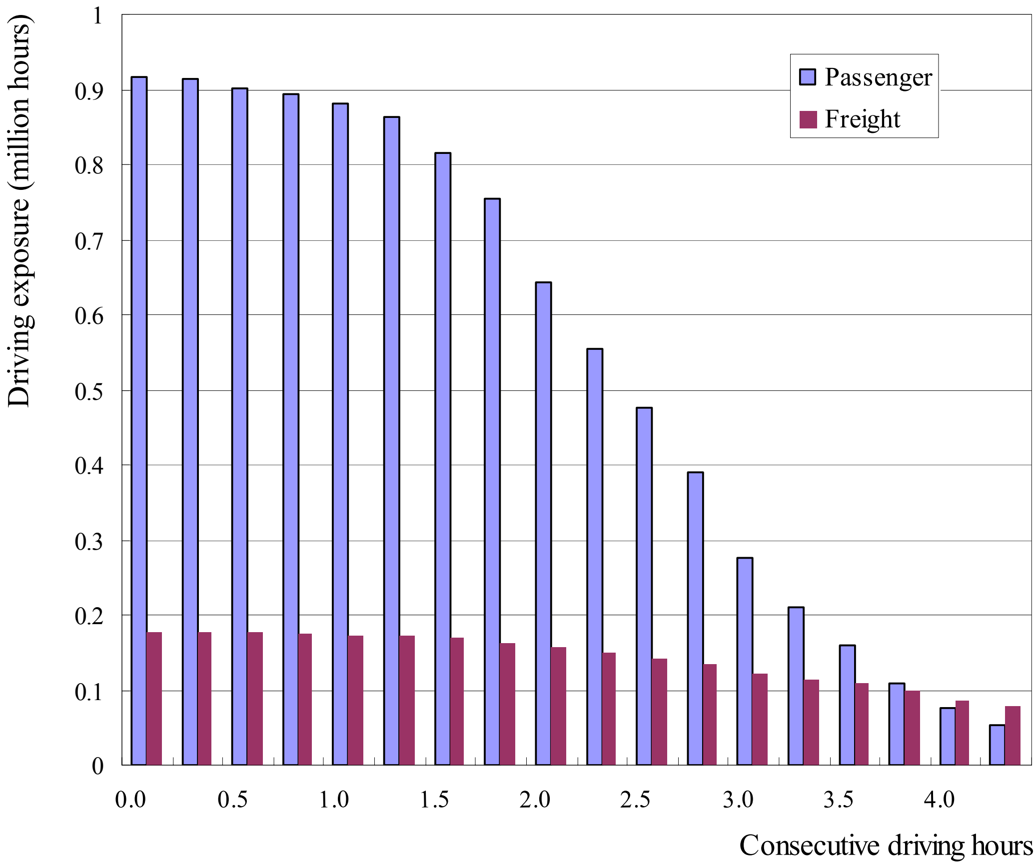

Fig. 5-1 passenger and freight train driving exposure for different consecutive driving hours

5.3 Accident rates for different time slots of consecutive train driving hours

Dividing the number of total accidents that occurred in the observation period by the total driving hours, we find that TRA experienced an average accident rate of 13.82 accidents per million driving hours from 1996 through 2006. If we further investigate the accident rates for freight and passenger train driving separately, we will find the freight and passenger train driving experienced 19.45 and 12.35 accidents per million driving hours, respectively, over the observation period. Freight train driving had a 58% higher accident risk than passenger train driving, which is consistent with the expectancy discussed in the previous section.

Furthermore, based on the collected data, the accident rates for each time slot could be measured by dividing the number of accidents that occurred in one time slot by its corresponding driving exposure (i.e., the on-board driving hours in the same time slot), indicating the accident risk for that time slot. That is, the accident rate for the i^{th} time slot can be expressed as

$$AR_i = A_i / H_i \tag{1}$$

where AR_i is the accident rate for the i^{th} time slot, A_i is the number of accidents that occurred in the i^{th} time slot, and H_i is the accumulated driving hours in the i^{th} time slot.

According to the above definition, the accident rates for different time slots for the consecutive driving of all trains, passenger trains and freight trains, are computed and illustrated in Figure 5-2. We find the accident rates for all train driving had a distinct peak after one hour of consecutive driving, followed by a relatively low level, which subsequently increased again. This study result is consistent with the findings of both Wharf (1993) and Kecklund et al's (1999) studies.

However, if the accident rates for different time slots are investigated separately for freight and passenger train driving, a significant difference in accident rates over time will be found between the two types of train driving, as can be seen in Figure 5-2. That is, the accident rates for freight train driving were significantly higher than those for passenger train driving during the first hour of driving, but this phenomenon disappeared after one hour of driving.

A further investigation indicates the average accident rate during the first hour of freight train driving was 34.04 accidents per million driving hours, which was about 3.2 times the average accident rate for passenger train driving (10.78 accidents per million driving hours) during the first hour. But these statistically significant differences in accident rates between the two types of train driving were not found at $\alpha = 0.05$ after one hour of driving. Further investigation indicates that, among the 24 freight train accidents that occurred in the first hour of initial driving, 20 accidents (83%) occurred in the marshalling yards. That result is consistent with the expectancy that freight train driving will experience higher accident risk for shunting in the marshalling yards than running on the main lines.

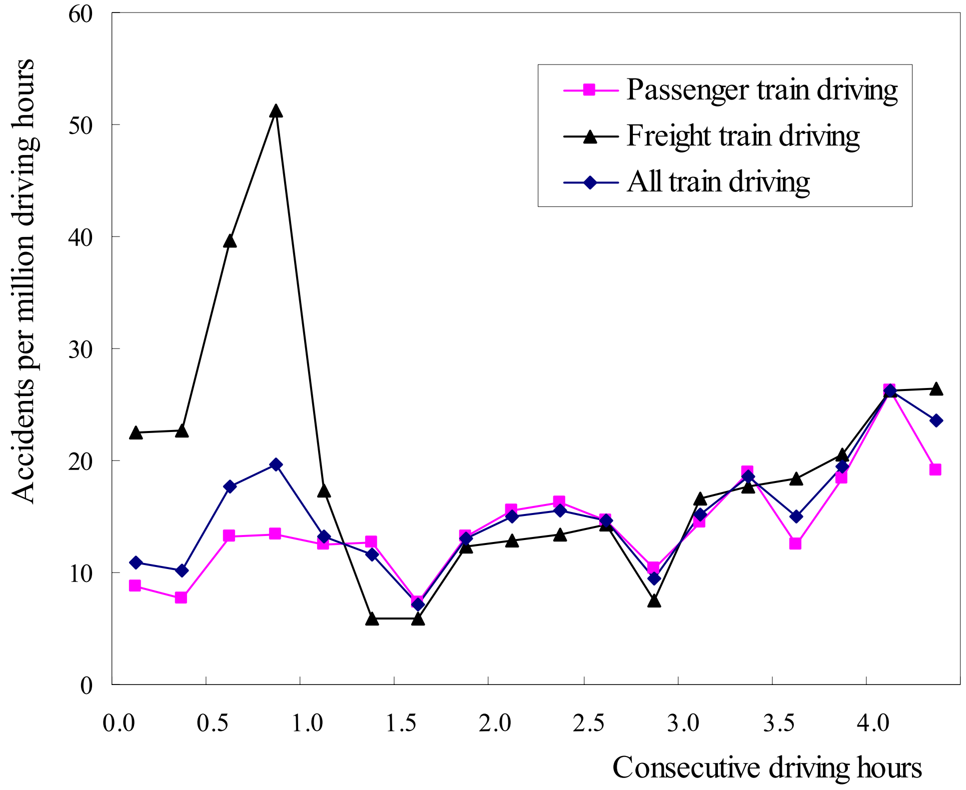

Fig. 5-2 The accident rate over consecutive driving hours for train driving

Figure 5-2 also indicates that the accident rate for freight train driving reached its peak after one hour of driving (i.e., the 4th time slot) and then dropped to the lowest accident rate for all time slots. Afterward, the accident rate increased again across consecutive driving hours. This result is similar to the findings of previous railway studies in that train drivers had a distinct peak of accident risk during the second and third hours of duty followed by a relatively low level, and then an increase again (Kecklund et al., 1999; Wharf, 1993). The only difference with the current study is the time of occurrence of this early peak of accident risk, which reflects the fact that pre-driving hours were included in the on-duty hours in previous studies, but not included in this study.

Interestingly, the peak accident rate in the early driving hours was not found for passenger trains. The accident rates for passenger train driving seemed to increase gradually as the driving hours were accumulated, which is consistent with the hypothesis that prolonged driving induces fatigue and then increases the accident risk for train driving. This phenomenon could also be found for freight train driving if we neglect the early peak of accident risk during the first hour of on-board driving. Therefore, the study results shown in Figure 5-2 seem to indicate the effect of consecutive driving on accident risk actually exists for both passenger and freight train driving, even within a short mission of 4.5 on-board driving hours. However, an extra accident risk was found for freight train driving in the first hour, which reveals a distinct early peak accident rate. This extra accident risk for freight train driving in the first hour could be explained by volume of shunting in the marshalling yards, which is expected to have a higher accident risk based on the complicated track layout and semi-automatic traffic guidance for TRA.

5.4 Modeling the accident risk for consecutive driving

Given the accident rates for different time slots over consecutive train driving hours, it is possible to explore the effect of continuous driving on the accident risk for train operations. Some previous studies indicated the relationship between accident rates and consecutive truck (or automobile) driving hours fit an exponential model (Chang and Hwang, 1991; FMCSA, 2000; Folkard 1997) or a quadratic model (Kecklund et al., 1999; Wharf, 1993). Therefore, four different regression models are considered to formulate the relationship between accident rates and consecutive driving hours for train driving, according to the trends of accident rates over different time slots demonstrated in Figure 5-3. These four models are expressed as follows:

Model 1 (Linear): $AR = a + bt$ (2)

Model 2 (Log linear): $\ln(AR) = a + bt$ or $AR = exp(a + bt)$ (3)

Model 3 (Quadratic): $AR = a + bt + c\,t^2$ (4)

Model 4 (Modified Quadratic): $AR = a + c\,t^2$ (5)

where a , b and c are the parameters to be estimated and t is the cumulative on-board driving hours. Models 1, 2, and 4 are used to formulate the increasing trend of accident risk for consecutive train driving hours, while Model 3 is especially considered to catch the trend shown in Figure 5-2, which had a distinct peak of accident risk during the first hour of driving followed by a relatively low level, which then increased again

Table 5-1 Accident rates and relevant statistics for different types of regression models

Model types	Accident rate (Accidents per million driving hours)	***a*** (*p*-value)	***b*** (*p*-value)	***c*** (*p*-value)	R^2
All trains					
Model 1	13.82	10.53(0.00)	2.13(0.01)	--	0.32
Model 2		10.81(0.00)	0.13(0.02)	--	0.29
**Model 3		15.05(0.00)	-3.89(0.16)	1.33(0.03)	0.51
Model 4		10.53(0.00)	--	2.13(0.01)	0.33
Passenger trains	12.34				
Model 1		8.29(0.00)	2.78(0.00)	--	0.62
Model 2		8.97(0.00)	0.19(0.00)	--	0.58
Model 3		10.10(0.00)	0.37(0.86)	0.53(0.27)	0.64
*Model 4		10.41(0.00)	--	0.61(0.00)	0.64
Freight trains	19.07				
Model 1		23.21(0.00)	-1.64(0.44)	--	0.06
Model 2		17.66(0.00)	-0.02(0.82)	--	0.01
*Model 3		36.91(0.00)	-19.87(0.01)	-4.05(0.02)	0.33
Model 4		20.13(0.00)	--	-0.09(0.84)	0.01

* The best model among the four candidate models.

** It is suggested to be the best model in terms of its explanatory power, though the parameter b is only marginally significant with a p-value of 0.16.

These four candidate models were applied to model the trends of accident risk resulting from consecutive driving for all trains, passenger trains, and freight trains separately. According to the model estimation results summarized in Table 5-1, Model 3 is suggested to be the best model for all train driving in terms of its explanatory power, though the parameter *b* is only marginally significant with a *p*-value of 0.16. For passenger train driving, Model 4 is the best model to describe the increasing accident risk over time for consecutive driving. As to freight train driving, Model 3 is obviously better than the other three models to catch the trend of accident risk over time for consecutive driving. However, the explanatory ability of any of the four candidate models is not good enough for freight train driving.

Apparently, the models for passenger train driving had much better fit than those of freight train driving due to the lack of a distinct risk peak in the first hour of driving. It was found that the pattern of increasing accident risk caused by consecutive driving for passenger trains is similar to that for automobiles or trucks. Conversely, although the accident rates over time for consecutive freight train driving are not significantly different from those of consecutive passenger train driving after one hour of driving, the abnormally high accident risk in the first hour of driving makes the continuous models unable to clearly depict the pattern of accident risk over time for freight train operation. Therefore, a combined model, which handles the additional accident risk for freight train driving in the first hour through a dummy variable and combines the accident rates of both passenger and freight train driving, is formulated as follows:

$$AR = a + bt + c\,t^2 + \mathrm{D}\,(dt + et^2) \quad (6)$$

where D is the dummy variable and D = 1 for freight train driving in the first hour, and D = 0 otherwise. A stepwise regression procedure using backward-elimination was employed to find the best model for Equation 6, and the estimated results are summarized in Table 5-2. The explanatory ability of the best model, with R^2 = 0.842, was significantly improved as compared to the single models for passenger and freight train driving, respectively.

Table 5-2 The estimated results for the combined model of accident risk over time

Parameter	*a* (*p*-value)	*b* (*p*-value)	*c* (*p*-value)	*d* (*p*-value)	*e* (*p*-value)	R^2
Step 1	13.08(0.00)	-3.48(0.11)	1.37(0.00)	33.83(0.04)	14.16(0.47)	0.854
Step 2	12.37(0.00)	-2.91(0.15)	1.27(0.00)	44.85(0.00)		0.852
*Step 3	9.73(0.00)		0.67(0.00)	46.40(0.00)		0.842

* The best model estimated by the stepwise regression procedure.

According to the estimation results of the best combined model shown in Table 5.2, the accident rates over consecutive driving hours for both passenger and freight trains are illustrated in Figure 5-3. It indicates the accident risk for passenger train driving increases with the accumulated driving hours, and shows the accident risk will double after four consecutive hours of driving, as compared with the accident risk of driving during the first hour. As to the extra accident risk for freight train driving, it is found to increase sharply with accumulated driving time during the first hour. That is, the accident rates for freight train driving were 3.3 and 5.5 times of those of passenger train driving after half an hour and one hour, respectively, of consecutive driving. This might be a function of the increasing train length accompanied by the accumulated driving hours in the marshalling yard that increases the difficulty of shunting and, therefore, increases the risk of accident. In addition, the accident rates for freight train driving went sharply down to the risk levels of passenger train driving after one hour of on-board driving in the marshalling yards for shutting.

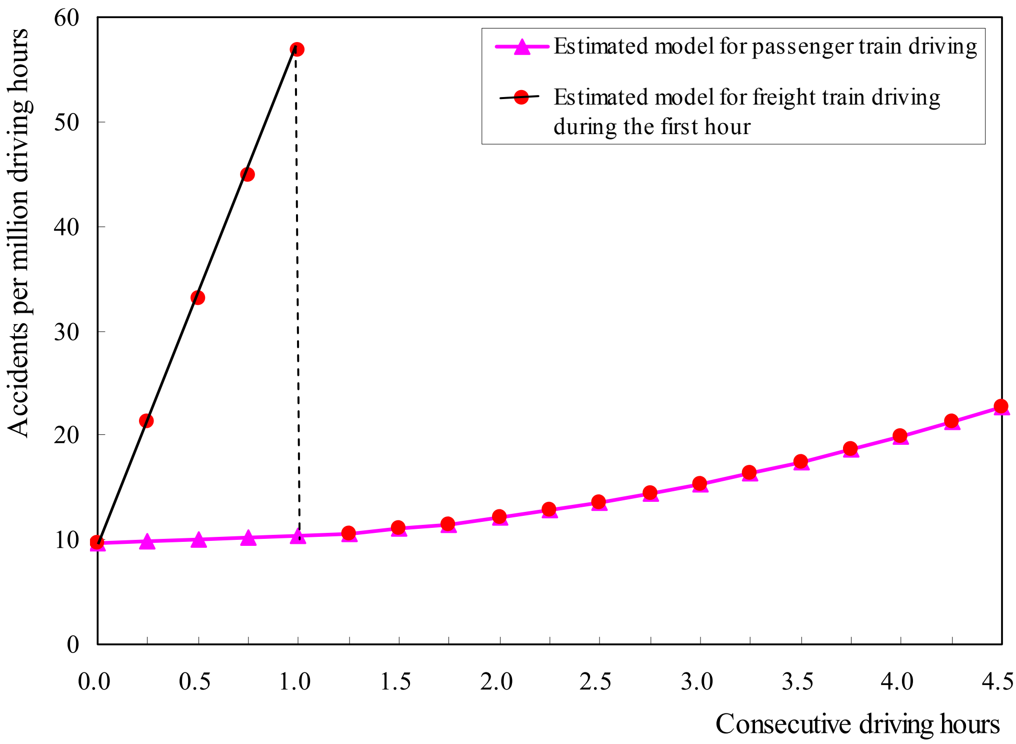

Fig. 5-3 The estimated accident rate model over consecutive driving hours for passenger and freight train driving

5.5 Discussion

This study investigated train-driver-responsible accidents by examining their accumulated on-board driving hours and the associated increasing trend of accident risk over time caused by consecutive driving. Differentiation of accident risk between passenger and freight train driving helps us to investigate the distinct early peak problem of accident risk for rail operation raised by previous literature. Some findings and their implications follow.

5.5.1 Accelerating accident risk of train driving compared with truck driving

The accident risk for train driving was found to double after four hours of consecutive driving, as compared to that for the first hour driving. The phenomenon of accelerating accident risk for train driving seems to occur earlier than that of automobile driving (Amundsen and Sagberg, 2003; Chang and Hwang, 1991; Elvik et al., 1997; Mackie and Miller, 1978). Mackie and Miller (1978) investigated 750 truck crashes and found crash occurrences began to increase after five hours of driving, and the risk during the second five hours was twice that of the first five. Elvik et al. (1997) reported truck accident risk significantly increases after eight hours of consecutive driving and there is a tendency for increasing risk when driving more than 9-11 hours (Amundsen and Sagberg, 2003). In addition, Chang and Hwang (1991) studied the effect of prolonged driving on accident risk for a U.S. trucking company and found the risk after five hours driving was double that of the first hour. Greater fatigue generated by higher working pressure and a more monotonous driving environment are considered to be two important reasons for an accelerated accident risk for consecutive driving during train operations.

Train driving is a dynamic control and decision-making task (Kecklund et al., 2001; Reinach and Raslear, 2001). The complexity of the operating environment and the work requirements (i.e., higher density of switches and signals, stations, track works, and grade crossings speed restrictions) affect the degree of salient environmental information that must be identified, processed, committed to memory, and used to take appropriate actions. Especially important is the fact that the train driver's job is largely governed by timetables and technical conditions (e.g., type of train and track layouts) that restrict the driver's ability to decide how the job should be done. Therefore, these harsher working requirements for train driving may result in accelerated fatigue for train drivers and, thus, increase train accident risk faster than it would for automobile driving.

Furthermore, highly automated duties, such as automatic train controls, can be perceived as boring and monotonous tasks. In particular, when driving during the night everything is dark and the driver cannot see anything but the signals. The working environment increases the monotony of train driving except when near signals or stations, and a monotonous and non-stimulating environment is likely to provoke sleepiness. Johnson (1982) found that tasks that are more monotonous and lacking in interest are more likely to make people fall asleep. In addition, performing monotonous tasks may gradually cause a decline in behavior performance (Thiffault, and Bergern, 2003), reduce levels of alertness, and increase crash risk (Horne and Reyner, 1995). The monotonous driving environment is, therefore, expected to be another reason for accelerating the accident risk of consecutive train driving.

5.5.2 The early peak of accident risk for freight train driving

In this study, freight train driving was found to be associated with a risk peak within the first hour of initial driving. This early peak phenomenon of accident risk was also found in previous railway studies, but lacked further investigation for its possible causes. Compared with passenger train driving, freight train driving is usually associated with higher working complexity. These working characteristics might lead to an earlier peak of accident risk for freight train driving.

Shunting in the marshalling yard is an unsafe activity, not only because the yard's track layout is more complicated than that of the main lines but also because circulation of freight trains in the yard is guided by a semi-automatic interlock system for TRA. Differing from passenger train driving, which is directed by an automatic interlock system in the main lines, the operation of shunting requires more attention by yard staff and freight train drivers. These operation characteristics for freight train driving in the marshalling yards are thought to be the reasons for TRA to experience higher accident risk for shunting in the marshalling yards.

A higher proportion of night work shifts for freight train driving is also expected to increase the accident risk for shunting in the marshalling yards. However, antithetically, compared with the 80% of work shifts for freight trains that are operated during the night, only nine of the 20 accidents (45%) that occurred in the marshalling yards happened during the nighttime. It is interesting to find that freight train driving in the marshalling yards during the nighttime resulted in a lower accident risk than during the daytime. It is suspected that when shunting in marshalling yards, TRA train drivers are more likely to miss flag signals under daytime lighting than to miss portable light signals at night. This suspicion is worth of further investigation and exploration.

To prevent errors in complex marshalling yard work, enhancing workers' cognitive and skill abilities through education and training is required. Rutter (2003) emphasized that improving safety should focus on altering behavior other than improving technology or altering structural operating conditions. Therefore, enhancing training programs to educate drivers to obey the rules and to be familiar with operation procedures, such as switching lines properly, ensuring safety equipment is correct, communicating clearly, and watching signals carefully should decrease accident rates. Additionally, enhancing pre-starting instructions for freight drivers to confirm the drivers have become familiar with the layout of the marshalling yard and the work requirements during their shifts plays an important role in preventing the occurrence of an accident in a complex operating environment.

Finally, building a standard operating procedure and establishing a sound auditing system are also required for shunting operations. There are many rules that confirm the operational safety of a shunting yard, but the staff can always be tempted to cut corners and not follow safe working rules. For example, train speed is strictly limited during marshalling yard operation because lower running speed can result in lower accident risk. A sound auditing system will encourage and assure that railroad workers obey the rules and best practices.

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study focuses on the more critical human factors with which to explore the difficulties of various stressors for train drivers and identifies the relationship between consecutive driving and train accident rates in order to increase railway safety.

6.1.1 Exploring perceptions of stressors confronted by train drivers

Based on the rail system safety theory, this study explored stressors within the “environment,” “equipment,” and “management” dimensions that influence train drivers’ driving safety. This study also developed questionnaire items concerning the stressors that affect driving safety. The analysis method included the Rasch measurement method, which was used to estimate the parameters to be obtained, and break through the statistical defects of using conventional “ordinal scale data” as the “interval scale data” for computation in which to infer the latent variables. Furthermore, the Rasch measurement model provided convenient goodness of fit indices to verify the estimated difficulty of each questionnaire item, so as to control questionnaire quality and attain the research goals. This study examined TRA drivers as the empirical subjects, in order to identify the difficulties drivers have in adapting to stressors. The results can be provided to the TRA as useful references for developing related driving safety strategies. Based on the empirical results, the following conclusions are provided for future researchers.

1. The success of a questionnaire relies on the design of the measure. A good measure design needs systematic analytical logic, as well as involvement of expertise knowledge. Besides referencing related literatures and theories in the initial period of scale design, this study also conducted several focus group discussions to screen numerous preliminary questionnaire items, and invited experts to assess the questionnaire both qualitatively and quantitatively, in order to make the final modification. Finally, 18 questionnaire items were obtained. The scrutinized measure design procedure is the main reason that all items met the goodness-of-fit test of the Rasch model. The questionnaire was proven to be reliable.

2. It was confirmed that all 18 questionnaire items selected concerning the stressors faced by train drivers comply with the model hypothesis and have high measurement reliability. The results showed that, the 5 major stressors that are considered most difficult to be adapted to by drivers include: "trees or buildings along railway cause signal identification difficulty," "control cabin noise is so loud that it affects drivers' attention to driving," "road signals along the railway affect identification of railway signals at night," "inability to use the toilet during duty service," and "limited control

cabin space brings pressure". Except for the fourth stressor, which belongs to "equipment," the other four belong to the "environment" dimension.

3. Among driving stressors in the "environment," "equipment," and "management" dimensions, the average fit difficulty of stressors in the "environment" is the highest (1.14 logits), that of "equipment" is -0.43 logits, and that of "management" is -0.45 logits, which is the lowest. It indicates that, although the TRA is a mass transportation system with exclusive railway ownership, driving safety cannot be waived under internal and external environment threats, thus it deserves the concern of related government units for improvement.

6.1.2 Identifying the relationship between consecutive driving and train accident rates

Using driver-responsible-accidents and on-board driving hours as it focus, this study provides information that can be used to effectively detect the impact of consecutive driving on the accident risk for TRA train operations. Computing accident rates for passenger and freight trains separately helps us explore the early accident risk peak problem raised in previous studies. The results show as the following conclusions.

1. The accident risk for train driving increased with an increase in consecutive driving hours, as expected, and doubled that of the first hour after four hours of consecutive driving, which is consistent with the hypothesis that higher pressure and more

complexity of the task of train driving will result in accelerated fatigue and accelerate the accident risk as compared with automobile driving.

2. Freight train drivers were found to experience additional accident risk during the first hour of driving. This is due to the requirements of shunting in the marshalling yards, where the track layout is more complicated than that of the main lines and the circulation of freight trains is guided by a semi-automatic interlock system for TRA. All of this contributes to higher accident risk for freight train operation.

6.2 Suggestions

1. All five factors of the "environment" dimension are stressors that TRA drivers considered most difficult to adapt to, thus, it is suggested the TRA improve such stressors immediately to safeguard driving safety (e.g.,, clearing the railway sides, identifying trees or buildings that affect drivers' sight or signal identification and fix the problems). To prevent drivers from confusing road and railway signals, it is recommended the location and display of the road and railway signals be recheck. As to the poor work environment in the control cabin, the TRA could enlarge the control cabin space and upgrade the sound-proofing in order to reduce drivers' work stress. Finally, in

regard to the driving stress due to larger grades, the TRA could check all such grades, and take the necessary warning and protective measures.

2. The main stressor of the "equipment" dimension is difficulty in meeting driver's physiological needs (e.g., going to toilet). It is suggested the TRA deliberate on feasible solutions, such as installing convenient toilets on railway platforms for drivers to use, or allocate additional drivers, thus allowing drivers to solve their physiological needs. Regarding the improper location of temporary signals at construction sites, training and safety education could be provided to engineers, and auxiliary signals could be installed as reminders to drivers.

3. The main stressors of the "management" dimension are fatigue after prolonged duty time, work stress due to lack of warning and signal reconfirmation on single-driver duty, and inability to arrange proper meal time when on duty. It is suggested the TRA examine the optimal duty time, and add driving auxiliary safety equipment, such as Automatic Train Protection (ATP) or Automatic Train Control (ATC), in order to help drivers release their driving stress. As for drivers' meals, it would be possible to provide convenient food (such as sandwiches or rice balls) to meet drivers' needs, or arrange two-driver duty, thus allowing the drivers to have a meal time.

4. Drivers feel it is easier to overcome problems, such as driving various types of locomotives, various operating skills, safety rules, and simple locomotive

troubleshooting, indicating driver training and on-the-job training provided by the TRA can allow drivers to achieve technical requirements. The call-response system is a recheck mechanism to confirm the condition ahead. Although drivers may feel stress, after becoming accustomed to the operation, drivers would no longer perceive these as being very difficult to overcome. Therefore, this system is effective in improving driving safety.

5. Even though driving hours for train drivers are strictly regulated under TRA's train operations, it is still impossible to eliminate the increasing accident risk generated by consecutive train driving. In order to deal with this accelerated accident risk caused by the fatigue generated by continuously driving in a high pressure working environment, several improvement strategies have been suggested and implemented for the railway transportation industry. These strategies include driver education and training programs, managerial arrangement (e.g., work shift management), working environment (e.g., driver cabin) improvement, as well as the employment of advanced technology for train operation safety, such as a positive train control system (Sussman and Coplen, 2000) and an automatic train protection (ATP) system. The ATP system provides a function to prevent trains passing signals at dangerous speeds or failing to stop on terminating lines. Actions initiated by the ATP system warn the train driver of speeding and activate emergency braking in an abnormal situation. Evans and Verlander (1996) found that

ATP systems identified and eliminated an estimated 3.66 ATP-preventable fatalities per year on British railways in 1964-1993.

6. To prevent errors in complex marshalling yard work, enhancing workers' cognitive and skill abilities through training is required. Rutter (2003) emphasized that improving safety should focus on altering behaviors other than improving technology or altering structural operating conditions. Therefore, enhancing training programs to educate drivers to obey rules and be familiar with procedures, such as switching lines properly, ensuring safety equipment is correct, communicating clearly, and watching signals carefully, should decrease accident rates. Additionally, enhancing pre-starting instructions to confirm drivers are familiar with the layout of the marshalling yard and the work requirements during their shifts plays an important role in preventing accidents in a complex operating environment.

7. Building a standard operating procedure and establishing a sound auditing system are also required for shunting operations. There are many rules that confirm the operational safety of a shunting yard, but the staff can always be tempted to cut corners and ignore safe working rules. For example, train speed is strictly limited during marshalling yard operation because lower running speeds result in lower accident risk. A sound auditing system will encourage and assure that railroad workers obey the rules and best practices.

6.3 Future research

1. The design of a competency measure for drivers' perceived difficulty of driving safety stressors is a unique and professional work. This study tried to build a measurement tool for the adaptability of TRA drivers to driving safety stressors, in order to identify the stressors and safety threats faced by the drivers when driving, and acquire preliminary research results. Nonetheless, the scale design still needs to be further improved and tested before becoming an efficient and reliable measurement tool. Therefore, future studies can continue to examine and promote this scale.
2. The observational accident data spanning the eleven years in the TRA's reporting system was applied through the endeavor of this study. However, accidents attributable to train drivers' errors were still relative small, on which only 122 cases for passenger drivers and 50 for freight drivers were based. The smaller samples might influence the stability of the estimated accident rates within the time slots and thus reduce the precision of the estimated regression models. In particular, lesser accident data occurred at the consecutive driving hours more than 3.5 hours. To improve the model's precision, it is suggested that a longer time on the TRA's reporting accident data be collected.

6.4 Research Contributions

The main contributions of this study can be summarized as follows:

1. The design of a competency measure to explore the perceived difficulties of various stressors for train drivers is very unique and professional work. This study aimed to build a competency scale to measure the perceived difficulties of drivers in the TRA. It will also prioritize the perceived stressors confronted by these drivers. Preliminary results have been obtained.
2. Another contribution of this study is to explore the different stressors encountered by train drivers and provide suggestions for prioritizing railway safety operations, as well as providing guidance for allocating limited resources most efficiently. For example, the five factors in the "Environment" dimension are driving safety stressors that are difficult to be adapted by TRA drivers. It is recommended to TRA that these stressors should be reduced immediately to enhance driving safety.
3. It was confirmed that both passenger and freight train drivers are similar to motor transport drivers in that the risk of being involved in an accident increases as the number of hours of consecutive driving increases. However, the harsher the working requirements for train driver the greater the acceleration of fatigue and, therefore, an enhanced accident risk, as compared with automobile driving. This result contributes a reference in making railway safety policy.

4. Computing accident rates for passenger and freight trains separately helps us explore the early accident risk peak problem raised in previous studies. This is due to the requirements of shunting in the marshalling yards, where the track layout is more complicated than that of the main lines and, for the TRA, the circulation of freight trains is guided by a semi-automatic interlock system. Based on this finding, management improvements, like enhancing training programs to educate drivers to obey the rules and be familiar with operation procedures, were offered. Also, enhancing pre-starting instructions for freight drivers to confirm that drivers are familiar with the layout of the marshalling yard.

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