Evaluation of traffic control policy in disaster case
by using traffic simulation model

DAISUKE OSHIMA1*, SHINJI TANAKA2, TAKASHI OGUCHI3
1. Institute of Industrial Science, the University of Tokyo, Japan (4-6-1 Komaba, Meguro, Tokyo 153-8505, TEL: +81-3-5452-6419, E-mail: dai-o@iis.u-tokyo.ac.jp)
2. Yokohama National University, Japan (79-5 Tokiwadai, Hodogaya, Yokohama 240-8501, TEL: +81-45-339-4032, E-mail: stanaka@ynu.ac.jp)
3. Institute of Industrial Science, the University of Tokyo, Japan (4-6-1 Komaba, Meguro, Tokyo 153-8505, TEL: +81-3-5452-6387, E-mail: takog@iis.u-tokyo.ac.jp)

Abstract
After the Great East Japan Earthquake, which occurred on March 11, 2011, heavy traffic congestion continued in Tokyo for a long time. In this study, the traffic situation in Tokyo following the earthquake is reproduced using a traffic simulation model, and the factors generating heavy traffic congestion are clarified. Moreover, traffic regulation scenarios in the center of Tokyo in the case of a disaster are examined using the simulation model, and their effectiveness is analyzed.

Keywords: Disaster mitigation, Traffic management, Network traffic simulation

Introduction
At 2:46 p.m. on March 11, 2011, the Pacific coast of Tohoku was struck by an earthquake of magnitude 9.0 on the Richter scale (the Great East Japan Earthquake), which had a strength of upper 5 on the Japanese intensity scale in Tokyo. Since the epicenter of the earthquake was offshore of the Sanriku coast, hundreds of kilometers away from Tokyo, there was little damage to structures such as buildings and roads in the center of Tokyo, but heavy traffic congestion occurred. As a contributory factor, it is considered that the proportion of commuters traveling by train is very high (74%) in Tokyo1, meaning that a large number of people had to change their means of journey home owing to the suspension of trains after the earthquake. Moreover, the Metropolitan Expressway (MEX), the main network in Tokyo, was closed for safety checks (which occurs when an earthquake of upper 5 or above on the Japanese intensity scale occurs), causing an increase in the traffic load on local roads. Traffic regulations in the case of an emergency in Tokyo have been amended on the basis of the experience of the Great East Japan Earthquake, since the possibility of a large earthquake centered directly underneath the metropolitan area in the near future has been pointed out.
In this study, the traffic situation in Tokyo after the Great East Japan Earthquake is reproduced using a traffic simulation model that can express the traffic situation based on a traffic flow theory, and the factors generating heavy traffic congestion are clarified. Moreover, traffic regulation scenarios in the center of Tokyo are examined using the model and their effectiveness is analyzed.

Model and study site

In this study, we used the wide-area road network traffic flow simulator SOUND (Simulation on Urban road Network with Dynamic route choice) developed by Yoshii et al. 2) and Okamura et al. 3) of the Institute of Industrial Science, University of Tokyo. The model consists of a route choice submodel and a vehicle movement submodel. It calculates the change in traffic flow with time by repeated application of these two submodels. The route choice submodel has a group of fixed routes that always choose the shortest route and a group of possible routes in which the proportion of vehicles choosing each link changes according to changes in the travel time of each link. In the vehicle movement submodel, vehicles move along links based on the FIFO (first in first out) principle and move to the next link depending on the capacity of each node (intersection).

The object network consists of the main highways in the 23 wards of Tokyo. The number of nodes is 526, the number of links is 1472 and the total length of the links is 1656.8 km. Each link has a length, a number of lanes and a capacity of each direction.

Centroid that traffic demand generates and concentrates is installed two or three in each of the 23 wards and endpoints of the network, hence, 91 centroids are set up in the whole network.

Model calibration

The simulation of the object area under usual conditions is performed by SOUND, and various parameters of SOUND are adjusted to reproduce the usual traffic situation in terms of data observed in the real world (model calibration). The results of a Person Trip Survey conducted by Tokyo Urban Area Transport Planning Conference 4) are used for the traffic demand. This survey was performed to determine movement in Tokyo metropolitan area on a weekday according to the origin and destination, purpose, means and time of travel. On the basis of this data, all trips for which either of the origin or destination is within the 23 wards of Tokyo are extracted. Then, the trips are assigned to each centroid, and an OD table of size 91 x 91 is created.
Because the data obtained here are numbers totaled on a person basis, the data must be converted to the number of vehicles for the simulation, which is carried out assuming 1.3 persons per vehicle. The road network in this study does not include the MEX and minor roads. Therefore, if the total traffic demand is applied to the simulation, unrealistic traffic congestion may be caused in the simplified network. Thus, the traffic demand is multiplied by a constant reduction rate to match the reproduced and observed traffic levels. Table 1 shows the setting parameters of SOUND. Figure 2 shows comparison of a simulated result and observed data measured by traffic detectors of the Metropolitan Police Department (MPD).

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>parameter of Dial distribution $\theta$</td>
<td>sensitivity to link cost</td>
<td>0.01</td>
</tr>
<tr>
<td>maximum speed</td>
<td>free flow speed</td>
<td>40km/h</td>
</tr>
<tr>
<td>route choice interval</td>
<td>time interval between updating route choice probability</td>
<td>60sec.</td>
</tr>
<tr>
<td>scan time</td>
<td>time interval between calculating vehicle movement</td>
<td>3sec.</td>
</tr>
<tr>
<td>packet size</td>
<td>group of vehicles with the same origin and destination</td>
<td>10</td>
</tr>
<tr>
<td>vehicle length</td>
<td>length per vehicle including distance from car in front</td>
<td>8m</td>
</tr>
</tbody>
</table>

Figure 2 - Travel speed of each link at 6 P.M. (Left: SOUND, Right: Observed)

Estimation of traffic demand during the disaster

To reproduce the traffic situation during a disaster, it is important to estimate the traffic demand after the occurrence of the Great East Japan Earthquake. In this study, the traffic demand after the earthquake is estimated by applying the results of various questionnaires on the journeys after the earthquake to the Person Trip Survey used for the model calibration.

First, we estimate how many extra journeys home by car were caused by the suspension of trains. According to the results of the survey 5), 24.0% of people who were away from home at the time of the earthquake went home by car, i.e., their own car, a company car, or by taxi. Under normal conditions, the proportion of journeys home made by car is 13.4%, meaning that the proportion of car journeys increased from 13.4% to 24.0%. As a result, the number of journeys home by car after 3 p.m. was about 2.3 million on that day, 1 million journeys more than usual. From census data, it was estimated that there are about 0.7 million passenger cars and about 0.35 - 0.4 million trucks parked in the 23 wards of Tokyo at any time 6). Since the additional 1 million journeys mentioned above is in good agreement with the number of
parked vehicles in the 23 wards of Tokyo, the increase in the number of the journeys by car is considered to be a realistic value.

Next, the time distribution of the journeys home is estimated. According to the results of a questionnaire 7), about 50% of people started their journey home before 5 p.m. on the day of the earthquake. Moreover, few people started their journey home after 1 a.m. on the following day. Therefore, the estimated 2.3 million journeys home by car were distributed over 10 hours from 3 p.m. to 12 a.m. according to the results of the questionnaire.

The closing of the MEX is considered to have had two main effects on the traffic flow. One is that the vehicles on the MEX at the time of the earthquake left by the nearest exit and entered to local roads. The other is that vehicles that usually use the MEX changed their route to use local roads. As a result of counting up the number of vehicles that left the MEX immediately after the earthquake, obtained from detector data for that day provided by Metropolitan Expressway, Co. Ltd., the number of outflow vehicles was about 6,400 between 2:45 p.m. and 3 p.m., about 12,500 between 3 p.m. and 4 p.m. and about 2,300 between 4 p.m. and 5 p.m. Therefore, in the simulation, about 18,900 outflow vehicles between 2:45 p.m. and 4 p.m. are added to the traffic demand between 3 p.m. and 4 p.m. and about 2,300 outflow vehicles are added to the traffic demand between 4 p.m. and 5 p.m. for each centroid that includes an exit of the MEX to take account of the first effect. The second effect is considered by adjusting the reduction rate by which the traffic demand is multiplied since the MEX and the minor roads are not included in the simulation network.

Fig. 3 shows the hourly traffic demand used for the simulation of traffic under usual conditions and during the disaster. It is estimated that about 0.6 million journeys started between 3 p.m. and 4 p.m., immediately after the earthquake, which is more than twice the usual.

Moreover, in the center of Tokyo, the roads were full of pedestrians, which is considered to have reduced the capacity of the road network owing to the reduced throughput of intersections. To consider this effect, the capacities of the intersections are uniformly decreased by 10% after the earthquake in the simulation.

**Reproduction of the traffic conditions in Tokyo during the disaster**

Fig. 4 - Fig. 6 show the travel speeds observed by the detectors of the MPD and the calculated speeds obtained by SOUND after the earthquake occurred. According to the observed data, gridlock traffic congestion that speed along links of 10 km/h or less had started...
in the center of Tokyo by 4 p.m. By 6 p.m., links with a speed of 5 km/m or less had spread to the suburbs, and the whole area of Tokyo was suffering from heavy traffic congestion. This traffic congestion was still continuing in some places at 5 a.m. the following morning. On the other hand, according to the simulation results, although the area of traffic congestion in the center of Tokyo at 4 p.m. was slightly narrower, the areas of congestion at 6 p.m. and 5 a.m. the following morning were in reasonable agreement with the observed data. Therefore, the time at which traffic congestion first occurred, the development of gridlock situation and its recovery could be reproduced by the simulation.

The occurrence and spread of the gridlock in the road network after the earthquake is considered to be the cause of the widespread and long traffic congestion. In addition to the data observed by the MPD, according to taxi probe data collected by Fujitsu Co. Ltd., the gridlock first occurred simultaneously at intersections in the city center where the density of links is high, then it spread from the city center to the suburbs and from the major roads to minor roads. This feature was also reproduced by the simulation. These findings show that although in some cases the main cause of the gridlock was the increase in traffic volume caused by the outflow from the MEX, the fundamental cause was the increase in traffic demand and the decrease in the capacity of intersections caused by the increase in pedestrians.
Evaluation of traffic control policy in disaster case by using traffic simulation model

Adjustment of starting time of return home

After the Great East Japan Earthquake, because of the concentration of return trips in a short time after the earthquake, the network became supersaturated in stretches, resulting in gridlock. It is considered that this led to the heavy and prolonged traffic congestion. We carried out simulations for two cases in which the start time of the journey home is uniformly distributed from 3 p.m. to 12 a.m. and from 3 p.m. to 3 a.m. assuming the total traffic demand after the Great East Japan Earthquake. Fig. 7 shows a comparison of the average travel speeds for the case of no adjustment of the starting time and for the two hypothetical cases. When the traffic demand is uniformly distributed between 3 p.m. and 12 a.m., although the sharp fall in the travel speed after the earthquake can be prevented, it falls gradually over time and becomes almost the same speed as that in the case of no time adjustment at 11 p.m. Even if the traffic demand is uniformly distributed, it still slightly exceeds the network capacity, meaning that the traffic congestion grew gradually. On the other hand, when the traffic demand is uniformly distributed between 3 p.m. and 3 a.m., the travel speed does not fall after the earthquake and journeys can be made at the usual travel speed (about 25 km/h). Therefore, limiting the number of journeys home starting immediately after the earthquake and ensuring a uniform distribution of the start time to keep the demand level below the network road capacity are effective for controlling the traffic congestion.
Evaluation of traffic control policy in disaster case by using traffic simulation model

Traffic regulation on designated roads

The traffic regulations in the case of a major earthquake of lower 6 and above and an earthquake of upper 5 on the Japanese intensity scale were corrected on the basis of experience of the Great East Japan Earthquake. That is, some routes will be designated for exclusive use by emergency vehicles and the inflow into roads inside of the Kan-nana ring road from outside the ring road will be regulated after the occurrence of such an earthquake.

Here, the simulation results in the case of introducing these regulations as above are compared with the traffic flow after the Great East Japan Earthquake. Fig. 8 shows the travel time of an emergency vehicle traveling to the center of Tokyo from outside the Kan-nana ring road. It can be seen that the travel time is greatly reduced by implementing the regulations. Since Route 1 has a long section that is designated for exclusive by emergency vehicles, the effect of the traffic congestion is eliminated and the travel time is drastically reduced. Although Route 2 does not have sections designated for emergency use, the effect of the regulations on improving the traffic conditions can be seen. However, in the areas surrounding designated roads and outside of the Kan-nana ring road, the traffic congestion tends to temporarily become more severe.

Figure 8 - Average travel speed in the case of traffic regulations on designated roads

Conclusions

In this study, the traffic situation in Tokyo after the Great East Japan Earthquake was reproduced using a traffic simulation model, and the effects of traffic regulation scenarios on traffic flow in the center of Tokyo in the case of a future major earthquake were analyzed. The results of this study reveal the importance of continually maintaining a level of traffic demand below the network capacity by promoting traffic flow from the center of Tokyo to the outside, by regulating the flow from the outside of Tokyo to the city center and by controlling the time distribution of traffic demand. Moreover, gridlock greatly decreases the network capacity, causing congestion to expand rapidly to a large area.

In addition, to regulate traffic and adjust traffic demand in Tokyo, which usually has a high
volume of traffic traveling around a complicated road network, building cooperation between related organizations and developing a strategy to ensure a smooth shift from the usual system to an emergency system are future issues. Moreover, the reproducibility of gridlock in traffic simulations still remains as a problem whose solution is an important technical subject.

Acknowledgement

This study is a collaborative work involving the Office for Youth Affairs and Public Safety of Tokyo Metropolitan Government, the Traffic Control Division of the Metropolitan Police Department and the Institute of Industrial Science, the University of Tokyo. The Metropolitan Police Department and Metropolitan Expressway Co. Ltd. provided the detector data and Fujitsu Co. Ltd. provided the probe data. The authors would like to thank the relevant parties for their support.

References