HEAVY VEHICLE TRAFFIC FLOW CHANGES ON EXPRESSWAYS IN THE TOKYO METROPOLITAN AND SURROUNDINGS CAUSED BY THE GREAT EAST JAPAN EARTHQUAKE

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This paper summarizes the detailed heavy vehicle traffic flow on expressways for three months from March 11, 2011 as a result of the Great East Japan Earthquake. Day-by-day traffic changes, compared with historical data, and analysis together with related statistics showed the following results: The Western route called Kan-etsudou experienced 20% increase in traffic caused by detour trip toward the disaster region Tohoku during the first week. From the fourth week until mid-July after the earthquake, the average traffic volume increased by 20% compared with 2010, and average trip length increased by 10%. One of the major reasons for this change was that ports in the Tokyo Bay area were used as alternative freight transport routes in place of damaged ports in Tohoku. The influence of the disaster to the Tokyo Metropolitan Expressway network was quite limited.

Key Words : the Great East Japan Earthquake, expressway, heavy vehicle, traffic flow change

1. INTRODUCTION

A great earthquake with 9.0 magnitude occurred in Japan on March 11, 2011, resulting in catastrophic damage to infrastructure in the Pacific Ocean side of the Tohoku region. Immediately after the earthquake, urgent lifesaving activities, transport of relief material supplies, and emergency recovery of infrastructure such as roads were implemented. With regard to the recovery of the road network, for example, urgent recovery operation or the so-called “comb strategy” was successfully carried out by the Tohoku Regional Development Bureau, Ministry of Land, Infrastructure and Transport. About 97% of the road network was functional within one week from day 1 and all towns and villages, including some detour routes, were connected within one month. The elevated expressway network operated by East Nippon Express Company Ltd. (hereafter NEXCO), was also damaged by the earthquake. The damage spread over to 5,800 points in 22 routes of the 1,200km-long expressway. As a result of emergency recovery works for 20 hours, the entire expressway network became available for specially designated emergency vehicles.

Various types of very specific traffic phenomena, which will be beneficial for traffic and transportation policies as well as research works in this field, were observed in the expressway network, including the Tokyo Metropolitan Expressway. These phenomena, however, were far from the normal business and routine jobs of the firm, thus, staff members were reluctant to analyze the data and/or store the data for future requirements. Those data sets were, therefore, quite perishable.

This paper aims to find out the real situation of the emergency traffic on the highway and to analyze the background of their time series changes. Since the...
study focuses on the physical distribution and logistics, three months worth of data of trucks/trailers were analyzed for this purpose. Nakagawa and Kobayashi \(^3\) analyzed the traffic changes on the urban toll road caused by the great Hanshin-Awaji earthquake. Kim et al. \(^4\) estimated the economic loss caused by the cut-off network. Tanaka and Yonekawa \(^5\) studied the time series changes of traffic at the border between Hanshin Expressway and other highways after the earthquake. There is no detailed traffic study of a wide area, such as the Kanto Plain with 40,000 km\(^2\), affected by the large-scale disaster.

After the East Japan Great Earthquake, many research committees and groups have conducted various traffic studies. Although these groups have published many reports and papers, all studies have focused on some specific sections of the expressway and/or highway or on short time period of at most two weeks. Three months after the disaster, Shimizu \(^6\) compared the traffic volume with the traffic before the disaster.

This paper aims to summarize the detailed heavy vehicle traffic flow on expressways for three months from March 11, 2011 resulting from the Great East Japan Earthquake. Day-by-day traffic changes, comparison with historical data, and analysis, together with related statistics, were carried out.

2. METHODOLOGY

(1) Study areas

As illustrated in Fig.1, the study area and study network cover some 400 km\(^2\) and 1600 km, respectively. These routes are the Tohoku Expressway (hereafter Exp.), Kan-etsu Exp., Jo-ban Exp. as a radial network, Ban-etsu Exp., and Kita-Kanto Exp. as a circular network, besides the Tokyo Metropolitan Exp.

### Table 1 Study Routes

<table>
<thead>
<tr>
<th>Expressway</th>
<th>Nickname</th>
<th>Type</th>
<th>Cover area</th>
<th>Section</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tohoku Expressway</td>
<td>Tohoku Do</td>
<td>Radial a part</td>
<td>Kawauchi-Kohriyama</td>
<td></td>
</tr>
<tr>
<td>Joh-Ban Expressway</td>
<td>Joh-Ban Do</td>
<td>Radial a part</td>
<td>Mito-Iwaki</td>
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<tr>
<td>Kan-Etsu Expressway</td>
<td>Kan-Etsu Do</td>
<td>Radial whole line</td>
<td>Nerima-Nagoka</td>
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</tr>
<tr>
<td>Hoku-Riku Expressway</td>
<td>Hoku-Riku Do</td>
<td>Radial a part</td>
<td>Nagaoka-Chuo</td>
<td></td>
</tr>
<tr>
<td>Nihon-Kai Tohoku Expressway</td>
<td>Nihon-Kai Tohoku Do</td>
<td>Radial whole line</td>
<td>Nigata-Chuo- Arakawa Takai</td>
<td></td>
</tr>
<tr>
<td>Ban-Etsu Expressway</td>
<td>Ban-Etsu Do</td>
<td>Ring</td>
<td>Iwaki-Nagata-Chuo</td>
<td></td>
</tr>
<tr>
<td>Kita-Kanto Expressway (west)</td>
<td>Kita-Kanto Do</td>
<td>Ring a part</td>
<td>Takasaki-Iwafune</td>
<td></td>
</tr>
<tr>
<td>Kita-Kanto Expressway (east)</td>
<td>Kita-Kanto Do</td>
<td>Ring a part</td>
<td>Tochigi-Tsuga-Mito-Inami</td>
<td></td>
</tr>
<tr>
<td>Higashi-Mito Expressway</td>
<td>Higashi-Mito Do</td>
<td>Ring</td>
<td>Mito-Inami-Hachinaka</td>
<td></td>
</tr>
<tr>
<td>Syutoken-Chuo-Ken Expressway</td>
<td>Ken-Oh Do</td>
<td>Ring a part</td>
<td>Iwashii-Tsukuba-Chi</td>
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<tr>
<td>Syutoken-Chuo-Ken Expressway</td>
<td>Ken-Oh Do</td>
<td>Ring a part</td>
<td>Hachi-Oji-Okegawa-Kamoto</td>
<td></td>
</tr>
<tr>
<td>Tokyo-Gaikan Expressway</td>
<td>Gaikan Do</td>
<td>Ring</td>
<td>Ohi-Izumi-Mito-Inami</td>
<td></td>
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<tr>
<td>Tokyo Metropolitan Expressway</td>
<td>MEX</td>
<td>Ring</td>
<td>Whole lines</td>
<td></td>
</tr>
</tbody>
</table>

(2) Study period and data sets

The earthquake broke out on March 11, 2011. The study period was subdivided into three periods for convenience:

1) From March 14 to 18 or the “first week”
2) From March 22 to April 15 or the “second to fifth week”
3) After April 18 to June 17 or “after six weeks.”

Weekly-based average traffic using five weekdays (Mon. to Fri.) was calculated. Because use of Tohoku Exp. became free of charge from July 20, 2011, traffic conditions drastically changed after that.

The data sets used for analysis are as follows:

1) Traffic volumes on Tokyo Metropolitan Expressway by vehicle detectors data
2) Traffic volumes on other expressway by vehicle detectors data
3) O-D (from origin to destination) traffic volume on Tokyo Met. Exp. by ETC O-D data.

ETC: Electronic Toll Collection System

Because of the difference in data sources stated above, we refer to all expressways except Tokyo Met. Exp. as East Japan Expressway or EJE. Hereafter Tokyo Met. Exp. shall be referred to as TME.

(3) Target traffic

Because of the transportation demands of emergency relief goods and materials for reconstruction works, large-size vehicles such as trucks and trailers rapidly increased on the expressways. This paper focuses on the large-size vehicle traffic, which includes mid-size trucks, large-size trucks, and king-size trucks/trailers depending on the limitation of classification sensitivity of detectors.

Changes in traffic volumes are increment or decrement amount from the traffic last year (2010).

3. CHANGES IN LARGE-SIZE VEHICLE TRAFFIC (LVT)

(1) LVT before the disaster

Fig. 2 shows the percentage changes in LVT compared with the previous year by route during year 2006 and 2011. The previously increasing rate of LVT had decreased from 2006 to 2008. Because of the Lehman economic shock (crisis) in September of 2008, LVT in 2009 decreased significantly. LVT enjoyed economic recovery in 2010 until the disaster on March 11, 2011.

(2) Time series changes in LVT on the East Japan Expressways (EJE)

a) General trend

Fig. 3 shows the time series changes in the average traffic volume on the EJE. The average traffic is a weighted average using the section length of two interchanges as the weight. After the event, traffic volume rapidly recovered in four weeks. The traffic volume hit a peak in the fourth week (March 28 to April 1) after the event. Because of slightly less traffic volume in 2010, the increment ratio against year 2010 hit the peak in the fifth week. The LVT after the event increased more than 20% after the East Japan Great Earthquake. Fig. 4 shows the changes in average trip length of LVT on EJE estimated using ETC OD data. The trip length of LVT is also increased by more than 10% after the event.
b) Time series changes in small size vehicle traffic (SVT) on the EJE

In order to identify the characteristics of LVT, Fig.5 and Fig.6 demonstrate the same statistics of small size vehicles (SVT) in the same period. We can identify a significant difference in average traffic volume and trip length between LVT and SVT. The LVT volume increased almost 20% compared with the previous year while the SVT maintained the volume level of year 2010. The change in trip length was more drastic. The trip length of SVT decreased 5% or so. It means that people living in Kanto area were reluctant to drive long distance after the event even after the full recovery of fuel supply in the beginning of April 2011. On the contrary, the trip length of LVT increased more than 10% or 10km after the event. If we suppose that the increased 20% of traffic realized the 10 km increase in average trip length, the trip length of added LVT increased more than 50km. It means that the LVT increased to transport the emergency relief goods and materials for recovery and reconstruction of the disaster area in the Tohoku region.

c) Changes in traffic pattern by route

Fig.7, 8, and 9 show the daily traffic pattern of large-size vehicles one week after the event, from the second week to the fifth week, and from the sixth week to the 12th week, respectively. Because of the traffic shutdown of Tohoku Do and Joh-ban EXPs Do at the border of the Kanto region and Tohoku region (points A and B), most of the LVT concentrated on the western routes, such as the Kan-Etsu Do and the Nihon-Kai Tohoku Do, at the end of the first week. In addition to the western routes, the LVT increased on the Tohoku Do and Kita-Kanto Do from the second week to the fifth week. The sections in the north that were near the affected Tohoku region recorded significant increase.

Although the LVT increased on all expressway networks in the study area after the fifth week, it was obvious that Tohoku Do played a central role in the freight transport to the disaster region in Tohoku.
d) Timing of the LVT changes

To identify the timing of the LVT changes, an increment/decrement traffic volume compared with the previous week and previous year is examined. A sample figure is demonstrated in Fig. 10. A period indicated as a plus side shadow rectangular means that the LVT has been continuously increasing.

Fig. 11 demonstrates the detailed analysis of increment volume on the Tohoku Do. Here, each line denotes an average increment/decrement volume by week. As time advanced, all the lines shifted up and down ((1)3/14-3/18 > (2)3/22-3/25 > (3)3/28-4/1 > (4)4-4/8). The horizontal axis denotes the geographical point from the Tokyo side end “Kawaguchi Junction” in the left, to the Tohoku side end “Kohriyama Junction” in the right. The LVT on all sections of the Tohoku Do, Tokyo side in particular, was found to decrease significantly in the first week after the disaster.

Fig. 8 The Large-Size Vehicle Daily Traffic Pattern from Second Week to Fifth Week after the Event.

Fig. 9 The Large-Size Vehicle Daily Traffic Pattern from Sixth Week to 12th Week after the Event.

Fig. 10 The Increment/Decrement Daily LVT Volume Compared with the Previous Week and Previous Year - Example: Tohoku Do -.

Fig. 11 Detailed Increment/Decrement in Daily Large-Sized Vehicle Traffic on the Tohoku Do (Below is the enlarged figure after April 11).
The traffic on the same section, however, recovered in the second week and even increased, compared with the traffic before the event. Although the traffic increased further after the third week, the increment rate decreased week by week. The traffic decreased after the sixth week and stabilized gradually.

The increment/decrement average LVT volume compared with the previous week in all study routes is shown in Fig. 12. It was found that the LVT on Kan-Etsu Do increased from the first week of the event, while the LVT on other routes started to increase from the second week. The LVT on all the routes except Joh-Ban Do decreased from the sixth week and became stable after the 11th week. It can be concluded that the East Japan Expressways has well worked as a network in terms of interdependence with LVT.

e) Changes in origin and destination of the LVT

Fig. 13 shows the changes in the LVT volume with its origin and destination in the study area. Fig. 14 shows the increment in the LVT with its origin or destination in the major affected area, Tohoku Region. Although paid LVT was less than that of the previous year until mid-April, the toll-free emergency trucks increased just after the disaster in March. The emergency trucks decreased after the sixth week from the event, while the paid LVT increased gradually. As a result, the total LVT volume was stable after the fifth week. Sixty-four percent of the increased LVT has its O/D outside the study area; particularly, the LVT with O/D in Tohoku increased the most. From the detailed statistics on the right of Fig. 14, it can be seen that the LVT increased in the northern part of the study area (northern Kanto plain) and in Fukushima Prefecture (south region of affected area).

f) The LVT volume at the border between Tohoku and the study area

There are four routes at the border between Tohoku region and the study area. They are Tohoku Do north, Nihon-Kai Tohoku Do north, Ban-Etsu-Do, and Joh-Ban Do north, as illustrated in Fig. 15. Fig. 16 shows the LVT volumes at the four routes of the border. The Nihon-Kai Tohoku Do and the Tohoku Do occupied almost 80% of traffic in the first week after the event. The LVT increased on the Tohoku Do from the second week to the fourth week, and its share exceeded 50%. In the sixth week and after, the traffic on other expressways increased gradually.

![Fig. 12](image1.png)
![Fig. 13](image2.png)
![Fig. 14](image3.png)
![Fig. 15](image4.png)
![Fig. 16](image5.png)
(3) Changes in the LVT on the Tokyo Metropolitan Expressway (MEX)

a) Changes in the LVT on the MEX

Fig. 17 shows the time series changes in LVT on the MEX in the years 2010 and 2011. Different from the Eastern Japan Expressway stated above, the LVT on the MEX does not show a significant increase.

b) Changes in the small size vehicle traffic (SVT) on the MEX

To compare the LVT and the SVT, the weighted average volume of the SVT on the MEX is shown in Fig. 18.

Although the SVT increased until mid-June, the timing of increasing SVT was slower than those of the LVT. The SVT did not increase up to the level of traffic in the previous year.

c) Changes in the LVT by route on the MEX

Changes in traffic patterns between the first and the sixth week on the MEX are shown in Fig. 19 and 20, respectively. The increased traffic in the first week was found to be remarkable along the Tokyo Bay and eastern part of MEX, which lead to the Tohoku Do. The increased sections of the LVT in the sixth week and after decreased and were scattered in the network. It means that the influences of the disaster were limited in terms of time period and area in the CBD in Tokyo.
d) Changes in origin and destination of the LVT on the MEX

Fig. 21 shows the changes in the LVT on the MEX with its origin or destination along the Tohoku Do area. Although the LVT from/to Tohoku Do remarkably decreased immediately after the event, it began to increase gradually after the second week from the event. The LVT to and fro Tohoku Do increased the volume of 600 vehicles per day compared with that of the previous year from the sixth week. This volume is almost equivalent to 4% of daily traffic.

Fig. 22 shows the origin or destination of the LVT on the MEX going to or coming from Tohoku Do. Most of the increased traffic occurred along the Tokyo Bay areas. This most interesting fact suggests that freight transportation from the Ports of Tokyo and Yokohama must have played a very important role during the sixth week and after the event.
4. UNDERSTANDING THE REASONS FOR THE INCREMENT OF LVT

(1) Changes in physical distribution through the sea ports

a) Changes in physical distribution by all transportation modes

Fig. 23 shows the cargo-handling amount by railway, seaport, and airport at Sendai City and nearby, which is the biggest city in the disaster-affected area. The decrement in cargo handling is most remarkable at the Port of Sendai-Shiogama followed by the railway and Sendai Airport. The Port of Sendai-Shiogama comprises the Sendai area facing the Pacific Ocean and Shiogama area located inside Matsu-Shima Bay. The Sendai area was completely destroyed by the earthquake and the following tsunami.

b) Cargo handling at the ports in the entire Tohoku region

All the ports located in the Pacific coast side of the Tohoku region were damaged seriously by the earthquake and the following tsunami. To transport the emergency relief goods, materials for reconstruction works, and raw materials and produced goods by manufacturing companies, these commodities were handled at the ports along the Nihon-Kai coast and the ports in Tokyo Bay. Fig. 24 shows the locations of the destructed ports and alternative ports and handling volume of cargo at alternative ports. As a result, The Nihon-Kai side ports, such as Niigata and Akita, and the ports inside Tokyo Bay, such as the Port of Tokyo, significantly increased their cargo handling.

Fig. 23 Cargo Handling Volume by Railway, Seaport, and Airport at Sendai City and Nearby.

Fig. 24 Locations and Handling Volume of the Destructed Ports and Alternative Ports.
Fig. 25 shows the cargo throughput at the Port of Tokyo from January to June 2011. Cargo handling at the Port of Tokyo apparently increased after the disaster and the increment in cargo handling in April was remarkable. Although cargo handling decreased as time went by, the volume in June was more than that in year 2010. Generally speaking, cargo handling at alternative ports has a one-month delay, i.e., in April, because of documentation exchange. The Port of Sakata, however, increased its cargo handling immediately after the event. This handling was realized by the real emergency transportation of fuel (kerosene for heating and gasoline/diesel oil for automobile) without formal documents.

c) The Effects of the physical distribution through the port of Tokyo on the LVT on the MEX

To analyze the effects of the physical distribution through the Port of Tokyo on the LVT on the MEX, Fig. 26 shows the decrement/increment volume of the LVT at nine ramps along the Port of Tokyo. These ramps are “Kosoku-Wangan Ariake,” “Rinkai-Fukutoshin,” “Oh-I,” “Oh-I-M inami,” “Shiba-Ura,” “Katsu-Shima,” “Suzuga-M ori,” “Hieijima,” and “Daiba.” The decrement/increment volume is estimated using the LVT volume identified by the ETC data. The traffic increased during the sixth week and the twelfth week at the average of 1,500 vehicles per day or 7% of the total traffic. Since the destinations of the increased LVT must be the Tohoku region, an average trip length was supposed to be extended.

(2) Traffic control and restriction on the Expressways

Table 2 shows the major traffic control and restriction on the expressways caused by the disaster in the study area. On March 11, the entire expressways were completely closed until 11:00 hours. The specially designated emergency vehicles for relief goods transport or urgent recovery purposes were allowed to drive through the routes leading to the disaster.
area (Tohoku region) from the second day of the event. Almost ten days after, large-size vehicles without permission were permitted to drive on the Tohoku Do. Almost all restrictions were lifted after the third week from the event except the areas deeply affected by the nuclear power station accident in Fukushima.

(3) Free-of-charge policy for the specially designated emergency vehicles

The Disaster Management Act of 2011 designated the Emergency Traffic Routes to stimulate the smooth recovery work in the disaster area. During the restricted time period, specially designated vehicles could use the designated routes toll-free. The designation policy started March 12 and continued until April 24, and the number of permitted vehicles reached up to 163,208. Since the permission was effective for one month, the number of designated vehicles gradually decreased after April 12. Fig. 26 shows the number of emergency vehicles in the study area and the remaining percentages of free-of-charge vehicles against peak time. The designated vehicles did not decrease after April 18, while the designated vehicles with free-of-charge privilege decreased as shown by the percentage decreasing line in Fig. 26. Therefore, the traffic volume on the routes designated by the Act was supposed to decrease after April 18.

(4) The effect of fuel shortage on the study area and affected area

A serious fuel shortage occurred in the study area and the disaster area. The most serious problem was the destruction of the Sendai Refinery Plant at Sendai Port, which supplied almost two-thirds of fuel demand in the Tohoku region before the event. According to the research work by Yamaguchi et al.13), fuel shortage in the Tohoku region has relaxed after the beginning of April. As the vehicles in the Tohoku area which could not move due to lack of fuel began to drive after April, the traffic on the expressway did not decrease in April.

(5) Production index of mining and manufacturing

Fig. 27 shows the production index of mining and manufacturing compared with the previous year. The production indices of both the Tohoku region and five prefectures in the Kanto region (which almost covered the study area) seriously declined in March, while Niigata Prefecture stayed constant compared with the previous year. The most specific feature of the statistics could be found in the sharply recovered Ibaragi production. Fig. 28 shows the production index by industry sector of Ibaragi Prefecture. The major cause of rapid growth in Ibaragi was the general machinery industry. Because of the large demand for recovery works, the production level of construction machineries increased remarkably. The surging production demand could well explain why the traffic in May and June only increased on the Joban-Do as shown in Fig. 12.
5. THE EFFECTS OF THE DESIGNATION OF EMERGENCY TRAFFIC ROUTES ON THE TRAFFIC DYNAMICS

(1) Scope of the analysis
As already mentioned in 4.3, the Disaster Management Act of 2011 designated emergency traffic routes and only vehicles with emergency vehicle permission could use the designated routes toll-free. Fig.29 shows the map of the designated routes at 11 a.m. on March 12, 2011. Traffic under extraordinary situation of large-scale traffic restriction is analyzed in a time slice manner. The results must be beneficial for a research work on dealing with physical distribution immediately after the great earthquake.

(2) Methodology
The traffic analysis study area covered the entire restricted route of the Tohoku Expressway, i.e., from Kawaguchi Junction to Ikariga-seki interchange (please refer to Fig.30). Traffic situations after the disaster (from Mar. 14 to 18) are compared with the traffic before the disaster (from Feb. 29 to Mar. 4). The period for analysis was decided to be the same period of the emergency traffic routes restriction.

Fig.29 Map of the Designated Routes at 11 a.m. on March 12, 2011.

Fig.30 The Tohoku Expressway and Major Control Lines for Analysis.
LVT from Tokyo to the disaster area (northbound traffic)

a) Daily LVT

Fig. 31 shows the averages of daily LVT during the period of emergency traffic control. Large-size vehicles driving on the Tohoku Do increased from Tokyo to the Joh-Ban Do JCT. Many of them got down from Tohoku Do at northern Fukushima and southern Miyagi (southern end of Sendai City). It means a lot of emergency relief goods by-passed the Sendai CBD and directly went to the municipal deposits or emergency evacuation shelters because most major deposits were located inside the Sendai CBD. The inflow and outflow traffic in the interchanges in nearby Sendai City and Morioka City were almost of the same volume.

b) Daytime and nighttime LVT - southbound

Fig. 32 and Fig. 33 show the daytime and nighttime LVT before the disaster and after the disaster, respectively. Before the event, LVT in the Kanto area was greater than in the Tohoku area and nighttime traffic was greater than that of daytime. After the event, however, LVT in Fukushima and nearby areas increased a lot and daytime traffic exceeded that of nighttime.

c) Analysis of peak traffic time based on the hourly rate of LVT - northbound

The hourly rate of LVT is defined as the hourly traffic divided by the daily traffic. It means that 0.0417 is the mathematical average figure. Table 3 shows the hourly rates of the northbound LVT after the disaster. The gray cells represent the hourly traffic rate over the average volume of traffic. As shown in Table 3, there are no special traffic concentration hours. The midnight traffic from 0:00 a.m. to 4:00 a.m. declined compared with

| Time  | 0:00m. | 0:10m. | 0:20m. | 0:30m. | 0:40m. | 0:50m. | 1:00m. | 1:10m. | 1:20m. | 1:30m. | 1:40m. | 1:50m. | 2:00m. | 2:10m. | 2:20m. | 2:30m. | 2:40m. | 2:50m. | 3:00m. | 3:10m. | 3:20m. | 3:30m. | 3:40m. | 3:50m. | 4:00m. | 4:10m. | 4:20m. | 4:30m. | 4:40m. | 4:50m. | 5:00m. | 5:10m. | 5:20m. | 5:30m. | 5:40m. | 5:50m. | 6:00m. | 6:10m. | 6:20m. | 6:30m. | 6:40m. | 6:50m. | 7:00m. | 7:10m. | 7:20m. | 7:30m. | 7:40m. | 7:50m. | 8:00m. | 8:10m. | 8:20m. | 8:30m. | 8:40m. | 8:50m. | 9:00m. | 9:10m. | 9:20m. | 9:30m. | 9:40m. | 9:50m. | 10:00m. | 10:10m. | 10:20m. | 10:30m. | 10:40m. | 10:50m. | 11:00m. |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
other time periods. Here, where a large vehicle was supposed to drive at the speed of 80km/h or 50miles/hour, we will notice that there were three major northbound traffic flows as follows:
1) LVT leaving the Tokyo metropolitan area between 9:00 a.m. and 2:00 p.m., and arriving at Fukushima and Miyagi Prefectures before 12:00 p.m.
2) LVT leaving Sendai area between 4:00 a.m. and 4:00 p.m., and arriving at Iwate Prefecture at 6:00 p.m.
3) LVT leaving Morioka area between 5:00 a.m. and 6:00 p.m., and arriving at Aomori Prefecture before 8:00 p.m.

Besides, we will notice that LVT in the Sendai area does not have a specific time of concentration. It means the Sendai area served as a major deposit center of supply chain and was the major origin and destination of the traffic.

(4) LVT from the disaster area to Tokyo metropolitan area (southbound traffic)

a) Daily LVT

Fig.34 shows averages of the daily LVT during the period of the emergency traffic control. Focusing on the traffic counted by the detector located south of the junctions of branch routes, most of the traffic was identified as inflow from the north area to the Sendai area, and was identified as outflow from the Sendai area and south. This fact obviously means that the southbound traffic from the north end up to Sendai includes much outward traffic, and that traffic from south of Sendai includes much homeward traffic.

b) Daytime and nighttime LVT- southbound

Fig.35 and Fig.36 show the daytime and nighttime LVT before the disaster and after the disaster, respectively. Before the event, both daytime and nighttime LVT did not differ in volume, particularly in the Kanto area. After the event, however, the nighttime LVT in Fukushima and in the north decreased a lot and the daytime traffic was more than double that of the nighttime traffic.
Fig. 35 Daytime and Nighttime LVT (South bound: Before the disaster).

Fig. 36 Daytime and Nighttime LVT (South bound: After the disaster).

c) Analysis of the peak traffic time based on the hourly rate of LVT - south bound

The hourly rate of LVT and the mathematical average have the same definition as above. Table 4 shows the hourly rates of the northbound LVT after the disaster. As you can see in Table 4, the midnight traffic from 0:00 a.m. to 4:00 a.m. was only a little compared with other time periods. The two major traffic flows bound for the south are as follows:

1) LVT leaving the Fukushima and Sendai areas between 9:00 a.m. and 7:00 p.m., and arriving at the Tokyo metropolitan area before 12:00 p.m.
2) LVT leaving the north end of Kosaka at 6:00 a.m. and 6:00 p.m., and arriving at Morioka and nearby areas before 8:00 p.m.; and LVT leaving Morioka area between 8:00 a.m. and 8:00 p.m., and arriving at Sendai area before 8:00 p.m.

(5) Discussion of the effects of emergency traffic control

LVT bound for the north did not have peak hours except at midnight. It means that the trucks for emergency relief goods left their origin whenever they were ready. On the contrary, the southbound LVT, i.e., from the disaster area, left its origin at daytime. It means that the trucks were filled with fuel oil in the morning and drove back to the Tokyo metropolitan area because of serious shortage of fuel oil in the disaster area and/or because of the need to escape from the damaged surface condition of the expressway in the disaster area.

Because both the inflow and outflow traffic in the Fukushima Prefecture were high, it can be concluded that the freight traffic volume in the prefecture was rather high. Physical distribution in Fukushima was quite large partially because of the nuclear accident. Considering that traffic characteristics changed at the Sendai and nearby areas, we can conclude that the Sendai area played a key role in the supply chain between the Tokyo metropolitan area and the disaster area in Tohoku.

6. CONCLUSION

(1) Summary of the LVT changes

Instead of coastal shipping destroying supply chains, the LVT increased remarkably after the event. During the end of April and mid-June, the average LVT volume increased 20% or more and the average trip length increased about 10%.

The Tohoku Do was a major logistics route between the Tokyo area and the Tohoku area except for the first week from the event. The Tohoku Do accommodated almost half of the traffic volume at the border between the disaster area and other areas. The average LVT volume in the study area also increased by about 20%. Considering the synchronizing traffic changes in the expressways in the study area, the expressway network in the Kanto area well functioned as one network.

Fig. 37 shows the summary of the traffic changes of large-size vehicles in the study area. Detoured traffic to the western routes immediately after the event was shifted to the Tohoku Do after the cancellation of traffic closure. The LVT on the Tohoku Do and other radial expressways such as Joh-Ban Do had increased even after the sixth week from the event.

The whole network of the Tokyo Metropolitan Expressway (MEX) was confused immediately after the event. The traffic at the ramps of the MEX nearby the Port of Tokyo increased 7% and the boundary leading to the Tohoku Do increased 4%.

The effects of the emergency traffic control were summarized as a different tendency from that before the disaster; less LVT was observed as homeward traffic from the disaster area at nighttime.

(2) Classification of the time series traffic changes based on situation changes

Table 5 shows the classification of the time series traffic changes based on situation changes such as road conditions, fuel supply conditions, emergency vehicle permission, and traffic restriction/control policies. This classification is a modified version of
the previous literature by Honma et al.\textsuperscript{14}) for the Hanshin-Awaji Great Earthquake. Focusing on the changes in traveling behavior, this paper classified the period into three stages: First, the urgent period is the time to evacuate from a dangerous situation and confirm the safety of family, relatives, neighbors, and friends. Second, the transition period is the time to find an evacuation shelter or a temporary settlement such as a temporary house. Third, the recovery period is the starting time for usual socio-economic activities and start of recovery works. This classification, of course, mainly takes account of the changes of the LVT analyzed in this paper. The recovery period was identified to have started from the end of April.

ACKNOWLEDGEMENT: We would like to express our great appreciation to Professor Masao Kuwahara who provided us many valuable information and suggestions. We would also like to offer our special thanks to Mr. Nishikawa of Nippon Expressway Research Institute Company Limited (NEXCO-RI) and Mr. Honma of East Nippon Expressway Company Limited, who kindly provided various very important traffic data sets that were necessary to carry out this study. We are particularly grateful for the assistance given by the members of the transportation research group at the Metropolitan Expressway Company Limited. Finally, we would like to extend our deep thanks to Professors Satoshi Inoue and Shigeru Morichi of the National Graduate Institute for Policy Studies whose valuable advice and suggestions have significantly improved this paper. We could not have carried out this research work without their cooperation.

REFERENCES

Table 5: Classification of the Time Series Traffic Changes Based on Situation Changes.

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Fig.37 Traffic Changes in Large-Size Vehicles in the Study Area\textsuperscript{7).}

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(Received May 17, 2013)