Analysis of travel behaviors during floods in Ubon Ratchathani city, Thailand

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Abstract. Cities in Southeast Asia frequently face urban floods, and transportation is often disrupted due to road closures. To reduce road transport vulnerability, the road network should be properly adapted for the flooding condition. To generate suitable adaptation measures for road transportation, travel behaviors under flooding condition, and their differences under normal conditions should be clarified. We aimed to understand the changes in travel behaviors caused by urban floods to compare with normal and flooding conditions in Ubon Ratchathani City, Thailand. A questionnaire survey was applied to understand the travel behaviors under both conditions, and its comparison revealed that under flooding, people prefer early departure time, and reduce the trip frequency depending on trip purpose. Moreover, we compared the route choice behaviors under both conditions using geographic information system (GIS) from collected data. Comparison with travel behaviors under both conditions, we clarified the change in travel behaviors under flooding and that differed from the affected extent depending on trip purpose.

1. Introduction
In recent years, approximately 40% of floods worldwide have occurred in Asia, disturbing people’s activities [1]. In Thailand, floods are usually caused by extreme weather and adversely affect people’s activities during the rainy season from May to October. In flooded areas, road sections can become disrupted in various places, impairing the mobility of residents. For instance, Ubon Ratchathani City in Thailand is hit by urban floods during the rainy season every year. To prevent flooding damages, several flood control measures have been implemented, such as waterproof walls, construction of dams and installation of drainage pumps by the local government. However, the flooding damages are still severe, and it is hard to avoid these damages. Therefore, it is necessary to reduce the flood effects on people's urban activities by implementation of multidisciplinary adaptation measures. In particular, to further reduce road transport vulnerability to floods, comprehensive adaptation measures should be adopted in road transportation considering actual travel behaviors.

We aimed to analyze the relations between travel behavior and flooding in Ubon Ratchathani City, Thailand. To this end, we applied a questionnaire survey to understand the travel behaviors under normal and flooding conditions considering the flood that occurred in 2019. We then applied the Chi-squared
test to the questionnaire data to confirm dependencies between variables, which analyzed travel behaviors according to departure time and sociodemographic factors. In addition, we compared route choice behaviors under normal and flooding conditions to understand detour conditions caused by flooding. In the remainder of this paper, we discuss related studies on travel behaviors and traffic under flooding in Section 2. The questionnaire survey and Chi-squared tests are detailed in Section 3. The results of the questionnaire and Chi-squared tests as well as the discussion are presented in Section 4. Finally, we draw conclusions in Section 5.

2. Literature Reviews
Many studies have analyzed flooding effects on urban activities considering travel behaviors extracted from questionnaire surveys [2-11]. These studies have addressed flooding-related changes in travel behaviors such as departure time (travel time), modal choice, and route choice from comparisons between normal and flooding conditions. From these studies, we know that the travel behaviors of some people in an area change during floods.

To prevent and reduce the adverse flooding effects on travel behaviors, adaptation measures against climate change and extreme weather have been devised in road transportation considering road transportation vulnerability [12-14]. In fact, to determine adaptation measures in road transportation, the impacts of climate change and extreme weather on the road network should be understood [15, 16]. In addition, vulnerable road sections and critical points should be identified to ensure mobility in the network by prioritizing the most effective adaptation measures.

Many studies on road transportation have identified transportation system vulnerabilities, especially regarding road transportation, through methods such as network analysis (e.g., multicriteria analysis, accessibility) based on graph theory. Other studies have analyzed traffic patterns under normal and flooding conditions [17-21]. Such analyses usually aim to minimize the adverse flooding damages under budget constraints. However, to the best of our knowledge, no study has determined changes in travel behaviors under flooding. Moreover, few studies have estimated the impacts of implementing adaptation measures for flooding while considering actual travel behaviors. In this study, we aimed to clarify travel behaviors such as modal choice, trip frequency, and route choice under normal and flooding conditions based on a questionnaire survey applied to residents of Ubon Ratchathani City, Thailand.

3. Materials and methods
To understand the flooding effects on travel behaviors, we applied a questionnaire survey considering normal and flooding conditions in Ubon Ratchathani City. From the collected questionnaire data, travel behaviors about modal choice, travel time (departure time), route choice, and other aspects were compared for both conditions. Moreover, to determine the relation between departure time and sociodemographic factors, we applied the Chi-squared test to the collected questionnaire data. This analysis allowed us to clarify the factor of change in departure time under the flooding condition.

3.1. Study area
In this study, we selected a case study area as Ubon Ratchathani City in northeastern Thailand as shown in figure 1. This city has suffered severe damages due to flooding attributable to climate change and extreme weather in recent years. As of 2015, the city population was 257,113 [22]. The city is divided into north and south areas by the Mun River, which can be crossed through four bridges, as shown in figure 1. Bridge 1 constitutes the western bypass, whereas bridges 2 and 3 are located in the middle area, and bridge 4 constitutes the eastern bypass.

Historical records show that the most severe floods in the city occurred in 1938, 1950, 1978, and 1998–2002 due to a large runoff in the upstream water. In 2002, several buildings and road sections, including the four bridges crossing the river, were disrupted, and inundated. The material losses were estimated at more than 1 Billion THB.

To ensure mobility under flooding condition, the local government has elevated the western and eastern bypasses by approximately 50 – 150 cm [23]. This measure was expected to prevent interrupting
all the Mun River crossings and maintain accessibility during floods for reducing the adverse effects in the residents’ routines and economic activities.

In September 2019, the severest urban floods in 17 years occurred in Ubon Ratchathani City [24]. Nevertheless, the western and eastern bypasses were not disrupted, thus being used as alternative routes (red lines in figure 1). Figure 2 shows photographs of the floods in 2019 on the middle bridge (bridge 2 in figure 1) and the western bypass (bridge 4 in figure 1).

![Figure 1. Map of Ubon Ratchathani city, Thailand](image)

![Figure 2. Photographs of road section 24 (left) and western bypass (right) during floods in September 2019 [24]](image)

### 3.2. Questionnaire survey

To understand the travel behaviors under the flooding condition in September of 2019, we applied a questionnaire survey between December 2019 and January 2020 to residents of Ubon Ratchathani City. The participants were asked to answer questions about their travel behaviors under normal and flooding conditions and the behavioral change due to the urban floods according to the following trip purposes: 1) commuting to office and school, 2) sending children to school, and 3) going shopping.

The survey was designed to determine the change in travel behaviors such as travel time (departure time), modal choice, and route choice according to the trip purpose, inundation depth, and sociodemographic factors. We collected and analyzed the responses from 300 participants. The
inundation depth was divided into six levels: 1) 0.01 – 0.10 m, 2) 0.11 – 0.30 m, 3) 0.31 – 0.50 m, 4) 0.51 – 1.00 m, 5) 1.01 – 1.50 m, and 6) 1.51 m and deeper. The inundation depth may influence the adopted travel behavior and adaptation measures during floods. We collected participants’ sociodemographic characteristics such as monthly individual and household income, vehicle ownership (e.g., bicycle, motorcycle, passenger car), occupation, age group, and driving experience.

3.3. Data analysis
3.3.1. Chi-squared test.
The Chi-squared tests provided significant relations between sociodemographic factors and decisions about departure time. We measured the test strength by applying Cramer’s V and p-value to the collected questionnaire data. The Chi-squared statistic on each variable was obtained by using equation (1). The p-value was calculated from the Chi-square statistic and degrees of freedom after applying the Chi-squared test to the observed and estimated values. We set p-value threshold to 0.05, with values below the threshold representing significant effects on the departure time. The Chi-square values ranged from 0 (no association) to 1 (maximum association). The Chi-squared test considered the hypothesis that travel behavior changes are independent of the evaluated factors.

$$\chi^2 = \sum_{i=1}^{k} \sum_{j=1}^{l} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$  \hspace{1cm} (1)

where $O_{ij}$ is the observed frequency in cell $(i, j)$ and $E_{ij}$ is the expected frequency in cell $(i, j)$. The Chi-square value was compared with a Chi-square distribution with $(i-1)(j-1)$ degrees of freedom.

$$V = \sqrt{\frac{\chi^2}{N \times \min(i-1, j-1)}}$$  \hspace{1cm} (2)

where $N$ is the sample size and $V$ is Cramer’s V.

3.3.2. Comparison of travel behaviors under normal and flooding conditions.
The participants were asked about their travel behaviors such as trip frequency, modal choice, and route choice under both normal and flooding conditions. Regarding route choice, the participants were asked to outline their route choices on a map of the city. These routes were visualized and compared using GIS (geographic information system) to understand route variations due to urban floods.

We estimated the inundation depth from the questionnaire survey data and overlaid the selected routes with the inundation depth distribution. By analyzing these data, we determined the flooding effects and whether the elevated bypasses enable effective alternative routes.

4. Results and discussion
4.1. Participants’ characteristics
In this study, 300 participants answered the questionnaire, and we obtained responses for different trip purposes: 1) commuting to office or school (157 responses), 2) sending children to school (76 responses), and 3) going shopping (168 responses). The participants only provided responses to their frequent trip purposes. The sociodemographic factors of the participants are listed in table 1. Approximately 40% of the participants were male, and around 90% of the participants belonged to the working age group (20–59 years old). In addition, 60% and 90% of the participants held driver licenses for cars and motorcycles, respectively. Almost all the participants who owned motorcycles had driving experience of over 5 years at the time of the study. Furthermore, 80% of households owned passenger cars mainly one or two vehicles per household. Indeed, motorcycles and passenger cars are the most widely used transportations in the city.
Table 1. Participants’ sociodemographic characteristics

| Characteristics            | Share(%) |
|----------------------------|----------|
| Gender (N=300)             |          |
| Male                       | 124(41.3) |
| Female                     | 176(58.7) |
| Age (N=298)                |          |
| 0 - 19                     | 16(5.4)  |
| 20 - 29                    | 97(32.6) |
| 30 - 39                    | 92(30.9) |
| 40 - 49                    | 52(17.4) |
| 50 - 59                    | 26(8.7)  |
| 60 - 69                    | 13(4.4)  |
| 70-                        | 2(0.7)   |
| Occupation (N=297)         |          |
| Employee                   | 74(24.9) |
| Public Officer             | 32(10.8) |
| Self Employee              | 124(41.8)|
| Part-time Job              | 6(2.0)   |
| Student                    | 45(15.2) |
| Unemployee                 | 15(5.1)  |
| Other                      | 1(0.3)   |
| Individual Income (Unit: Bath) (N=300) |          |
| No Income                  | 59(19.7) |
| 1 - 19,999                 | 147(49.0)|
| 20,000 - 29,999            | 77(25.7) |
| 30,000 - 39,999            | 9(3.0)   |
| 40,000 - 49,999            | 4(1.3)   |
| 50,000 - 59,999            | 2(0.7)   |
| 60,000 - 69,999            | 1(0.3)   |
| More than 70,000           | 1(0.3)   |
| Household Income (Unit: Bath) (N=299) |          |
| No Income                  | 3(1.0)   |
| 1 - 19,999                 | 59(19.7) |
| 20,000 - 29,999            | 118(39.3)|
| 30,000 - 39,999            | 80(26.7) |
| 40,000 - 49,999            | 20(6.7)  |
| 50,000 - 59,999            | 15(5.0)  |
| 60,000 - 69,999            | 2(0.7)   |
| More than 70,000           | 3(1.0)   |

The results of the Chi-squared test applied to the participants’ characteristics are listed in table 2. The p-value of five factors, namely, occupation, household income, motorcycle ownership, age, and gender were below 0.05. Hence, people who decided to change in the departure time (mainly earlier departs) under flooding were related to occupation and household information (income, gender, and age group). Other factors such as driving experience and car/motorcycle ownership did not affect the departure time because people without alternative transportation did not have a modal choice.
Table 2. Chi-squared test results from participants’ sociodemographic characteristics

| Variables                  | χ² Statistic (dof) | p-value  | Cramer’s V |
|----------------------------|-------------------|----------|------------|
| Occupation                 | 30.856(5)         | 0.000    | 0.325      |
| Household Income           | 17.58(7)          | 0.014    | 0.243      |
| Motorcycle Ownership       | 8.304(2)          | 0.016    | 0.166      |
| Age                        | 13.68(5)          | 0.033    | 0.215      |
| Gender                     | 6.594(2)          | 0.037    | 0.113      |
| Driving License (MC)       | 5.677(3)          | 0.128    | 0.14       |
| Car Ownership              | 2.310(2)          | 0.315    | 0.088      |
| Individual Income          | 7.828 (7)         | 0.348    | 0.162      |
| Experience of Driving (PC) | 3.168(5)          | 0.674    | 0.076      |
| Driving License (PC)       | 1.317(3)          | 0.725    | 0.08       |
| Experience of Driving (MC) | 1.693(5)          | 0.889    | 0.076      |

4.2. Travel behaviors

Figure 3 shows the results of modal choice under normal and flooding conditions. In normal condition, approximately 80% of the participants selected passenger cars or motorcycles for every trip purpose, and only around 10% of the participants selected public transportation. These results are consistent with the modal split of the household travel survey data from 2015 [22]. In addition, the modal choice did not notably change under flooding condition.

![Modal choice according to trip purpose under normal and flooding conditions](image)

Figure 4 shows the percentage of participants’ departure times in three categories (i.e., early, usual, and late) with respect to normal condition under flooding condition. Approximately 20% of the participants who commuted to school or office departed earlier than usual during the floods of 2019, whereas only approximately 5% who went shopping departed earlier. These results are related to the nature of the trip purpose, as people should be at school or office on time. On the other hand, going shopping may not change the departure time because it is usually a less restrictive activity.
Table 3 lists the changes in trip frequency and destination under normal and flooding conditions. Approximately 3.7% of the participants changed their destination for purposes of going to school/office and sending children to school. On the other hand, most participants (96.1%) did not change their trip frequency and destination when going to school/office and sending children to school. When going shopping, approximately 21% of the participants changed their destination, and 50% either decreased their trip frequency or suspended their trips. This behavior may be explained by people going shopping before or after urban floods.

Table 3. Relations between trip frequency and destination change according to trip purpose

| Going school or office | Frequency/Destination change | Yes | No  |
|------------------------|------------------------------|-----|-----|
|                        | Usual                        | 2.5% | 89.2% |
|                        | Decrease                     | 0.6% | 6.4%  |
|                        | Never                        | 0.6% | 0.6%  |

| Sending children to school | Frequency/Destination change | Yes | No  |
|----------------------------|------------------------------|-----|-----|
|                            | Usual                        | 1.3% | 90.8% |
|                            | Decrease                     | 0.0% | 2.6%  |
|                            | Never                        | 1.3% | 3.9%  |

| Going shopping | Frequency/Destination change | Yes | No  |
|----------------|------------------------------|-----|-----|
|                | Usual                        | 1.8% | 45.2% |
|                | Decrease                     | 13.1% | 27.4% |
|                | Never                        | 6.5% | 6.0%  |

Note “Usual”, “Decrease” and, “Never” mean the trip frequency under flooding condition compared with under usual condition. Residents have chosen trip frequency for each trip purpose as follows; no change in trip frequency: “Usual”, decrease in trip frequency: “Decrease” and, cancellation in all trip for this trip purpose: “Never”.

To understand the flooding effects on route choice, we estimated the inundation depth based on the subjective depth data obtained from the participants about the flooding in September 2019. The resulting distribution map is shown in figure 5, where darker blue indicates higher inundation depth. The area along the Mun River presented the highest inundation depth estimation.

To validate the estimated inundation depth obtained from subjective data, we compared actual flooded area data in 2019 as shown in figure 6. This figure shows the flood area observed from satellite images. This area is similar to the estimated inundation depth, thus validating the estimation.
To relate the route choice and inundation depth, we compared the selected routes under normal and flooding conditions and overlaid the estimated inundation depth distribution using GIS. The corresponding results are shown in figure 7, where the usual route is shown in green color, and the alternative route during flood is shown in red color. As people could not pass through the two middle bridges (bridges 2 and 3 in figure 1) during the floods, they selected the western or eastern bypasses (bridge 1 or 4 in figure 1) as alternative routes to avoid deeply flooded areas. Given that the western and eastern bypasses are elevated, they are not disrupted during floods. Note that the travel distance may be substantially shortened by traveling through the elevated western bypass instead of the eastern bypass. If available, elevated western bypass may notably influence travel behaviors during flooding. By understanding the route choice under the flooding condition, it is possible to refer to prioritization of adaptation measures and could earn more effectiveness.
5. Conclusion
We conducted a questionnaire survey to understand travel behaviors such as modal choice, route choice, and trip frequency during the floods of September 2019 in Ubon Ratchathani City, Thailand. We found changes in travel behaviors under flooding condition according to the trip purpose from comparisons with behaviors under normal condition. The questionnaire results showed that people changed their departure time and route choice to avoid flooded road sections, particularly for going to work or school and arrive on time. We also found that shoppers did not change their departure time and route choice when going shopping, and people tend to obtain supplies either before or after urban floods. Regarding modal choice, most travelers rely on private transportation, mainly motorcycles and passenger cars, under both normal and flooding conditions due to the lack of transportation alternatives in the city. Regardless of the trip purpose, people...
take detours, with the elevated bypasses providing alternative routes and helping to reduce adverse flooding effects on travel behaviors. Even if travel behaviors under flooding change according to the trip purpose, the elevated bypasses is an effective mobility measure during floods.

On the other hand, mobility of public transport user has probably reduced because of the lack of alternative modes. Thus, public transport is re-routed to connect on both sides of the flooded bridges (in the middle area which cannot be elevated as bypass roads) under flooding condition in order to secure mobility for those who do not own private vehicles. Also, the extra high vehicles (e.g., military trucks) which are higher than passenger cars and buses have been used during the inundation period for crossing bridge 2 (in figure 1) in 2019. Therefore, it is important to plan for operating flood rescue trucks under the flooding condition for public transport users.

In further study, we will identify vulnerable road sections that should be upgraded for ensuring road availability during flooding. Furthermore, we will evaluate elevated of bypass measure and other adaptation measures on transport sector based on combination to identification of the vulnerable road sections and actual travel behavior data. These measures should be designed such that they do not cause problems in other areas.

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