



Effect of consecutive driving on accident risk: A comparison between passenger and freight train driving

Hsin-Li Chang^{a,1}, Lai-Shun Ju^{a,b,*}

^a Department of Transportation Technology and Management, National Chiao Tung University, 1001, Ta Hsueh Road, Hsinchu 300, Taiwan, ROC

^b Department of Transportation, Taiwan Railway Administration, 318, Jianguo, 2nd Road, Kaohsiung City 80723, Taiwan, ROC

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ABSTRACT

This study combined driver-responsible accidents with on-board driving hours to examine the effect of consecutive driving on the accident risk of train operations. 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 the part of the reason. To prevent human errors accidents, enhancing safety equipment, driver training programs, and establishing a sound auditing system are suggested and discussed.

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1. Introduction

Shinar (1978) suggested that driving is a form of information processing requiring sustained vigilance to safely navigate roads. However, working and driving for sustained periods generates fatigue and reduces productivity (Okogbaa et al., 1994; Smiley, 1998; Smith, 1981; Sussman and Coplen, 2000) and many studies have identified fatigue as a significant cause of accidents (Hakkanen and Summala, 2001; Thiffault and Bergeron, 2003). Therefore, the risk of being involved in an accident is expected to increase as the number of hours of consecutive driving increases.

Some studies have explored the effect of continuous driving on accident risk for motor carriers. Mackie and Miller (1978) investigated 750 truck crashes and found crash occurrences began to increase after 5 h of driving, and the risk during the second 5 h was twice that of the first five. Elvik et al. (1997) reported that truck accident risk significantly increases after 8 h of consecutive

driving and there is a tendency for increasing risk when driving more than 9–11 h (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 5 h driving was double that of the first hour. Although risk estimates vary somewhat among studies, the findings are fairly consistent in showing accident risk increases with prolonged driving.

Train driving has many demands and responsibilities. Train drivers are responsible for both the safety and punctuality of train operation; a job that requires high levels of concentration and alertness to react to oncoming signals, information, switches, and the immediate environment (Kecklund et al., 1999). Train driving requires numerous cognitive functions, including sustained attention, object detection and recognition, memory, planning, decision-making, and workload management (Reinach and Raslear, 2001). Dorrian et al. (2006) demonstrated, through laboratory experiments, that complexity of work requirements influences the extent to which a task is affected by sleep loss and fatigue. As such, harsher working requirements for train drivers mean greater acceleration of fatigue and, therefore, enhanced accident risk, as compared to automobile driving.

Few studies have examined the risk of train accidents as a function of consecutive driving time. Wharf (1993) analyzed the frequency of signals passed at danger per million driving hours for

* Corresponding author at: Department of Transportation, Taiwan Railway Administration, 318, Jianguo, 2nd Road, Kaohsiung City 80723, Taiwan, ROC. Tel.: +886 7 2353512; fax: +886 7 2352549.

E-mail addresses: hchang@cc.nctu.edu.tw (H.-L. Chang), tr297326@ms1.tra.gov.tw, laishun@seed.net.tw (L.-S. Ju).

¹ Tel.: +886 3 5731908, fax: +886 3 5712365.

British Rail drivers and found a distinct peak during the second and third hours of duty, followed by a relatively low level, which subsequently increased. When investigating the 1980–1997 accident records from the Swedish National Rail Administration, Kecklund et al. (1999) found a risk peak existed at the third hour of the shift, followed by a period of low risk. Additionally, van der Flier and Schoonman (1988) explored the relationship between driver errors (missed signals) and working hours and found the probability of error peaked during the second and third hours of the shift. Both Kecklund et al. and van der Flier and Schoonman discussed possible reasons for the findings and speculated such mistakes are due to fatigue accumulated from previous shifts, or drivers might relax too much during the start of a shift.

One must also consider the influence of differential requirements for passenger and freight train driving, which may also reveal some important insights regarding accident risk. Freight train drivers usually have irregular work schedules, boredom during operations (Sussman and Copen, 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.

This study explores the effect of consecutive driving on accident risk and also examines the difference in accident risk over time between passenger and freight train driving. The data for this empirical study were collected from the Taiwan Railway Administration (TRA), including accidents caused by train drivers' errors and records of all drivers work shifts from 1996–2006. Only the actual driving hours were used to compute accident rates for different amounts of consecutive driving, because they are the only spans that possess commonalities across all work shifts. Furthermore, accident rates for passenger and freight train driving were computed separately to determine whether accident risks for the two types of train driving are different. The results contribute to railway operation safety and can guide improvements in railway transportation safety.

2. Train operations and work shift regulations of the TRA

The TRA is the only institution in Taiwan providing 24 h service for both passenger and freight railway operations with 219 stations and 1097.2 km of track. The TRA has 1250 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:

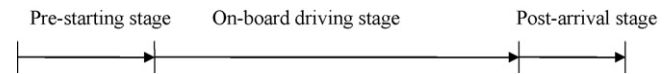


Fig. 1. Three stages of one driver's work shift under TRA operation.

- (1) driving distance for each shift must be less than 300 km;
- (2) each shift must not exceed 6 h from 6 a.m. to 10 p.m.;
- (3) each shift must not exceed 5 h from 10 p.m. to 6 a.m.;
- (4) drivers' rest duration between consecutive shifts must be longer than 6 h; and
- (5) drivers must have at least one off-duty day a week (duration must exceed 24 h).

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. 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 train from the origin depot to the starting station. Generally, completing all of the tasks at this stage takes about 40–60 min depending on different types of work shift patterns.

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.

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 min depending on the type of shift pattern.

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 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

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

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

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.

3. Data collection

3.1. Driver-responsible accidents

According to the TRA’s operation rules, a train accident is defined as an event causing more than 10 min 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 used in this study. Of the 10,990 total TRA accidents, 10,371 were non-human errors and 619 were human error accidents. Among the human error accidents, 193 were attributed to driver errors, which accounted for 31% of all human error accidents. Based on this study’s purpose, only the driver-responsible accidents are counted. 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 9 at the post-arrival stage. For the purpose of studying the effect of consecutive driving on accident risk, the 172 on-board driving accidents were examined for this study, which included 122 passenger train accidents and 50 freight train accidents.

3.2. Driving exposure to the risk of accident

Chapman (1973) defined “exposure” as the amount of opportunity a driver has to be involved in an accident. Although exposure has been defined in various ways, one would expect accident frequency to increase as travel time increases (Rodrigue, 2006). In practice, exposure is the denominator when the accident rate is calculated. Dividing 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. 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 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, on-board driving hours is selected as the exposure measure in this study. On average, there were 1072 work shifts per day and approximately 4.3 million shifts were collected to calculate on-board driving hours during 1996–2006.

Since TRA regulations limit the hours of a shift, virtually all on-board driving time is shorter than 4.5 h. Therefore, a maximum of 4.5 h of consecutive driving was observed in this study. To determine whether the accident rate rises as driving hours increase, the length of on-board driving time was further divided into several time slots—15 min for each slot; 18 slots total. Shifts were then distributed into the 18 time slots based on length of on-board driving.

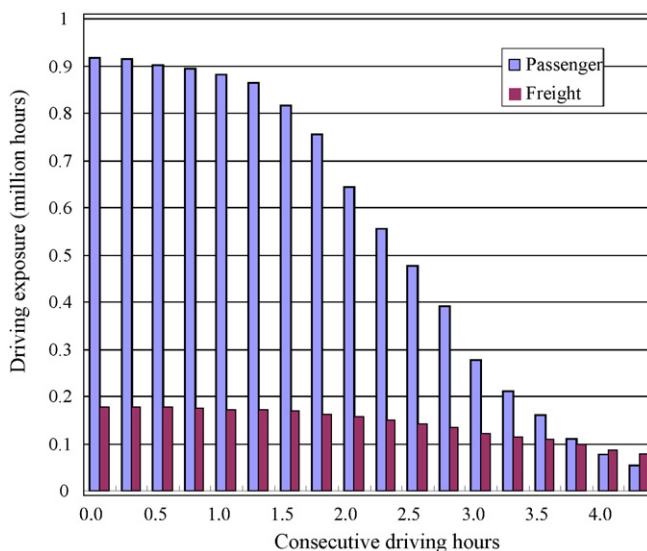


Fig. 2. Passenger and freight train driving exposure for different consecutive driving hours.

Taking 3 h and 10 min of on-board driving as an example, the 3 h were assigned to the first 12 time slots (i.e., 4 (15-min slots per hour) × 3 = 12 slots) and the last 10 min were assigned to the 13th time slot. Hence, the accumulated on-board driving hours within each time slot could be calculated.

On average, passenger train drivers had 2 h and 45 min of on-board driving, while freight train drivers had an average of 3 h and 20 min. In addition, the variation in on-board driving time for passenger train drivers (S.D. = 89 min) was greater than for freight train drivers (S.D. = 42 min). This shows the length of on-board driving was consistently longer for freight train drivers. The accumulated on-board driving hours in each time slot for both types of train driving are shown in Fig. 2. The total on-board driving hours for passenger trains was 9.88 million hours and for freight trains was 2.57 million hours, which comprised only 20.6% of total on-board driving hours.

4. Accident rates for different time slots of consecutive train driving hours

Dividing the number of total accidents in the observation period by the total driving hours, we found an average accident rate of 13.82 accidents per million driving hours, and freight and passenger train drivers experienced 19.45 and 12.35 accidents per million driving hours, respectively. Freight train driving had a 58% higher accident risk, which is consistent with the expectancy discussed in the previous section.

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

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

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.

Based on this formula, the accident rates for different time slots for all trains, passenger trains, and freight trains, are computed and

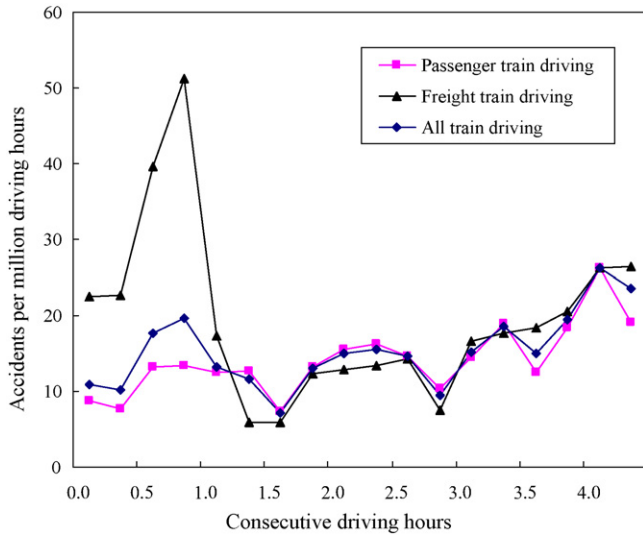


Fig. 3. The accident rate over consecutive driving hours for different train driving.

illustrated in Fig. 3. The accident rates for all train driving had a distinct peak after 1 h of consecutive driving, followed by a relatively low level, which subsequently increased. This is consistent with the findings of both Wharf's (1993) and Kecklund et al.'s (1999) studies. The only difference with the current study is the time of occurrence of this early peak, which reflects the fact that pre-driving hours were included in the on-duty hours in previous studies, but not included in this study.

If the accident rates are investigated separately for freight and passenger train driving, a significant difference in accident rates over time is found, as can be seen in Fig. 3. That is, accident rates for freight train driving were significantly higher during the first hour of driving, but this phenomenon disappeared after 1 h. Further investigation shows 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 that for passenger trains (10.78 accidents per million driving hours). Among the 24 freight train accidents that occurred in the first hour of driving, 20 (83%) occurred in the marshalling yards. That is consistent with the expectancy that freight trains have higher accident risk when shunting in marshalling yards than when running on the main lines.

Interestingly, the peak accident rate in the early driving hours was not found for passenger trains. Those accident rates seemed to increase gradually as driving hours were accumulated, which is consistent with the hypothesis that prolonged driving induces fatigue and then increases accident risk. This phenomenon could also be found for freight train driving if we ignore the early peak during the first hour of driving. Therefore, the results shown in Fig. 3 indicate the effect of consecutive driving on accident risk actually exists for both passenger and freight train driving, even within a span of 4.5 h. The extra accident risk for freight trains in the first hour could be explained by volume of shunting in the marshalling yards.

5. Modeling the accident risk for consecutive driving

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 (AR) and consecutive driving hours for train driving. These four models are expressed as follows:

Model 1 (Linear):

$$AR = a + bt \tag{2}$$

Model 2 (Log linear):

$$\ln(AR) = a + bt \text{ or } AR = \exp(a + bt) \tag{3}$$

Model 3 (Quadratic):

$$AR = a + bt + ct^2 \tag{4}$$

Model 4 (Modified Quadratic):

$$AR = a + ct^2 \tag{5}$$

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 Fig. 3 (i.e., distinct peak – relatively low level – increase again).

According to the model estimation results summarized in Table 2, Model 3 is the best model for all train driving in

Table 2 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					
Model 1	12.34	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					
Model 1	19.07	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.

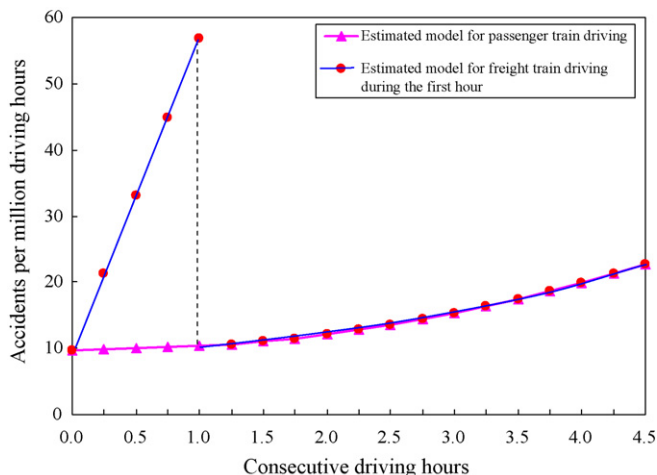


Fig. 4. The estimated accident rate model over consecutive driving hours for passenger and freight train driving.

terms of its explanatory power, though parameter *b* is only marginally significant with a *p*-value of 0.16. For passenger train driving, Model 4 is best at describing increasing accident risk over time for consecutive driving. As for freight train driving, Model 3 is better than the others in catching 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.

The models for passenger train driving had much better fit than those for freight train driving due to the lack of a distinct risk peak in the first hour of driving. The pattern of increasing accident risk caused by consecutive driving for passenger trains is similar to that for automobiles or trucks. Although the accident rates over time for consecutive freight train driving are not significantly different from those of passenger trains after 1 h of driving, the abnormally high accident risk in the first hour 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:

$$AR = a + bt + ct^2 + D(dt + et^2) \tag{6}$$

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 Eq. (6), and the estimated results are summarized in Table 3. The explanatory ability of the best model, with *R*² = 0.842, was a significant improvement over the single models for passenger and freight train driving, respectively.

The estimation results of the best-combined model shown in Table 3 are illustrated in Fig. 4. It indicates accident risk for passenger train driving increases with accumulated driving hours, and shows the accident risk doubles after four consecutive hours of driving, as compared with the accident risk 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, accident rates for freight train driving were 3.3 and 5.5 times of those of passenger train driving after half an hour and 1 h, respectively. This might be a function of increasing train length paired with 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 trains went down sharply to the risk levels of passenger trains after 1 h of on-board driving in the marshalling yards.

6. Discussion

This study investigated train-driver-responsible accidents by examining 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 investigate the distinct early peak problem of accident risk for rail operation raised by previous literature. Some findings and their implications follow.

6.1. Accelerating accident risk for train driving compared with truck driving

Accident risk for train driving was found to double after 4 h of consecutive driving, as compared to the first hour driving. Accelerating accident risk for train driving seems to occur earlier than for automobile driving (Amundsen and Sagberg, 2003; Chang and Hwang, 1991; Elvik et al., 1997; Mackie and Miller, 1978). Greater fatigue generated by working pressure and a monotonous driving environment are considered as important reasons for an accelerated accident risk 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 work requirements (e.g., 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 may result in accelerated fatigue and, thus, increase train accident risk faster than is seen in automobile driving. Furthermore, highly automated duties, such as automatic train controls, can be perceived as boring and monotonous. Monotonous tasks may gradually cause a decline in performance (Thiffault and Bergeron, 2003), reduce levels of alertness, and increase crash risk (Horne and Reyner, 1995). The monotonous driving environment is, therefore, another reason for accelerating the accident risk of consecutive train driving.

Even though driving hours are strictly regulated under TRA's 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 several strategies have been sug-

Table 3 The estimated results for the combined model of accident risk over time

Parameter	<i>a</i> (<i>p</i> -value)	<i>b</i> (<i>p</i> -value)	<i>c</i> (<i>p</i> -value)	<i>d</i> (<i>p</i> -value)	<i>e</i> (<i>p</i> -value)	<i>R</i> 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.

gested and implemented in the railway transportation industry. These include driver education and training programs, managerial arrangements (e.g., shift management), working environment (e.g., driver cabin) improvement, as well as the use of advanced technology for train operation safety, such as a positive train control system (Sussman and Copen, 2000) and an automatic train protection (ATP) system. The ATP system prevents trains from passing signals at dangerous speeds or failing to stop on terminating lines. Actions initiated by the ATP system warn the train driver and activate emergency braking in abnormal situations. Evans and Verlander (1996) found that ATP systems identified and eliminated an estimated 3.66 fatalities per year on British railways in 1964–1993.

6.2. The early peak of accident risk for freight train driving

Freight train driving was found to be associated with a risk peak during the first hour of driving. This early peak was also found in previous railway studies, but lacked further investigation of possible causes. Compared with passenger train driving, freight train driving is usually associated with greater working complexity. These working characteristics might contribute to an earlier peak accident risk for freight trains.

Shunting in the marshalling yard is an unsafe activity, not only because the yard's track layout is more complicated than the main lines but also because circulation of trains in the yard is guided by a semi-automatic interlock system. 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 drivers. These operation characteristics for freight train driving in the marshalling yards are considered to be the reasons TRA experiences higher accident risk for shunting.

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.

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 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.

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