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Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation



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Stjepan Lakušić

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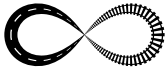
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BEHAVIORAL ANALYSIS OF DEPARTURE TIME DECISION CONSIDERING REDUNDANCY OF RAILROAD NETWORK

Kazuyuki Takada¹, Makoto Fujii², Shigeki Sugiyama¹

¹ Tokyo Denki University, Japan

² The University of Tokyo, Japan

Abstract

Reliability of travel time is one of the important factors affecting mode choice and route choice behaviors. Recently, many studies have investigated variability of travel time and engaged in developing methodology to evaluate economic value of the travel time reliability. We have investigated the travel time reliability of the railroad from the point of departure time decision of railroad users. As the results of our previous studies, it becomes clear that railroad user prepares buffer time to deal with the delay of railroad. Furthermore, it indicates that the buffer time is influenced by several factors such as travel distance, usages frequency of railroad, and number of times of transfer. Meanwhile, reliability as a function of transport network was not considered in the previous studies. Therefore, this study aims to develop a methodology to evaluate the travel time reliability with considering the level of redundancy of the railroad network. The data collected by internet survey was utilized to estimate a departure time decision model which can describes the length of buffer time.

Keywords: railway, redundancy, departure time decision

1 Introduction

Reliability of travel time is one of the important factors affecting mode choice and route choice behaviour. Recently, many studies have investigated variability of travel time and engaged in developing methodology to evaluate economic value of the travel time reliability. Most of them have focused on the reliability of road traffic. Meanwhile, research on the travel time reliability of railroad and air transport which operates based on the planned timetable has not sufficiently advanced so far.

We have investigated the travel time reliability of the railroad from the point of departure time decision of railroad users [1],[2]. As the results of our previous studies, it becomes clear that railroad user prepares buffer time to deal with the delay of railroad. Furthermore, it indicates that the buffer time is influenced by several factors such as travel distance, usages frequency of railroad, and number of times of transfer.

Meanwhile, reliability as a function of transport network was not considered in the previous studies. However, robustness of railroad network should be considered when user benefit by improving travel time reliability is evaluated. Therefore, this study aims to develop a methodology to evaluate the travel time reliability with considering the level of redundancy of the railroad network.

At first, some indices which represent the level of redundancy of railway network were developed. Then, these indices for each railway passengers who were respondent of the questionnaire survey were calculated. Secondly, the information included in these indices was consolidated by factor analysis. As the result of the analysis, four kinds of factors were extracted. Thirdly, the

departure time decision of railway commuter was analyzed. In this study, Fosgerau's approach was applied to build the decision model [3],[4]. Regression model regarding buffer time estimated. Four indices which represent each factor extracted by the factor analysis were considered as explanatory variables of the model. It is demonstrated that the level of redundancy influences on buffer time of railway commuters.

2 Data

This study focused on the influence of railway network redundancy on the departure time decision of railway commuters. Therefore, the data regarding travel behaviour of railway commuters was collected by conducting internet survey. Detail of the data was described in [1].

3 Indices of railway network redundancy

3.1 Development of railway network redundancy

To evaluate the level of the redundancy, we developed indices as described below.

3.1.1 Index.1

Index.1 is defined as number of available routes between origin and destination. This index presents the robustness of redundancy. The larger value of index.1 indicates the higher redundancy, because number of available routes increase. The maximum of the index is set to 10.

3.1.2 Index.2

Index.2 is defined as travel time difference between first best and second best routes. This index presents effectiveness of the second best routes. The smaller value of index.2 indicates the higher redundancy, because the additional time is not large in case the value is small.

3.1.3 Index.3

Index.3 is defined as travel time difference between first best and third best routes. This index presents effectiveness of the third best routes. The smaller value of index.3 indicates the higher redundancy, because the additional time is not large in case the value is small.

3.1.4 Index.4

Index.4 is defined as number of routes of which increase ratio of travel time is less than certain percentage. Index.4-1, 4-2, 4-3 and 4-4 are assessed by number of routes of which increase ratio of travel time against the best route is less than 10%, 20%, 50% and 100% respectively. The larger value of index-4 indicates the higher redundancy, because number of available routes increase.

3.1.5 Index.5

Index.5 is defined as minimum number of available routes of each boarding section. This index presents the section level redundancy. The larger value of index.5 indicates the higher redundancy, because the redundant level of most vulnerable section is increase.

3.1.6 Index.6

Index.6 is defined as the largest travel time difference between first best and second best routes among boarding sections. This index presents the section level redundancy. The larger value of index.6 indicates the higher redundancy, because the redundant level of most vulnerable section is increase. Index.6-1 and 6-2 are assessed by the largest travel time difference between first and second best routes among each section and also first and third best routes among each section.

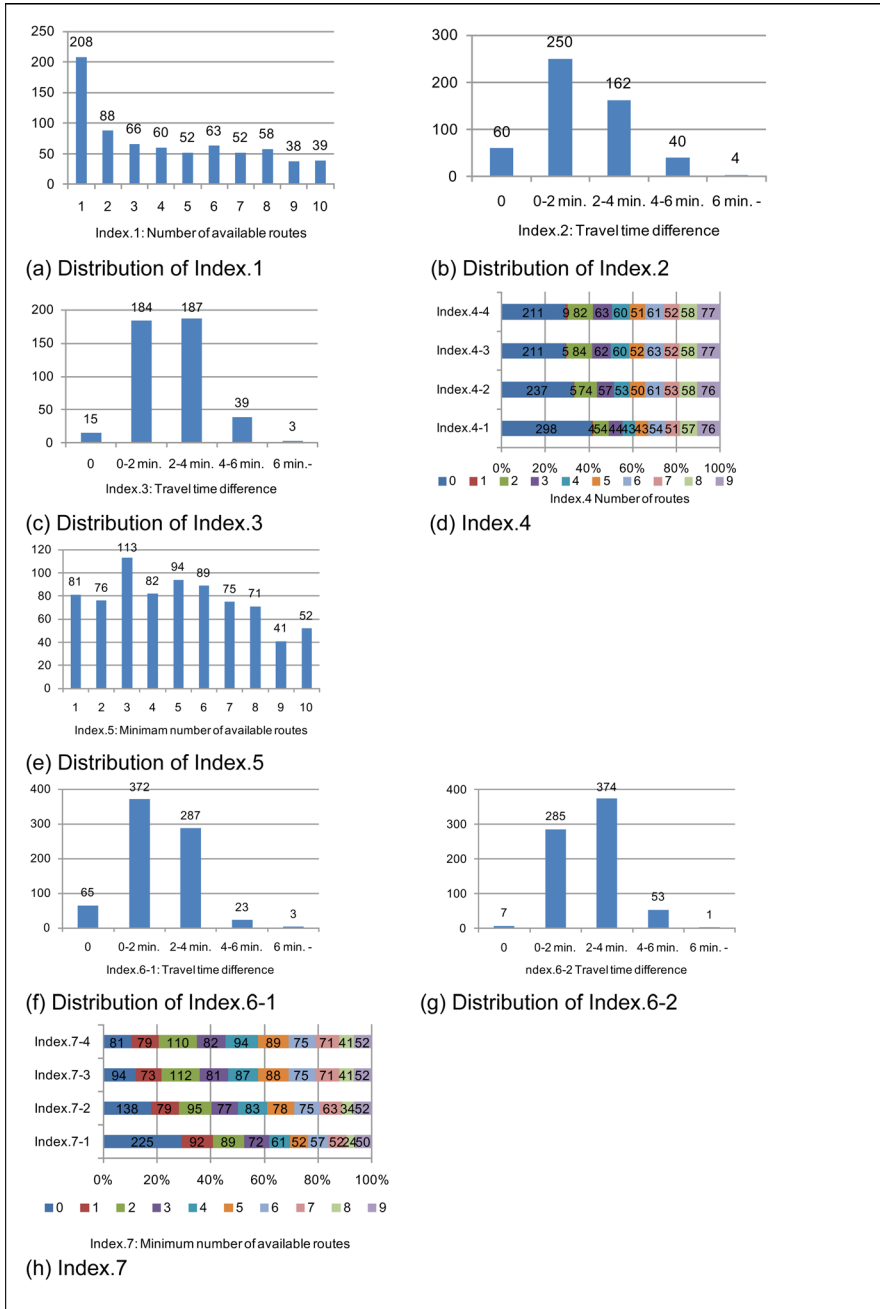


Figure 1 Calculation results of the indices

3.1.7 Index.7

Index.7 is defined as minimum number of available routes among boarding sections of which increase ratio of travel time against best route is less than certain percentage. This index presents the section level redundancy. The larger value of index.7 indicates the higher redundancy, because the redundant level of most vulnerable section is increase. Index.7-1, 7-2, 7-3 and 7-4 are assessed by the minimum number among boarding sections of which increase ratio of travel time against the best route is less than 10%, 20%, 50% and 100% respectively.

The indices developed in former section were calculated for the respondent of the survey. The results are shown in figure 1.

4 Factor analysis of redundancy of railroad network

Factor analysis is applied to consolidate the information which is comprised in the developed indices. The result of factor analysis is shown in Table 1. The value in each cell is factor loading of correspondent variable. As shown in the table, four factors were extracted. Meaning of each factor is explained according to the largeness of the factor loadings. First factor represents robustness of redundancy between O-D. Second factor represents Robustness of redundancy in boarding sections. Third factor represents the Effectiveness of alternative routes between O-D. Fourth factor represents Effectiveness of alternative routes in boarding sections. One variable represents each factor was considered as explanatory variables of departure time decision model in next chapter. Index.2, 4-3, 5 and 6-2 with the largest factor loading of each factor were selected as the variables.

Table 1 Result of factor analysis

Variable	Factor-1	Factor-2	Factor-3	Factor-4
	Robustness of redundancy between O-D	Robustness of redundancy in boarding sections	Effectiveness of alternative routes between O-D	Effectiveness of alternative routes in boarding sections
Index.1	0.981	-0.022	-0.136	-0.004
Index.2	-0.321	-0.019	0.820	-0.008
Index.3	-0.457	-0.022	0.773	-0.039
Index.4-1	0.821	-0.027	-0.429	-0.038
Index.4-2	0.936	-0.008	-0.283	-0.008
Index.4-3	0.987	-0.029	-0.145	-0.010
Index.4-4	0.983	-0.032	-0.148	-0.015
Index.5	-0.037	0.984	-0.015	-0.137
Index.6-1	-0.006	-0.368	-0.021	0.750
Index.6-2	-0.042	-0.351	-0.013	0.757
Index.7-1	-0.008	0.797	0.005	-0.405
Index.7-2	-0.013	0.918	-0.001	-0.294
Index.7-3	-0.022	0.975	-0.018	-0.171
Index.7-4	-0.037	0.984	-0.014	-0.139
Eigen-value	5.5	5.2	1.00	0.75
Variance explained	34.07%	33.06%	11.41%	10.41%

5 Departure time decision considering

5.1 5.1 Description of departure time decision

In this study, Fosgerau's methodology was applied to formulate departure time decision problem [3],[4]. A cost function depending on departure time D is written in eqn. (1).

$$U(D, T) = \alpha D + \omega T + \beta(T - D)^+ \quad (1)$$

α, β, ω is unknown parameters. The first term is the cost of starting early which is opportunity cost of interrupting a prior activity. The second term is the cost of travel time τ . And, the third term is the cost of being late where $(T - D)^+$ is schedule delay late.

Meanwhile, travel time τ is composed by two terms as seen in eqn. (2).

$$T = \mu + \tau_L \quad (2)$$

First term is a minimum travel time based on timetable and second term is recognized delay time. The recognized delay time is set by each commuter considering the occurrence of operation delay. Meanwhile, τ_L is a random variable whose probability density function is $f(\tau_L)$ and distribution function $F(\tau_L)$. In this study, the distribution of recognized delay time is assumed to be exponential distribution.

The problem of departure time decision is express by eqn. (3) which is disutility minimum problem.

$$E(U(D)) = \min \left[\alpha D + \omega \mu + \beta \int_{D - \mu}^{\infty} (\mu + \tau_L - D) f(\tau_L) d\tau_L \right] \quad (3)$$

The optimal departure time D^* is derived by solving eqn. (3).

$$D^* = \mu + F^{-1}(1 - \frac{\alpha}{\beta}) \quad (4)$$

Moreover, it is thought that the distribution of the recognized delay time τ_L is differ by commuter. Therefore, exponential distribution with covariates x_i is utilized to express the difference of distribution. Then, the probability density function of the recognized delay time is as shown in eqn. (5).

$$f(\tau_s) = \lambda \exp(\sum_i \theta_i X_i) \cdot \exp\left\{(-\lambda \tau_s) \exp(\sum_i \theta_i X_i)\right\} \quad (5)$$

Therefore, the optimal departure time in eqn. (4) is rewritten in eqn. (6).

$$D^* = \mu - \frac{\ln\left\{-\left(1 - \frac{\alpha}{\beta}\right) + 1\right\}}{\lambda \cdot \exp\left(\sum_i \theta_i X_i\right)} \quad (6)$$

In this study, regression analysis regarding the buffer time is executed. The buffer time is calculated by eqn. (7).

$$D^* - \mu = - \frac{\ln\left\{-\left(1 - \frac{\alpha}{\beta}\right) + 1\right\}}{\lambda \cdot \exp\left(\sum_i \theta_i X_i\right)} \quad (7)$$

5.2 Estimation Result

Two kinds of model are estimated. Travel distance and number of transfers are considered as covariates (explanatory variables) in Model 1. Meanwhile, In model 2 consider the railway network redundancy indices as covariates beside the explanatory variables in model 1.

Hierarchical Bayesian method is applied and Markov Chain Monte Carlo simulation is utilized to estimates the parameters in each model. Prior distribution of each parameter is shown in Table 2. Estimation result is shown in Table 3.

Plus sign of the estimates indicates that the buffer time increases in accordance with the increase of the value of correspondent variable. For example, the longer travel distance become, the longer the buffer time become. Sign's condition of all variables is reasonable.

Estimates of travel distance and number of transfers, index.2 and index.4 are statistically significant with 95% confidence. Meanwhile, the estimates of index.5 and index.6-2 are statistically significant with 90% confidence. As the results, it indicates that the redundancy is the factor affecting the buffer time of railway commuters.

Table 2 Prior distribution

	Distribution form	Prior distribution
α	Uniform distribution	$\alpha \sim U[0,2]$
β	Normal distribution	$\beta \sim U[0,2]$
λ	Uniform distribution	$\lambda \sim U[0,2]$
θ	Log-normal distribution	$\theta \sim LN(0,10)$

Table 3 Result of parameter estimation

	Explanatory variables	Model1		Model2	
		Estimates	t value	Estimates	t value
α	Head start	0.416	1.25	0.208	1.28
β	schedule delay late	1.385	3.33	1.255	2.63
λ	Scale parameter	0.409	1.40	0.518	1.76
θ_1	Logarithm of traveling distance(km)	-0.133	-2.29	-0.150	-2.17
θ_2	Number of transfers(times/trip)	-0.195	-3.82	-0.233	-4.02
θ_3	Index.2			-0.055	-1.96
θ_4	Index.4-3			0.048	2.40
θ_5	Index.5			0.016	1.60
θ_6	Index.6-2			-0.041	-1.71
DIC:DevianceInformation Criterion		3045.7		3082.6	
Number of samples		424			

6 Conclusion

In this study, we developed some indices to assess the level of railway network redundancy. Through the factor analysis, four evaluation factors were extracted. The departure time decision model is formulated and solved considering the variables regarding network redundancy. As the result of parameter estimation, redundancy of railway network is affecting departure time decision of railway commuters.

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