Empirical Analysis on the Impact of Rain Intensity on Commuters’ Departure Decision on Torrential Rain Day

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Abstract: This paper analyzes the relationship between rain intensity and commuters’ return home behavior to clarify the extent to which rain affects commuters’ departure decisions. Results show that about 60% of respondents changed their departure time. Although weather forecasts predicted torrential rain for the day examined in this study, the percentages of respondents who checked the weather directly or obtained weather information were only 42% and 26%, respectively. In order to statistically analyze the above relationship, an ordered logit model was estimated. The result showed that commuters are likely to change their departure time early when rain intensity is 50 mm/h or more. This result can thus serve as a criterion of commuters’ departure decision on days of torrential rain. Additionally, those who obtained weather information while in their destination area and who went home at peak rush hour showed a strong tendency to change their departure time early.

Keywords: rain intensity, change travel decision, travel behavior

1. INTRODUCTION

Japan faces a severe risk of natural disasters. In particular, many urban areas face instances of torrential rain almost every year, which creates widespread problems in the urban transport network. For example, on August 28, 2008, torrential rain fell in the Tokai region. It triggered floods that led to transport systems stoppages; as a result, many commuters struggled to return home, with some abandoning their journey and staying at the station, a hotel, or relative’s house.

Why did this torrential rain cause such widespread disruption? That morning, the day’s newspaper, Chunichi Shimbun, August 28, 2008, clearly stated: “Today, humid air will come from south, and the weather will change from cloud to rain; in addition, torrential rain with thunderstorm will happen in some areas.” Moreover, the evening’s newspaper, Chunichi Shimbun, August 28, 2008, provided the following specific weather information: “Torrential rain (130 mm–180 mm/ day) will happen in the region. Nagoya local meteorological observatory ordered warning of heavy rains and local flooding, and they note the potential for landslides and floods. Most commuters seemed to recognize the likelihood of poor weather; however, they could not assume that such a torrential rain would happen in their area.

One of the reasons for such misconceptions is a lack of understanding about rain intensity. Most commuters seem unable to accurately imagine what a rain intensity of 130 mm–180 mm/day would feel like. This lack of knowledge is clearly demonstrated by Sakamoto et al. (2007), who implemented a sensitive preference survey. In the survey, respondents first chose a rain intensity at which they would change their departure time late (first answer). Then, they read material about rain intensity and viewed an image provided by the Japan Meteorological Agency, and they chose the rain intensity that would induce them to change their departure time.
again (second answer). The result of this survey indicated that the rain intensity given in the first answer is greater than that in the second answer. This implies that respondents were unable to fully conceive of the impact of a torrential rainfall situation just from rainfall intensity information. However, this research does not track actual commuters’ behavior because of its structure as a sensitive preference survey. Hiroi et al. (2013) also implemented a similar survey to high school students and showed that it was difficult for commuters to imagine an atmosphere and recognize a risk by the information of hourly rainfall such as 50mm/h.

This paper aims to clarify the extent to which rain affects actual commuters’ departure decisions on days of torrential rain. By using a questionnaire survey focusing on commuters’ return home behavior on a specific day of torrential rain, namely August 28, 2008, the relationship between rain intensity and commuters’ return home behavior is analyzed.

2. LITERATURE REVIEW

Weather conditions are known to affect mode choice, departure time choice, and route choice. Nankervis (1999) analyzed the impacts of weather conditions on bicycle commuting patterns. The numbers of riders are likely to be less on adverse weather days. Palma et al. (1999) determined that departure time decisions are much more sensitive to adverse weather than mode or route decisions. Khattak et al. (1997) developed the model of mode change and departure time change in adverse weather. These models demonstrate that commuters change their travel patterns in systematic ways when adverse weather occurs. Mario et al. (2010) also analyzed the impact of conditions on travel demand. The changes in travel behavior: mode change, time-of-day change, location change, trip cancellation, and route change, in response to weather conditions: cold, snow, rain, fog, warm and storm, are highly dependent on the trip purpose.

Okumura et al. (2001) focused on fact-based and probabilistic information about rain, and they developed a model to determine the impact of this information upon inhabitants’ responses. Fact information consisted of time of rainfall, flood, and landslides; probabilistic information consisted of torrential rain advisory, torrential rain alert, and evacuation order. The result showed that fact information proved too difficult for inhabitants to understand, and probabilistic information could result in evacuation behavior.

Kakimoto et al. (2012) implemented a survey of evacuation behaviors during the Northern Kyushu torrential rains in July, 2012, and analyzed factors that encouraged self-evacuation. Observing a river and calling an evacuation were found to stimulate decision making. Sato et al. (2013) clarified the problem of residents’ and fire-fighting organizations’ actions with respect to disaster damage, residents’ behavior, and fire-fighting’s rescue efforts during Typhoon No. 12 in September, 2011. Approximately 80% of residents did not predict the torrential rain on the previous day. Even when the disaster happened, approximately 40% of residents did not evacuate immediately; it was assumed that the disaster occurred at night. Although these studies did not address commuters’ departure decisions, they reveal some triggers of peoples’ behavior.

However, no research has analyzed the relationship between rain intensity and commuters’ departure decisions.

3. CASE STUDY

This study analyzes commuters’ return home behavior during a day of torrential rain in Tokai region on August 28, 2008, as a case study. Figure 1 shows the amount of rainfall during the
period as recorded by Ichinomiya and Nagoya Observatory, Meteorological Agency, and Figure 2 shows the one-km-mesh hourly rainfall, derived from the data on rain gauge-analyzed precipitation, also provided by the Japan Meteorological Agency. The torrential rain affected both public transportation and road traffic systems. Both Central Japan Railway and Nagoya Railroad decided to stop a number of trains on the Tokaido line, Nagoya main line, and Tokaido Shinkansen. Commuters could not move; some of them ended up lying down in Nagoya station while waiting for a train, and others slept in the Shinkansen as a napping room. This trouble persisted until early next morning, and many stations around Nagoya city were crowded. In addition, the road traffic situation was severe; a cabstand was flooded in Nagoya station, and some cars could not move due to floods.

4. METHODOLOGY

This research analyzes commuters’ departure decisions using questionnaire data, rain intensity data, and address data. Figure 3 shows the flow of data creation.

The first involved matching rain intensity data and address data. Rain gauge-analyzed precipitation, provided by the Japan Meteorological Agency, was used as rain intensity data. This data include the hourly rain intensity for a one-square-kilometer area (Figure 4). Address data is set at the municipal level; therefore, hourly rain intensity in each municipal area could be calculated. In order to analyze commuters’ departure decisions during torrential rain, a maximum rain intensity was defined as actual peak rain intensity per municipality; therefore, these data contain errors; especially, when the area of a municipality is large, the range of the error is larger.

Next, the weather and address data were matched with questionnaire data. This entailed matching the rain intensity corresponding to each commuter’s departure time (two hours before or after departure time) and departure point. For example, for a commuter who departed at 20:30 in Nakaku (Nagoya city), the hourly rain intensity at 19:00, 20:00, and 21:00 were 40 mm/h, 60 mm/h, and 80 mm/h, respectively, meaning that the rain intensity corresponding to this commuter is 80 mm/h. This method was implemented in order to capture linkages between more serious rain intensity and changing departure times.

Although there are some researches analyzing studies that have analyzed the relation between rain intensity and people’s behavior, these case study areas are small (e.g., Katada et al., 2005). One of the functions of this research is to clarify the relation between rain intensity and a person’s departure time and point in large case study area. The method here analyzes the above relation in detail; however, it cannot set exact rain intensity corresponding to each person’s behavior due to bias in the rain gauge data (precipitation), size of municipality, and respondents’ memories.

The main analysis of this study applies the ordered logit model to detect the cause of departure time. The model is estimated by commuters’ departure times on normal and torrential rain days (August 28 and 29) and their meteorological information sources on that day.

5. DATA COLLECTION

5.1 Outline of Questionnaire Survey

Table 1 presents an outline of the questionnaire survey, and Figure 5 shows the questionnaire distribution points (Ichinomiya Sta. and Konomiya Sta.). In this survey,
respondents answered questions about individual attributes, return home behavior (usual
behavior and behavior on the torrential rain day (8/28~29), access to information, and past experiences with torrential rain (Table 2). It was a paper survey. Respondents answered the following questions: departure time on usual and torrential rain day: August, 28th and 29th, and their information acquisition on that day in their house and returned to authors’ laboratory in the mail.

The sample size for this study is the calculated formula (1). In the variable of population size is determined the number of commuters by train in the area, Eastern Owari area, 66,234. It was calculated on the basis of the person trip survey in Chukyo Metropolitan Area, implemented in 2011. 1.96, 0.1, and 0.05 were assigned to \( z \), \( e \), and \( P \), respectively. As a result, sample size \( n \) became 138. Since the number of sample used in this study was 205; therefore, it was satisfied with above accuracy.
\[ n \geq \frac{N}{\left(\frac{e}{z}\right)^2 \frac{N - 1}{P(1 - P)} + 1} \]  \hspace{1cm} (1)

Where,

- \( n \) : Sample size
- \( N \) : Population size
- \( z \) : Z value
- \( e \) : Margin of error
- \( P \) : Percentage picking a choice, expressed as decimal

5.2 Respondent Characteristic

Respondent attributes are shown in Table 3. Many of respondents were middle-aged male commuters. 96% of respondents’ cited trains as their main transportation mode. This clearly reflects the fact that the survey was distributed at train stations at night, and further reflects the fact that the behavior of interest here is that of train commuters. Therefore, the distribution of the survey accurately reached the intended targets, and survey respondents are highly proportionally comprised of the desired target respondents.

Departure time and travel time on the torrential rain day and normal days are shown in

<table>
<thead>
<tr>
<th>Distribution Area</th>
<th>Distribution Period</th>
<th>Distribution Method</th>
<th>Circulation</th>
<th>Collection</th>
<th>Collection Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ichinomiya Station</td>
<td>16 ~ 18 December, 2008*</td>
<td>By Hand</td>
<td>1,860</td>
<td>503</td>
<td>27%</td>
</tr>
<tr>
<td>Konomiya Station</td>
<td>16 December, 2008*</td>
<td></td>
<td>240</td>
<td>49</td>
<td>20%</td>
</tr>
<tr>
<td>Around Konomiya Station</td>
<td>26 December, 2008</td>
<td>Posting</td>
<td>330</td>
<td>12</td>
<td>4%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>2,430</td>
<td>564</td>
<td>23%</td>
</tr>
</tbody>
</table>

* Distribution time is mainly after 21 pm

<table>
<thead>
<tr>
<th>Table 2. Content of Questionnaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual attribute</td>
</tr>
<tr>
<td>Return home behavior (Usual day, Torrential rain day (8/28–29))</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
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<tr>
<td>Access to information (Usual day, Torrential rain day (8/28–29))</td>
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<tr>
<td>Past torrential rain experience</td>
</tr>
</tbody>
</table>
In terms of departure times, on normal days, 70% of the commuters left between 19:00–22:00, while, on the torrential rain day, 74% of the commuters left between 20:00–23:00.

About travel time, on a normal day, 80% of the commuters made their journeys in under 80 minutes; on the torrential rain day, however, the probability of a commuters having a travel time less than or equal to 80 minutes was only 38%, and the probability of the commuters having a travel time over or equal to 180 minutes was 20%. These results indicate that commuters tended to delay their departure time, and then they struggled to return home on the torrential rain day. In fact, some commuters gave up returning home and stayed at the station or a relative’s home.

Table 3. Respondent Attribute

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>Family Structure*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>69%</td>
<td>10–19 2% Single 12%</td>
</tr>
<tr>
<td>Female</td>
<td>31%</td>
<td>20–29 15% Family of two 36%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>30–39 28% Nuclear family 35%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40–49 31% with children who are in early elementary school 20%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50–59 20% with elderly persons 22%</td>
</tr>
<tr>
<td></td>
<td>60–</td>
<td>4%</td>
</tr>
</tbody>
</table>

*: Multiple Answers

80% of the commuters made their journeys in under 80 minutes; on the torrential rain day, however, the probability of a commuters having a travel time less than or equal to 80 minutes was only 38%, and the probability of the commuters having a travel time over or equal to 180 minutes was 20%. These results indicate that commuters tended to delay their departure time, and then they struggled to return home on the torrential rain day. In fact, some commuters gave up returning home and stayed at the station or a relative’s home.
Departure time changes on the torrential day are shown in Figure 7. A departure time change is defined as the difference between departure time on a normal day and the departure time on the torrential rain day. For example, a commuter whose departure time is normally 18:00 but who departed at 20:00 on the torrential rain day is categorized as being “more 90 minutes late”; a commuter whose departure time is 18:00 on a normal day who departs at 18:05 on the torrential rain day is categorized as having “no change.” The results show that the ratio of the commuters who did not change departure time is 41%; on the other hand, the ratio of commuters changing departure times to earlier or later are 20% and 39%, respectively.

Weather checks on the torrential rain day are shown in Figure 8. The variable “Checked weather directly” means that the commuter checked the weather by means of looking out of the window; the variable “Get weather information” and “Get road and traffic information” means that the commuter checked weather and traffic information via the internet, mobile phone, TV and/or radio; the variable “Contact with family” indicates whether commuters contacted their family at that time. For the variable “Check weather directly,” the percentage of the respondents who checked right before departure is the highest (42%). On the other hand, those who checked weather information before departure is only 26%. In addition, the percentage who checked road and traffic information or got in touch with their family were only 13–14%. The result implies that many commuters departed without up-to-date information, despite the forecast of bad weather made that morning.
Figure 8. Commuters’ behavior on Torrential Rain Day

Figure 9. Commuter’s Origin/ Destination Point

Figure 9 shows a comparison of commuters’ origin and destination points of returning home behavior between normal days and the torrential rain day. Places of origin did not show great differences between average days and the torrential rain day: about 70% of the
respondents were commuters that commute into Nagoya city. However, destinations differed across the different types of days: the percentage of commuters whose destination was Ichinomiya city was 78% (normal day) and 62% (torrential rain day), respectively, and the percentage of commuters whose destination was Nagoya city was 0% (normal day) and 12% (torrential rain day), respectively. This indicates that many commuters could not return home on that day.

6. ANALYSIS

6.1 Modeling departure time: Methodology

To investigate the effect of torrential rain on departure time and travel time, an ordered logit model was estimated. The model was selected because of its ability to analyze ordered categorical response data, that is, the response to changes in departure time. It uses following form:

\[ y_i^* = x_i^\prime \beta + u_i \]  

where,

- \( y_i^* \): Dependent variable
- \( x_i^\prime \): Vector of independent variables
- \( \beta \): Vector of estimated parameters
- \( u_i \): Error term.

The dependent variable was defined by changes in the returning home time: more 90 minutes late = 0, more 30 minutes late = 1, no change (−30 minutes< \( y \) ≤ 30 minutes) = 2, 30 minutes or more early = 3, and 90 minutes or more early = 4. The vector of independent variables consisted of usual departure time, whether they checked weather directly, whether they got weather information, and usual travel time. Although the variables of “Get road and transport information” and “Contact with Family” were necessary to decide upon changes in return home time, these were not included because the main purpose of this model was to investigate the relationship between rainfall intensity and commuters’ decisions. The observed ordinal variable \( y_i \) takes a value of 0 through 4 according to the following form:

\[ \alpha_{j-1} < y_i^* \leq \alpha_j, \quad j = 0 \ldots 4 \]  

where, \( \alpha_0 = 0 \) and \( \alpha_4 = +\infty \). For the ordered logit model, the probabilities of a given observation are of following form:

\[ p_{ij} = \Pr(y_j = i) = \Pr(\alpha_{j-1} < x_i^\prime \beta + u_i \leq \alpha_j) = \frac{1}{1 + \exp(-u_i + x_i^\prime \beta)} - \frac{1}{1 + \exp(-u_{j-1} + x_i^\prime \beta)} \]  

6.2 Estimation result

Table 4 shows the estimation results for departure time changes. It also reveals the marginal effects of changing variable \( x \). Marginal effect of independent variable is the probability difference when the independent variable is changed. The dependent variables are responses to
departure time changes. A positive sign for the estimated parameter indicates increased propensity to change departure time to a later time. The signs of the parameters $\beta$ are intuitively reasonable and their magnitudes are plausible.

The usual departure time effects are shown in the model. Commuters departing at 17:00–18:00 usually were more likely to change departure time to earlier than other departure time groups, especially, the marginal effects of “90 minutes or more early” are greater than those of others (0.840). Under peak rush hour, a slight traffic delay can result in serious commuter congestion; therefore, this finding explains that those who depart at 17:00–18:00 changed their departure time to earlier to avoid the congestion.

For the rainfall intensity, those who had knowledge of torrential rain (50 mm/hour or more) in their destination area as determined by checking the weather directly or getting weather information are more likely to change departure time to earlier: these parameters were 1.925 and 1.070, respectively. However, compared to the variables of usual departure time dummies: 17:00–17:59pm, these affections to dependent variable are less (these marginal effects of “90 minutes or more early” are 0.087, 0.035, respectively). Other variables were insignificant. This finding indicates that rainfall more intense than 50 mm per hour is a threshold criterion for commuters to change their departure times. These variables are the rainfall intensity in the destination area at the usual departure time. This implies that commuters predict that torrential rain would approach their current place. It is anticipated that providing weather information in the early stages of a weather system will lead commuters to move forward their departure times. Considering that the variables of rainfall intensity in the origin area are insignificant, it is assumed that they could not depart appropriately at that time. In fact, some of them decided to go home even in case of torrential rain; however, they struggled to reach their nearest station. In other words, they were stuck around origin area after leaving the
Finally, why they changed departure time to earlier after checking weather directly in their destination area is assumed that their commuting distance is short: approximately 80% respondents’ commuting distance is approximately 20 km: from Nagoya city to Ichinomiya city. It implies that the result cannot fit in case of long commuting distance.

6.3 Sensitivity Analysis

The results in the preceding section revealed that usual departure time and rainfall intensity can affect commuters’ departure time decision; therefore, in this section, in order to grasp the patterns of behavior changes in detail, a sensitivity analysis was performed. On the basis of the ordered logit model developed in the previous section, the variability characteristic of commuters’ decisions regarding departure times in terms of the event significant variables change was simulated.

The results of sensitivity analysis were 17:00–19:00 and were likely to depart more than 30–90 minutes early (See dark blue and yellow line chart, Figure 10, and orange and light blue line chart, Figure 11). Those whose usual departure times were 20:00–22:00, despite knowing about the torrential rain, were not likely to change their departure time (Figure 12).

7. CONCLUSION

This paper presented the results of a commuter behavior survey focusing on a specific day of torrential rain in Tokai region, Japan. The results revealed that although a weather forecast on the news provided information that torrential rain was likely to occur in the evening, over half of the commuters departed without seeking any updated weather information. In addition, most did not change their departure time. As a result, they struggled to return home, with some abandoning their journeys to stay at the station, a hotel, or a relative’s house.

The threshold of rain intensity needed to change commuters’ departure time was 50 mm/h. This is not the rain intensity occurring at the commuters’ current place but the intensity at their destination, such as their home. 50 mm/h is torrential rain; such intense rain can cause landslides and floods. It is considered that those who recognize the risk facing their home or public transportation stop are likely to depart early. In the event examined as a case study in this research, the day’s weather forecast clearly predicted that torrential rain was likely to occur at 21:00 in Ichinomiya City, where most commuters live (destination) place, and one hour later, i.e., 22:00 pm, torrential rain occurred in Nagoya City, where most of the commuters work. Those who sought up-to-date weather information and departed early could avoid involvement in the resulting serious transportation situation.

About 90% of the commuters who knew about the torrential rain and whose usual departure time was around peak rush hour: 17:00–19:00, were likely to change their departure time to earlier. The result implies that they sought to avoid serious public transport congestion as a result of the predicted rain.

There are some studies using a scenario simulator to evaluate an evacuation plan under disaster based on residents’ evacuation behavior (e.g., Futagami et al. (2010)). The result of this study can apply the scenario simulator: when or how residents decide to evacuate.

Although it has become easier to obtain weather information due to the popularization of mobile phones, this study reveals the fact that commuters are not likely to know the weather information; in addition, they tend to not check weather information immediately before departure. This result points out the necessity of fostering improved risk communication. In
Japan, the number of companies making Business Continuity Plan (BCP), involving a business...
plan for how someone’s business can prepare for, and continue to operate after an incident or crisis, has been increasing. In order to reduce chaos during commuters’ return home journeys on torrential rain days, companies should provide clear guidelines regarding employees’ departure decisions and early departure times.

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