AN EMPIRICAL ANALYSIS ON THE BEHAVIORAL ADAPTATION OF LONG-DISTANCE TRAVEL UNDER URBAN ROAD NETWORK DISRUPTION: A CASE OF JULY 2018 HEAVY RAIN DISASTER IN HIROSHIMA

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Heavy rains that occurred in Japan in July 2018 caused devastating landslides, resulting in a massive transport network disruption in the Hiroshima metropolitan area, including cities of Hiroshima, Kure, and Higashi-Hiroshima. Due to the road network disruption, heavy congestions had been observed in the metropolitan area for more than two months. Due to the congestions, several adaptations in travel behavior have been seen, including changes in departure time, travel mode, routes, and cancellation of trips. It is crucial to understand such behavioral adaptions, which had contributed to the reduction of congestions. In this study, we focus on such behavioral adaptations for long-distance travel. It is expected that some drivers originally using Sanyo National Expressway (passing through the metropolitan area) may shift to other routes such as Chugoku National Expressway and Sanin National Expressway during the network disruption. This study reports quantitative empirical evidence on such behavioral adaptations for the long-distance travel (e.g., how many vehicles had been shifted, from when to when did the drivers change their route, etc.) by using loop detector data.

Key Words: *behavioral adaptation, road network disruption, heavy rainfall disaster, long-distance travel, loop detector data, Hiroshima*

1. INTRODUCTION

Japan experienced significant rainfall, particularly from western Japan to the Tokai region, mainly in early July, which is called “The Heavy Rain Event of July 2018” - an official name was given by the Japan Meteorological Agency (JMA). This event caused devasting landslides, leading to disruption of the transport network in the Hiroshima metropolitan area. Naturally, after the occurrence of a disaster event, some areas would be less accessible (e.g., road closures or a collapsed bridge because of landslides, or flooded, blocking of major arteries, and inaccessible roads due to heavy rainfall). This had resulted in the closure of road traffic, which caused severe struggle traveling not only for ordinary cars but also for large vehicles.

Consequently, heavy congestions had been observed in the metropolitan area for more than two months. Therefore, the necessity for the development of a traffic management system that can maintain a level of road network functionality as high as possible even when partially disabled by events such as heavy rainfall disaster or other disasters. Noted that a traffic management system against a heavy rainfall disaster must be able to respond adequately to changing traffic conditions through time. Accordingly, countermeasures must be implemented before and after a disaster event, which consists of not only the construction and maintenance of physical infrastructures but also the implementation of system operation. To adapt to such transport network disruption, some changes in travel behavior have been seen during this period (e.g., changes in departure time, travel mode, routes, or cancellation of trips). In this study, we focus on such behavioral adaptations for long-distance travel. It is expected that some drivers originally using Sanyo National Expressway (passing through the metropolitan area) may shift to other routes such as Chugoku National Expressway and Sanin National Expressway during network disruption.

Due to the significant impact of disasters on travel conditions, a quantitative empirical evidence study should be performed to observe the change of travel flow by using loop detector data. As such, this study could result in proactive and cost-effective decision-making (Oswald & Treat, 2013) and the prioritization in the planning and maintenance of an urban road network, and the development of an emergency response plan or traffic diversion plan (Balijepalli & Oppong, 2014).

This study would directly analysis the traffic condition of not only the Sanyo National Expressway but also the Chugoku National Expressway, Sanin National Expressway, and Hamada Expressway, which would show that these expressways could be alternative routes for car users going to and from the western and eastern cities of the Chugoku area in the disaster event. Furthermore, this paper examines an over 1-year traffic flow all over the Hiroshima metropolitan area wherein link capacity would vary before, during and after the rainfall disaster. In this study, the change-point detection algorithm was applied to detect multiple changes in the traffic volume of the Chugoku Expressway network such as an increase or decrease of traffic flow and when the change started.

This paper is divided into some sections. Section 2 focuses on issues related to travel behavioral adaptions. Section 3 describes the study area. Section 4 describes the change-point dectetion algorithm method using in this study. Section 5 shows preliminary data analysis. Section 6 concludes the research as presented in the paper and provides recommendations for policy and future research work.

2. TRAVEL BEHAVIORAL ADAPTIONS IN THE EVENT OF HEAVY RAINFALL DISASTER

Government policies, investments, construction, and other measures should assist people to adapt to the impacts of climate-related disasters. However, the mismatch between people's needs/behavior and adaptation measures in practice could result in ineffective and failed responses to disasters. Governments should be aware of these behavioral differences, propose transport network recovery policies, and plan for traffic congestion solving solutions accordingly, for example, the adaptations of daily travel to disasters. Transportation infrastructure and travel activities are especially exposed to climate-related disasters, and people's travel behavior may differ according to types of climate-related disasters and their impacts on transportation infrastructure. Because traffic was in absolute chaos following the climate-related disaster due to extensive damage over a wide range of railway and road networks, the question is how people will respond to climate-related disasters. There are numerous unidentified behavior adaptations to traffic conditions in case of climate-related disasters. The right and effective choices in adapting to traffic conditions would differ and depend on government countermeasures and differences in individual characteristics such as knowledge, education, income, and government policies. Little is known, however, about how the impact of a climate-related disaster affects every travel behavior, such as destination choice, frequency of travel, route choices, and mode choices, thereby creating traffic patterns that differ significantly from ordinary ones. The use of automobiles for travel after a disaster event differs greatly from such use before, and travel behavioral adaptations are particular not seen under normal conditions.

Travelers are completely exposed to the weather and disasters during extreme weather events. During adverse or severe weather events, people adjust their travel plans to avoid or alleviate the impacts. Travel plans may be canceled or changed, and travel may be delayed. It is essential to understand changes in travel behavior caused by climate change because transportation network performance depends mostly on responses to traffic conditions (Khattak & De Palma, 1997; Lu *et al.*, 2012). Travel behavior analysis under adverse weather conditions attracts the most attention from the literature reviewed for this study. Khattak and De Palma (1997) reported that half of the automobile travelers among their respondents changed their travel patterns under adverse weather conditions in Brussels, Belgium, and observed that bad weather had a stronger influence on departure time than did the route and mode changes. Heavy rain was found to reduce traffic volume in Melbourne, Australia by 2–3 % (Keay & Simmonds, 2005), and the impacts of weather on travel demand have also been noted in other studies (Van Berkum *et al.*, 2006). In addition, almost all the literature reviewed addresses the behavioral adaptation of short-distance travel, emphasizing the use of private cars, buses, bicycles, and walking (Aultman-Hall *et al.*, 2009; Elias *et al.*, 2013) while changes in long-distance travel receive less attention. Moreover, long-distance travel differs from short-distance travel in terms of distance, purpose, and alternative routes (that is, there are fewer redundant travel routes in long-distance travel than in short-distance travel). These all make travel behavior under conditions of climate change different from long-distance travel.

3. CASE STUDY AREA: CHUGOKU REGION

The Heavy Rain Event of July 2018 caused severe widespread flooding and landslides damage, leading to disruption to the transportation network in the Hiroshima area (Fig. 1), including the Chugoku National Expressway, Sanyo National Expressway, many general and local roads. The restoration of services at some sections was expected to take at least a month, mainly in Hiroshima and Yamaguchi prefectures. Cargo and passenger transport disruptions would also affect other regions, hindering efforts to bring regional economies back to normal. Meanwhile, the rain disaster also wreaked havoc on expressways, suspending up to around 2,268 kilometers of road sections at one point. The Sanyo National Expressway - primary east-west corridor traffic providing an important connection between the Okayama and Yamaguchi metropolitan areas, had some areas suspended, with workers scrambling to fully restore damaged sections. General roads in disaster-hit areas are also witnessing heavy traffic jams even when they have no damage.

The significant severe damage occurred to the Hiroshima-Kure Toll Road. Before the rainfall disaster, the road shared the main traffic volume between Hiroshima and Kure. A landslide hit a section between the Saka-minami and Tenno-nishi interchanges in Hiroshima Prefecture, causing a segment of the road to collapse and blocked the JR Kure Line and National Route No. 31. Due to this closure, all vehicles usually used this road have to reroute through a section of the Sanyo National Expressway (i.e., Hiroshima – Hiroshima-higashi segment) and Hiroshima-higashi – Kure road. This change might cause an overload of traffic volume in the Sanyo National Expressway, which might lead to traffic shifting from the Sanyo National Expressway to the Chugogu National Expressway and Sanin National Expressway.

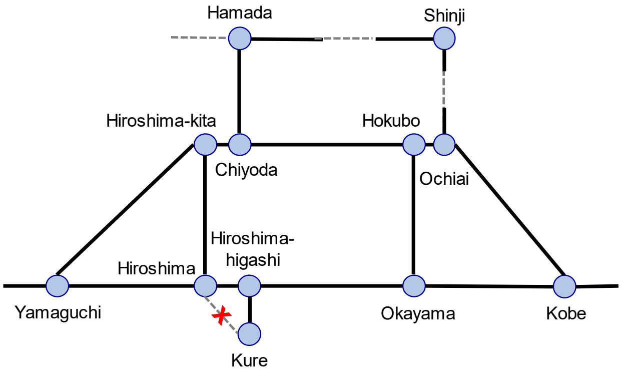

Fig.1 Expressway network of Chugoku region

4. CHANGE-POINT DECTION ANALYSIS

Change-point detection is the task of finding changes in the underlying model of time series. The first works on change-point detection go back to the 50s: the goal was to determine a shift in the mean of independent and identically distributed Gaussian variables for industrial quality control purposes. Since then, this problem has been actively investigated and is periodically the subject of in-depth monographs. This subject has generated important activity not only in statistics but also in various ap-

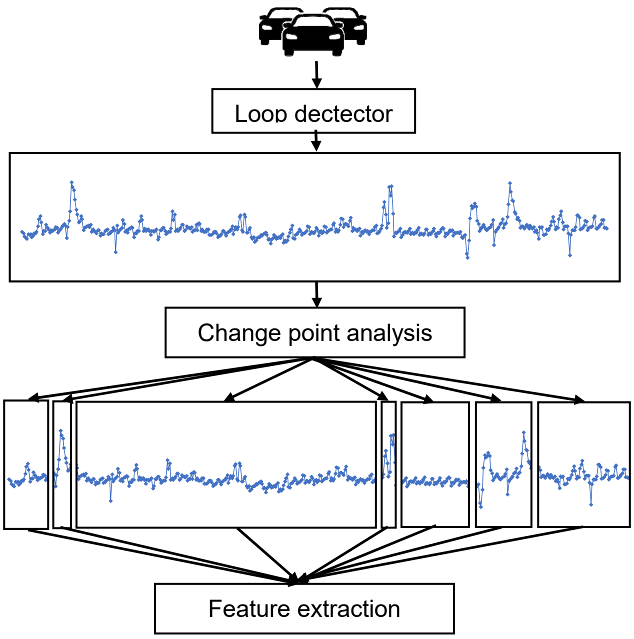

Fig.2 Flowchart of change-point analysis of traffic volume

plication settings such as speech processing (Desobry *et al.*, 2005; Seichepine *et al.*, 2014), financial analysis (Bai & Perron, 1998; Frick *et al.*, 2014; Lavielle & Teyssiere, 2007), and road traffic data analysis (Liu *et al.*, 2008; Wang & Meng, 2004)

Fig. 2 illtrulates the flowchart of change point analysis using in this study.

5. PRELIMINARY ANALYSIS

Fig. 3 to 5 represents the daily traffic volume for west-bound vehicles traveling on the Sanyo National Expressway between Hiroshima and Yamaguchi. As can be seen, total traffic volume dropped directly after the rainfall disaster, then one month later, gradually returned to the prior level of 6 months before. From the middle of 2018 August, it dramatically increased for half month before steadily decreased to normal condition while the traffic volume of large cars plunged a half of normal traffic volume before increasing to normal traffic from the end of 2018 August. This might explain that drivers shifted from the Sanyo National Expressway to alternative ways (e.g., Chugoku National Expressway or Sanin

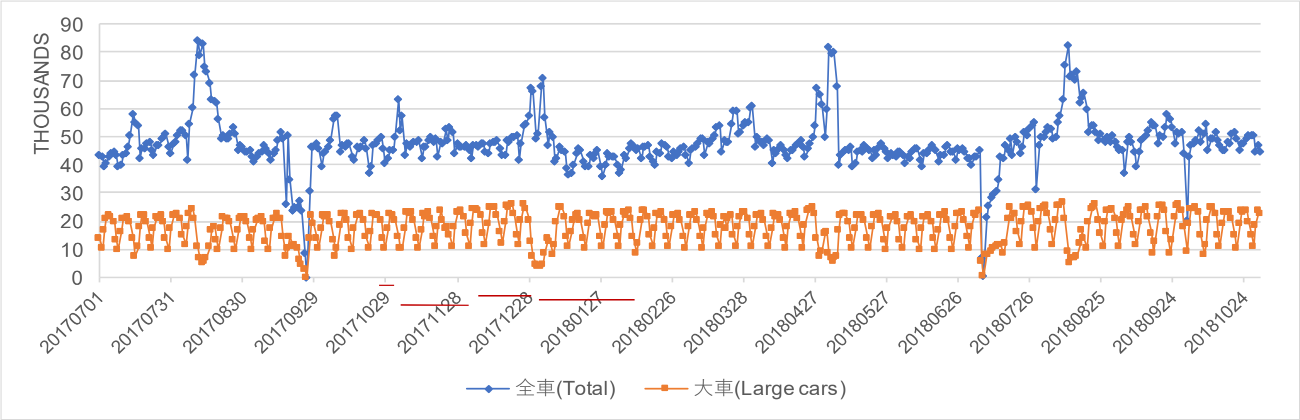

Fig.3 Variation in daily traffic flow from Okayama to Hiroshima-higashi

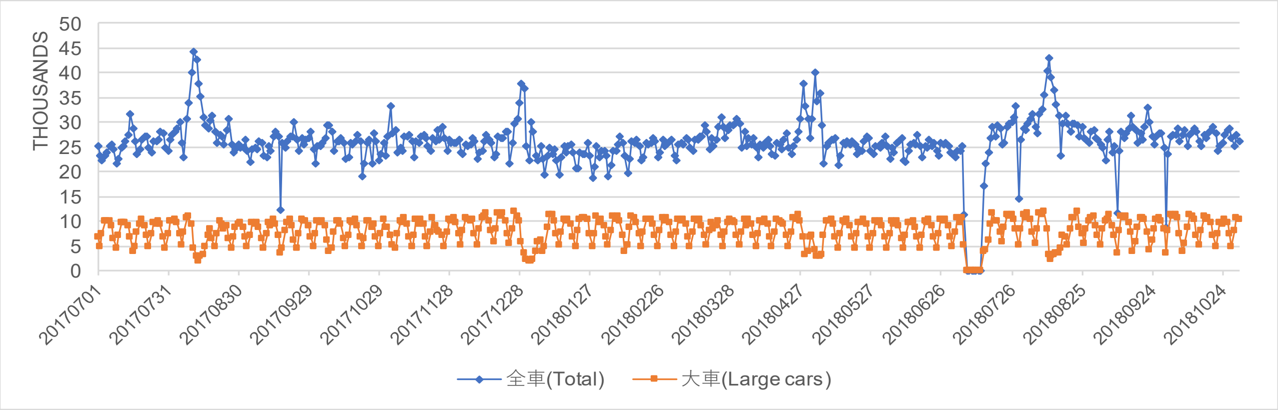

Fig.4 Variation in daily traffic flow from Hiroshima-higashi to Hiroshima

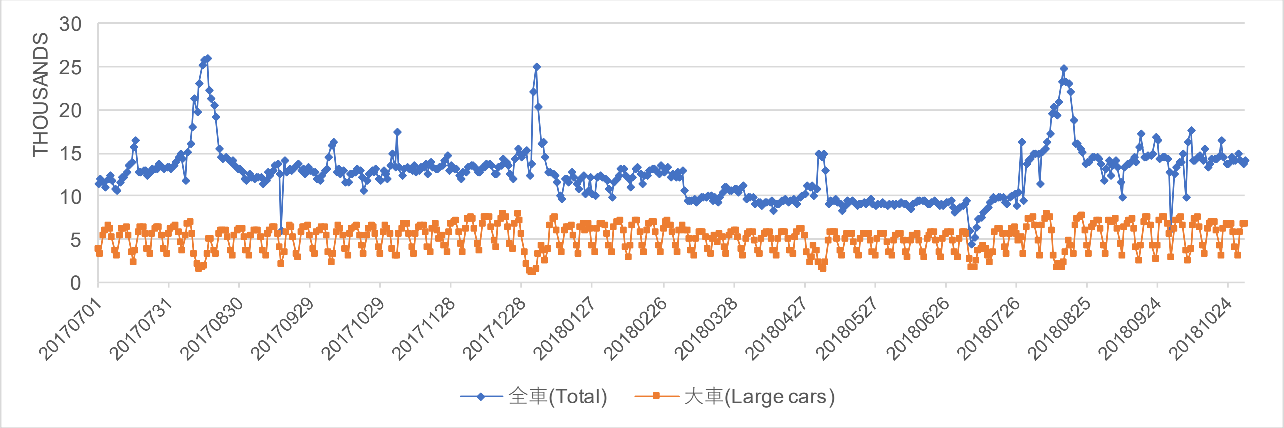

Fig.5 Variation in daily traffic flow from Hiroshima to Yamaguchi

Expressway).

In case of west-bound vehicles traveling on the Chugoku National Expressway, let look at Fig. 6 to 9. After the rainfall disaster, traffic volume started to increase and then go up to three times as usual. The reason to explain this phenomenon is that, due to traffic congestion in the Sanyo National Expressway, vehicles had been rerouted to the Chugoku National Expressway to get through Hiroshima metropolitan area.

In the Hamada National Expressway (Fig. 10 and Fig.11), the same phenomenon also was observed as in the Chugoku National Expressway. However, in the Sanin National Expressway (Fig. 12 to 13), the total traffic volume also decreased after the disaster but the traffic volume of large cars had double increase before returning to as normal volume.

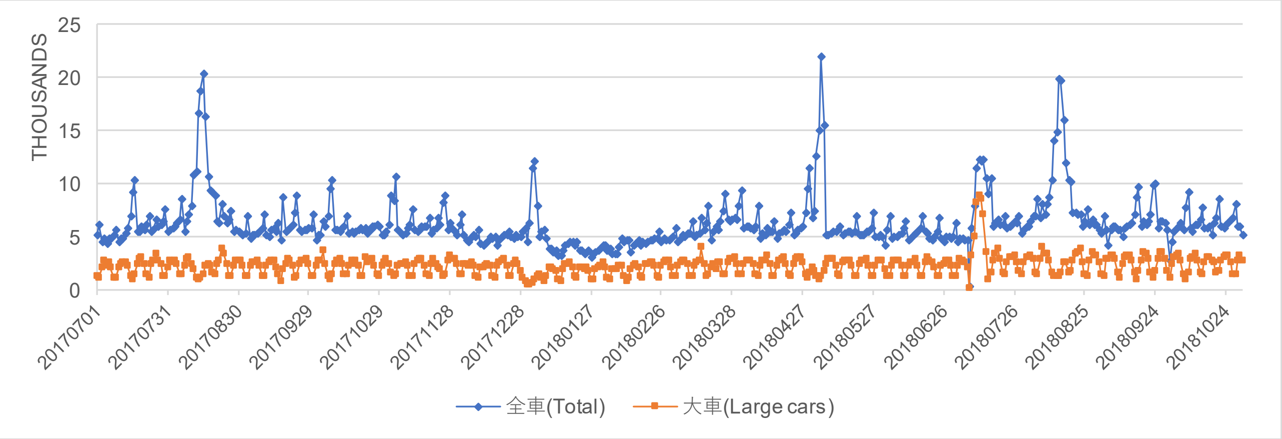

Fig.6 Variation in daily traffic flow from Sayo to Sakuto

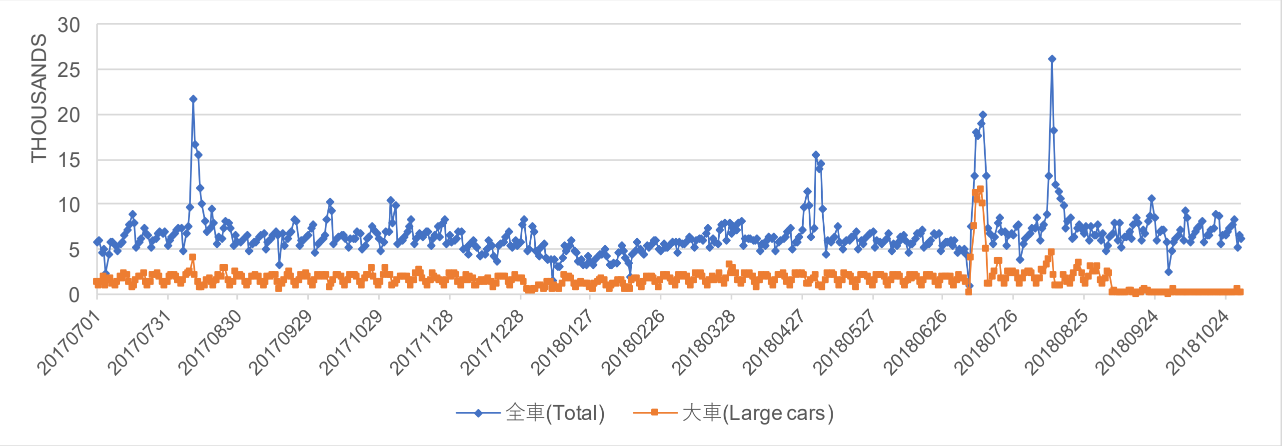

Fig.7 Variation in daily traffic flow from Takada to Chiyoda

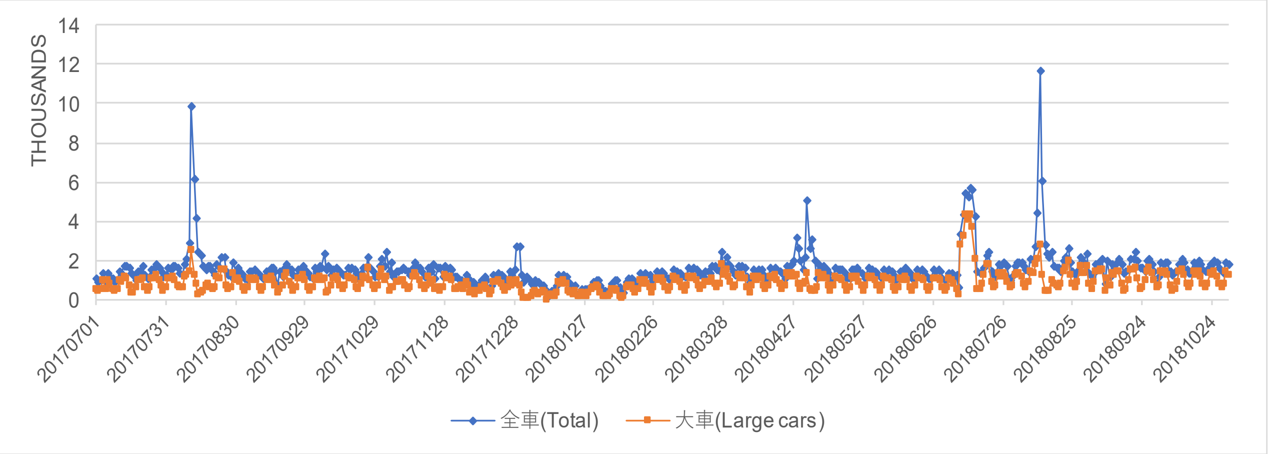

Fig.8 Variation in daily traffic flow from Chiyoda to Kake BS

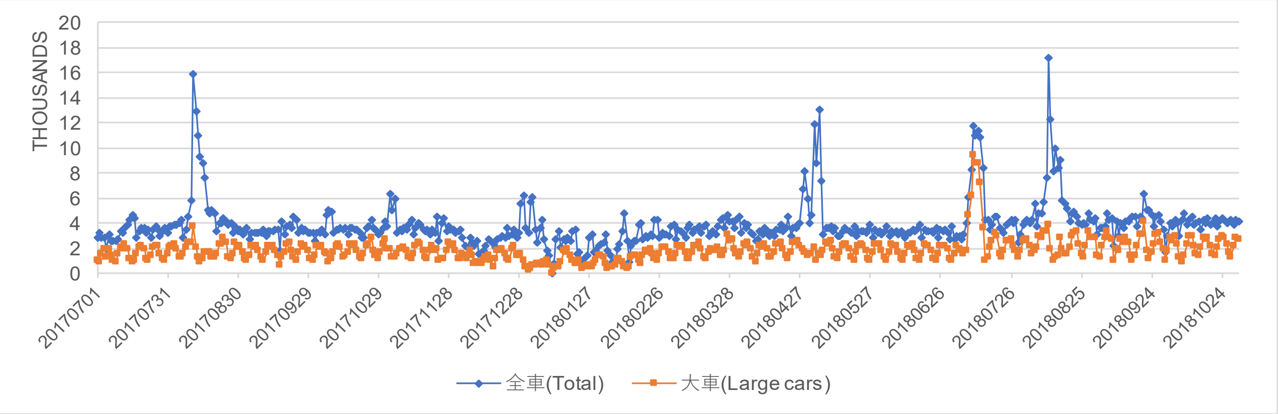

Fig.9 Variation in daily traffic flow from Togouchi to Yoshiwa

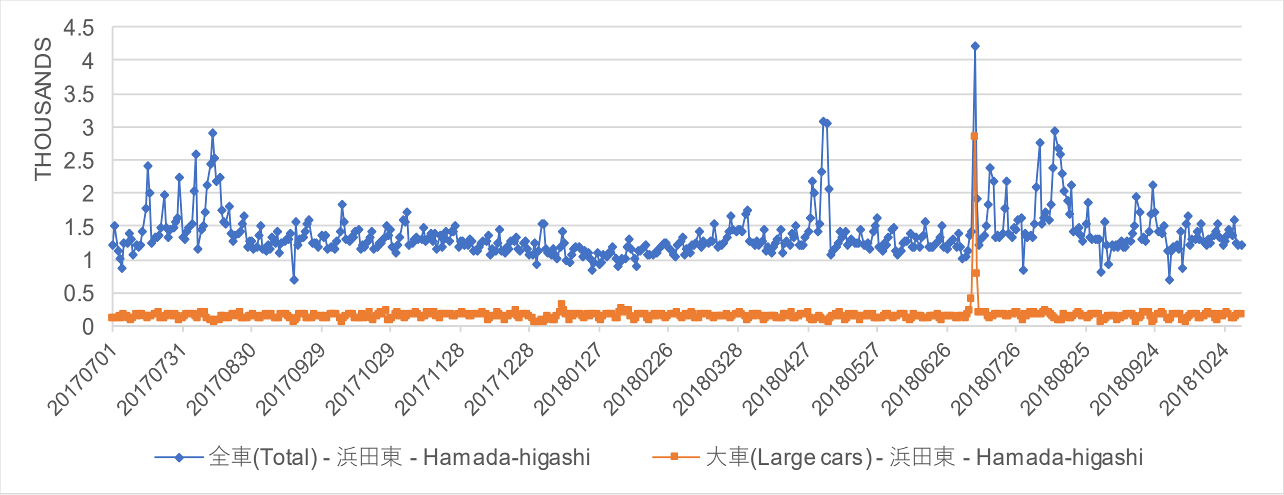

Fig.10 Variation in daily total traffic flow from Hamada-higashi to Hamada and Hamada-higashi to Asahi

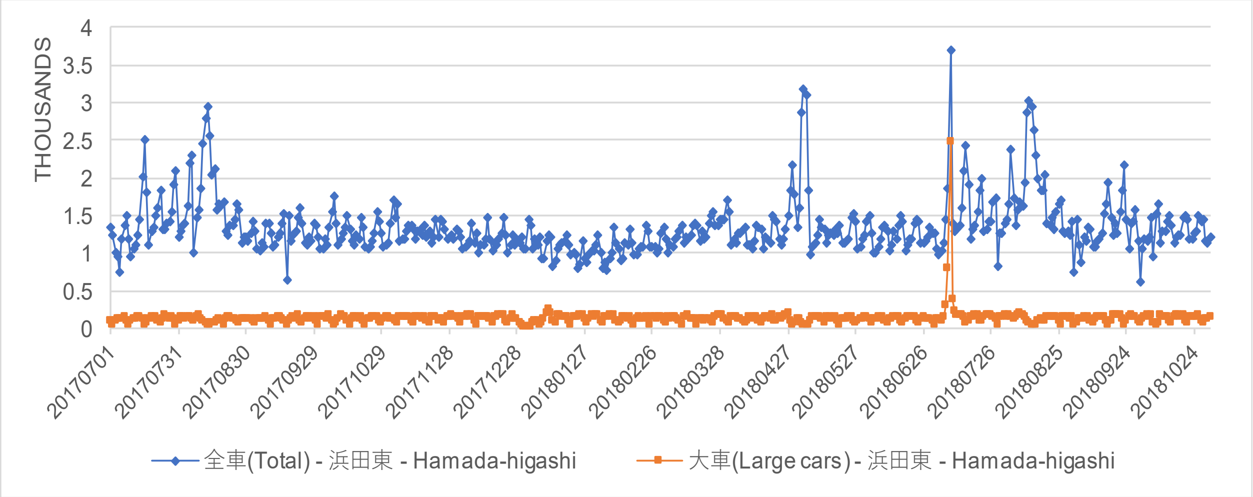

Fig.11 Variation in daily total traffic flow from Hamada to Hamada-higashi and Asahi to Hamada-higashi

6. CONCLUSIONS

This paper reports on the brief aggregation results of traffic flow patterns one year before and three month after the Heavy Rain Event of July 2018. The detail and complete analysis results will be reported in the presentation at the conference. However, it is expected that the Chugoku National Expressway, Hamada National Expressways, and Sanin National Expressway would be alternative routes for the Sanyo National Expressway in the case of traffic jams happening during the climate-related disaster event as well as holiday events such as New Year holidays, Golden Week holidays, and Obon holidays. Also, this study results would be useful for not only immediate post-disaster transport planning, but also performance restoration over the course of the re-construction period.

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