(29) ANALYSIS ON HEAVY CONGESTION SITUATION DURING TYPHOON USING TAXI PROBE DATA WITH ANIMATED SIMULATION AND QUESTIONNAIRE SURVEY

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Extreme traffic congestion during a typhoon occurred repeatedly. Educating drivers about the congestion locations and the severity level can help alleviate the traffic in future disasters. A good countermeasure cannot be prepared without an understanding of drivers' behaviors during a disaster. In this study, an animated simulation of commuters returning home during a massive downpour during Typhoon Roke is prepared using taxi probe data. The simulation is prepared in order that the actual traffic condition is properly represented. In addition, the causes of the unusual traffic congestion are analyzed from a questionnaire survey in order to find proper countermeasures to alleviate the congestion severity.

Key Words: *congestion, taxi probe, simulation, commuter, typhoon, modeling*

1. INTRODUCTION

In recent years, Nagoya city is one of the most frequent victims of the marine calamity. It has experienced a devastating typhoon named Roke on 20th September 2011. Train services from Nagoya were stopped due to strong wind and driving rain. Consequently, car was the only available transport option for returning home. Moreover, several companies closed their facilities and allowed their workers leave early due to the typhoon. This resulted in more number of commuters bound for home at early hours. An excessive rainfall caused flash floods and extreme river waves which in turn covered roads and bridges and reduced the capacity of road space. This generated a further dimension to the congestion severity. It is a prerequisite to be well-aware of the congested location and its severity in order to determine a proper countermeasure.

Some literature regarding the homebound commuters during downpour such as the work of Fujita et al [1)] which empirically examined the attitude and awareness of individuals to evacuate during typhoon using a questionnaire survey. However, the work focused mainly on public transport users.

GIS software can easily visualize the location of the probe vehicles together with the speed and time. Taylor et al.[2)] described the method to use GIS for the analysis of travel time, delay and congestion in urban area. They analyzed the GPS data from probe vehicles using the GIS technique. Only a few studies analyzed the travel behavior using GPS data during a downpour. Khan et al.[3)] discussed the potential of using taxi probe data to represent the congestion situation under typhoon.

Given these backgrounds, this study aims to develop an animated simulation based on the GPS data of taxis operating during the date of the typhoon. Then, a questionnaire survey on each individual's returning home trip is analyzed in order to understand the causes of congestion and plan a practical countermeasure. In the next section, a brief detail about the preparation of animated simulation and the congestion situation is described. In Section 3, the congestion bottlenecks and the reasons are explained. In Section 4, the statistical analysis of the questionnaire is presented. Finally, the conclusion and recommendation are provided.

2. ANIMATED SIMULATION TO REPRESENT THE ROAD SITUATION UNDER TYPHOON

(1) Outline of the Taxi probe data

The taxi probes (positioning, time, speed, angle and vehicle status) which were operating on the day of typhoon were received from a Taxi Probe Research Center. The positions of taxi were recorded at approximately every 200 m or 20 sec. Only taxis carrying passenger were included in the analysis in order to avoid unusual driving behavior and misrepresenting the actual traffic stream.

(2) Animated Simulation

In this section, the method to construct and validate the animated simulation using the taxi probe data is discussed. The purpose of this simulation is to communicate with drivers for a comprehensive recognition of the congestion. In general, the number of probe data during the disaster is inadequate to represent the real traffic situation. The probe vehicles were also hardly running along with other vehicles during severe traffic congestion. Also, many other vehicles existed between the probe vehicles. This study aims to portray the real traffic and congestion situation using the limited number of probe vehicles. Here, we use the duration for the probe vehicles to be remained on screen as a method to expand the probe data, so that other vehicles in the traffic stream are represented and the data is expanded to the real extent of traffic volume. The remaining time on screen is the time duration that the probe vehicles are kept stagnant on each frame of the animated video.

The animated simulation by GIS plots the most recent object on the top over other objects at the same location. Therefore, when moving to the next time frame, the changes in the new frame can be noticed from the new plots at the same locations.

The validity of the animated simulation is examined through a comparison between the simulated travel time with the actual travel time from probe data. We use 13 segments in which each segment consists of more than 100 positions of probe vehicles to calculate the actual time required to traverse the segment. A number of simulations of different expanding patterns (with different remaining times, speed classes and colors) are validated with the actual travel time between an origin/destination pair using RMSE as a criterion. **Fig.1** shows the animated simulation using the expanding pattern with the least RMSE. **Table 1** shows the parameters used in the expanding pattern of the selected animated simulation.

Fig.1 displays the simulation output window of 05:01 pm till 05:49 pm wherein circles denote the probe vehicles. Using the parameters in **Table 1,** the slower vehicles are presented in larger circles and in more red color. On the other hand, the faster vehicles are depicted in smaller circles and more in blue color.

Fig. 1 shows that other than the central part of Nagoya city, Kasugai, seto and Route 19 to Tajimi are congested. Kasugai city has experienced flooding and most of the roads adjacent to the train stations were inundated. From the overall view, the North-eastern part of the region in **Fig. 1** is significantly congested. In the next section, we will focus on this area for a more detailed analysis.

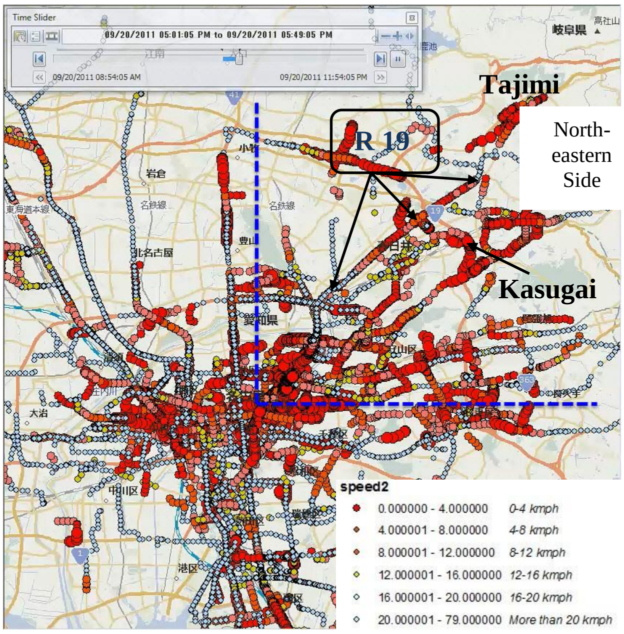

Fig.1 Simulation Output window

Table 1: Parameters of pattern that used in the simulation

Speed Classes (Km/h)	Circle Diameter (m)	Remaining time on screen (min)
0 to 4	52	52
4.1 to 8	43	52
8.1 to 12	43	52
12.1 to 16	43	52
16.1 to 20	43	49
20 or more	37	48

3. CONGESTION BOTTLENECKS AND THE REASONS BEHIND

Route 19 was reported heavily congested and most road closures were in the North-eastern side of Nagoya city including some portions of Route 19. Therefore, the North-eastern part of the region is especially focused for a comprehensive understanding of the traffic situation due to the road closures.

Fig.2 shows the congestion on the day of typhoon, when some roads and bridges were inundated and closed to traffic. This road closure caused a huge congestion on the arterial roads as well as some other non-arterial roads. Besides, **Fig.2** also exhibits that route 19 nearby Kasugai and the surrounding of Tajimi is severely congested. In addition, some taxi cars chose northward diversion (R41 and R248) and some other chose southward diversion (R363 and R248) to travel to Tajimi. These diversions created unusual traffic load on the north and southward roads. Since the southward roads are the shorter, therefore, we can observe that the roads are heavier congested than the northward ones.

The representation through animated simulation taxi of the probe data might help to understand the congestion situation. However, thinking of a countermeasure using the simulation alone is not practically enough for a successful implementation. Thus, further insights into the core reasons of this intense traffic situation are necessary. For this reason, the commuters' behavior and attitude is analyzed using a questionnaire survey. This analysis may assist us in seeking a more practical solution to the problems.

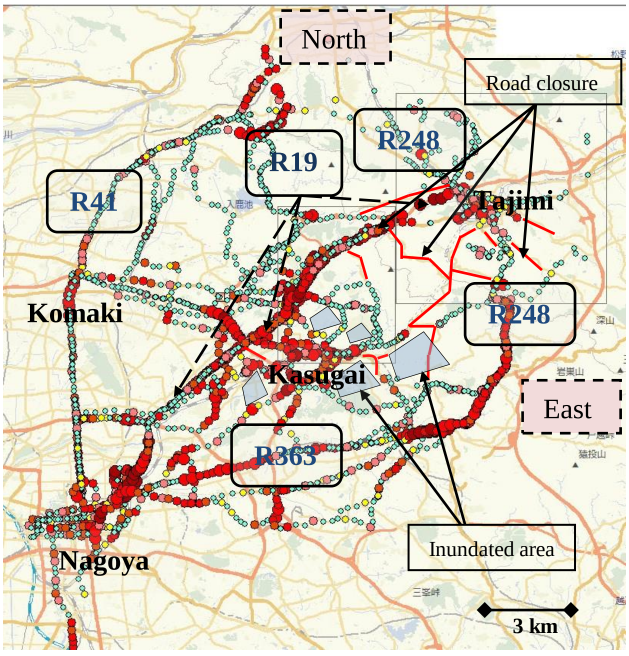

Fig.2 The congestion on the day of Typhoon

4. QUESTIONNAIRE SURVEY AND ITS ANALYSIS

(1) Outline of the Questionnaire Survey

Questionnaires were distributed to commuters who used the JR Tokaido, Chou, and other lines along Route 19. T Roughly, this data consisted of 634 respondents with the return rate of 12.67%. The survey covered five cities and moriyama ward of Nagoya city. This study focuses on both automobile and public transport users.

(2) Statistical Analysis

A regression model is constructed to explain the congestion situation using personal attributes (e.g., age, sex) and travel characteristics (e.g., expressway usage, departure hours etc.) from the questionnaire data. The mean speed of a trip was considered as an objective variable. This mean speed of a trip was deduced by dividing the distance of the shortest route by the travel time for each trip. The distance of the shortest route is obtained from the suggested route with the minimum travel time for car on a regular day by navigation software.

Table.2 shows the analysis results in two models in which only the significant parameters are retained. Different from Model 1, Model 2 includes the parameter for female commuters and the parameters for the earlier departure by 3 hours or more and delayed departure by 1 hour or more. Here, the parameter for earlier departure by 3 hours or more denotes the case when the individual departed 3 hours or earlier than usual. Similarly, the parameter for the delayed departure by 1 hour or more indicates the case when the individual departed 1 hour or later than the regular time. Both models have an acceptable value of R-square (0.592 and 0.447).

In the models, the distance of the shortest route is positive. Usually, the congestion is limited at some particular bottlenecks; therefore, a detour helps to increase the average travel speed. Then, the travel distance without expressway demonstrates that the usage of expressway helped to reduce the travel time. The large negative value of the dummy variable of Kasugai IC indicates that the vehicles that passed Kasugai IC experienced heavy congestion. In fact, on the day of typhoon, the section between Nagoya-Kasugai of Tomei Expressway was eventually closed twice after reopening for a few hours. Subsequently, all cars passing Kasugai IC using the expressway was bound for the exit to Route 19; and hence increases the congestion at that portion.

The dummy variable "other than cars" indicates the commuter who specially used car on the day of typhoon although they use another travel mode on a regular basis.

Table 2: Mean Speed model

Explanatory Variables	Model 1		Model 2	
	Estimate	t-stat	Estimate	t-stat
Intercept	6.549	8.27***	6.444	6.51***
Distance for Shortest route	0.00041	6.15***	0.00043	5.51***
Travelled distance without Expressway	-0.00021	-2.96***	-0.00024	-2.94***
Kasugai IC	-6.346	-1.9*	-6.618	-1.72*
Other than Car	-2.798	-2.7***	-2.844	-2.31**
Elderly People	-2.322	-1.82*	-	-
Female	-	-	-1.817	-1.86*
Earlier Departure of 3 hours or more	-	-	-2.27	-1.92*
Delayed Departure of 1 hour or more	-	-	2.52	1.84*
Departure 11:00 hrs	14.624	3.73***	18.364	4.00***
Departure 14:00 hrs	-4.077	-2.54**	-	-
Departure 15:00 hrs	-3.989	-3.24***	-	-
Departure 16:00 hrs	-3.649	-3.38***	-	-
Departure 21:00 hrs	10.802	5.08***	-	-
Departure 22:00 hrs	11.602	4.66***	-	-
Departure 23:00 hrs	12.701	3.26***	10.541	2.35**
Arrival at Ichinomiya	6.289	4.92***	6.379	4.26***
Arrival at Gifu	9.923	6.55***	11.365	6.62***
Arrival at Seto	4.906	4.6***	4.585	3.71***
Number of Samples	207		206	
R Square	0.592		0.447	

Note: *** is significant at 99% level of confidence, ** is significant at 95% level of confidence, * is significant at 90% level of confidence

In both models, the sign for "other than car" is negative, meaning that the drivers who does not use car regularly faced more congestion. Elderly people and female dummy parameter in both models are negative, meaning that elderly or female take a longer time for travel. Especially, an elderly required a longer travel time than a female for a similar distance to travel.

Next, in Model 1, the dummy parameters of the departure at 11:00, 21:00, 22:00 and 23:00 are positive, which means that commuters who left the office before the typhoon hit or late at night will arrive home quicker since they did not face a heavy congestion. In turn, the dummy parameters of the departure at 14:00, 15:00, and 16:00 are negative, meaning that the commuters departed between 14:00 and 16:00 had face the congestion. This is because most of the road closures commenced from 14:00 as a result of heavy rain and flood. These commuters faced road closures, were forced to detour, and consequently encountered severe traffic congestion. The departures at 11:00 and 23:00 are positive and significant in both models. It can be stated as, departing at 11:00 was before the road closures and the consequent traffic jam. And, departing later from 23:00, the information on road closure are well acquainted to the drivers, therefore, they could avoid those sections while making their route to destination. In both of the models, the dummy variables for the destinations at Ichinomiya, Gifu, and Seto are positive. It indicates that the commuters bound for those locations did not face significant delay in their trips.

5. CONCLUSION

This paper presented a comprehensive representation of the congestion situation through developing an animated simulation using taxi probe data. The representation exhibits that the northeastern direction from central Nagoya including Moriyama ward, Kasugai, Tajimi faced huge congestion due to sudden inundation and road closure.

Then, a questionnaire survey on the commuter heavier during the downpour was analyzed in order to investigate further the causes of congestion. The results revealed that the commuters who departed between 14:00 and 16:00 had faced severe congestion since they did not receive the information on rainfall and traffic status.

Consequently, this study recommends that the rainfall and traffic update information should be gathered prior to the departure in order to avoid the severe congestion. In the future study, countermeasures and the impacts on commuters' travel behavior are to be investigated using a traffic simulation.

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