# Estimation of Travel Demand and Network Simulators to Evaluate Traffic Management Schemes in Disaster

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## 1. Introduction

Traffic management in disaster has been a hot issue among traffic engineers since the Kobe earthquake in January 1995. Because unusual traffic demand was generated onto the damaged network, enormous traffic problems were encountered even in highways without any damage. In addition, we faced quite a number of urgent traffic demand such as rescue, emergency medial care, restoration of life lines, and so on. Through this experience, the importance of traffic management during disaster is realistically noticed.

After the earthquake, many issues on road and traffic management have been vitally discussed. And, for the scenario earthquake in Tokyo, government officials made disaster mitigation plans which include infrastructure planning, enforcement schemes, supply logistics, information provision, traffic regulation, traffic demand management, etc. However, we may not quite understand that how much and what kind of demand appears, what traffic condition arises under the mitigation policy, and if the plan is feasible.

To answer these questions, this research first proposes a method to estimate traffic demand mainly for a 2-week period after a disaster and second develops traffic simulation models which can evaluate management strategies beforehand.

## 2. Estimation of Traffic Demand in a Disaster

### 2.1. Outline

In order to evaluate management strategies, we have to know the damage in the infrastructure supply side as well as the traffic demand characterized by the disaster. Although many researchers and practitioners have analyzed the level of damage expected due to a certain magnitude of an earthquake in the supply side, the demand estimation has not been well studied yet. Since our travel behavior would be quite different from the ordinary situation, this research proposes a method to estimate the demand based upon the interview survey in Kobe/Osaka on travel behavior after the Kobe earthquake. Then, the method is applied to the Tokyo prefecture to evaluate the Origin-Destination (OD) traffic demand due to the scenario earthquake set up by the Tokyo Metropolitan Government[6)].

Roughly speaking, travel demand can be considered in two kinds: trips by ordinary people and trips by emergency vehicles. We expect that the total amount of trips by emergency vehicles may be much smaller than trips by ordinary people. Also, the demand due to the emergency activities can be separately estimated based on the degree of damage and its spetial distribution. Therefore, in this study, we focus only on the trips by ordinary people during a 2-week period after an earthquake.

### 2.2. Interview Survey in Kobe/Osaka

Japan Safe Driving Center implemented the interview survey to drivers who visited the Driving License Centers to renew their licenses[5)]. The total number of 3,200 interviewees replied their travel behaviors during a 2-week period after the Kobe earthquake. This survey is quite valuable to understand trip purposes, times, modes and distances immediately after the earthquake.

### 2.3. Trip Purposes Considered

In the interview survey, trips are classified into the following six purposes: (1) immediate evacuation (within 48 hours), (2) relief and rescue, (3) inquiry on safety, (4) evacuation for temporal stay, (5) acquisition of foods and clothes, and (6) checking up offices/schools. On the other hand, as mentioned later, we intend to estimate the demand in the Tokyo prefecture under the scenario earthquake occurred at 6 pm. in the evening on a weekday. In this occasion, lots of return-to-home trips would be generated, although the interview survey did not include this trip purpose. As a whole, this research considers the five trip purposes below:

(1) evacuation: both immediate evacuation within 48 hours and evacuation for temporal stay to secure places to live mainly after 48 hours from the earthquake.
(2) return-to-home: trips from offices/schools to homes.
(3) relief/rescue and inquiry on safety: trips on relief/rescue as well as trips to confirm safety of relatives and acquaintances. This category also includes trips checking up their homes from evacuation camps.
(4) acquisition of foods and clothes: trips to obtain foods and clothes to live.
(5) checking up offices/schools: trips to check up offices and schools from homes and also from evacuation camps.

### 2.4. Demand Estimation

For each of the above trip purposes, the demand estimation method is explained below.

(1) Evacuation

Trips for evacuation within 48 hours are assumed to arise in damaged districts and go to designated open spaces for evacuation. Daytime population in each district is multiplied by the percentage of this trip purpose and by the temporal distribution of the trip during a 2-week period. The percentage of trip purposes and the temporal trip distribution are based upon the interview survey as shown in Fig. 2.1.

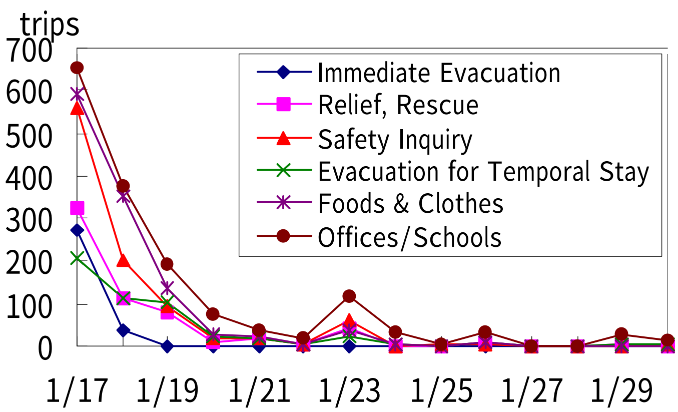

Fig. 2.1 Trip Shares by Purposes over the 2-week Period

Trips for evacuation for temporal stay are assumed to be generated after 48 hours and go to evacuation camps such as high schools, public halls, etc. or to relatives outside the damaged area. Nighttime population is multiplied by the percentage of this trip purpose and by the temporal trip distribution to obtain the generated trips in each district. Then, to estimate the trip distribution, the generated trips are allocated to each of the districts in proportion to capacities of evacuation camps in a district. (Trips to relatives outside are neglected, since the locations of relatives' homes cannot be known.)

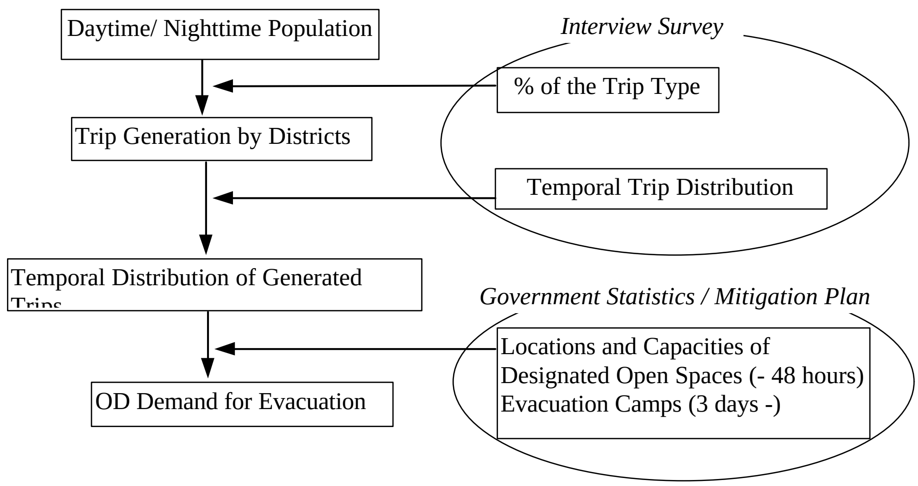


Fig. 2.1. Estimation of Trips for Evacuation

(2) Return-to-Home

This is a trip purpose from a place at the earthquake to a district of his/her home. First, daytime population in each district is multiplied by the percentage of commuters to estimate the generated trips by districts. Second, assuming that the temporal trip distribution is the same as one for evacuation, the temporal distribution of the generated trips is obtained. Third, based upon the person trip survey in a normal situation, the trip distribution is estimated.

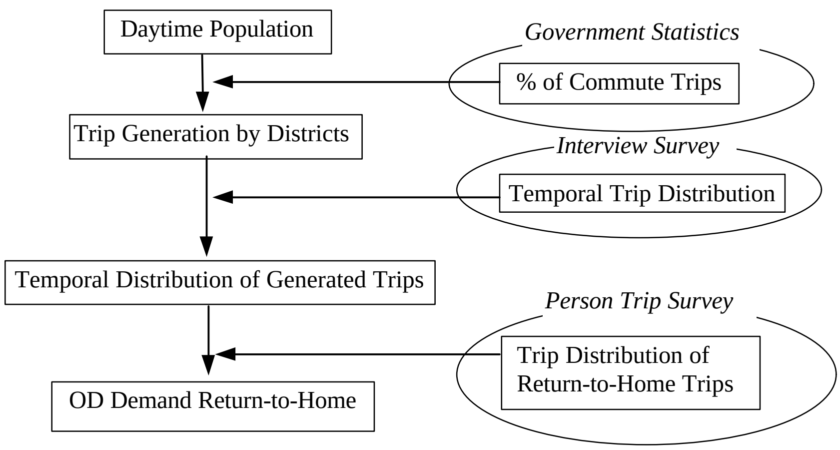


Fig. 2.2. Estimation of Return-to-Home Trips

(3) Relief/Rescue and Inquiry on Safety

All these trips are assumed to be generated from residential districts just for simplicity, although in reality the trips would be also generated from designated open spaces for evacuation and evacuation camps. And their destinations are either districts with casualties or hospitals. Similarly, Nighttime population is multiplied by the percentage of the trip purpose and by the temporal trip distribution to obtain generated trips. Then, the generated trips are allocated to each of the districts in proportion to the number of hospitals and casualties.

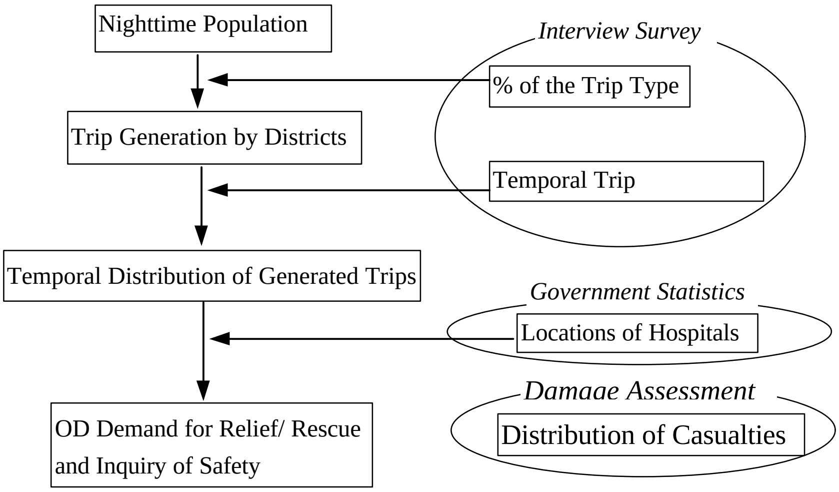


Fig. 2.3. A Flow-chart of Relief/ Rescue and Inquiry on Safety Trip Estimation

(4) Acquisition of Foods and Clothes

Trips in this purpose are assumed to start from residential districts to distribution center for emergency supply such as municipal offices/ schools and to private shops. Nighttime population is multiplied by the percentage of the trip and by the temporal trip distribution to obtain the trip generation over the 2-week period. Then, the generated trips are allocated to districts in proportion to the number of shops and the distribution centers.

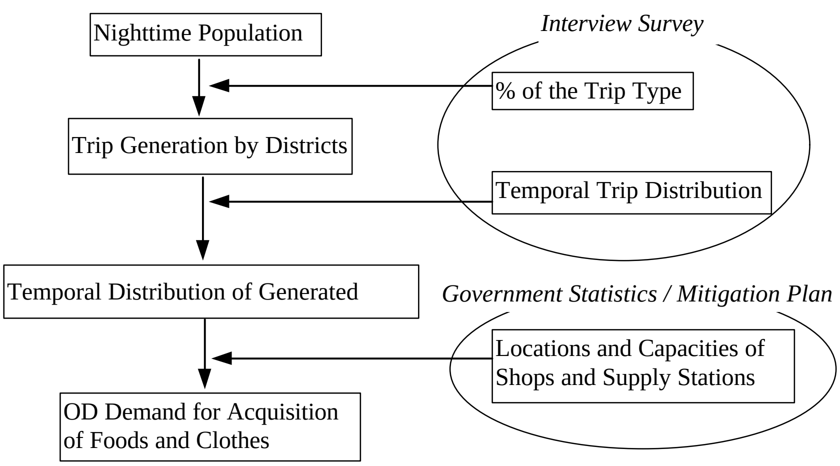


Fig. 2.4. A Flow-chart for Estimation of Acquisition of Foods and Clothes

(5) Checking up Offices/ Schools

These trips are assumed to be generated from residential districts and absorbed in the working places. Nighttime population is multiplied by the percentage of the trip purpose and by the temporal trip distribution to obtain generated trips. Then, the trip generated is allocated to the districts according to the person-trip survey in a normal situation.

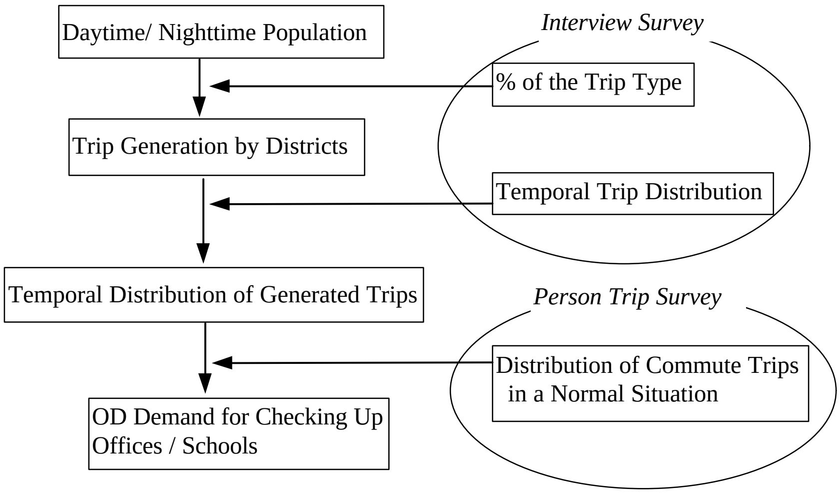


Fig. 2.5. A Flow-chart for Estimation of Checking Up Offices / Schools

The above procedure for each of five trip purposes estimates the origin-destination demand in person trips by all modes. Person trips by vehicles are then obtained by multiplying the share of vehicle use observed from the interview survey. In order to estimate vehicle trips, we further need the car occupancy. However, the occupancy cannot be known under the disaster condition, but it is expected larger than in a normal condition.

## 3. Application to the Tokyo Prefecture

### 3.1. Premises

This study follows the amount of damage estimated in the damage accessment for the scenario earthquake by the Tokyo Metropolitan Government. An earthquake of magnitude 7.2 is supposed to hit the center of Tokyo at 6 pm. in the evening. The government estimates infrastructure damages, the number of casualties, etc. by each of the districts. We also follow the disaster mitigation plan by the government to figure out locations and capacities of evacuation camps and stocks of foods and clothes. Daytime and nighttime populations, distributions of schools, public halls and shops are based upon the national statistics. And the data from the person trip survey are utilized especially for estimation of commute and return-to-home trips.

### 3.2. Results

Figure 3.1 shows the share of person trips by purpose. On the first day, return-to-home trips share more than 50% because the scenario earthquake occurs at 6 pm. in the evening.  On the other hand, on the third day, activities of relief/ rescue and inquiry on safety share about 25% and the almost same share is found for acquisition of foods and clothes.  For Fig. 3.1 (b), the number of person trips on the first day is about 1.4 trips/day, which is smaller than the normal dayly trips of about 2.5 trips/day. And, on the third day, only 0.2 trips/day was observed, since the survey is just on activities related to the earthquake.  There must be quite a number of trips not closely related to the disaster on the third day and thereafter.

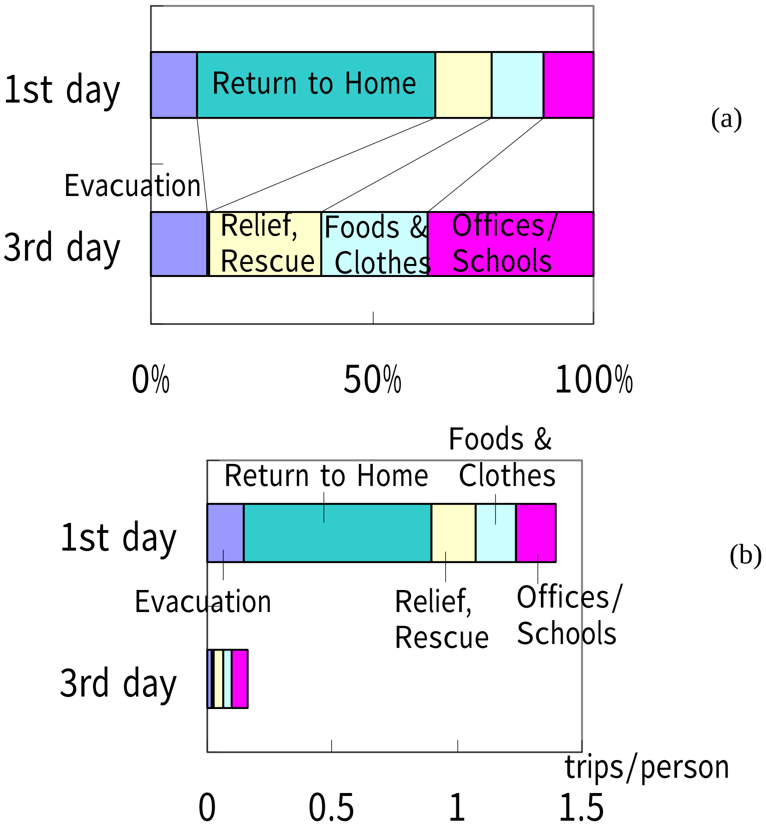


Figure 3.1  The share of Person Trips by Purpose

Figures 3.2 shows total generated person trips by all modes in each of ten districts on the first day after the scenario eqrthquake.  Compared with the number of trips in the normal condition, more trips are concentrated at the center of Tokyo.

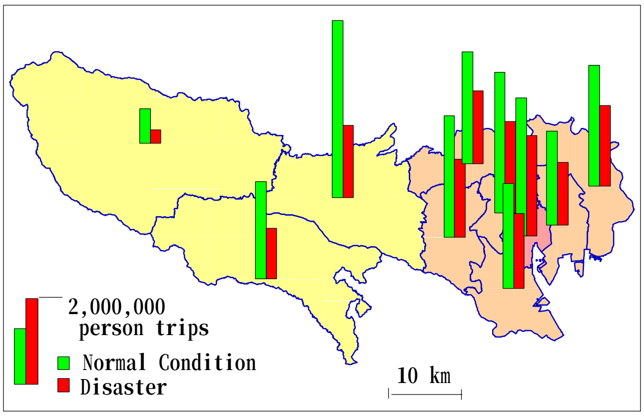


Fig. 3.2 Total Generated Person Trips by All Modes on the First Day

Figure 3.3 shows person trips by vehicles on the first day. At the center of Tokyo, more than double of trips are generated by vehicles than those in a normal condition. Although the exact vehicle occupancy cannot be known, the occupancy during disaster seems higher than about 1.2 - 1.3 [persons/vehicle] in a normal condition. Therefore, the number of vehicles traveling immediately after the scenario earthquake may not be larger as seen in the person trip base.

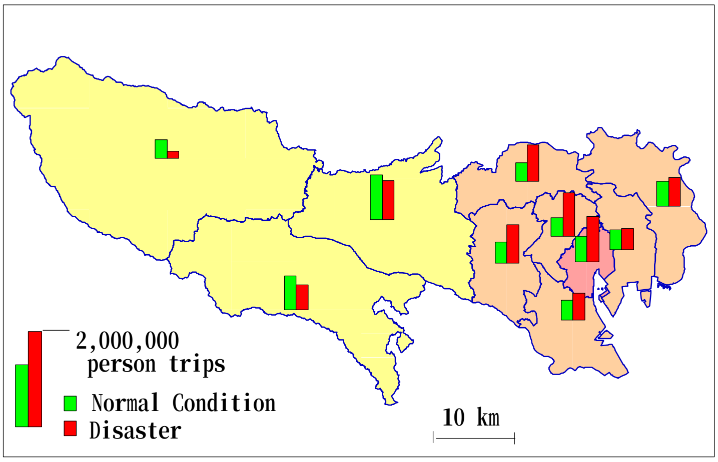


Figure 3.3 Person Trips by Vehicles on the First Day (Vehicle Users)

Figures 3.4 and 3.5 compare the trip distribution by vehicles on the first day with one in a normal condition. As we see in the trip generation, widths of lines are generally wide during disaster. Although change in the OD pattern is not very obvious, the 23 wards seem to be tightly connected by the larger amount of trips.

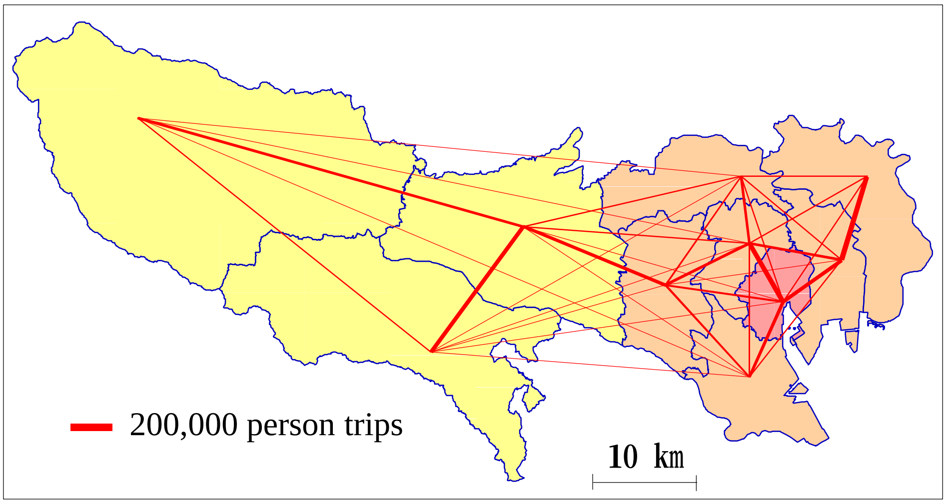


Fig. 3.4 Trip Distribution in a Normal Condition on the First Day (Vehicle Users)

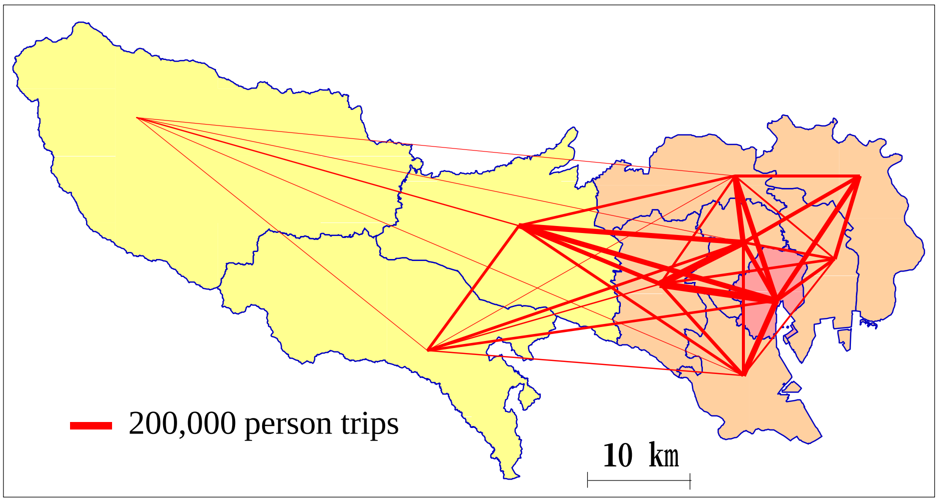


Fig. 3.5 Trip Distribution in the Disaster on the First Day (Vehicle Users)

## 4. Microscopic Simulation Models to Evaluate Traffic Management Schemes

In order to evaluate traffic management scheme in advance and to prepare reliable mitigation plan, it is necessary to develop tools which estimates the traffic condition during disaster. For the recent several years, we have been developing two types of microscopic traffic simulation models with dynamic route choices, AVENUE[1, 2] and SOUND[3]. AVENUE may be applied to a surface street network of which maximum sizes are approximately 5 x 5 square kilometers. On the network, AVENUE has detailed traffic signals and lanes so as to evaluate the effects of signal control scheme and traffic regulations. On the other hand, SOUND deals with a larger network with a few thousands of links and nodes. In SOUND, a link has no lane (always one lane), but traffic density is properly controled based on the flow-density relationship even for a highway with two or more lanes in one direction.

Our Simulation models requires the following input data:

- network data (link connection data)
- link capacity (including signal parameters)
- time dependent Origin-Destination matrices
- parameters in route choice model

In addition to the basic function of the models, traffic management scheme in disaster may require the following special properties in the models:

- closing roads for non-urgent vehicles,
- traffic regulations such as one-way treatments, turning prohibitions,
- on-street parking,
- exclusive lanes for urgent vehicles or buses,
- travel information broadcast,
- signal control with priority direction,
- routing around for special district, etc.

The evaluation of these scheme requires to manage different types of drivers and vehicles on the same network. Microscopic simulation offers advantages to the conventional approaches based on flow assignment technique because of the following reasons:

1) microscopic simulation can directly evaluate the service level of urgent vehicles or buses by computing their travel times,
2) flow assignment technique hardly incorporates lane management and signal control,
3) microscopic simulation easily incorporates route choice behavior for multiple drivers' layers, etc.

Following sections demonstrate the applications of AVENUE and SOUND for the evaluation of traffic management scheme in disaster.

### 4.1. Evaluation of Bus Lane Configurations using AVENUE

Through the survey at the Kobe earthquake in 1995, several remarkable bottleneck intersections were pointed out and some of them could be fixed with slight modifications on lane usage or signal control[4)]. Figure 4.1 illustrates Nishinomiya-honcho-crossing on Route 43. This intersection was the major bottleneck for the traffic from Kobe to Osaka, and the length of the traffic jam heading from this intersection sometimes reaches more than 15 kilometers.

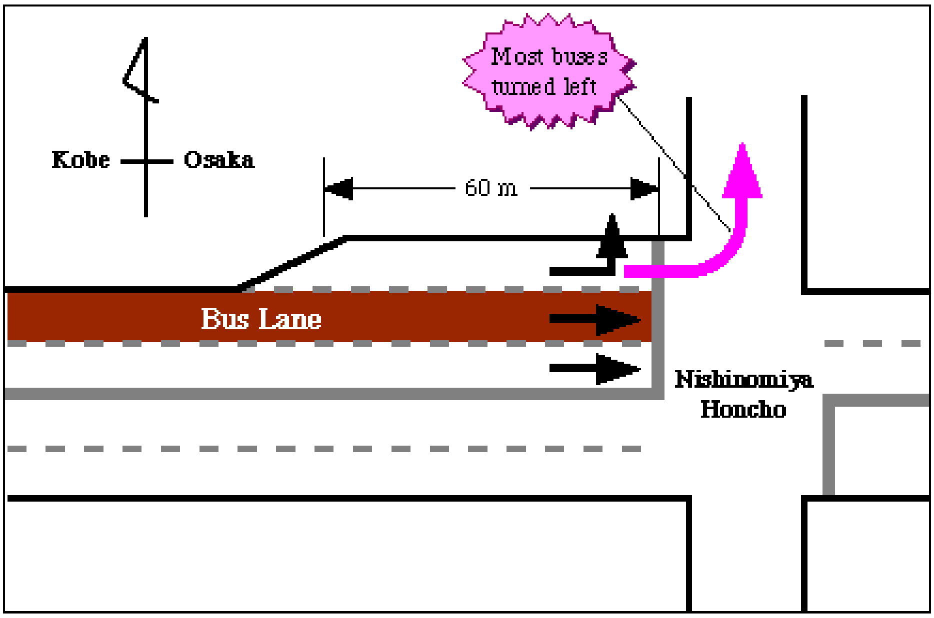


Fig. 4.1. Nishinomiya-Honcho Intersection

At this intersection, the left lane on the link bound to Osaka was designated as a bus lane. The bus lane reached to the downstream end of the link, nevertheless most buses turned left through the left side turn pocket. Therefore, the downstream end of the left lane was not fully used by ordinary vehicles, which reduces the capacity at this section.

Figure 4.2 illustrates one of the measures to fix this bottleneck with modification on the bus lane designation4), i.e. to shorten the bus lane up to 60-70 meters upstream and let the both two lanes be open for ordinary vehicles near the intersection. This idea may increase the throughput for the through traffic flow.

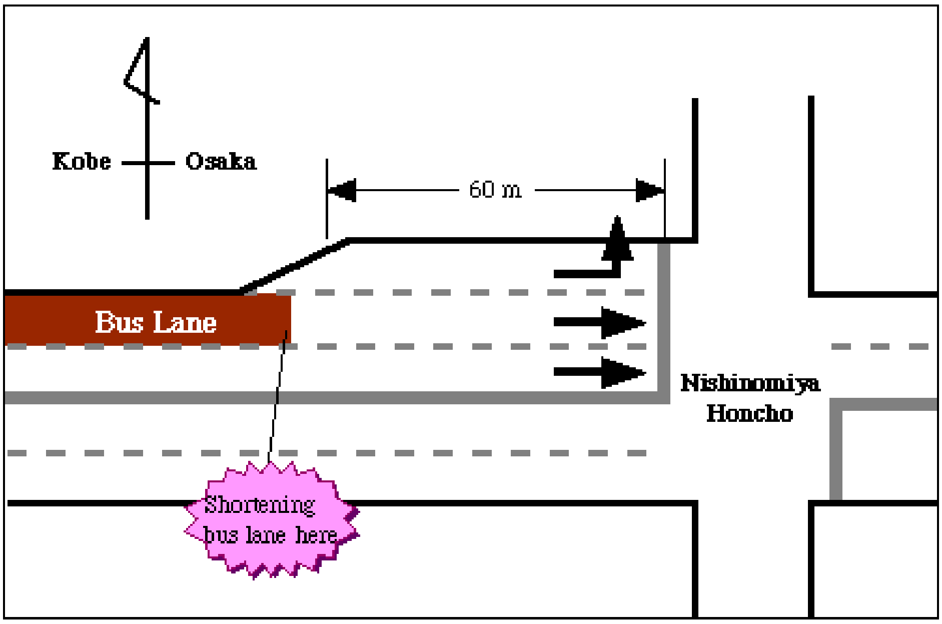

Fig. 4.2. Modification on the Bus Lane Configuration

In order to evaluate how this modification would improve the bottleneck capacity, we applied AVENUE for both "Before" and "After" the modification cases. As listed below, both cases have the same saturation flow rate, the same signal cycle and split, and the same arrival traffic demand, but have different designations of bus lanes.

| | "Before..." | "After..." | |
|---|---|---|---|
| S.F.R. | 1800 | 1800 | [veh/hour of effective green/lane] |
| Cycle | 120 | 120 | [sec.] |
| Split | 62.5 | 62.5 | [%] for major direction |
| Demand | 1150 | 1150 | [veh/hr] for straight |
| | 180 | 180 | [veh/hr] for left turn |

Figure 4.3 shows display image of the simulation with AVENUE. The displayed scene is at the time of 11'56" passing from the beginning, however the upper link of "Before" case has been already congested while the lower link of "After" case has not.

The result of both cases are compared in terms of cumulative throughput at the intersection and travel times of buses. Figure 4.4 is the comparison of the cumulative number of vehicles passing the intersection in straight direction. Clearly the slope of "Before" case is less steep than "After" case, i.e. the capacity at this section has been improved by the modification on the bus lane designation. Figure 4.5 shows the travel time of buses (from time a bus generated to time it passes through the intersection) for both cases. Big difference can not be found but even getting better in this comparison, therefore we may conclude that shortening bus lane as in this modification will not affect the service level of buses.

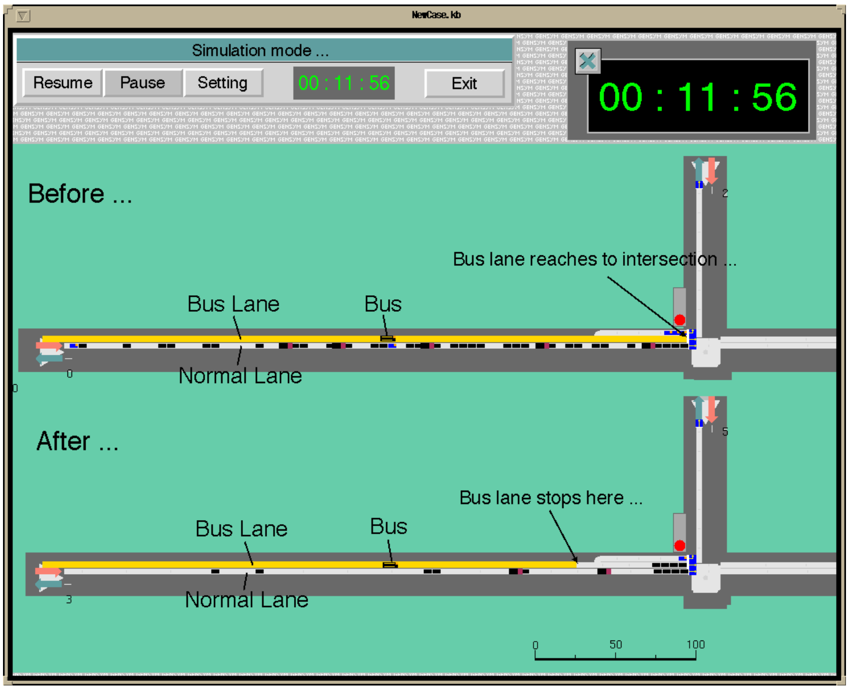


Fig. 4.3. Display Image of AVENUE

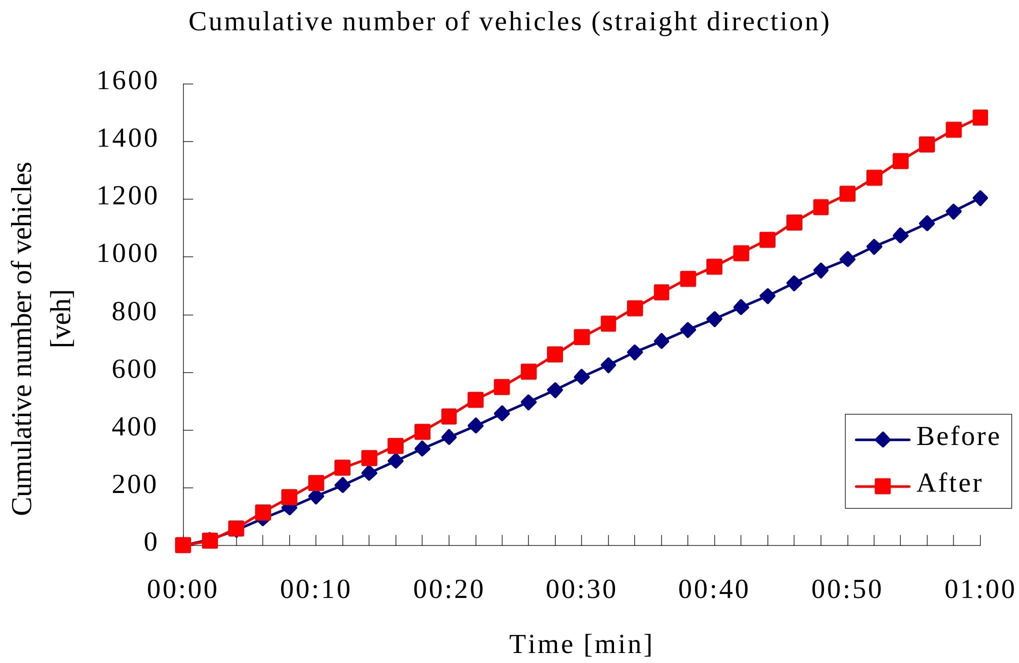


Fig. 4.4. Comparison of Throughputs at the Intersection

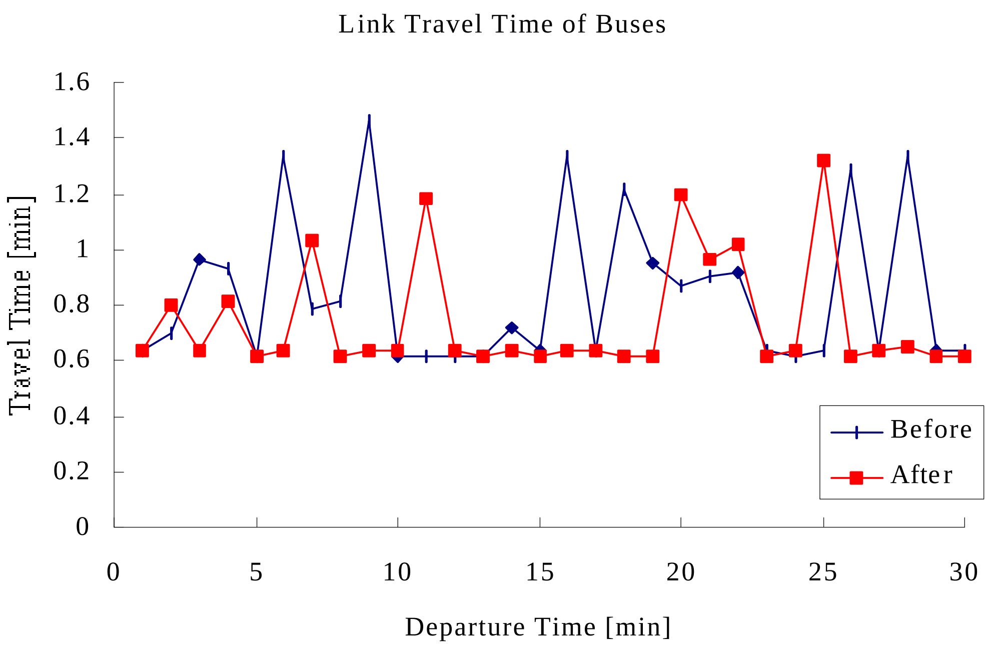


Fig. 4.5. Comparison of Travel Times of Buses

## 4.2. An Application of SOUND

### 4.2.1. A Study Network

Fig. 4.6 shows the network used in our case study. It must be time consuming that we prepare network data and link capacities. Therefore, we developed an software to prepare these data. The software requires digital road map data, and digital road map are displayed and only thing we have to do is selection of simulation areas on the display like Fig. 4.7. Once simulation areas are selected, our software automatically prepares network connection data with link data such as distance, width(number of lanes) etc. Link capacities are also required and it depends on signal parameters. We have to preset signal parameters together with link capacities.

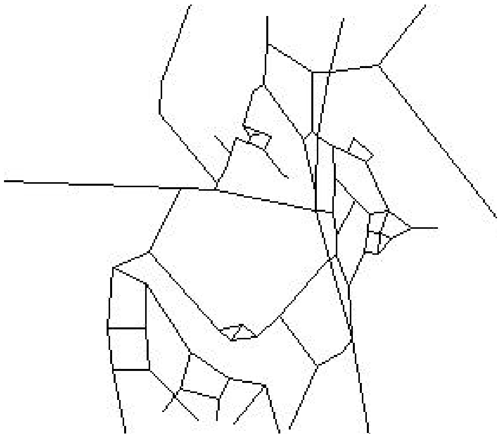

Fig. 4.6. A Study Network

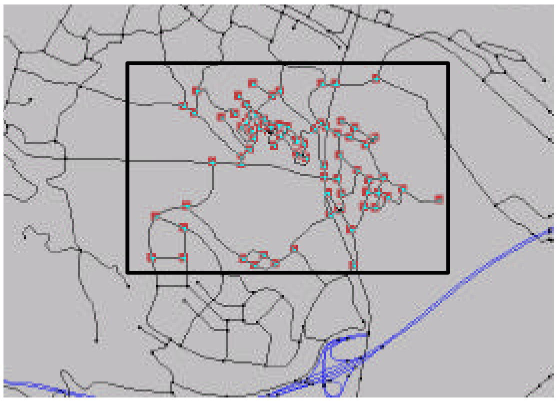

Fig. 4.7. Display Image on the Software

### 4.2.2. OD Demand

Time dependent OD matrices are also required in our simulator. Generally, it is prepared through an investigation and using an estimating method. And more, as it is difficult to estimate OD volumes after an earthquake, we have to prepare several scenarios in which OD pattern is changed from usual one, and the simulator should be implemented for every scenarios.

### 4.2.3. Route Choice Behavior

Depending on network traffic condition, each vehicles must change his route. In order to estimate this kind of behavior, the simulator has to incorporate driver's route choice. We employ the Dial's Logit assignment with parameter in which route choice probabilities are calculated from Eq.(4.1).

$$Prob(r) = \frac{exp(-q \cdot T_r)}{\sum_i exp(-q \cdot T_i)} \qquad (4.1)$$

where

| | | |
|---|---|---|
| *Prob(r)* | = | route choice probability of route *r*, |
| $T_r$ | = | travel time of route *r*, |
| q | = | non-negative parameter |

### 4.2.4. Scenario

As an example, we suppose traffic condition just after an earthquake. In this scenario, it is assumed that all signal systems are damaged and OD pattern does not changed caused by earthquake. We express this effect of damage as reduction of saturation flow rate at each intersection approach. The reduction rate at each approach is set between 20-80% using random sequence numbers. Fig.4.8 shows the display image of our tool. Displayed area size can be changeable. Fig.4.9 and 4.10 show traffic conditions at 30 min. after the earthquake in the average speed and in the vehicle density of each link respectively. Using these images, we can understand what will be happen in a road network. These results would be useful to propose a effective and feasible plan.

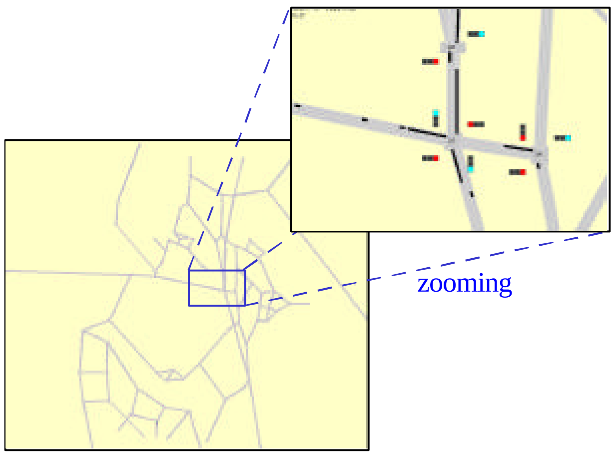


Fig. 4.8 Display Image of SOUND

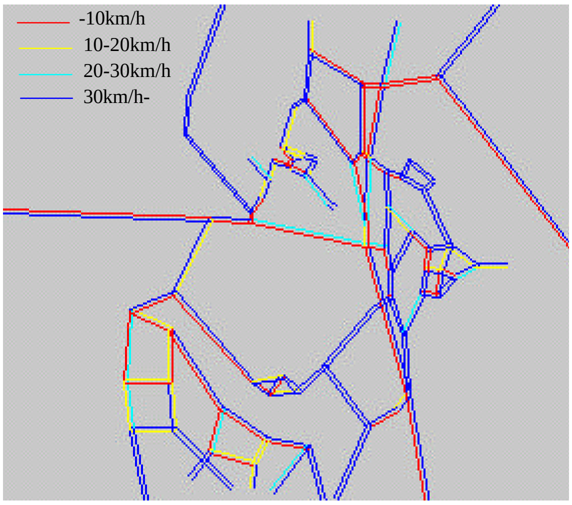


Fig. 4.9. Average Speed at 30 min. After the Earthquake

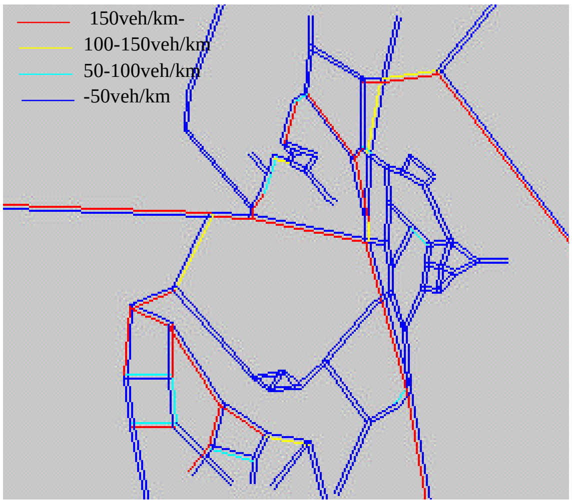


Fig. 4.10. Vehicle Density at 30 min. After the Earthquake

## 5. Summary and Future Research Needs

This research first proposes a methodology to estimate travel demand during a disaster and applies to the Tokyo prefecture based upon the damage accessment for the scenario earthquake by the Tokyo Metropolitan Government. Second, two kinds of traffic simulation models are developed to evaluate traffic condition in advance when several management schemes such as information provision, traffic regulations, travel demand management, etc. are implemented.

There would be still many rooms for future research especially on travel demand estimation. The major research needs are summarized as follows:

(1) The proposed method should be validated. The validation can be only possible by applying to the Kobe earthquake.
(2) Travel behaviors investigated by the interview survey after the earthquake should be interpreted in relation to the regional and network structures so as to hold the transferability of the estimation

method.

(3) Reliable range of the estimated travel demand should be analyzed.

(4) Travel demand should be also estimated more time-dependently to represent phases after the earthquake.

(5) Traffic demand on emergency activities should be added to the demand of ordinary people.

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