This paper explores the variation properties of trip generation, trip attraction, intrazonal trips, and travel time under transport network disruption in Tenno district in July 2018 due to landslides. The empirical results obtained by using multiple passive transport data show that (1) traffic volume per hour on the National Route 31 went down to around 300 vehicles at maximum due to a large number of short-distance trips traveling between the affected area and a disaster response base, (2) recovery of the train line did not really reduce the travel time on the National Route 31, and the average travel time had been 1.5 times longer compared to that before the disaster for more than two months after the disaster, and (3) travel time variability, which could not be explained by day of week and time of day, had been dominant for the first one month after the disaster.

Key Words: disrupted transport network, trip generation and attraction, intrazonal trips, travel time

1. INTRODUCTION

A landslide disaster associated with torrential rainfall causes a significant damage to a transport network. However, unlike other natural disasters, such as an earthquake, many residents are not directly affected by this type of disaster. Thus, even in the aftermath of the disaster, a transport demand, which is almost the same level as that in ordinary time, may be generated. In addition to the transport demands for meeting the daily needs of residents, it is highly possible that a supply and demand balance is lost during the transport network disruption caused by landslide disasters. Specifically, transport demands related to rescuing people or removing mud occur. Thus, it is crucial to properly manage both the demand and supply of transportation.

The 2018 Japan Floods (Heavy rain in July Heisei 30) was a typical case of disaster that posed challenges to transport management described previously. In particular, the National Route 31 connecting Hiroshima City and Kure City experienced heavy traffic congestions for a long period of time, because the highway (Hiroshima-Kure Expressway) and train line (JR (Japan Railway) Kure line), which run parallel with the National Route 31, were damaged and disconnected by the disaster, and took more than two months to reopen. Several actions were taken to alleviate the traffic congestions in the affected area, including introduction of emergency BRT (Bus Rapid Transit), operation of temporary maritime transport, emergency intersection improvements, extention and addition of right-turn/left-turn lanes, and provision of public transportation information during the disaster, all of which achieved some results1; however, these actions did not work well enough to alleviate the traf-
fic congestions drastically as will be described later. Tenno and Koyaura, the districts enormously affected by the disaster, are located along National Route 31. So, from a viewpoint of ensuring a smooth passage of vehicles related to the disaster, which should be highly prioritized, we consider that more measures should have been in place to alleviate the traffic congestion. To this end, we consider that it is necessary to understand points, such as what type of transport demand increase contributed to causing traffic congestions, or how the traffic flows changed qualitatively as a result of the disaster, and then implement countermeasures against the traffic congestion by adapting to such points.

To gain more understanding on transport demands and traffic states, it is desirable to utilize passive data, including GPS trajectory (probe) data, mobile phone’s location data, and loop detector data, as much as possible, from a perspective of minimizing workload of the people affected by the disaster, because such workload will occur when a survey is conducted. In existing studies 2), 3), 4), 5), 6), 7), 8), transitional characteristics of population distribution in case of abnormal conditions have been analyzed by using a sojourn population data based on mobile phones’ GPS data. The sojourn population data gained from mobile phones’ GPS data enable us to identify the place where unusual population density is observed. Also, by combining statistical analysis methods with the sojourn population data, population distribution and characteristics of activities performed during the recovery process have been extracted 5), 6). In addition, there are studies 9), 10) in which traffic states on a road or travel time of automobiles have been analyzed by using probe data. Especially, Kawasaki et al. 10) have paid attention to a recovery process of traffic states, and revealed a traffic issue that occurred during the recovery period after the Kumamoto earthquakes in a quantitative manner by analyzing the situation in which travel time of the same origin and destination with different routes gradually balanced, traffic conditions on a transport network, and changes in trip frequency by destination.

Though results of the studies shown above have been accumulated, the number of studies using multiple types of passive data is limited. To promote development of a data platform that will play an important role in responding to disasters, we consider it is important to build up cases of empirical analyses to indicate what can be grasped using multiple types of data and in what way such analysis can contribute to transport management during disaster.

By taking the 2018 Japan Floods as a case, this study shows the facts that it is possible to understand the factors that impact the variation properties of transport demands after the disaster took place and increase of travel time on a certain level by using multiple types of passive data, and that such information can provide several useful suggestions for governmental policies. Based on the above, we finally verify the importance of developing a platform in advance so that the multiple types of passive data can be utilized on a real time basis as much as possible once a disaster occurs.

In this paper, we first briefly describe the damage conditions of traffic networks in the affected areas at the time of the 2018 Japan Floods. Then, we indicate the fact that a unique traffic state, which is very different from that of ordinary times, occurs when the transport network is disrupted by a disaster, by utilizing ETC 2.0 data and loop detector data owned by the Hiroshima prefectural police. Subsequently, we consider day-to-day variation and within-day variation in trip generation, trip attraction, and travel time in Tenno district in Kure City, which was heavily affected by the disaster. Specifically, we explain that an increase of trips after the disaster is mainly triggered by transport demands from those who live outside the district, including volunteers or disaster response vehicles, based on the aggregate analyses using Mobile Spatial Statistics data and ETC 2.0 data. Afterwards, we specify points of time during disaster, which significantly change statistical characteristics of travel time (i.e., mean, variance), by utilizing a change-point detection, which is one of the unsupervised machine learning methods. For each piece of data set split by change point, we analyze how far variation of traffic volume has contributed to variation of travel time. Our analysis indicate a high possibility that the increase in intrazonal trips, which occurred as a result of the disaster, may have affected the increase in travel time. Finally, based on the above analysis results, suggestions and challenges are summarized to promote a transport management at a time of disaster.
2. CONDITION OF TRANSPORT NETWORK DISRUPTION AFTER THE 2018 JAPAN FLOODS

(1) Transport network disruption as a result of the disaster

The 2018 Japan Floods caused tremendous damage in many areas in western Japan, such as landslide disasters and floods due to overflowing rivers. Particularly, the landslide disasters, which occurred in coastal areas such as Saka-cho and Tenno district connecting Hiroshima city and the central area of Kure City, not only caused personal sufferings and damage to houses but also inflicted enormous damage to the transport network connecting Hiroshima, Kure, and Higashihiroshima cities (On Fig.1, “Naka Ward” shows the central area in Hiroshima, “Chuo” shows the central area in Kure, and “Saijo” shows the central area in Higashihiroshima.”) Especially, some areas in Kure were temporarily isolated after the disaster, because the highway network and railway network connecting the city area and neighboring cities and towns were disrupted in many places simultaneously, including the Hiroshima-Kure Expressway and JR Kure Line, along with the Kure’s geographic condition of being surrounded by the Seto Inland Sea and mountains. After the disaster occurred, efforts to recover the disrupted transport network were carried out step by step, but the transport network in the affected area was disrupted for more than two months until JR Kure Line (running between Kure Station and Hiroshima Station) was able to restart operation on September 9 in 2018, and Hiroshima-Kure Road reopened on September 27, 2018. According to the National Census in 2015, about 16,000 workers/students commute between Hiroshima and Kure cities. Therefore, we can confirm that the disrupted transport network affected a huge number of trip demands for a long time.

(2) Scope of analysis

Given the conditions of the disrupted transport network described above, this study conducts an analysis focusing on the double lane section on the National Route 31 (Fig.2). The subject of the analysis is the road section (of about nine kilometers) on which we have observed no physical damage disrupting road traffic since the reopening of the National Route 31 on July 11. Therefore, if a road traffic condition had changed before and after the disaster, we can consider that the reason for such change would be attributed to usage of the road. In particular, the road section included Koyaura district in Saka-cho (located near loop 3 in Fig.2. See Photo 1 on the damage condition in the area) and Tenno district in Kure city (located near loop 7 in Fig.2. See Photo 2 on the damage condition in the area.), which had special demands related to the disaster, such as traffic of volunteers and removal of mud, which generated transport demands different from those in ordinary time. The subsequent analysis was focused on the section in the outbound direction (moving towards Kure from Hiroshima city), which experienced the...
heaviest traffic congestion among the sections in scope. The 9-kilometer road section subject to the analysis has 23 signalized intersections. A transport capacity at a signalized intersection is theoretically defined by a saturation flow rate and a split, and if a traffic demand exceeds such transport capacity at an intersection, its signal cannot handle all the incoming vehicles, resulting in a traffic congestion (11). Also, a delay caused by a traffic congestion is determined by a relationship between the accumulated excessive demand (length of a queue) and the bottleneck capacity. Therefore, in theory, once each signalized intersection’s saturation flow rate, split, and excessive demand are identified, we can consider that it is possible to figure out the delay because of the traffic congestion. However, considering the following three facts: (1) the saturation flow rate fluctuates on a very broad scale (12), (2) the queue due to the traffic congestion extended to several signalized intersections in the case of this disaster, and (3) the split changed on a daily basis as a temporary measure to deal with the congestion, the method to understand the whole picture of the traffic congestion, by observing delays at each signalized intersection and piling up the observation data, causes many difficulties in the case of disaster response conditions, because a large number of parameters need to be observed and readjusted. In fact, as will be described in the next section, the prolonged situation in the aftermath of the disaster made it difficult to accurately capture temporal/spatial patterns of traffic bottleneck occurrence. Therefore, rather than focusing on a mechanism causing traffic congestions, this study is more focused on variation in travel time (which occurs as a result of traffic congestions), and variation in trip generation, trip attraction, and intrazonal trips, which are contributing factors to such travel time variation.

3. DATA USED FOR ANALYSIS

In this study, we conduct an analysis using three types of data: ETC 2.0 probe data, loop detector data, and Mobile Spatial Statistics (data gained from mobile phone base stations). An overview of each type of data is described as follows:

(1) ETC2.0 probe data

ETC 2.0 probe data is a GPS movement locus data collected from a vehicle mounting an in-vehicle ETC 2.0 device. When such vehicle passes the spot where a device for collecting the vehicle’s route information is placed, the vehicles’ movement locus data are collected. ETC 2.0 probe data is not fit for understanding the traffic volume or the route sharing ratio because: (1) a number of vehicles mounting in-vehicle ETC 2.0 device is limited (about 3.7 million vehicles as of March, 2019), (2) only the information on the history of the vehicle’s last 80 kilometer driving is collected, and (3) the device for collecting ETC probe data is not placed on narrow city roads. But the benefits of ETC 2.0 probe data are: (1) a traffic bottleneck point can be determined with GPS movement locus data, and (2) it can provide information on accurate travel time for arbitrary sections. This study primarily uses ETC 2.0 probe data to gain information on travel time for the section indicated on Fig.2. The applicable period of data gathering is about four months from June 1 until September 30 in 2018.
(2) Loop detector data managed by Hiroshima prefectoral police

On the road section in scope, 13 loop detectors managed by the Hiroshima prefectoral police, are in place in the outbound direction from Hiroshima, enabling us to understand the traffic volume and the time occupancy (or traffic density). However, as the loop detector data is the fixed-point observation data, it is not possible to understand the complete details of the traffic states at the road section in scope spatially. We were given the permission to utilize such loop detector data as part efforts to respond to the disaster. Therefore, the data gathered only during the two months from July 1 to August 31 in 2018 were available for the study.

(3) Mobile spatial statistics

Mobile Spatial Statistics data is a population statistic data based on information from mobile phone base stations. This data is sold by DOCOMO Insight Marketing Inc. The Mobile Spatial Statistics data has the following two categories: (1) sojourn population data at area by time of day (i.e., population distribution statistics) and (2) OD (Origin-Destination) data (i.e., population flow statistics). This study used the category (2) data. The data used for the analysis is the OD data generated under the rule that if a move of a mobile phone user is detected by two base stations and a distance between such two stations exceeds one kilometer, it would be considered a trip. Also, as it is possible to identify such user’s place of residence with his/her registered address, it is beneficial to understand: (1) how many of the residents stopped their usual trips because of the disaster, and (2) when and how much trip demands related to the disaster occurred, including volunteers’ trips and mud removal, to a certain degree. This study used the OD data gathered between 30 zones indicated in Fig.1 from June 1 to September 30, 2018.

4. TRAFFIC STATES UNDER TRANSPORT NETWORK DISRUPTION

In this section, we consider the traffic states in the aftermath of transport network disruption due to the disaster by using ETC 2.0 probe data and loop detector data.

Fig.3 indicates the time-space diagram among the sections subject to the analysis from July 16 through July 20, 2018 (which is developed based on ETC 2.0 probe data). This figure shows a high possibility that Koyaura in Saka (around loop 3), and Tenno in Kure (around loop 7), both of which were heavily affected by the disaster, became the major traffic bottleneck spots. On the contrary, we have confirmed that temporal/spatial patterns of the traffic congestion were not stable, as shown in the time slot of 15:00 to 17:00 (3 p.m. to 5 p.m.) on July 20, when there was a decrease of the trip speed in the whole section subject to the analysis, because the traffic congestion stretched from the upstream side of the traffic.

Figs. 4, 5, 6, 7, 8, 9, and 10 indicate the relations between the per-hour trip and the time occupancy (percent) identified at the loop detectors placed on spots of loop 1 through loop 7 (See Fig.2). Based on these figures, we have confirmed that the number of observation points increased within the traffic congestion area after the disaster (since July 12), and that passing traffic volume per hour decreased to about 300 vehicles at maximum (except for loop 7). Considering the fact that the base saturation flow rate at signalized intersections is 2,000 pcu per 1 hour green time\(^{15}\), we have concluded that such traffic volume per hour value can be incredibly low.

No clear relationship has been confirmed between the per-hour traffic volume and the time occupancy at loop7. The following two factors are considered as the reasons for this result. First, we point out the possibility that it has been directly affected by the increase of pedestrians who worked on volunteer activities as well as the increase of the vehicles turning left and right for removing mud, because there are two intersections: (1) the intersection with the pedestrian control signal at the north end of Oyabashi Bridge, which is located about 300 meters from the loop detector installation spot in the downstream direction, and (2) the intersection at the eastern end of Oyabashi Bridge leading to Tenno district, a heavily affected area (located on the mountain side. When a driver moves towards Kure city on the National Route 31 and turns left, he/she can arrive at Tenno). In addition, the signal control applied in the section, including that for the pedestrian control signals, has been manipulated to prioritize the passage of the main road at maximum during the disaster response period. Also, there is the other possibility that the traffic control performed by police at the intersection at the eastern end of Oyabashi Bridge had an impact, too. Secondly, we point out that the short-distance transport demands between Tenno, the heavily affected area and the Kure Portpia Park occurred so often, because the park was used for many purposes, such as a parking lot for the volunteers, a temporary bathing spot for the residents affected by the disaster, and a place for temporary piling up the mud. When a driver moves towards Kure city on the National Route 31 and turns right, he/she can arrive at Kure Portpia Park located about 100 meters in the upstream direction from the observation point. In fact, unlike the data from other loop detectors, we have confirmed that the loop 7 data maintained the high per-hour passing traffic volume even under the condition that the time occu-
pancy exceeded 20 percent.

The findings shown above suggest the following two points: (1) the passing traffic volume decreased to about 300 vehicles per hour during the disaster response period, (2) as a possible reason for such traffic volume decrease, the increase of short-distance transport demands for coming and going between the areas heavily affected by the disaster including Tenno district, and Kure Portopia Park, which was used as a disaster response base, may have led to the decline of the transport capacity. However, the loop detector data apparently cannot provide information on each trip’s distance. Thus, in the next section, by utilizing Mobile Spatial Statistics data, we analyze and examine day-to-day variation and within-day variation of trip generation, trip attraction, intrazonal trips in Tennno district at the time of disaster.

5. VARIATION PROPERTIES OF TRIP GENERATION, TRIP ATTRACTION, AND INTRAZONAL TRIPS

This section considers variation properties of trip generation, trip attraction, and intrazonal trips in Tennno district (Tenno/Yoshiura zone shown on Fig.1). Hereafter, a variation in traffic volume on a daily basis is called day-to-day variation, and a vari-

![Fig.4 Traffic volume per hour (vehicles)-Time occupancy (%) [loop1].](image1)

![Fig.5 Traffic volume per hour (vehicles)-Time occupancy (%) [loop2].](image2)

![Fig.6 Traffic volume per hour (vehicles)-Time occupancy (%) [loop3].](image3)
Fig. 7 Traffic volume per hour (vehicles)-Time occupancy (%) [loop4].

Fig. 8 Traffic volume per hour (vehicles)-Time occupancy (%) [loop5].

Fig. 9 Traffic volume per hour (vehicles)-Time occupancy (%) [loop6].

Fig. 10 Traffic volume per hour (vehicles)-Time occupancy (%) [loop7].
rati in traffic volume on a time slot basis is called within-day variation. As already stated, the Mobile Spatial Statistics data is able to specify a mobile phone user’s place of residence by using the address which he/she has registered. In the following analysis, we describe observations by dividing the mobile phone users into two categories: the residents (who live within Tenno/Yoshiura zone), and the non-residents (who live outside Tenno/Yoshiura zone). But regarding the transport demands by the non-residents, it is still desirable to distinguish the transport demands related to lives of those who live near Tenno/Yoshiura, from the transport demands related to disaster recovery efforts, including trip of volunteers who come from far. To differentiate these two transport demands by the non-residents, the non-residents are then divided into two groups: (1) residents of Hiroshima, Kure, and Higashihiroshima (called the residents of three cities), and (2) the other non-residents, as required. In addition, we should keep in mind that Mobile Spatial Statistics is just to capture movements of people, which are not strictly aligned with the number of vehicles.

**Fig.11** Day-to-day variation in trip generation, trip attraction, and intra-zonal trips.

(1) **Day-to-day variation of trip generation, trip attraction, and intra-zonal trips**

Fig.11 shows day-to-day variation in trip generation, trip attraction, and intra-zonal trips in the Tenno/Yoshiura zone. At first, when the trip generation, trip attraction, and intra-zonal trips by the residents are monitored, we have confirmed that any of these three types of trips does not increase very significantly compared to those before the disaster. Rather than that, we confirmed that the volume of trip generation, trip attraction, and intra-zonal trips slightly decreased in the aftermath of the disaster, but gradually were prone to returning to the original level in two months after the disaster. On the contrary, when the trip generation, trip attraction, and intra-zonal trips by the non-residents are checked, we have confirmed the volume of the non-residents’ trip generation and trip attraction to Tenno/Yoshiura zone decreased after the Obon summer holiday period. On the other hand, by examining
the volume of the intrazonal trips, we have confirmed that the number of such intrazonal trips decreased in the aftermath of the disaster, but rapidly increased after the Obon summer holiday period. The cause of this trend is considered to be an increase of traffic coming and going between the Kure Portopia Park and the affected area as stated earlier, and reopening of schools on August 20. For reference, a steep drop of traffic volume on July 29 seen on the figure is because people refrained from going out voluntarily due to the approaching typhoon.

(2) Within-day variation of trip generation, trip attraction, and intrazonal trips

In this section, we describe the within-day variation of trip generation, trip attraction, and intrazonal trips on weekdays by dividing the applicable period into four phases as follows:
1) Before the disaster [Weekdays from June 1 through July 5]
2) From the disaster to the beginning of Obon summer holiday period [Weekdays from July 12 through August 10]
3) From the end of Obon summer holiday period to restoration of JR Kure Line [Weekdays from August 17 through September 8]
4) From restoration of JR Kure Line to reopening of Hiroshima-Kure Road [Weekdays from September 10 through September 26]

Fig.12 through Fig.14 show within-day variation of trip generation, trip attraction and intrazonal trips. In terms of the box whisker plots, the line inside the box shows the median; the range from the top to the bottom end of the box shows the interquartile range, and the whisker lines drawn from the both ends of the box indicate the data observation range. The upper/lower limit of the whisker lines are no greater than 1.5 times the interquartile range. Black dots are the observation point data which exceeded 1.5 times the interquartile range.

a) Trip generation

By observing the within-day variation of trip generation (by the residents) at first, we have confirmed the trend that trip generation from 7 to 8 a.m. reduced significantly after the disaster, and then it gradually came back to that on the original level before the disaster. On the other hand, we have checked the trip generation during that time frame increased right after the disaster, but it decreased slowly afterwards. Based on the above, we have presumed that there were certain number of the residents who left their

Fig.12 Temporal variation in trip generation.
home earlier than usual to avoid being involved in the traffic congestions. Besides, except for the time slot from 5 to 9 a.m., no significant change has been observed for the residents’ trip generation and time slot before and after the disaster.

Then, by confirming the within-day variation of trip generation by the non-residents, we have found that there was the increase of trip demands, which was about 700 people per hour at maximum, reaching a peak at 5 p.m. Also, as the other prominent feature, we have found that the variation of trip generation was extremely large during the period from right after the disaster on July 12 through August 10. There is a possibility that such fluctuating demands may have hindered a learning process of those who sought transport and tried to avoid traffic congestions, resulting in the cause of preventing effective road usage (through those people’s spontaneous adjustment of departure time).

By looking at the overall trip generations including those by both the residents and the non-residents, we have confirmed that the traffic volume reduced from 7 a.m. to 8 a.m., the period when the volume reaches the peak in ordinary times, but found the increase of trips from 5 a.m. to 6 a.m. and around 5 p.m.

b) Trip attraction

By observing the within-day variation of trip attraction by the residents, we have found their trips increased from 5 a.m. to 6 a.m. while the trips decreased from 9 p.m. As we have already described as the findings on the trip generation, we have confirmed the trip attraction and its generation period had a certain level of changes in the aftermath of the disaster, but they gradually went back to the original level before the disaster as a general trend.

By looking at the within-day variation of trip attraction by the non-residents, we have confirmed in particular that their trip attractions increased significantly from 4 a.m. to 11 a.m. in the aftermath of the disaster. We find it highly possible that such increase was because of the demands related to the disaster response, including movement of volunteers. Also, during the period from July 12, the day right after the disaster to August 10, we have confirmed that the traffic volume varied day by day drastically even on the same time of day (the quartile deviation is about 150 (people) at maximum).

Overall, we have observed that trip attraction apparently increased from 5 a.m. to 10 a.m. in the morning after the disaster, and many of such trip attraction
increases were driven by movement of the non-residents.

c) Intrazonal trips

By checking the within-day variation of intrazonal trips by the residents, we have confirmed that the intrazonal trips decreased in all time slots of day in the aftermath of the disaster. On the other hand, as time passed from the disaster, we have found that the intrazonal trips increased especially during the period from 7 a.m. to 5 p.m., which exceeded those in the ordinary times.

In terms of the intrazonal trips by the non-residents, we have observed that the non-residents’ intrazonal trips reduced in the aftermath of the disaster from July 12 to August 10, but increased by about 200 people per hour afterwards. However, the volume of the non-residents’ intrazonal trips was prone to decreasing after September 10.

As a whole, we have confirmed that the volume of the intrazonal trips reduced in the aftermath of the disaster, but it increased more than that in ordinary times during the time slot from 7 a.m. to 5 p.m. after the Obon summer holiday period. As already stated earlier, a potential reason for this phenomenon may be the fact that the Kure Portpia Park was used as a disaster response base. Also, given the facts that a travel within 1 kilometer is not counted as a intrazonal trip, and that the distance to the Kure Portpia Park from some areas in Tenno district is less than 1 kilometer, there is a possibility that more intrazonal trips than that shown in Fig.14 may have been generated in reality.

Major insights gained from the analysis shown the above are as follows: (1) trip generation/trip attraction volumes by the non-residents increased much more significantly than those by the residents (the increase of demands equivalent to about 2,500 people per day both for trip generation and trip attraction), (2) large variations were especially observed for the transport demands by the non-residents from 5 a.m. to 9 a.m. (Quartile deviation was about 150 people) at maximum), and (3) demands of intrazonal trips (probably centered in trips between the Kure Portpia Park and Tenno district, which was heavily affected by the disaster) continued to increase for two months after the disaster. Apparently, variations of these demands influence occurrence of traffic congestions and increase of travel time. In the next section, variations of travel time are confirmed first, and then we analyze and consider relations between travel time and trip generation/trip attraction/intrazonal trips.
6. VARIATION PROPERTIES OF TRAVEL TIME

Day-to-day variation and within-day variation of travel time, which we have calculated from ETC 2.0 probe data, are considered below at first. Then, by utilizing the change-point detection method, we capture the timing when the travel time changed remarkably (i.e., change-point) and consider what sort of relationship is observed between trip generation/trip attraction/intrazonal trips and travel time for each period separated by the change points.

(1) Day-to-day variation and within-day variation in travel time

Fig.15 shows the day-to-day variation of the average travel time. With this figure, we have found that the average travel time per day of the section in scope was around 12 through 15 minutes before the disaster, but it changed to 15 through 30 minutes after the disaster, which has indicated the fact that there was a remarkably large increase of the mean value and its variance after the disaster. Travel time on weekends was relatively shorter than that on weekdays in both of the periods before and after the disaster.

Fig.16 shows the within-day variation of travel time on weekdays. The figure has revealed the fact that the travel time between 7 a.m. and 8 a.m. was the longest of the day before the disaster, which was about 22 minutes on average with quartile deviation of about 5 minutes. Besides, the figure also has shown the trend that both the mean and the quartile deviation values increased significantly throughout the observation period after the disaster, but its travel time and variance differed depending on the number of days elapsed since the disaster. Specifically, during the period in the aftermath of the disaster from July 12 to August 10, the following points have been confirmed: (1) a trend that the travel time got longer even between 4 a.m. and 5 a.m. (compared to that in the other period), (2) another trend that the travel time got longer in all hourly time slots between 7 a.m. and 6 p.m., and (3) large variation of travel time especially between 7 a.m. and 8 a.m. and between 3 p.m. and 4 p.m. (i.e. quartile deviation exceeded 10 minutes.) Regarding the period from August 17 to September 8, the following observations have been confirmed: (1) travel time was longer in periods between 7 a.m. to 12 a.m. and between 5 p.m. and 7 p.m. during the above period than that right after the disaster, and (2) in particular, during the time slot between 10 a.m. and 12 a.m., the variation of the travel time during the above period got larger than the travel time variation in the aftermath of the disaster (i.e. quartile deviation was about 10 minutes). In terms of the period from September 10 through September 26, the following points have been observed: (1) the travel time increased between 10 a.m. and 12 a.m. more than that of the period from August 17 through September 8, but (2) its variance was relatively smaller than that of the period from August 17 through September 8.

Based on the analysis result shown the above, we have found that the travel time of the section in scope hardly improved for two months after the occurrence of disaster as long as the mean value was concerned. Especially, JR Kure Line’s restoration on September 9 was expected to improve the road traffic states because some of the transport demands covered on the road would be shifted to the train. However, the significant reduction of travel time hasn’t been confirmed after the railway restoration. This seems to be attributable to the following facts: (1) use of JR Line was effective only for dealing with the long-distance transport demands, and (2) use of automobile traffic was the only option for intrazonal trips even after restart of JR Kure Line operation. As we have already considered in Section 4, if we assume the intrazonal trips are the main cause of traffic congestions, it is then understandable that restart of JR line hasn’t contributed to improving the road traffic conditions because it was difficult for JR to cover the demands of intrazonal trips. Thus, in the next section, an analysis is undertaken by primarily focusing on the relationship between intrazonal trips and travel time.

(2) Relationship between traffic volume and travel time

As already stated in the Section 2, the relationship between traffic volume and travel time relies on cumulative excessive demands and other factors, it is thus not possible to understand its cause-and-effect logic with the simple statistical analysis alone. Meanwhile, as described in the Section 2, considering the facts that the traffic states were unsteady at the time of disaster, and that some measures were taken to mitigate the traffic congestions, including frequent changes of the signal control parameters and the traffic control performed by police, there are many difficulties in describing the relationship between traffic volume and travel time in a way consistent with the

![Fig.15 Day-to-day variation of travel time.](image-url)
We tried to utilize the state-space model in which modeling is carried out among the variables whereas taking the unsteady condition into account, but the results differed very much depending on how we established the hypothesis in the process of generating background data. In addition, it was difficult to determine whether accurate hypothesis was established in the data generation process. Due to these factors, we had difficulties in making inferences based on the reliable analysis results.

Therefore, in the following section, we specify the period when a variation pattern of travel time is stable and comparable in terms of quality as much as possible by using a change-point detection method, calculate the correlation between traffic volume and travel time for each period specified in the previous step, and conduct the regression analysis to verify how far the traffic volume is able to explain the constituents of travel time variation.

a) Change-point detection

We describe the overview of the change-point description as follows (for details of the change-point detection method, refer to the review article 14) etc. A change point means a point of time when statistical characteristics of time-series data show an abrupt change. In the change-point detection method, when time-series data: \( y_{1:n} = (y_1, \ldots, y_n) \) is divided into \( \{y_1, \ldots, y_\tau\} \) and \( \{y_{\tau+1}, \ldots, y_n\} \), and then it is concluded that the two groups of data divided have different statistical characteristics based on a given standard, the time: \( \tau \in \{1, \ldots, n - 1\} \) is determined as a change point. In some cases, multiple change points may exist. For example, if there are \( m \) change points, time-series data \( y_{1:n} \) would be divided into \( m + 1 \) data sets at change points \( \tau_{1:m} = (\tau_1, \ldots, \tau_m) \).

In this case, if \( \tau_0 = 0 \), and \( \tau_{m+1} = n \), the \( i \)-th data divided is \( y_{(\tau_{i-1}+1): \tau_i} \).

In this study, we use the change-point detection based on likelihood. A problem of the change-point detection can be generally formalized as a minimization problem of the following function:

\[
\sum_{i=1}^{m+1} [LL(y_{(\tau_{i-1}+1): \tau_i})] - \beta f(m)
\]  

In this formula, \( LL(y_{(\tau_{i-1}+1): \tau_i}) \) is a log likelihood function to data: \( y_{(\tau_{i-1}+1): \tau_i} \). In this study, we postulate a normal distribution (unknown parameters are mean/variance). Data is divided at the point of time when mean/variance of the travel time was considered to change remarkably. \( \beta f(m) \) is a penalty term designed to prevent over-training, which uses Akaike’s Information Criterion, Bayesian Information Criterion, Hannan-Quinn Information Criterion, etc. However, if the information criterion described the above is adopted in the context of change-point detection on travel time, variations within-day such as peak time in the morning are also detected as a change point. Therefore, this study has manually adjusted the penalty term so as not to detect within-day variations. For reference, Picard et al. 15) have conducted the change point detection of mean and
variance parameters, for example. R package change-point \(^{16}\) was used in this study.

b) Result of change-point detection

Fig. 17 and Table 1 indicate the result of the change-point detection applied to the travel time gathered from ETC 2.0 probe data. The horizontal axis of Fig. 17 puts ID of each trip from ETC 2.0 probe data in chronological order. Based on the result, although some divergences are observed, the following five places of time are detected as change points: (1) disaster occurrence (July 6), (2) typhoon approaching (July 29), (3) Obon summer holiday period (August 11 through 16), (4) consecutive national holidays (September 15 through 17), and (5) reopening of Hiroshima-Kure Road (September 27). By looking at the mean/standard deviation of travel time in each period (Table 1), we have confirmed that the mean/standard deviation of travel time in the period from September 18 through September 28, which exceeded more than 40 days after the disaster occurred, are on the same level as those in the aftermath of the disaster. Besides, as described in the previous section, the restart of JR Kure Line operation (September 9) is not detected as a change point. Accordingly, we have confirmed that the travel time got back to the level before the disaster, after the Hiroshima-Kure Road reopened.

c) Correlation between travel time and trip generation, trip attraction and intrazonal trips

Fig. 18 through Fig. 20 show the correlations between travel time and trip generation/trip attraction/intrazonal trips in the following four periods: [Period 1] June 1 through July 5, [Period 2] July 12 through August 10, [Period 3] August 16 through September 15, and [Period 4] September 19 through September 27.

Looking at the correlation between the travel time and trip generation, we have found that only the residents’ trip generation had high positive correlation with travel time during Period 1 before the disaster. This correlation is presumed to correspond to peak time in the morning due to commuting, etc. On the contrary, during the period after the disaster, high correlation is observed between travel time and the non-residents’ trip generation as well. This correlation is presumed to correspond to the peak of travel time in the daytime (See Fig. 16), which is specifically observed at the time of the disaster. For reference, there is no big difference of mean/variance of travel time throughout the whole period, but we have confirmed that the correlation between travel time and trip generation returned to the normal condition seen before the disaster as time passed after the disaster.

In terms of a correlation between travel time and trip attraction, just as observed in the correlation between travel time and trip generation, it has corresponded to the peak time in the morning attributed to commuting, etc. Therefore, a very high positive correlation has been observed between the non-residents’ trip attraction and travel time. After the disaster occurred, we observed a higher correlation between the residents’ trip attraction and travel time whereas the correlation between non-residents’ trip attraction and travel time lowered. In addition, as observed in

<table>
<thead>
<tr>
<th>Period</th>
<th>Mean (min)</th>
<th>Std. deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0 a.m. on Jun. 1 thru 7 a.m. on Jul. 6</td>
<td>13.46</td>
</tr>
<tr>
<td>2</td>
<td>7 a.m. on Jul. 6 thru 7 a.m. on Jul. 29</td>
<td>21.49</td>
</tr>
<tr>
<td>3</td>
<td>7 a.m. on Jul. 29 thru 5 p.m. on Jul. 30</td>
<td>10.38</td>
</tr>
<tr>
<td>4</td>
<td>5 p.m. on Jul. 30 thru 8 a.m. on Aug. 11</td>
<td>21.35</td>
</tr>
<tr>
<td>5</td>
<td>8 a.m. on Aug. 11 thru 4 p.m. on Aug. 16</td>
<td>15.76</td>
</tr>
<tr>
<td>6</td>
<td>4 p.m. on Aug. 16 thru 10 a.m. on Sept. 16</td>
<td>19.11</td>
</tr>
<tr>
<td>7</td>
<td>8 p.m. on Sept. 16 thru 6 p.m. on Sept. 18</td>
<td>14.63</td>
</tr>
<tr>
<td>8</td>
<td>6 p.m. on Sept. 18 thru 4 p.m. on Sept. 28</td>
<td>21.37</td>
</tr>
<tr>
<td>9</td>
<td>3 p.m. on Sept. 28 thru 0 a.m. on Oct. 1</td>
<td>11.71</td>
</tr>
</tbody>
</table>

\[\text{Table 1} \quad \text{Travel time mean and standard deviation per period based on change points.}\]
the trend of correlation between trip generation and travel time, there is also a trend that the correlation between trip attraction and travel time went back to the condition before the disaster as time passed after the disaster. Though there is a part where the coefficient of correlation is negative, it seems unlikely that there is any negative correlation exists between traffic volume and travel time in principle. Therefore, it is highly possible that it is a spurious correlation which has occurred through the time slot of trip generation. Specifically, most of trip generations (by the non-residents) are considered to be trips for going home, and most of intrazonal trips are considered to be trips for going out for lunch or shopping, which lead to the situation in which trips carried out during time slots other than the morning peak time become predominant. As a result, the negative correlation has been presumably observed between travel time and traffic volume in appearance.

Regarding the correlation between travel time and intrazonal trips, no correlation has been noticed before the disaster. However, after the disaster, we have observed that the positive correlation began to appear. Furthermore, unlike trip generation/trip attraction volumes, the more time has passed after the disaster occurred, the higher correlation has been observed between travel time and intrazonal trips. There is no big difference observed for the correlation change patterns between the residents and the non-residents. As it is also verified in Fig.16, we have confirmed that there was a trend after the disaster that travel time reached the longest during the period between 8 a.m. and 12 a.m., which passed the peak time of commuting to work or school, suggesting that the travel time has been affected by the intrazonal trips which increase between 8 a.m. and 12 a.m., including those for restoration/recovery activities in particular. This has been also observed by looking at the relation between per-hour traffic volume and time occupancy by time slot. Fig.21 shows the relationship between traffic volume and time occupancy by time of day on August 30, Thursday in 2018. This figure has revealed that high values are kept between 8 a.m. and 12 a.m., for the record of loop7, the loop detector placed in the section between Kure Portopia Park, the place used as a disaster response base, and Tenno district, the area heavily affected by the disaster, in contrast to the fact that the observation point on the upstream side has indicated a drop of traffic volume to about 300 vehicles per hour at maximum. We also consider that completion of emergency temporary houses, which started to accommodate the affected people from early September, contributed to the increase of intrazonal trips. Based on the above results, there is a high possibility that the traffic congestion was stretched to the upstream side because of the intrazonal trips concerning and going between the affected area and the disaster response base. In addition, implications of such intrazonal trips are considered to continue occurring until reopening of the Hiroshima-Kure Road on September 27.

d) Variance decomposition of travel time

In order to verify how much of variation components of travel time can be explained by traffic volume, three types of regression models have been established for each period. Model 1 is the one which includes day of week dummy variable and time of day dummy variable only. We have presumed that many of travel time variation components can be explained with these variables only at ordinary times in which only the influence of periodic components such as weekends and commuting to work, stand out. Model 2 has added trip generation/trip attraction volumes to Model 1 as explanatory variables. If travel time fluctuates because of variation of the traffic volume which cannot be explained with day of week or time of day, coefficient of determination must be improved by adding the explanatory variables such as trip generation/trip attraction volumes. Besides, as there is a strong correlation between traffic volume and day of week dummy variable/time of day dummy variable, it makes little sense to examine the parameter values of the model established with these two dummy variables. Therefore, we only focus on changes of $R^2$ in the following observations. Model 3 has added intrazonal trips to Model 2 as explanatory variable.

Table 2 shows the result of regression models ($R^2$). The number of samples for each period is 1366, 1755, 2311, and 693 respectively. Because a coefficient of determination is a ratio of regressive variation in relation to the total variation of travel time, the coefficient of determination directly indicates how much of travel time’s variation components can be explained with the explanatory variables introduced. We have four major findings as follows: (1) before the disaster, even if trip generation, trip attraction, and intrazonal trips are introduced, the coefficient of determination hardly shows any changes. This suggests that variation of travel time in accordance with variation of traffic volume is mostly explainable with day of week dummy variable and time of day dummy variable. (2) in the aftermath of the disaster (from July 12 through August 10), improvement of $R^2$ by 0.043 (accounting for 4.3% of the total variation) is verified, especially by adding trip generation and trip attraction volumes as explanatory variables. This leads to the observation that variations of trip generation and trip attraction volume, which cannot be explained with day of week dummy variable and time of day variable, have caused variation of travel time during the period in the aftermath of the disaster, compared to the condi-
Note (1): All of Model 1, 2, and 3 are the multiple regression model.

Explanatory variables used are as follows: [Model 1] Day of week dummy variable, Time of day dummy variable, [Model 2] Day of week dummy variable, Time of day dummy variable, Trip generation, trip attraction and intrazonal trips by residents, non-residents (residents of three cities), and non-residents (other non-residents) , and [Model 3] Day of week dummy variable, Time of day dummy variable, Trip generation, trip attraction and intrazonal trips by residents, non-residents (residents of three cities), and non-residents (other non-residents)

Note (2): "*" shows that a significant difference (1% significance level) was observed between models, as a result of the likelihood ratio test (Model 2 was compared with Model 1; Model 3 was compared with Model 2).

7. SUGGESTIONS FOR FUTURE POLICIES

Based on the results of our analysis shown the above, we identify the following two points as key suggestions for policies of traffic management at the

Table 2 Goodness of fit of regressive model considering travel time as objective variable.

<table>
<thead>
<tr>
<th>Period</th>
<th>Model 1 $R^2$</th>
<th>Model 2 $R^2$</th>
<th>Model 3 $R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1] Jun 1 thru Jul. 5</td>
<td>0.691</td>
<td>0.693</td>
<td>0.694</td>
</tr>
<tr>
<td>2] Jul. 12 thru Aug. 10</td>
<td>0.342</td>
<td>0.385*</td>
<td>0.392*</td>
</tr>
<tr>
<td>3] Aug. 16 thru Sept. 15</td>
<td>0.628</td>
<td>0.658*</td>
<td>0.665*</td>
</tr>
<tr>
<td>4] Sept. 19 thru Sept. 27</td>
<td>0.802</td>
<td>0.811*</td>
<td>0.826*</td>
</tr>
</tbody>
</table>

Note (1): All of Model 1, 2, and 3 are the multiple regression model.

Explanatory variables used are as follows: [Model 1] Day of week dummy variable, Time of day dummy variable, [Model 2] Day of week dummy variable, Time of day dummy variable, Trip generation, trip attraction and intrazonal trips by residents, non-residents (residents of three cities), and non-residents (other non-residents) , and [Model 3] Day of week dummy variable, Time of day dummy variable, Trip generation, trip attraction and intrazonal trips by residents, non-residents (residents of three cities), and non-residents (other non-residents)
time of the disaster.

Firstly, it is highly possible that a location of a disaster response base, which is used as places to provide bathing service for affected people, put the removed mud temporarily, or to park volunteers’ vehicles, has an extremely big impact to traffic conditions. For Tenno district, which is the area in the scope of this paper’s analysis, Kure Portpia Park was used as one of the disaster response bases. As a result, it led to the situation in which people had to use the National Route 31 to access from the affected area to Kure Portpia Park. We believe it is important to set up the disaster response base at a place where people can access to without using major roads as much as possible.

Secondly, the traffic conditions were extremely confusing for a month in the aftermath of the disaster in particular, and it was far from the state of balance enabling users to gain the complete traffic information and take actions. Under such circumstances, we believe it is important to set up the disaster response base at a place where people can access to without using major roads as much as possible.

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In fact, effective measures may differ depending on the particular disaster. Considering this point, on top of the observations gained as a result of the analysis shown the above, we believe it is critical to establish a system in which a series of processes to obtain observations (data acquisition, analysis, and provision of observations/measures) can be implemented immediately just after the disaster occurs. From this viewpoint, we look back the procedures taken to gain the data used for this study. As for ETC 2.0 data, there is a system in place, enabling Chugoku Regional Development Bureau to take initiative and share the information with relevant organizations on the following day of the observation date. However, in terms of the Mobile Spatial Statistics data and Hiroshima prefectural police’s loop detector data, the procedure to gain such kinds of data was not often done on a real-time basis, because we needed to go through the processes for data purchasing/negotiation/manual work. In order to set up the disaster response bases and control the time slots to deal with demands related to disaster response which we stated the above, quick decision-making is essential. To this end, it is necessary to come up with measures so that

![Fig.21 Per-hour traffic volume (vehicles) -Time capacity(%) by time of day [August 30, Thursday, 2018].](image)
as many types of data as possible are made available on a real-time basis as early as possible, by concluding the agreement on mutual cooperations in case of disaster, for example. Observations made through this paper have been identified by specifying the bottleneck point with ETC 2.0 data, detecting the unusual increase of the traffic volume near Tenno district (loop 7 in Fig.2) with the loop detector data by Hiroshima prefectural police, understanding trip generation, trip attraction, and intrazonal trips with the Mobile Spatial Statistics data, and understanding correlations between travel speed, which was gained from ETC 2.0 data, and the traffic volume. If any of the data shown above is not available, it will cause a certain level of difficulties in understanding the real traffic conditions in a similar way. In order to respond to the disaster, we believe it is extremely crucial to prepare the condition in which multiple kinds of data are put together so that a data analysis can be carried out on a real-time basis as much as possible.

8. CONCLUSIONS

In this study, we analyzed variation properties of trip generation, trip attraction and intrazonal trips and travel time under transport network disruption by using ETC 2.0 probe data, loop detector data, and Mobile Spatial Statistics data. The following shows the key findings as a result of our analysis of the double-lane section on the National Route 31, which was heavily affected by the disaster.

1) After the disaster occurred, the passing traffic volume on the National Route 31 dropped to about 300 vehicles per hour at maximum. We believe this phenomenon was due to the traffic congestions driven by the generation of many intrazonal trips within a part of the road section on the upstream side that come and go between the affected area and the disaster response base. Also, improvement of travel time was not observed in accordance with restart of JR line operation, because it was probably difficult to replace demands of short-distance intrazonal trips with railways. As a result, the long travel time, which exceeded 1.5 times more than that at ordinary times, continued for more than two months after the disaster occurred.

2) The extremely large variation of travel time was confirmed for a month after the disaster occurrence. As a result, there occurred the prolonged condition that only 35 percent of the total variations of travel time could be explained with variables such as day of week or time of day (variables which the users are typically considered to utilize in predicting travel time).

The observations shown above suggest that it may be effective to establish a disaster response base in a place where people access to without passing major roads, and implement various measures to mitigate variations of travel time. Also, as it is highly possible that appropriate measures differ depending on the disaster, we have pointed out the importance of developing a platform in which multiple types of data can be utilized on a real time basis as much as possible.

In this study, we have indicated that if data from multiple sources is available in particular, a fair amount of valuable information can be extracted with passive data only, and that such information can provide suggestions worthwhile to develop traffic management policies at the time of disaster. On the contrary, as seen in the case in Kure this time, if disaster response efforts are undertaken for a long time, it is extremely important to take measures such as designing/providing new transport service temporarily, given the fact that long-term disruption of road network has a significant impact to economic activities in the affected area. In this case, conducting the analysis with passive data alone has revealed the following limits. First, as the passive data is merely the information on peoples’ behavioral outcomes, it is not a data including there preference information, such as the answer to the following question: if a temporary transport service is provided, how many people want to use it on what kind of trip purposes? Secondly, as long as supply of transport is restricted, we believe it is desirable to prioritize trips by vehicles with high urgency and allocate supply of transport to such vehicles in principle. However, it is normally difficult to presume the degree of urgency of the vehicles with passive data only. Taking the above points into consideration, it is necessary to establish an investigation system to gain necessary information on a real time basis whereas minimizing a burden to residents in the affected area, and examine procedures/algorithms for determining allocation of transport supply by utilizing such data, prior to the disaster.

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