Effects of Traffic Incident Information on Drivers’ Route Choice Behaviour in Urban Expressway Network

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Abstract

Traffic incidents such as traffic accidents are the major causes of severe congestion in urban expressway networks. Providing traffic incident information to travellers is considered to be important for maintaining the level of service in urban expressways. The purpose of this study is to describe drivers’ route choice behaviours when traffic incident information is provided on a Variable Message Sign (VMS) in urban expressway networks. A stated-preference (SP) survey was conducted to observe travellers’ behaviours. The results showed that travellers can assume travel time of their alternative routes according to the congestion information of the road section provided by VMS.

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Keywords: Traffic incident management; Variable message sign; Route choice behaviour; Probe person survey;

1. Introduction

One of the negative impacts of traffic incidents on urban expressways is the sudden reduction in road capacity. Temporal but severe congestion may make travellers change their initially chosen route under insufficient experience and information. Traffic incident information displayed on the roadside Variable Message Signs (VMS) is important sources for travellers in determining whether to change the route for the trip. This information will improve drivers’ route choice behaviour and mitigate the impacts of traffic incidents. Thus providing traffic incident information to drivers can be considered effective for maintaining the level of service in

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urban expressway networks. And, investigating effects of the information provision is needed for traffic incident management and operation in such networks.

Wardman et al. (1997) conducted a stated-preference (SP) survey to investigate route choice behaviour when incident information is displayed on a VMS board. They analysed the factors that had effects on drivers’ route choice, such as the existence of queuing, delay, and causes of delay. Chatterjee et al. (2002) conducted an SP survey and analysed the impact of a VMS using a logistic regression model. Peeta et al. (2000) analysed the relationship between information and detour behaviour. Levinson (2003) analysed the effects of an information provision by the Advanced Traveller Information System in recurring and non-recurring congestion.

Incident information that is provided on a roadside VMS board often contains location and type of the incident and degree of the effects to the road sections. The travel time and length of the congestion are the indices representing the degree of effects of the incident. Although the travel time would affect travellers’ cost, it would be difficult to properly predict the accurate travel time during the incident. The physical length of the congestion may not directly affect the travellers’ cost. However, it can be easily obtained using traffic detectors, videos, etc. When travellers try to find the route which mitigates the travel time increase caused by the congestion, they would estimate the travel time of their possible alternative routes. Each type of information provides only the information about the road sections directly affected by the incident congestion. Travellers have to estimate the travel time of the other routes by combining with the provided information and their experiences.

The purpose of this study is to describe travellers’ route choice behaviours when traffic incident information is provided on a VMS in urban expressway networks. This study develops the model that describes the expressway user’s off-ramp choice behaviour when the incident information is provided to travellers on their way. This model focuses on the relationship of travel time and congestion length information with respect to the travellers’ response to such information. SP survey is designed to obtain the travellers’ route choice behaviours. We discuss the characteristics of travellers’ route choice behaviours in incident congestion with the results of the model analysis of SP data.

2. Off-ramp Choice Model

This section describes the route choice model when information of the incident congestions is provided to travellers by the VMS on the expressway. The traveller chooses the off-ramp that is originally intended or one of the ramps locating after the VMS. We assume that only one VMS is available on the route and travellers choose their route once after seeing the VMS. Under these assumptions, the choice model can be simply defined as a multinomial logit model because they do not have chance to change their route afterwards. Although we assume VMS provide the information on congestion length or travel time of expressway section, travellers would estimate travel time increase on alternative routes when they revise their route. It means that the length of the section which is affected by the incident congestion is different in their alternative routes. This study introduces the model which considers the travel time increase of the alternative routes affected by the effective length of the incident congestion in order to confirm whether travellers understand the information and how they convert the information into travel time of the routes.

Fig.1 shows the definition of the model variables. Ramp 1 represents the ramp immediately after the VMS. Ramp 2 is located between Ramp 1 and the intended off-ramp, Ramp 0. The distance between Ramp 0 and Ramp i is denoted as $X_i$. The section of congestion is between the head position $z$ and the nearest ramp of the tail position Ramp $j$. The distance between Ramp 0 and the head position $z$ is $Z$. $Y_j$ is the distance between Ramp 0 and the Ramp $j$. When the travel time information $Y_t$ is provided by the VMS, $Y_t$ is the travel time between the head position $z$ and Ramp $j$ that is the nearest ramp of tail of the congestion. When the congestion length is provided, $Y_d$ is the actual length of the congestion from the head position $z$. When travellers choose to go off their originally intended ramp, they are affected by an increase in their travel time caused by driving through the incident congestion. The utility function in such case is described as
where $V_{c0}$ is the utility of the travel time increase caused by incident congestion before they arrive at Ramp 0.

When travellers choose Ramp 1 or 2 to avoid congestion, a travel time increase is also caused by driving through congestion before they arrive at these ramps. At the same time, their travel time increases while driving through arterial roads between Ramp $i$ and Ramp 0 because the speed on the arterial road is less than that of the expressway. The utility function when travellers choose the ramps neighbouring the VMS ($i=1,2$) is expressed by

$$V_i = V_{ci} + V_{ai} + \alpha_a$$

where $V_{ci}$ is the utility at travellers’ travel time increase caused by incident congestion before they arrive at Ramp $i$. $V_{ai}$ is the utility of the travel time increase caused by driving through arterial roads after they arrive at Ramp $i$. The variable $\alpha_a$ represents the bias caused by deviating from their daily route. If the section has more than three ramps between the VMS and the intended ramp, we can also express the utility function of these ramps using Eq.(2).

### 2.1. Increase in utility caused by driving through arterial road

When a traveller chooses to go off at Ramp $i$ and drive the arterial road, the travel time of the arterial road is defined using the perceived speed of the arterial road $v_a$. The increase in the travel time compared with the travel time at their usual situation using the expressway is expressed as

$$\Delta t_{ai} = \frac{1}{v_a} X_i - \frac{1}{v_f} X_i$$

$$= \left( \frac{1}{v_a} - \frac{1}{v_f} \right) X_i$$

where

$v_a$: Speed on arterial road perceived by travellers;

$v_f$: Speed on expressway perceived by travellers in usual situation;

In this equation, we assume that the distance of the arterial road between Ramp $i$ and their destination is same as the distance of the expressway section between Ramp $i$ and their destination. This is because the network of arterial road is usually dense in urban road network. The variables $v_a$ and $v_f$ are not observed directly in the SP survey. When $\theta$ is defined as a marginal utility of the travel time unit, the marginal utility of the remaining distance of the expressway can be expressed as
\[ \beta = \theta \left( \frac{1}{v_a} - \frac{1}{v_f} \right) \] (4)

The increase of utility caused by driving through the arterial road from Ramp \( i \) is defined as
\[ V_{ai} = \beta X_i \] (5)

2.2. Increase in utility caused by driving through congestion

In the SP survey, either length of congestion or travel time is presented to the travellers as the information on the degree of the effects of the incident congestion. First, the increase in the utility is defined in the case travel time information is represented. When the VMS displays the travel time \( Y_t \) of the section between the head of the congestion \( z \) and the tail of the congestion \( j \), the increase in the travel time between \( j \) and Ramp \( i \) is defined as
\[ \Delta t_{ij} = \begin{cases} Y_i - \frac{1}{v_f}(Y_j - Z) & \text{if } Y_j > X_i \text{ and } Z > X_j, \\ \frac{Y_j - X_i}{Y_j - Z} Y_j - \frac{1}{v_f}(Y_j - X_i) & \text{if } Y_j > X_i \text{ and } Z < X_j, \\ 0 & \text{otherwise} \end{cases} \] (6)

The first equation in Eq.(6) represents the case in which the head of congestion is closer to the position of the VMS than Ramp \( i \). This case is only defined near the initially intended off-ramp (Ramp 0) because travellers would no longer be intended in changing their route after passing through the congestion. The second equation represents the case in which Ramp \( i \) is located between the head and tail of the congestion. The third equation represents the case in which the tail of the congestion does not reach Ramp \( i \). The first terms of the first and second equations represent the travel time through the congested section before arriving at Ramp \( i \). The second terms of the first and second equations represent the travel time during a usual situation for the section corresponding to the first term. This term is derived from the speed in a usual situation \( v_f \) that is perceived by the traveller.

The marginal utility of the expressway distance in an ordinary situation can be defined as
\[ \gamma_f = \frac{\theta}{v_f} \] (7)

The increase in the utility caused by increasing the travel time during the incident congestion can be expressed as
\[ V_{ci} = \begin{cases} \theta Y_i - \gamma_f (Y_j - Z) & \text{if } Y_j > X_i \text{ and } Z > X_i, \\ \theta \left( \frac{Y_i - X_i}{Y_j - Z} Y_j - Y_j \right) + \gamma_f (X_j - Y_j) & \text{if } Y_j > X_i \text{ and } Z < X_i, \\ 0 & \text{otherwise} \end{cases} \] (8)

When the VMS displays the length of congestion \( Y_d \) and the section between the head of congestion \( z \) and the tail of congestion Ramp \( j \), the increase in the travel time between Ramp \( j \) and Ramp \( i \) is defined by modifying Eq.(6). When the length of the congestion \( Y_d \) is provided, the tail of the congestion can be defined more accurately as \( Y_d + Z \). The equations of Eq.(6) are modified using \( Y_d \) and the perceived speed during the incident congestion \( v_c \), as follows:
where

\[ v_c : \text{Speed on congestion section perceived by travellers.} \]

The marginal utility of the congestion length can be defined as

\[ \gamma_d = \theta \left( \frac{1}{v_c} - \frac{1}{v_f} \right) \] (10)

The increase in the utility caused by the distance increase during the incident congestion can be expressed as

\[ V_i = \begin{cases} 
\gamma_d Y_d + \alpha_d & \text{if } Y_j > X_i \text{ and } Z > X_i \\
\gamma_d (Y_d + Z - X_i) + \alpha_d & \text{if } Y_j > X_i \text{ and } Z < X_i \\
0 & \text{otherwise}
\end{cases} \] (11)

where \( \alpha_d \) represents the bias caused by converting the distance information to travel time.

2.3. Relationship of parameters

Although the parameters \( \theta, \gamma_d, \gamma_f, \beta, \alpha_0 \) and \( \alpha_d \) are determined using the parameter estimation of the logit model, \( v_f, v_a \) and \( v_c \) are not directly estimated. These parameters are derived from the estimated parameters. The speed of the expressway in an usual situation perceived by travellers is defined using Eq. (7) as

\[ v_f = \frac{\theta}{\gamma_f} \] (12)

The speed of the expressway during congestion perceived by travellers is defined using Eqs. (7) and (10) as

\[ v_c = \frac{\theta}{\gamma_d + \gamma_f} \] (13)

The speed of the arterial road perceived by travellers is

\[ v_a = \frac{\theta}{\beta + \gamma_f} \] (14)

These estimates of the perceived speeds do not consider the bias terms \( \alpha_d \) and \( \alpha_d \). However, these biases would influence the perceived speed when travellers do not consider the relationship between the travel time and length of the congestion to be linear. Considering these biases, the perceived speed of traveller in the expressway during congestion is defined as
The perceived speed of the arterial road is

\[ v_a' = \frac{\theta X_i}{(\gamma_f + \beta)X_i + \alpha_a} \]  \hspace{1cm} (16)

3. Empirical Survey

An SP survey was conducted employing results of probe person (PP) (see Asakura and Hato (2004)) and web diary surveys, which help us build more realistic hypothetical situations for SP questionnaires. A PP survey is a tracking survey using mobile phones and a web diary system. The daily routes of the travellers are tracked for several weeks by the PP survey, and then, the route choice behaviours during incident congestion on the daily route are asked by the SP survey. When completely imaginary situations are displayed in the SP survey, the respondent may have difficulty in understanding the state of the congestion because it does not happen occasionally. Observing travellers’ reactions to incident congestion by the PP survey is also difficult because each traveller rarely encounters incident congestion although incident congestion occurs daily on the expressway.

3.1. Design of SP survey

The target section for the SP survey is the Kobe line and Ikeda line of the Hanshin expressway located in the Osaka and Kobe metropolitan area, the second largest dense area in Japan. The Kobe line connects Kobe city to Osaka city and the Ikeda line connects the suburban area of Osaka to the city centre.

Fig.2 shows the stated situation in the SP survey. This study assumes that the travellers obtain the incident congestion information from the VMS on the expressway. Travellers choose to drive through either their initially intended off-ramp (Ramp 0) or any off-ramps (Ramp 1, 2) locating after the VMS. If they choose Ramp 1 or 2, they use the arterial road to their final destination. In this case, the VMS displays either one of two types of the degree of the incident congestion: the estimated travel time of the congestion or the length of the congestion. The information is provided with the names of two ramps representing the head and tail of the congestion. The displayed messages on the VMS correspond to the actual design used in Japan though the travel time information is not often provided during the actual severe incident congestion.

Table 1 shows the scenarios of the SP survey. Each scenario has a different VMS position, incident position, and available off-ramps. The scenarios are determined by travellers’ daily routes obtained from the PP survey. A scenario whose section includes part of the travellers’ route observed by PP survey between the VMS position and the head of the incident congestion is selected for the questionnaire. The trip purpose and intended off-ramp are determined by corresponding travellers’ daily behaviours. The choice set of the SP survey is the available ramps located between the on-ramp and off-ramp of their daily routes. Travellers are asked to assume two different sets of situations for each type of impact information. The values of the degree of congestion, which are travel time or length of the congestion, are randomly generated.

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Fig. 2 Incident information and route in SP survey
Table 1 Scenarios of SP survey

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Route</th>
<th>Head of Congestion (km from beginning of the line)</th>
<th>Position of VMS (km from beginning of the line)</th>
<th>Number of Available Off-ramps</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>Kobe line (inbound to Osaka)</td>
<td>Maya (27.3)</td>
<td>Minatogawa (36.1)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Amagasaki-Nishi (10.7)</td>
<td>Fukae (21.4)</td>
<td></td>
</tr>
<tr>
<td>A-2</td>
<td>Kobe line (outbound to Osaka)</td>
<td>Yanagihara (34.2)</td>
<td>Uozaki (22.7)</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ashiya (17.4)</td>
<td>Himejima (4.2)</td>
<td></td>
</tr>
<tr>
<td>B-1</td>
<td>Kobe line (outbound to Osaka)</td>
<td>Ikeda line (inbound to Osaka)</td>
<td>Umeda (1.0)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Toyonaka-Minami (9.8)</td>
<td></td>
</tr>
</tbody>
</table>

3.2. Summary of survey on number of samples

The survey was conducted for two weeks from the 9th to 22nd of December 2010. Twenty respondents participated in this pilot survey. In total, 1200 trips were observed during the survey period. The number of trips including the survey section for the SP survey was 42. The SP survey collected 168 responses because each traveller responded to the questions four times.

4. Estimation Results

The analysis focused on the validation of the proposed model by using survey data. It means that the analysis confirms whether travellers can convert the information about road section into travel time of their alternative routes. By analysing the estimated parameters, we also investigated their recognition of travel time in the incident congestion. That is, the relationships are discussed between the distance of the arterial road section of the alternative route, length of congestion, and travel time.

Table 2 shows the estimation results. The sign conditions of all parameters are satisfied. All the t-values and ρ parameters except for γ_f indicating the marginal utility of the expressway distance in the ordinary situation are significant. The parameter γ_f is less significant because some travellers may consider the magnitude of the displayed information, although they do not consider the increase in their travel time.

Table 3 shows the perceived speed estimated by Eqs.(12), (13), and (14). The speed in the ordinary situation and in the arterial road appears to be larger than the actual situation. This is caused by biases α_0 and α_d and shows that travellersprobably do not consider the relationship between the travel time and distance of congestion to be linear. The perceived speed can be analysed by Eqs.(15) and (16), in detail.

Fig.3 shows the utility of the incident congestion length with respect to the driving distance along the arterial road, which is derived from Eqs.(3) and (11). According to the y-axis intersection in the figure, when the length of congestion is less than 5.4 km, travellers tend to continue on their planned routes. The gradient of the line shows that a 0.95-km increase in the congestion length is equal to a 1-km increase in the arterial road distance.

Fig.4 shows the utility of the travel time during incident congestion with respect to the distance of the arterial road, which is derived from Eqs.(8) and (11). Whenever the travel time increase is less than 23.5 min., the travellers’ utility of driving on the expressway is greater than that of driving on the arterial road. The perceived speed of the arterial road is less than 35 km/h, when the remaining expressway distance is less than 30 km.

Fig.5 shows the travel time increase of the incident congestion with respect to information regarding the length of the congestion. This figure shows that when travellers know the length information, they assume a travel time increase of more than 14.27 min. even if the length of the incident congestion does not exist. When the length of the congestion is less than 10 km, they assume that the speed of the congested section is slower than 17.0 km/h.

When we assume that the travel time information represents the real travel time that a traveller will experience, the information of length can be evaluated using the relationships of Eqs.(8) and (11). If the real travel time t^* is larger than the assumed travel time of the corresponding length of congestion shown in Fig.5, a traveller would underestimate the travel time. This can be expressed as
\[ t^* > 2.17 \times Y_d + 14.27 \]  \hspace{1cm} (17)

On the other hand, if the real travel time is less than the corresponding length, a traveller would overestimate the travel time. This can be expressed as

\[ t^* < 2.17 \times Y_d + 14.27 \]  \hspace{1cm} (18)

Although providing information regarding congestion length is easier than providing estimated travel time information, congestion length information may cause travellers to over or underestimate their travel time because the travel time required to pass through the congestion section caused by incident can vary even if the length of congestion does not change. The capacity of a bottleneck is variable because the capacity of a bottleneck changes constantly according to the situation of the incident processing. When the processing time of the accident is definitely larger than Eq.(17), providing the information on congestion length is not enough because travellers can underestimate their travel time.

Table 2 Results of estimation

<table>
<thead>
<tr>
<th></th>
<th>Coefficient</th>
<th>t-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias of Driving through Arterial Road</td>
<td>( a_a )</td>
<td>-2.91</td>
<td>-5.88</td>
</tr>
<tr>
<td>Bias of Converting Distance to Travel Time</td>
<td>( a_d )</td>
<td>-1.77</td>
<td>-2.78</td>
</tr>
<tr>
<td>Rest of Distance of Driving Arterial Road</td>
<td>( \beta )</td>
<td>-0.0601</td>
<td>-3.02</td>
</tr>
<tr>
<td>Travel Distance of Congestion</td>
<td>( \gamma_d )</td>
<td>-0.212</td>
<td>-2.51</td>
</tr>
<tr>
<td>Travel Distance in Ordinary Situation</td>
<td>( \gamma_f )</td>
<td>-0.0571</td>
<td>-0.4</td>
</tr>
<tr>
<td>Travel Time</td>
<td>( \theta )</td>
<td>-0.124</td>
<td>-3.55</td>
</tr>
</tbody>
</table>

| Number of Samples | 168 |
| Adjusted \( R^2 \) | 0.45 |

Table 3 Results of estimation of perceived speed

<table>
<thead>
<tr>
<th>Speed</th>
<th>Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>v_f</td>
<td>130.3</td>
</tr>
<tr>
<td>v_c</td>
<td>27.6</td>
</tr>
<tr>
<td>v_f/c</td>
<td>63.5</td>
</tr>
</tbody>
</table>

![Fig. 3 Length of congestion and distance of arterial road section](image)
Fig. 4 Travel time of congestion and distance of arterial road section

\[ Y_c = \frac{Y_c + \frac{\beta}{\alpha} X_c + \frac{\alpha}{\beta}}{0.95 X_c - 23.5} \times 60 \]

Fig. 5 Relationship of travel time and length of congestion

\[ Y_c = \frac{Y_c + \frac{\beta}{\alpha} Y_c + \alpha + \beta}{2.17 Y_c + 14.27} \times 60 \]
5. Conclusion

This study investigated route choice behaviour on expressways when the traffic incident information was displayed on a VMS. The route choice behaviour was observed by SP survey on the Web system. Although a VMS gives the information about only expressway section, travellers estimate travel time increase on their alternative routes and change their routes. In order to understand whether travellers logically assume the travel time of each route, a simple route choice model was proposed considering traffic information. The model focuses on the relationships between the distance of the arterial road section of the alternative route, length of congestion, and travel time.

The results of the survey showed several characteristics of off-ramp choice behaviour when the incident information is available on the expressway. The results showed that travellers can assume travel time of their alternative routes according to the congestion information of the road section provided by VMS. The perceived speed when travellers assume travel time of the alternative routes is quantitatively represented. This result may be applied to analysis to understand when the information most effectively affects travellers. When the actual observed speed is significantly slower or faster than the perceived speed of travellers, the effectiveness of the information is insufficient for the travellers. That is, travellers may overestimate or underestimate their travel time. This may be mitigated by additional information such as trend information on increasing and decreasing of congestion. Although the results quantitatively suggest when such additional information can be effective, analysing the effectiveness of the additional information is left as one of the future tasks.

This study focused on how travellers assume travel time of the alternative route based on incident information. Some factors that would affect their estimates of travel time are still not analysed in this study. For example, the travellers in this study seem to assume the information on travel time is as accurate as that of presently being provided in ordinary congestion because the travel time information during severe incident congestion is not often provided in Japan. It would be difficult to predict travel time in actual situation when an incident occurs. Further discussion on the effects of the reliability of information is also expected.

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References