Analysis of Traffic Conditions on Expressways and Ordinary Road Network during Incident Congestion with Road Closures using Detector Data and Probe Data

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Abstract: The impact of incident congestion on urban expressways must be minimized to provide reliable expressway services. Quick detection and assessment of incidents, and provision of relevant information of traffic conditions are required. In this study, we used traffic detector data and probe data to analyze changes in traffic conditions on expressways and ordinary roads because of incidents. We set the origin and destination and compared the changes in travel time along the routes. The analysis results show that changes in traffic conditions occur even at locations far from the incident location on the expressway, and the route with the shortest travel time differs depending on the time elapsed after the incident. Based on our findings, we consider that it is possible to reduce the impact of incident congestion by providing information on traffic conditions according to the elapsed time as well as the destinations.

Keywords: Incident, Probe data, Driving Behavior, Traffic Flow, Route Choice

1. INTRODUCTION

Urban expressways that are spread across the Tokyo metropolitan area have high vehicle speed and reliability requirements compared to ordinary roads. Approximately 130 “incidents” occur per day on the Metropolitan Expressway, as shown in Table 1. Such incidents can lead to lengthy road closures, resulting in massive congestion. For example, as shown in Table 2, in 2015, there were 11 incidents involving road closures of more than three hours, four of which were on a large scale and lasted more than seven hours. To provide reliable expressway traffic services, it is necessary to reduce the impact of traffic congestion after an incident, for which a quick detection and assessment of incidents is required. Moreover, it is essential to provide information that is appropriate to traffic conditions.

Table 1. Number of incidents on Metropolitan Expressway in 2014

Type	Number of accidents	One-day average
Accident	10342	28.3
Vehicle failure	11209	30.7
Falling object disposal	25522	69.9

Table 2. Number of incidents involving road closures for three hours or more

Year	Date	Road closure duration	Cause
2015	Apr. 27	5 h 31 min	Accidents involving marine container trailers
	Jul. 11	7 h 30 min	Hit-and-run accident
	Aug. 3	3 h 39 min	Rollover accident of a freight vehicle
	Oct. 16	7 h 23 min	Fallen objects cleaning
	Oct. 29	5 h 49 min	Facility contact and rollover accident
	Nov. 17	3 h 30 min	Single fire in a freight vehicle
	Dec. 7	3 h 27 min	Chasing sudden fatal accidents
	Dec. 21	8 h 42 min	Trailer vehicle fire
	Dec. 23	3 h 36 min	Facility contact accident
2016	Jan. 12	8 h 32 min	Multiple chase fatal accidents
	Mar. 19	3 h 26 min	Hit-and-run accident

To provide such information, it is necessary to examine the traffic conditions at the time of an incident. In addition, it is necessary to understand the traffic conditions on ordinary roads simultaneously since there may be an option to get off the expressway when choosing a route. Traffic congestion on expressways can be predicted in advance, but it is challenging to predict incident congestion in advance. In addition, there are few similar examples of incidents because they occur at different places, times, and scales. Therefore, traffic operations to deal with incidents have not been established.

Although previous studies investigated route choices in traffic congestion, relatively few studies investigated route choices in case of incident congestion. Previous studies considered hypothetical scenarios using simulations and questionnaires, such as an analysis of route choice during incidents using SP surveys, but there have been no studies using actual data.

Based on the above background, the purpose of this study is to understand the traffic conditions on urban expressways and the surrounding ordinary roads when an incident involving a road closure occurs. First, to compare the total road network, data from vehicle detectors with and without incidents were collected. Changes in traffic volume and travel time on expressways and ordinary roads were analyzed in Chapter 4. Next, to compare the differences in individual vehicle behavior, changes in route choice on expressways with and without an incident from probe data during the same period were also analyzed in Chapter 5. Then, based on the analysis results, it was verified whether vehicles select the shortest route for specific O-D pairs in Chapter6. Finally, from this analysis, discussions of proposals for more reliable expressway traffic services will be conducted.

2. SUMMARY OF PREVIOUS STUDIES

This study focuses on driving behavior, especially route choice, during incidents. In this section, we discuss previous studies that analyzed traffic conditions and route choice during incidents.

2.1 Studies on the Prediction of the Traffic Scenario in case of Incidents

Tamura et al. (2013) conducted a sensitivity analysis of the accident response module of the Real-time traffic Information by dynamic Simulation on urban Expressway (RISE), which was developed to accurately determine the actual traffic conditions when an incident occurs the Tokyo Metropolitan Expressway. The accuracy of predicting the traffic conditions during an incident using simulation was 83%, with a threshold of actual value ±10 min. When the speed of each section was classified as “free flow,” “crowded,” or “congested flow,” the accuracy rate for the target route was shown to be 73% after 30 min and 40% after 60 min. To improve the prediction accuracy, the modules in the simulation need to improve their accuracy. The accuracy of the “lane closure time prediction” module has the most significant impact on improving speed prediction accuracy.

Kusakabe et al. (2015) developed a method for detecting incidents with probe car data using the shock wave velocity. The bottleneck location is identified based on the shock wave velocity and position information obtained from the probe data of the vehicle arriving at the end of the traffic congestion, and the accuracy and detection time are verified. The results show that it is possible to identify bottlenecks with a sure accuracy if the probe car ratio in the traffic flow is more excellent than 5%. This result suggests that it is possible to detect the location of bottlenecks even when it is not possible to conduct fixed-point observations using traffic detectors.

Parkany et al. (2005) reviewed methods for predicting traffic conditions during sudden events outside of Japan. It has been shown that existing algorithms developed for detecting incidents on expressways can be broadly classified into the following seven categories:

1) Comparative algorithms: A threshold value is set based on the traffic flow conditions and the accumulated data observed by traffic detectors. When the deal is exceeded, it is determined as an incident.
2) Statistical algorithms: Probability distributions of variables representing traffic flow are estimated using cumulative data, and incidents are determined according to probability distributions.
3) Time-series algorithms: Assuming that normal traffic flow is a predictable pattern, an incident is determined when the detector measurements deviate significantly from the model output.
4) Smoothing/filtering algorithms: Weighted averages and linear filters are used to remove nonuniformity and determine an incident.
5) Traffic modeling algorithms: A traffic flow model is constructed using traffic flow theory, and its parameters are compared with observed traffic flow parameters to determine an incident.
6) Artificial intelligence algorithms: Neural networks are used to detect an incident automatically.
7) Image processing algorithms: Images and videos are used to predict traffic volume, detect stationary and slow-moving vehicles, and determine an incident.

In later research, Yukimasa et al. (2005) proposed a model for estimating path flows and modifying O-D flows simultaneously, in which probe vehicle information and traffic counts are used. The proposed model is constructed as a two-stage model. The first stage model is the estimation model of path flows, and the second stage model is the modification model of O-D flows. The proposed model was applied to the Sioux Falls network. Moreover, it was clarified that the proposed two-stage model had enough ability to estimate path flows and to modify O-D flowed accurately even when prior O-D flows had inconsistency with the current traffic conditions.

Maarten et al. (2017) conducted research aimed at demonstrating the feasibility of a live Automated Incident Detection (AID) system using only Floating Car Data (FCD). An FCD AID system is presented compared to the installed AID system (using loop sensor data) on two different highways in the Netherlands. Their results show that the FCD AID can adequately monitor changing traffic conditions and follow the AID benchmark. Additionally, FCD allows for AID on roads without installed sensors, allowing road safety improvements at a low cost.

Piotr et al. (2018) conduct an analysis based on probe data to find the best reliability performance measures for assessing congestion frequency and severity. Results of pilot surveys conducted on the A2 motorway and S6 expressway confirm the usefulness of PVD for assessing existing traffic conditions and identifying the location of congested regions.

Hakmat et al. (2021) conducted research in which they analyzed Floating Car Data (FCD) to estimate route choices at different spatial scales using actual trajectory data collected on a motorway network in Germany. As a result, an aggregated set of FCD can estimate highly accurate and realistic route choice proportions.

Thus, many studies determined traffic conditions during incidents. However, most of them considered only expressways, and few studies analyzed the scenario on ordinary roads at the time of incidents or the plan of vehicles getting off the expressway.

2.2 Study on Route Choice in case of Incidents

Chatterjee et al. (2002) analyzed the driver's response to the variable message signs (VMS) information in avoiding incidents using a questionnaire survey. A survey of drivers' actual responses to a message activation showed that only one-third of drivers saw the information presented to them, and few of these drivers diverted. They discussed that the current usage to display advance warnings may be detracting from its effectiveness as a means of disseminating current information.

David (2003) analyzed saving traffic congestion time using advanced traveler information system (ATIS) technology. Simulation is used to analyze the savings in congestion time when alternative routes are used for various cases of congestion using ATIS. The greatest time-savings for ATIS are non-recurring congestion, incidents that cannot be easily anticipated. Furthermore, ATIS reduces the variance in travel time, making private vehicle transportation more reliable.

Kim et al. (2008) conducted a driving experiment on an ordinary road to analyze drivers' route choices according to the information obtained from the car navigation system and passengers. The data of the routes chosen among six predefined routes were collected, and a route choice model based on the logit model was constructed using these data. These results indicated that even during an incident, the provision of information allows for a steady route choice.

Xuan et al. (2011) analyzed the impact of information on drivers in a congested network under the assumption that better-informed travelers will choose better routes. It is indicated that *en route* real-time information increases the network's travel time saving and reliability under the specific setting of the experiment, yet FP information has the opposite impact.

Kusakabe et al. (2012) developed and analyzed a driving behavior model using information from probe person data and web-based questionnaire data during incidents on expressways. The analysis results indicated that when information on the length of traffic congestion is provided, users expect to pass through the section at 20 km/h or slower. If this expected speed is higher or lower than the actual speed, it is considered necessary to take some measures.

Kusakabe et al. (2013) used an SP survey to determine route choice behavior when information about incidents is provided by a variable message sign (VMS) while driving on an urban expressway. Based on the survey results, a route choice model was developed, and the relationship between information messages and route choice behavior during incidents was analyzed. Then, the influence of information on the length and travel time of congested sections, as well as on the trend (increase or decrease) of the route choice of road users during incidents, was examined.

Vladimir et al. (2017) build and analyze the effectiveness of simulation-based strategies to reduce the total travel time when an incident destroys part of the road network and limits its capacity. The analysis results show that by appropriately distributing the vehicles over the alternative routes in the simulation, the total travel time can be significantly reduced compared to doing nothing.

As shown above, several studies investigated route choice during incidents. However, due to the difficulty of obtaining traffic data, most studies have been based on questionnaires or simulations, and there have been few analyses based on actual data.

3. TARGET OF THIS STUDY AND ANALYSIS METHOD

3.1 Target areas and dates

For analyzing traffic conditions on urban expressways and ordinary roads during an incident, this study considered the Tokyo Metropolitan Expressway and ordinary roads that run along the expressway, as shown in Figure 1. Since the target incident (described below) occurred on the upper and lower lines from Metropolitan Expressway Route 3 to the Central Circular Route at Ohashi JCT, the urban expressways considered are Route 3 and the Central Circular Route. The ordinary roads are Tamagawa Avenue, Roppongi Avenue, and Yamate Avenue, parallel to these sections. Metropolitan Expressway Route 3 is elevated. Moreover, Tamagawa Avenue (on the west side) and Roppongi Avenue (on the east side) exist under the expressway. The Central Circular Route is underground, and Yamate Street exists above it. The locations of the target routes are shown as thick blue lines in the figure, but ordinary roads and expressways are represented as overlapping because they differ only vertically. The numbers in the figure represent the locations of the traffic detectors used in this analysis.

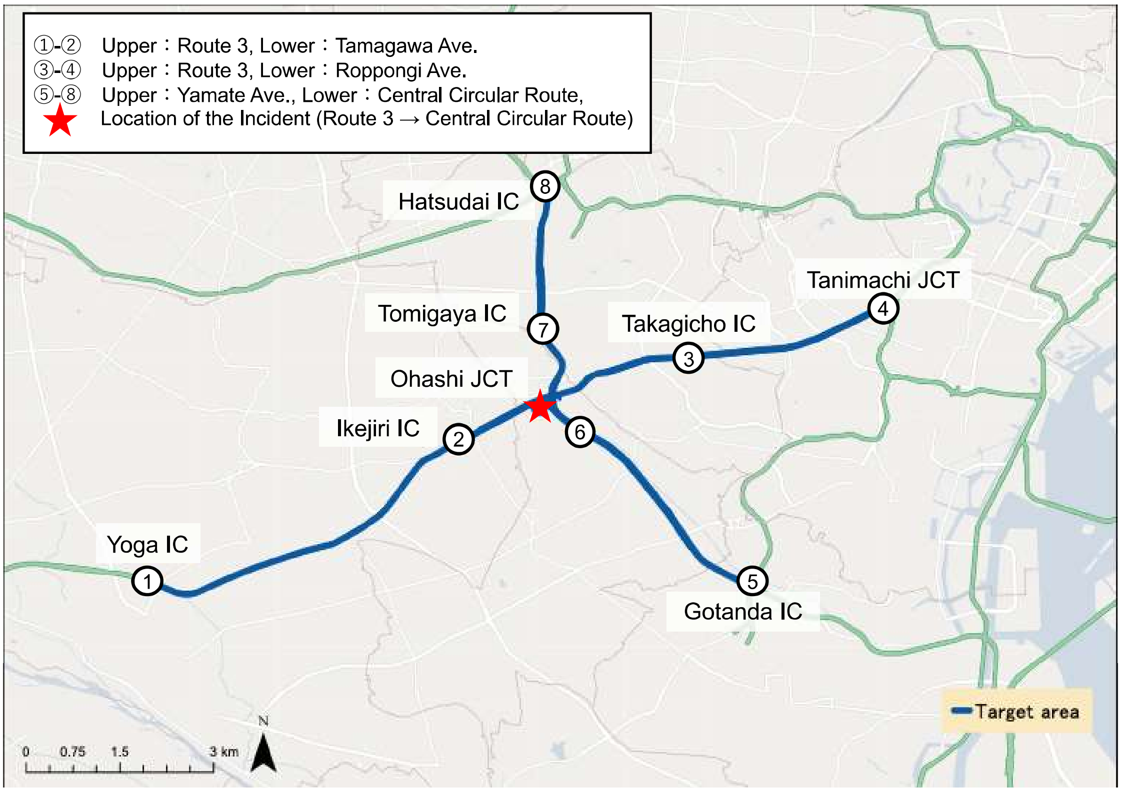

Figure 1. Target area

Based on the results of interviews at the Metropolitan Expressway Company, Ltd., the target incident day of the analysis was October 16, 2015, which was the day with the most considerable congestion loss time on all Tokyo Metropolitan Expressway lines in 2015. For comparison, October 2 and October 9, 2015, were considered, provided that no road closures occurred, the daily traffic volumes (10,000 veh/day) were similar, and the days of the week were the same. The details of the incident and daily traffic volumes are summarized in Table 3. In the following analysis, comparative data will be compared and analyzed based on the date of the incident and the candidate dates for which data could be obtained.

Table 3. Traffic conditions on incident date and comparison date

	Year	Date	Road closure duration		Congestion loss time (veh*h)	Location	Daily traffic (mil veh/day)	Available data
Target day	2015	Oct 16	7 h 23min	14:17→21:40	59369.8	Ohashi JCT	1.054	Traffic detector / Probe
Candidate days		Oct 2					1.060	Traffic detector
		Oct 9					1.103	Probe

3.2 Analysis Method

First, we determined the traffic conditions on urban expressways and ordinary roads based on the traffic detector data received from Metropolitan Expressway Company, Ltd., and the Metropolitan Police Department. A traffic detector is a system that measures the number and speed of traffic by detecting vehicles traveling between two detector heads installed at 5m intervals on the road, using ultrasonic waves transmitted periodically by the detector heads. From the obtained data, traffic volume and travel time were extracted as indicators of traffic conditions. Based on this data, we compared the traffic conditions with and without an incident and on different types of roads.

Next, based on the above analysis results, we analyzed the driver's route choice during and after the time when a change in traffic conditions occurred based on the incident. We used the probe data of vehicles traveling in the target section to analyze the changes in route choice.

Finally, the results of these analyses were used to verify whether the route selected by the driver at the time corresponding to the minimum travel time. The origin and destination were set in advance, and the travel time, including ordinary road conditions, was calculated, and the results were used for comparison.

4. ANALYSIS OF TRAFFIC CONDITIONS USING TRAFFIC DETECTOR DATA

Using 24 hours of traffic meter data from the target and candidate days, we analyzed the overall traffic conditions caused by the incident. The candidate day is October 2, 2015, when the traffic detector data was available. Eight points were selected as the target sections for analysis in this study because there are interchanges and major intersections around the obtained locations. Traffic conditions are differently affected by the inflow and outflow of these. A number in Figure 1 indicates each section. The details of the sections are summarized in Table 4. As shown in the following figures, the timing of the increase and decrease in traffic volume and travel speed on the ordinary roads and expressways in all the target locations was confirmed to be different. From these results, it was determined that the traffic conditions were other.

Table 4. Details of target sections

Number	Location	Expressway	General road
①	Yoga IC	Metropolitan Expressway Route 3	Tamagawa Ave.
②	Ohashi JCT		
③	Takagi-cho IC		Roppongi Ave.
④	Tanimachi JCT		
⑤	Gotanda IC	Metropolitan Expressway Central Circular Route	Yamate Ave.
⑥	Ohashi JCT		
⑦	Tomigaya IC		
⑧	Hatsudai IC		

4.1 Traffic Conditions on Metropolitan Expressway Route 3 and Ordinary Roads along Route (①–④)

We analyzed the traffic conditions on Tokyo Metropolitan Expressway Route 3 and the ordinary roads along the route (Tamagawa Avenue and Roppongi Avenue). First, traffic conditions on the inbound lane of Tokyo Metropolitan Expressway Route 3 were determined using traffic detector data. Figure 2 shows the traffic conditions on the day of the incident and the day of the comparison. The left side of the figure corresponds to the inbound lane, and the right side corresponds to the outbound lane.

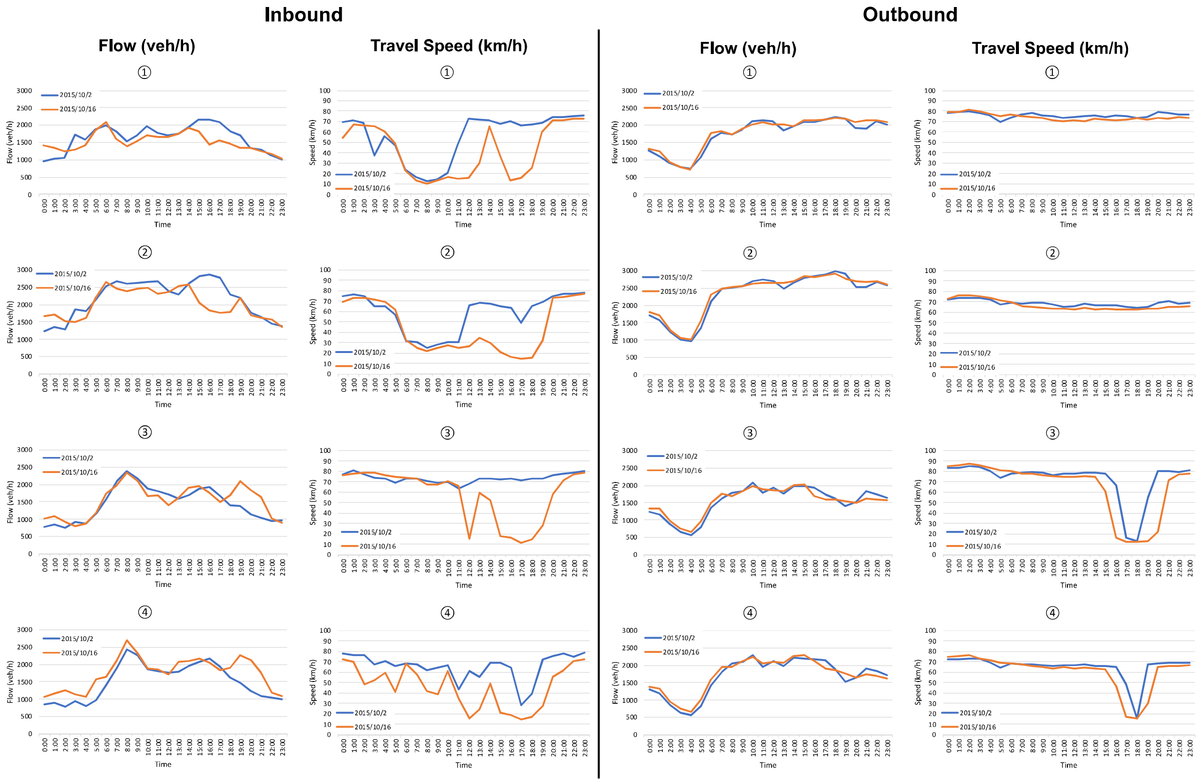

Figure 2. Traffic conditions on Tokyo Metropolitan Expressway Route 3

From Figure 2, the decrease in travel speed owing to the incident is significant in the inbound lane. When focusing on travel speed from 2:00 p.m. to 9:00 p.m., seeds decreased by more than 40% from the comparison day at all locations. The most significant decrease was seen at ③, with a decrease of about 61%. Then, focusing on the traffic volume, it was found that the traffic volume decreased by nearly 20% during the incidents in ① and ②. Several hours after the incident, the traffic volume increased in the section beyond the incident location. Throughout the day, the traffic volume increased by about 6% in ③ and about 17% in ④. However, a decrease in travel speed was observed in the section before the incident location. The speed decreased by about 45% in ③ and 25% in ④. In the outbound lane, there was no significant change in traffic volume. Moreover, there was no location where the change during the incident exceeded 2%. The same change can be seen on the day of comparison, but the time of the decrease in speed is longer, which is considered an effect of the incident. From the analysis results, even in sections far from the incident, the incident affected the traffic flow.

Thus, the incident had a significant impact on the traffic scenario in the inbound lane. In the section beyond that location, the traffic volume increased, and the travel speed decreased, implying that the incident may have an impact not only upstream but also downstream. Downstream, the traffic volume was affected several hours after the incident. This suggests that it was affected by the presence of vehicles that chose the ordinary road in response to the incident and took the expressway after passing there or vehicles that chose a detour route because the sudden event had not been processed and the JCT was not available.

Next, we clarify the traffic conditions on ordinary roads parallel to the expressway on the same target date. Figure 3 shows the traffic conditions on an ordinary road. The left side of the figure depicts the inbound lane, and the right side depicts the outbound lane.

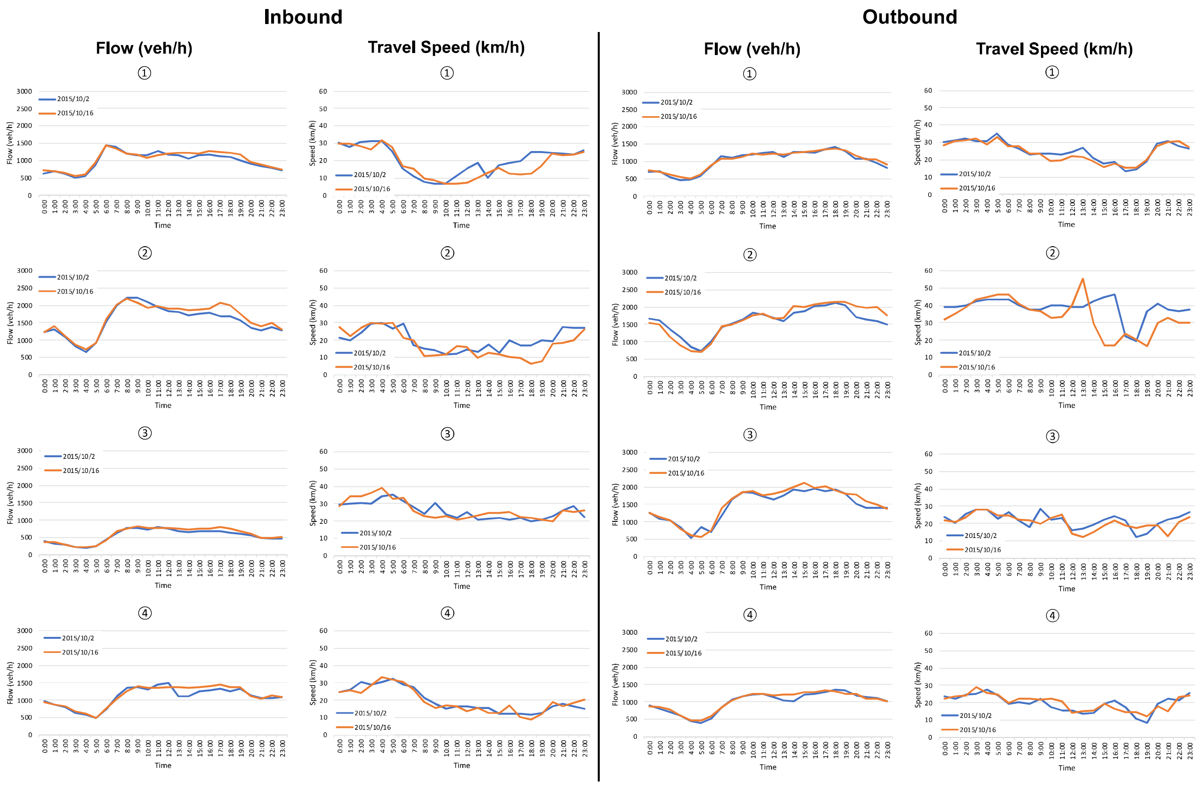

Figure 3. Traffic conditions on Tamagawa Avenue and Roppongi Avenue

From Figure 3, it is observed that the traffic conditions on ordinary roads during incidents are not significantly affected compared to those on expressways. When comparing the locations in the inbound lane during the incident, the most significant change was ② and ③. There was an increase of about 12% in traffic volume. Furthermore, ① and ②, there was a decrease of about 24% and 37%, respectively, in travel speed. A similar comparison was made for the outbound lane, showing that traffic volume did not change by more than 10% at all locations, but travel speed decreased by about 40% at ②. These analyses suggest some vehicles may have changed their route from the expressway to the ordinary road by the incident.

4.2 Traffic Conditions on Central Circular Route and Ordinary Roads along Route (⑤–⑧)

We analyzed the traffic scenario on the Tokyo Metropolitan Expressway Central Circular Route and Yamate Avenue, which is a public road along the route, during the incident. First, the traffic conditions on the Tokyo Metropolitan Expressway Central Circular Route were determined using traffic detectors. Figure 4 shows the traffic conditions on the day of the incident and the day of the comparison. The left side of the figure corresponds to the inner lane, and the right side corresponds to the outer lane.

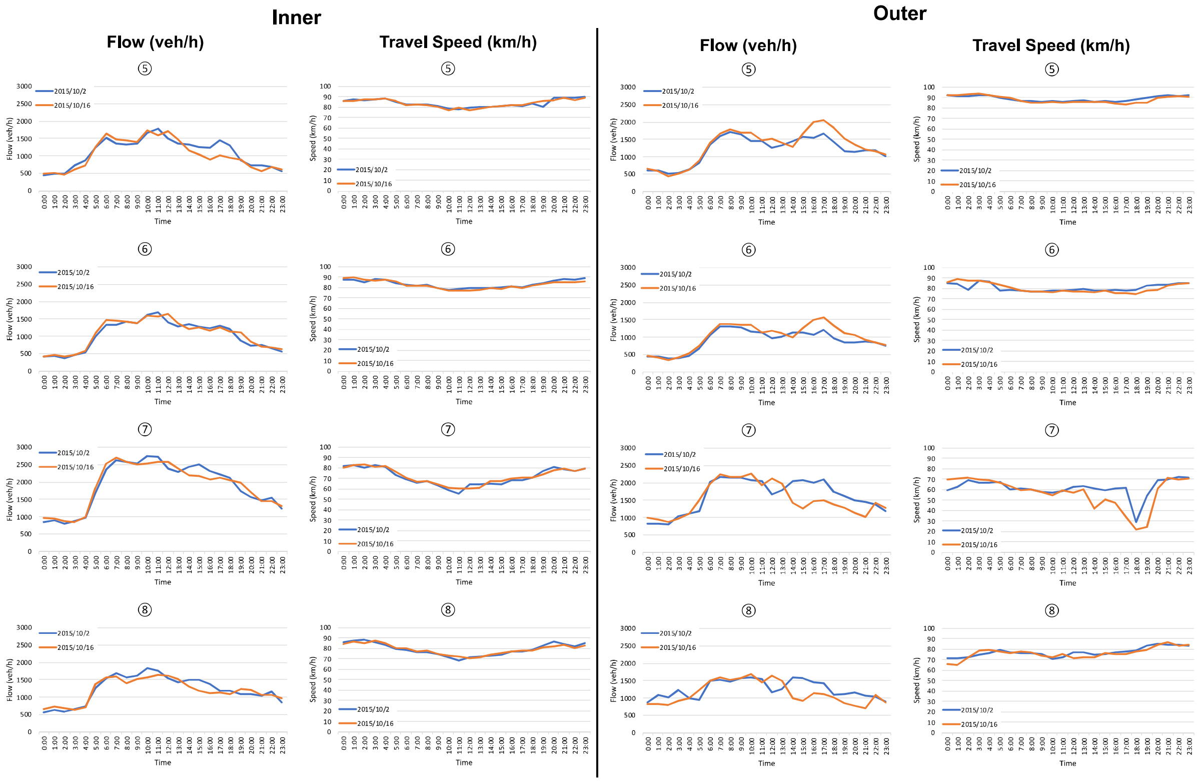

Figure 4. Traffic conditions on Central Circular Route

As shown in Fig. 4, there was no significant change in the traffic volume or travel speed in the inner lane. When focusing on the traffic volume during the incident, a decrease of about 18% was observed at ⑤. However, no change exceeding 10% was observed at the other locations. In terms of travel speed, the changes were less than 10% in all locations. There was an increase in traffic volume upstream from the incident location in the outer lane, with an increase of about 18% at ⑤ and about 22% at ⑥ during the incident.

On the other hand, a decrease in traffic volume was observed downstream, with a decrease of about 28% at ⑦ and ⑧. Travel speed decreased by about 29% at ⑦, but there was no more than 5% change at the other locations, suggesting that travel speed was not affected. From these, it is considered that the traffic flow has not reached the traffic capacity in ⑤ and ⑥. In addition, because the traffic conditions changed between ⑥ and ⑦, the incident's location was considered a bottleneck.

Next, we analyzed the traffic conditions on ordinary roads parallel to the expressway on the same target date. Figure 5 shows the traffic conditions on ordinary roads. The left side of the figure shows the results for the inner lane, and the right side shows the results for the outer lane.

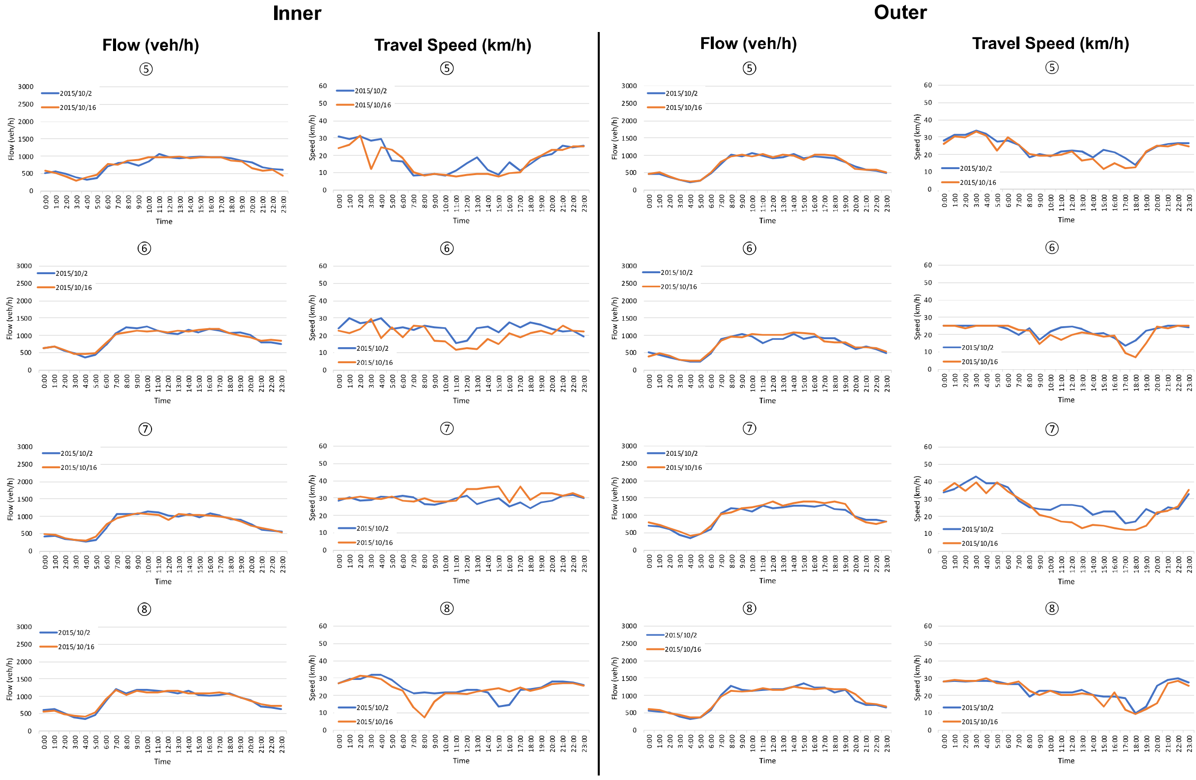

Figure 5. Traffic conditions on Yamate Avenue

From Figure 5, there is no significant impact on traffic volume, as there is no change of more than 10% in either the inner or outer lane. About travel speed, there is a decrease at the closest point upstream from the location of the incident in both directions (Inner: ⑥, Outer: ⑦). During the incident, the traffic volume change was about 22% at ⑥ and 29% at ⑦. Given that there was no significant change in traffic volume, it is considered that the travel speed may have decreased owing to the entry of vehicles that were rerouted to avoid the incident in the section that had initially reached the saturated traffic flow rate.

5. ANALYSIS OF ROUTE CHOICE DURING AN INCIDENT

We determined the route choices made by actual individual vehicles during the incident and whether there was a change in route choices compared to a typical day. For the analysis, probe data for cars driving on the expressway on the incident day and the comparison day were used. We analyzed the routes chosen by vehicles heading to the location of the sudden event by dividing the data into three categories: immediately after the incident, during the incident, and after the resolution of the incident.

5.1 Data Details and Target Section

First, we describe the probe car data. The probe car data used in this study were uploaded to the Internavi floating car data server on October 9 and October 16, 2015. The aggregation of the data was on an hourly basis, describing the route for one hour before and after the vehicle passed through the target section and only recorded if multiple vehicles traveled the same route.

Based on the results shown in section 4, we focused on the inbound lane of the Tokyo Metropolitan Expressway Route 3, where there was a substantial change owing to the incident. The acquired data included the trajectory of vehicles traveling near the Ikejiri Interchange, which is the closest interchange to the incident's location. The data acquisition location is point ②, as shown in Figure 1. From Table 3, the time to be compared are 14:00 (immediately after the incident), 17:00 and 19:00 (during the incident), and 22:00 (after the incident is resolved).

5.2 Probe Car Data Analysis

Figure 6 shows the change in the selected route between the day of the incident occurrence and the day of the comparison, as obtained from the probe car data. The right side shows results for the date of the incident, and the left side shows results for the date of comparison. Because of the obtained data, some of the lines are broken; however, because the vehicles are considered traveling on the expressway, there is no increase or decrease in the number of vehicles in the broken sections.

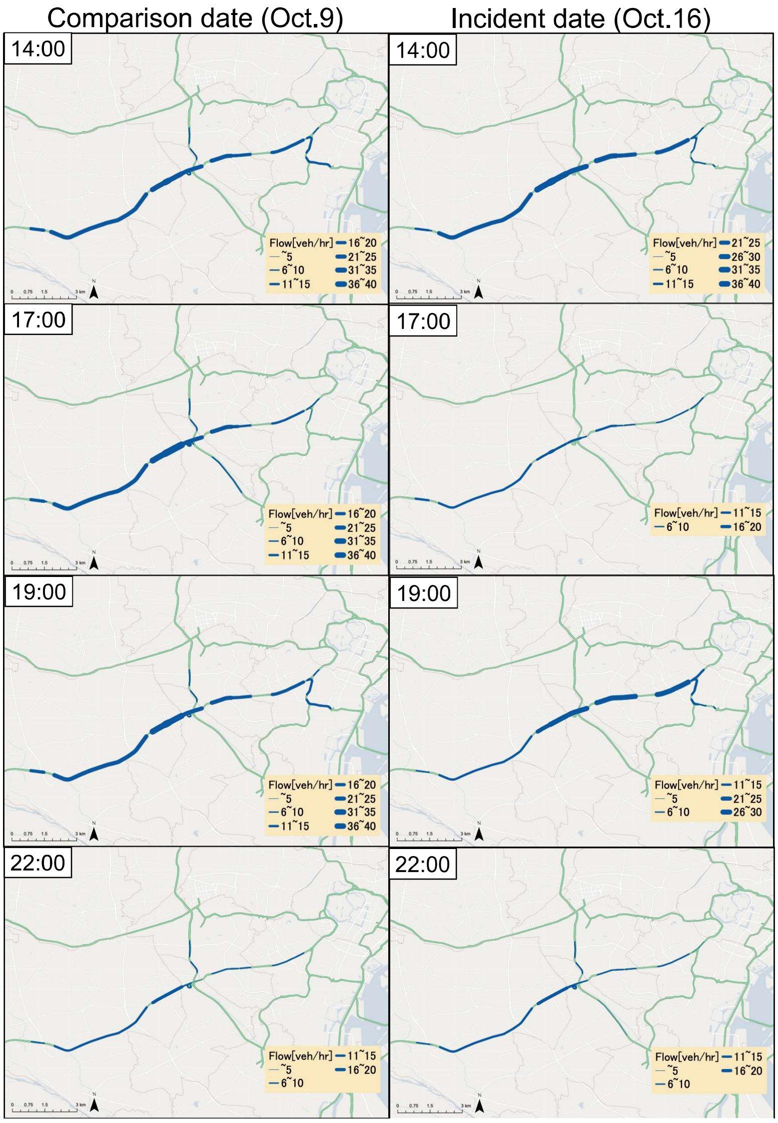

Figure 6. Change in chosen route obtained from probe data

From Figure 6, we can see that the number of vehicles traveling on the target section decreased, and the use of the Ohashi JCT ceased owing to the incident. In other words, a certain number of vehicles chose to avoid traveling in the incident section. This decrease reflects the influence of vehicles that got off the expressway or did not use the expressway in advance. From the changes in the selected routes at 19:00, it can be observed that the number of vehicles passing through Tanimachi JCT increased. This change suggests that vehicles that could not pass through the Ohashi JCT owing to the road closure traveled to the Tanimachi JCT. The change was huge at 19:00; this is likely because a certain amount of time had elapsed since the incident, and several vehicle users may have thought that the problem had been resolved when they reached Ohashi JCT.

As mentioned above, more vehicles are expected to avoid using the expressway or get off at the nearest IC immediately after the incident. After a particular time elapsed since the incident, more vehicles use the expressway, assuming that the incident has been resolved; however, when they reach the location of the incident, they cannot pass through and choose to detour.

In this study, owing to data limitations, we focused on one incident and one target section. Therefore, the changes in route choice may differ depending on the time of day and location of the incident. However, based on the probe car data, we can suggest that the time elapsed since the incident may affect the change in route choice.

6. COMPARISON OF TRAVEL TIMES DURING AN INCIDENT

On Japan's major roads, traffic detectors are installed about every 500 meters, so it is possible to obtain the traffic conditions of the road network simultaneously and in an excellent range. The traffic detector data were used to analyze the route choice that takes the minimum travel time to reach the destination when an incident occurs, and there is a closed section of the road to the destination. Based on the probe data analysis results, it can be assumed that more vehicles avoid the expressway immediately after the incident, and after a few hours, more vehicles choose a detour route that does not pass through the closed section. In this analysis, we discuss whether this actual choice results in the minimum travel time.

6.1 Route Settings

We set up the route to be analyzed. For this analysis, we selected target routes from Yoga to Hatsudai or Gotanda, where the impact of the incident on traffic volume and travel speed was significant. Figure 7 shows the key locations and available interchanges in the target area. Blue boxes indicate interchanges at the beginning and end of the set route. On the Metropolitan Expressway, some Interchanges can be available, and some cannot be available depending on the direction. The red circles in the figure show the interchanges that can be used in the set route. The red route shows the detour route that would be selected if the driver avoided the incident location and continued the expressway.

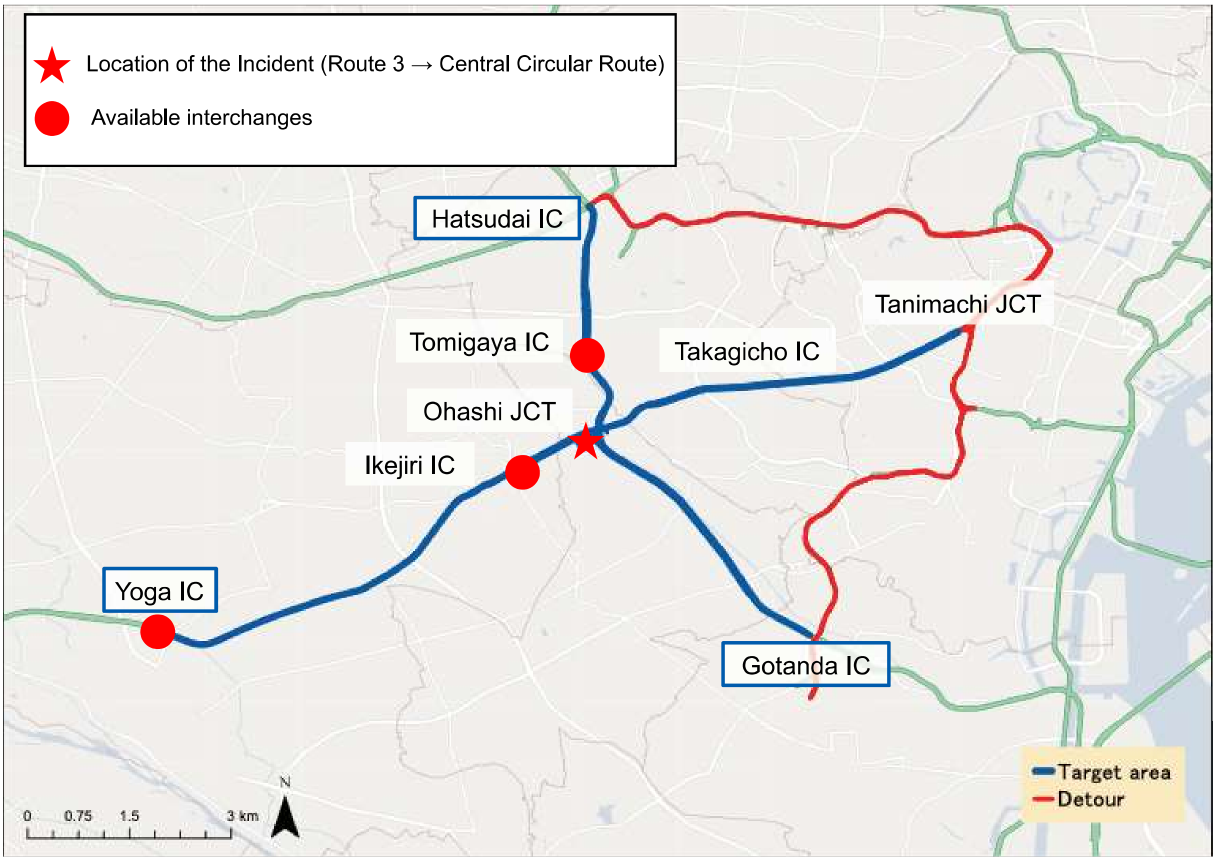

Figure 7. Key locations and available interchanges

From this figure, it is possible to combine expressways and ordinary roads in the direction of Hatsudai. If a detour route on the expressway is chosen, the vehicle should pass through the Tanimachi JCT (upper right of the figure) and choose the route indicated by the thin blue line. Table 5 summarizes the possible routes for each direction.

Table 5. Target routes

Yoga - Hatsudai	Expressway (EW) only (via Tanimachi JCT)
	General road (GR) only
	EW → GR
	GR → EW
	EW → GR → EW
Yoga - Gotanda	Expressway (EW) only (via Tanimachi JCT)
	General road (GR) only
	EW → GR

6.2 Result

The traffic detector data observed at the time of the incident were used to calculate the travel time from the origin to the destination. Because the data on ordinary roads is the average travel speed every 15 min, it is assumed that the effect of traffic signals in the target section is considered by using this data. In addition, due to data aggregation, there is only one-speed data per hour. Therefore, this study compares only the average speed. As in the probe data analysis, the targets were 14:00 (immediately after the incident), 17:00 to 19:00 (during the incident), and 22:00 (after the resolution). A comparison of travel time in each time zone is summarized in Table 6.

Table 6. Comparison of travel times

Yoga - Hatsudai [min]	14:00	17:00	19:00	22:00
Expressway (EW) only	29.4	95.8	56.2	23.4
General road (GR) only	24.2	40.4	33.8	17.3
EW → GR	18.7	48.7	30.5	11.8
GR → EW	19.9	33.4	27.6	14.7
EW → GR → EW	14.5	41.7	24.3	9.2
Yoga - Gotanda [min]	**14:00**	**17:00**	**19:00**	**22:00**
Expressway (EW) only	24.1	66.1	35.7	14.8
General road (GR) only	27.3	33.8	27.8	19.8
EW → GR	21.9	42.1	24.4	14.3

Focusing on Hatsudai, we can see the choice of getting off the expressway once and getting on again at 14:00, 19:00, and 22:00 results in the shortest travel time. While the choice of getting on the expressway after avoiding the incident at 17:00 leads to the shortest travel time. It can also be seen that the most prolonged time results when the detour route is chosen for all periods. This result may be because the road is congested due to originally existing excessive demand, even in the section passing through the location of the incident; thus, it may take longer than using a part of the ordinary road. Figure 2 and Figure 6 show that some vehicles use the expressway detour route at 19:00. This result suggests that some vehicles may not choose the route with the shortest travel time.

Focusing on Gotanda, we can see that the choice to use the ordinary road from the expressway at 14:00, 19:00, and 22:00 provides the route with the shortest travel time while using the ordinary road only at 17:00 provides the route with the shortest travel time. In this case, we can see that the shortest route is not the route where users stay on the expressway detour route.

This analysis shows that the shortest travel time route differed depending on the time of the day, even for the same incident. This is considered due to the influence of changes in traffic conditions on the roads in the target area at different times of the day. Depending on the route selected, the drive may take more than twice as long. Based on these considerations, to reduce incident congestion, it is essential to monitor the traffic conditions in real-time and provide the shortest route information according to the destination. In some cases, it will also be important to guide the route.

7. CONCLUSION

This study focused on an incident involving the closure of urban expressways and used traffic detector data and probe data to understand traffic conditions on expressways and ordinary roads. The analysis of the traffic detectors showed that the expressway's traffic flow was affected even far from the incident. Furthermore, there was no significant impact on the ordinary road except around the location of the incident.

The results of the probe data analysis showed that the number of vehicles passing through the target section decreased immediately after the incident and that the number of vehicles choosing the detour route increased several hours after the incident.

Next, the traffic detector data were used to calculate the route that resulted in the shortest travel time among the routes that avoided the location of the incident. The comparison of travel times showed that choosing a detour route on an expressway does not result in the shortest travel time. It showed that the route with the shortest travel time differed depending on the time of day. A certain number of vehicles were thought to have chosen the detour route, and it was considered that the impact of incident congestion could be reduced from the current situation by providing information on routes according to destinations and times of the day.

However, this study focused on only one incident, and the changes in traffic conditions may differ depending on the location and time of the incident. In the future, it will be necessary to analyze incidents that occurred at other locations and times and sort the parts that are common and different from the results of this study. These results will help us determine ordinary changes in traffic conditions caused by incidents on urban expressways. In addition, due to the data obtained in this study, it was not possible to compare standard deviations in the analysis of travel speed. When conducting a similar analysis, it is necessary to compare standard deviations and clarify whether there are significant differences in the time required for each route.

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