Analysis of Driving Performance Data to Evaluate Brake Manipulation by Railway Drivers

Daisuke Suzuki[1(✉)], Naoki Mizukami[1], Yutaka Kakizaki[2], and Nobuyuki Tsuyuki[2]

[1] Ergonomics Laboratory, Railway Technical Research Institute, 2-8-38 Hikari-cho, Kokubunji-shi, Tokyo, Japan
suzuki.daisuke.55@rtri.or.jp

[2] Transportation and Marketing Department, Central Japan Railway Company, 1-3-4 Meieki, Nakamura-ku, Nagoya, Japan

Abstract. Here, we aim to investigate the relationship between the braking operations used to stop a train at a station and the errors in the train's stopping position. Hence, using driving performance data, a logistic regression analysis was conducted. This analysis revealed that the train stopping-position errors at stations were associated with the standard deviation of the sum of brake notches, the mean of the additional brake notches, and the duration of driving experience. Drivers with a larger dispersion of brake notches in the individual were more prone to cause stopping-position errors at stations. Further, drivers who frequently used additional brake notches were more likely to cause stopping-position errors at stations. Furthermore, operators with more driving experience were less likely to incur stopping-position errors.

Keywords: Driving performance data · Brake manipulation · Railway driver · Human error · Driving skill

1 Introduction

Driving performance data from railway vehicles are often saved in data-recording devices. These data can be used to analyze accidents, prevent human error, and improve crew skills. There have been several studies of data describing the driving performance of railway drivers. Sakashita et al. [1] analyzed more than 20 elements of driving performance data from approximately 100 drivers recorded over six months. The following evaluation indices related to braking operations for stopping a train at a station were used: (1) duration of strong braking (seven notches) used when stopping, (2) number of additional times brakes stronger than 3 notches used when stopping, (3) amount of brake notch changes used when stopping, (4) number of times coasting position used when stopping, and (5) train speed at a fixed point (five seconds before train stops). It was demonstrated that the use of strong braking (1) and many brake notch changes (3) strongly influenced whether the drivers experienced train stopping-position error at stations. Moreover, it was found that the train speed at a fixed point

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five seconds before the train stopped varied widely before an error occurred. Marumo et al. [2] analyzed the braking behavior of train drivers in a driving simulator to estimate drivers' mental conditions. The results showed that the relationship between the velocity deviation and the braking operation could be used as an indicator of abnormal driving behavior. Further, Marumo et al. [3] analyzed the braking operation when stopping at a station and found that simultaneously performing secondary tasks was associated with significantly greater variance in the brake handle operation.

Although several examples of the factors influencing driver error have been studied, the relationship between brake manipulations and train stopping-position errors at stations has not been studied in depth. Therefore, we aim to investigate how the brake manipulation is related to the occurrence of stopping-position errors at a station by analyzing driving performance data.

2 Methods

2.1 Analysis Data

The data concerning driving operations (i.e., distance, velocity, and braking notches) when stopping at one train crew depot were extracted from the driving performance data recorded by railway vehicles in Japan. The sampling rate was 1 Hz. The data were collected over a period of two months beginning in August 2016.

2.2 Participant Group

118 drivers aged 25–61 years (mean age: 33 years, standard deviation: 9 years) participated in the study. The driving experience of the participants ranged from 0 to 29 years (mean: 7 years, standard deviation: 7 years). The "expert" group comprised 12 drivers, who were instructors of trainees, and selected by a manager of the train crew depot. These drivers were aged 30–57 years (mean age: 36 years, standard deviation: 7 years), and their driving experience ranged from 2 to 29 years (mean: 8 years, standard deviation: 7 years). The "error" group included 22 drivers who had made a train stopping-position error at a station in the previous nine months. These drivers were aged 25–61 years (mean age: 33 years, standard deviation: 11 years), and their driving experience ranged from 0 to 29 years (mean: 6 years, standard deviation: 9 years). Table 1 summarizes the age and driving experience of each group.

Table 1. Age and driving experience of each group

		All drivers (118)	Expert group (12)	Error group (22)
Age (years)	Range	25–61	30–57	25–61
	Mean	33	36	33
	SD	9	7	11
Driving experience (years)	Range	0–29	2–29	0–29
	Mean	7	8	6
	SD	7	7	9

SD: Standard Deviation

2.3 Evaluation Indices and Analysis Method

As described in the previous study [1] and summarized in Table 2, five evaluation indices regarding velocity and brake manipulation for stopping a train at a station were utilized. Figure 1 shows a schematic of the brake manipulations used when stopping.

Table 2. Evaluation indices

Evaluation indices	Explanation
(1) Train speed at a fixed point	Velocity five seconds before the train stops
(2) Number of brake notch changes used when stopping	Number of times the brake notch was changed during the five second period before stopping
(3) Additional brake notches when stopping	Brake notches added during the five second period before stopping per 10 stops
(4) Sum of brake notches when stopping	Sum of brake notches at each second during the five second period before stopping
(5) Maximum brake notch when stopping	Maximum brake notch during the five second period before stopping

"when stopping" implies "during the five seconds immediately before the stop"

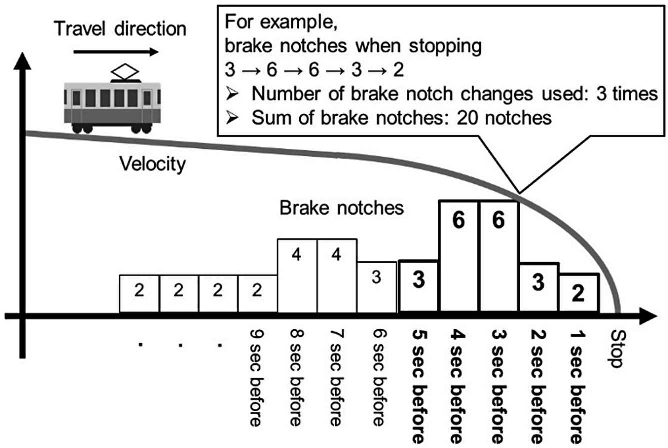

Fig. 1. Schematic of an example of brake manipulations when stopping

Each of the evaluation indices in Table 2 was evaluated for each stop, and the means and standard deviations of all the stops were evaluated for each driver. The means were used to compare the evaluation indices among the drivers, and the standard deviations were used to investigate the variability of each individual.

A logistic regression analysis was conducted to identify the influence of the brake manipulations that are used to stop the train at the station on the occurrence of a stopping-position error at a station. The objective variable was the participant group, and the explanatory variables were the means and the standard deviations of the five evaluation indices and the duration of driving experience. The step-wise method was used to select the variables. The statistical level of significance was 0.05. BellCurve for Excel, which is statistical software made by Social Survey Research Information Co., Ltd., was utilized to perform the analysis.

3 Result

Table 3 shows a list of objective and explanatory variables used in logistic regression analysis.

Table 3. List of objective and explanatory variables

	Objective variable	Explanatory variables										
No.	Participant group	Mean of the train speed at a fixed point (km/h)	Standard deviation of the train speed at a fixed point (km/h)	Mean of the number of brake notch changes (times)	Standard deviation of the number of brake notch changes (times)	Mean of the additional brake notches (notches)	Standard deviation of the additional brake notches (notches)	Mean of the sum of brake notches (notches)	Standard deviation of the sum of brake notches (notches)	Mean of the maximum brake notch (notches)	Standard deviation of the maximum brake notch (notches)	Driving experience (years)
1	Expert	8	2	1	1	5	7	8	3	2	1	29
2	Error	9	2	2	1	5	7	10	4	3	1	29
3	Error	11	3	2	1	8	16	14	5	4	2	7
4	Expert	7	2	1	1	3	6	7	3	2	1	3
5	Error	8	2	1	1	3	5	7	3	2	1	10
6	Expert	7	2	1	1	3	6	7	3	2	1	10
7	Expert	7	2	1	1	3	5	7	3	2	1	9
8	Expert	9	2	1	1	2	4	9	3	3	1	6
9	Error	8	3	1	1	6	8	9	4	2	1	20
10	Expert	8	2	1	1	3	5	8	3	2	1	2
11	Error	8	2	1	1	4	7	8	4	2	1	6
12	Expert	8	1	1	1	2	5	8	2	2	1	9
13	Expert	9	2	1	1	4	7	9	3	3	1	6
14	Expert	8	2	1	1	3	5	7	3	2	1	7
15	Error	8	2	1	1	3	6	7	3	2	1	6
16	Expert	9	2	1	1	1	4	10	4	3	1	6
17	Expert	9	2	1	1	1	4	9	3	3	1	8
18	Error	7	2	1	1	5	7	7	3	2	1	5
19	Expert	7	2	1	1	4	6	7	3	2	1	5
20	Error	8	2	1	1	3	5	8	3	2	1	3
21	Error	7	2	1	1	3	5	7	3	2	1	0
22	Error	8	2	1	1	2	5	9	4	2	1	1
23	Error	8	2	1	1	4	6	8	4	2	1	3
24	Error	8	2	1	1	5	6	8	3	2	1	3
25	Error	7	2	1	1	3	5	6	2	2	1	1
26	Error	8	2	1	1	4	5	9	4	2	1	2
27	Error	7	2	1	1	7	7	7	4	2	1	0
28	Error	8	2	1	1	3	5	8	4	2	1	0
29	Error	8	2	1	1	6	9	8	4	2	1	1
30	Error	7	2	1	1	4	6	6	3	2	1	0
31	Error	8	2	1	1	6	8	9	4	2	1	0
32	Error	10	3	2	1	11	11	11	5	3	1	29
33	Error	8	2	1	1	3	5	8	3	2	1	0
34	Error	7	2	1	1	6	9	7	4	2	1	0

The variance-information factors (VIFs) were calculated to evaluate the multi-collinearity. Generally, it is said that there is a possibility of multicollinearity if the maximum VIF is above 10 or the average VIF is significantly more than 1 [4]. In this case, the maximum VIF among the explanatory variables used in this study was 1.78; thus, it was concluded that multicollinearity was not an issue for this analysis.

Table 4 shows the results of the logistic regression analysis. In case that the p value is lower than 0.05, the occurrence of a train stopping-position error is significantly associated with the explanatory variable. The p values revealed that the occurrence of a train stopping-position error was significantly associated with the mean of additional brake notches used, the standard deviation of the sum of brake notches used, and the driving experience.

Table 4. Results of logistic regression analysis

Explanatory variables	Partial regression Coefficient	Standardized partial regression coefficient	Odds ratio	95% confidence interval of the odds ratio		p value	*: $p<0.05$
				Lower limit	Upper limit		
Mean of additional brake notches (notches)	2.58	5.04	13.25	1.71	102.72	0.01	*
Standard deviation of sum of brake notches (notches)	2.43	1.59	11.40	1.14	114.25	0.04	*
Driving experience (years)	-0.21	-1.71	0.81	0.67	0.98	0.03	*
Constant	-7.43		0.00	0.00	0.47	0.03	*

Furthermore, evaluating the odds ratios revealed that when other variables do not change, the possibility of a train stopping-position error increases by 13.25 times when the mean of additional brake notches used increases by 1 notch per 10 stops; similarly, it increases by 11.40 times when the standard deviation of the sum of brake notches used increases by 1 notch. Moreover, when other variables do not change, the possibility of a train stopping-position error changes by a factor of 0.81 when the driver's experience increases by 1 year.

The standardized partial regression coefficients were determined as shown in Table 4. The larger the absolute value of the standardized partial regression coefficient is, the larger the influence of the explanatory variable is. These results revealed that the mean of the additional brake notches used had the largest influence on the possibility of a train stopping-position error among these three variables.

4 Discussion

The results of the logistic regression analysis revealed that the mean of the additional brake notches, standard deviation of the sum of brake notches, and driving experience influenced the possibility of the driver committing a stopping-position error.

Regarding the sum of brake notches, drivers that used a larger dispersion of brake notches were more likely to make train stopping-position errors. A previous study regarding automobile drivers [5] revealed that drivers who used a larger dispersion of brake manipulations were more likely to cause accidents. This finding is consistent with that in the present study.

Further, regarding the additional brake notches, drivers who frequently used additional brake notches were more likely to cause train stopping-position errors; this likely occurs because additional brake notches are associated with the delay in brake manipulations and high speeds when approaching stations. However, further study is required as the approach speed is somewhat dependent on the characteristics of a particular station.

Aside from the influence of a driver's brake manipulation tendencies, drivers with longer driving experience were less likely to cause train stopping-position errors at stations. Education to drivers with short driving experience is one of important problems. Further study is required as this study did not give feedback regarding driving performance data.

5 Conclusion

In this study, logistic regression analysis on the train stopping-position error was conducted to identify the effects of brake manipulations for stopping a train at a station. Drivers were categorized according to whether they committed a train stopping-position error at a station in the past nine months; this categorization was used as the objective variable. The explanatory variables were the means and standard deviations of five evaluation indices and duration of prior driving experience.

The p values showed that the mean of additional brake notches, the standard deviation of sum of brake notches, and driving experience influenced the potential for a train stopping-position error. The standardized partial regression coefficient revealed that the mean of additional brake notches used had the strongest influence among these three variables. The odds ratios indicated that drivers who frequently used additional brake notches were more likely to cause train stopping-position errors at stations. Similarly, drivers with larger brake notch dispersion were more likely to cause such errors, which implies that it is possible that stable manipulations enable drivers to prevent train stopping-position errors. Additionally, drivers with more driving experience were less likely to cause such errors.

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