PRELIMINARY STUDY ON POST-EARTHQUAKE INFORMATION SHARING FOR FACILITATING EMERGENCY ACTIVITIES

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Abstract

Earthquake damage to road structures can disrupt traffic flow. Since car drivers do not have disrupted road information immediately after earthquakes, they can aggravate the disrupted traffic by being involved in it. Such traffic transition to more congested states can severely delay emergency activities. Recently, speedy damage detection technologies for road structures such as bridges have been developed. If damage to road structures is adequately detected and disrupted road information is wisely shared as well as congested road info, emergency activities can be facilitated by traffic flow optimization. However, we can not dismiss the possibility that ordinary vehicles disturb emergency activities by taking optimal routes. In this paper several information sharing cases are assumed and exercised through dynamic traffic simulations, and their effectivities are discussed.

Introduction

Road traffic flow can be disturbed by earthquake damage to road structures. Since post-earthquake damage assessment for national highways is basically conducted by inspection tour, it takes time to figure out overall damage information. In the case of the 1995 Kobe Earthquake it took 6 hours to figure out half of the overall damage to nationally administrated roads. Thus, car drivers generally do not have disrupted road information immediately after earthquakes. The delay in collecting and sharing disrupted road information can further aggravate earthquake-induced traffic congestion and severely disturb post-earthquake emergency activities such as rescue and fire fighting operations.

Recently, speedy damage detection technologies for road structures such as bridges have been developed so that the time for damage assessment can be shortened [e.g. Sakai et al., 2006]. Technologies to collect and share traffic flow information have been also developed and introduced into practices so that ordinary car drivers can optimize their route choices. If earthquake damage to road structures is adequately detected and disrupted road information is wisely shared as well as congested road information, traffic congestion may be relieved and emergency activities can be facilitated. However, if the post-earthquake road information is shared among ordinary car drivers as well as emergency personnel without any consideration, emergency activities can be disturbed by optimal route selection conducted by ordinary vehicles. Therefore, effectivities of various information sharing strategies should be evaluated and discussed.

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In this preliminary study, dynamic traffic simulation program is first developed in order to reproduce post-earthquake traffic states under variously assumed information sharing cases. The developed program is verified based on Standard Verification Process for Traffic Flow Simulation Model [Traffic Simulation Committee, Japan Society of Traffic Engineers, 2002]. Dynamic traffic simulations are conducted under the following three information sharing cases. (1)Priority case: Immediately after earthquakes only emergency personnel share disrupted road information. (2)Sharing case: Immediately after earthquakes both of emergency personnel and ordinary car drivers share disrupted road information. (3)Basic case: Disrupted road information is not shared immediately after earthquakes.

Since ordinary car drivers optimize their routes to destinations based on obtained road information, traffic state changes over time depending on the employed information sharing cases and the traffic transition impacts on emergency activities. In order to evaluate the effectivities of the information sharing cases, travel times for emergency vehicles with various origins and destinations are observed. The effectivities of the assumed information sharing cases are discussed by comparing the observed travel times.

Fundamental Theory for Dynamic Traffic Simulation

Car Following Model [Kuwahara et al., 1993] is employed in the dynamic traffic simulation program. In the model vehicles on road sections are moved at every scanning time intervals dt from downstream side based on pre-specified flow-density relationship. Figure-1 shows the concept of how to move vehicles on a road section. Suppose two vehicles A and B are running on a road section at time t as shown in the upper picture of Figure-1. At time $t + dt$, front vehicle A is first moved by some distance as in the lower figure. If vehicle B moves by the distance L in this situation, the space between vehicles A and B is S at time $t + dt$. The corresponding density is inverse of the space. Based on the pre-specified flow-density relationship, corresponding flow q is specified. The assumed speed v for the movement of vehicle B is now derived from the speed-density relationship shown in equation (1) and moving distance L' can be obtained. Vehicle B is moved so that the distance L' agrees with the distance L assumed in the above.

$$q = k \times v \qquad (1)$$

where:

q : Traffic flow [veh/hr]

k : Traffic density [veh/km]

v : Velocity [km/hr]

Verification of the Developed Simulation Program

The reproducibility of traffic states simulated by the developed program is verified according to Standard Verification Process for Traffic Flow Simulation Model [Traffic Simulation Committee, Japan Society of Traffic Engineers, 2002]. Some examples of the verification are shown in the appendix.

Optimal Route Choice Function Employed in Traffic Simulation Program

Optimal route choice function is introduced in the developed traffic simulation program. Link travel time for each vehicle is memorized in simulations so that average link travel time is periodically updated. Route choice probabilities in turn are reevaluated according to the Dial's Logit assignment shown in equation (2). The route choice probabilities are reflected in both of route changes conducted on ways to destinations and route choices conducted at origins. Note that the optimal route choice function employed in the simulation program just approximately reproduce equilibrium flow state since travel times for various routes change over time in simulations.

$$\mathrm{Pr}\,ob(r) = \exp(-\theta Tr) / \sum_i \exp(-\theta Ti) \qquad (2)$$

where:

$\mathrm{Pr}\,ob(r)$: Route choice probability of route r

Tr : Average travel time of route r, which is regularly updated based on updated average link travel times

θ : Non-negative parameter

Assumed Types of Vehicles

Three types of vehicles are assumed in traffic simulations; (1) Emergency vehicles: they update the routes to destinations based on average link travel time information which is regularly updated and obtained through hypothetical information sharing system operated by emergency personnel. (2) Ordinary vehicles with VICS (Vehicle Information and Communication System): They update the routes to destinations based on average link travel time information which is regularly updated and obtained through VICS. (3) Ordinary vehicles without VICS: They update the routes to destinations based on average link travel time which is regularly updated and obtained through road information boards only when they pass through the boards.

Disrupted road information is also included in the information obtained from the information sharing system operated by emergency personnel, VICS and road information boards, if the disrupted road info is already released to the corresponding types of vehicles. The information sharing system operated by emergency personnel and VICS update the average link travel time information every 5 minutes, while road information boards update the average link travel time information every 15 minutes. Emergency vehicles and ordinary vehicles with VICS update the routes as soon as the information is updated. Ordinary vehicles without VICS update the routes based on the information most recently updated and displayed on road information boards as they pass through the boards. Ordinary vehicles with and without VICS are assumed to account for 90% and 10%, respectively.

Developed Road Network

Hypothetical road network shown in Figure-2 is assumed for traffic simulation. The area size is about 5 km times 5 km. River runs down through the road network and six bridges cross the river. In the traffic simulations the two bridges with circular marks on are assumed to collapse due to the earthquake event. Speed regulations, traffic capacity and number of traffic lanes are assumed as shown in Figure-3. Black rectangles indicate road information boards.

Assumed Information sharing Cases

For all the assumed information sharing cases, emergency vehicles chose or update the routes based on the average travel time information obtained from the information sharing system operated by emergency personnel. Similarly, ordinary vehicles with VICS chose or update the routes based on the information obtained from VICS. Ordinary vehicles without VICS chose the routes at origins providing free flow speed for all links and update the routes based on the information most recently updated and displayed on road information boards when they pass through the boards. In the case that emergency vehicles and ordinary vehicles with VICS accidentally get to the collapsed bridges after earthquake event, they turn around and update the routes based on the information obtained from the system operated by emergency personnel or VICS. On the same occasion, ordinary vehicles without VICS also turn around and update the routes based on the information most recently obtained from road information boards.

After earthquake damage detection to the bridges is completed, following information sharing is assumed for each case.

1) Basic case: 60 minutes after the earthquake event, disrupted road information is reflected in information sharing system operated by emergency personnel, VICS and road information boards.

2) Priority case: 10 minutes after the earthquake event, disrupted road information is provided only to emergency vehicles. 60 minutes after the event, the information is reflected in VICS and road information boards.

3) Sharing case: 10 minutes after the event, disrupted road information is reflected in information sharing system operated by emergency personnel, VICS and road information boards.

Assumed Interaction between Emergency and Ordinary Vehicles

Several assumptions are employed for interactions between emergency vehicles and ordinary vehicles considering the Road Traffic Law. Ordinary vehicles have to slow and stop aside as emergency vehicles are within 50m behind them. However, they never stop in intersections. They do not follow emergency vehicles within 30m. As compared with ordinary vehicles, 30%-increased speed limits are assumed for emergency vehicles. Emergency vehicles slow down to 60% of the assumed speed limit as they have ordinary vehicles within 50m ahead. Emergency vehicles basically take the roads with relatively high-speed limits, namely 50 or 60km/hr. However, in the case emergency vehicles get to the collapsed bridges, they can take routes including links with low speed limit.

Effectivity Assessment of Information sharing

Immediately after being called out, emergency personnel leave for afflicted sites and stay there to extinguish fire or provide first aids until they move to next afflicted sites or carry the injured to hospitals. Various scenarios can be assumed for emergency activities. In this study three emergency activity bases are installed on the developed road network to consider several origins and destinations for emergency activities as shown in Figure-2. Emergency vehicles leave these bases and move to next ones in counterclockwise direction under the assumed information sharing cases. Travel time for each emergency activity trip is measured so that effectivities of the information sharing cases can be evaluated.

Figure-4 shows time history of various events assumed in traffic simulation. First, travel time for emergency vehicles are measured 5 minutes before the earthquake event. The travel time is regarded as baseline in regular traffic state and compared with the post-earthquake travel time. The baseline is measured after 30 minute-simulation running, since the number of vehicles on the road network increases and the traffic state is not stable for a certain period of time. Emergency personnel start their activities 5 minutes after the earthquake occurrence. They repeatedly leave installed bases for the other bases in counterclockwise direction every 6 minutes. Travel time for each trip is measured over time in order to evaluate the effectivities of the information sharing cases in the process of time.

Ordinary vehicles are generated in temporally random order at origins so that generated numbers of vehicles agree with pre-specified traffic demands and the randomly generated vehicles have different effects on each traffic simulation. Therefore, travel times measured in a simulation differ from those measured in other simulations, even if all the simulations are executed under completely same assumptions. In order to evaluate average characteristics of the observed travel times, average travel time over 5 simulations is employed as effectivity indexes of the information sharing cases.

Traffic simulation is conducted under differently assumed traffic demands and VICS installation rates so that effectivities of the information sharing cases are evaluated under various traffic conditions. Following conditions are employed in simulations.

(1) Relatively high traffic demand enough to nearly fill up certain road sections with ordinary vehicles and 10% installation rate of VICS
(2) 80% of the traffic demand assumed in (1) and 10% installation rate of VICS
(3) 80% of the traffic demand assumed in (1) and 90% installation rate of VICS

Simulated traffic flow varies according to the reality and assumptions considered in computational program. In the present study, post-earthquake traffic regulations, pedestrians, bicyclists, debris from collapsed buildings, dysfunctional signals and abandoned vehicles are ignored for computational simplicity, though they presumably impacts on the simulated traffic flow. The present study does not cover precise predictions of traffic. However, the author believes that the simplified simulations work for the preliminary study to understand fundamental characteristics of the assumed information sharing cases.

Computational Results and Discussion

(1) Relatively High Traffic Demand and 10% Installation Rate of VICS

Traffic simulations are conducted for all the information sharing cases under the assumptions of relatively high traffic demand and 10% installation rate of VICS. Figure-5(a) shows average travel times for trip BC. In basic case emergency personnel don’t have disrupted road information until 60 minutes past the earthquake event. Since one of the collapsed bridges exists on the shortest travel path, they have to take long detour to the base C after encountering the road disruption and the average travel time rises up consequently. The average travel time decreases temporarily 60 minutes after the event since disrupted road information is released to emergency vehicles and they stop taking the routes including the disrupted sites from the start. However, the same information is released to ordinary vehicles through VICS and road information boards as well. As a result they also avoid the disrupted sites and take other routes. This route changes delay the travels of emergency vehicles and the average travel time rises up again. In priority case emergency vehicles avoid selecting the routes including the collapsed bridges after they receive disrupted road information 10 minutes past the event. Consequently, the average travel time declines. However, 60 minutes after the event, the disrupted road information is also released to ordinary vehicles through VICS or road information boards, and they start to take other routes. Since the route change delays emergency activities, the average travel times increase. Ordinary vehicles have almost same influence on the emergency activities over time in basic and priority cases since the disrupted road information is released to them 60 minutes after the earthquake event in either case. Therefore, the average travel times for priority- and basic- cases come to converge. In sharing case ordinary vehicles as well as emergency vehicles receive disrupted road information 10 minutes after the earthquake event. However, the average travel time is smaller than those for basic and priority cases during 2 hours after the event. Average travel times for sharing case eventually come to converge to those for the other cases.

Figure-5(b) illustrates the average travel time for trip CA. As compared with basic case, priority and sharing cases give smaller average travel time until 60 minutes past the earthquake event. Eventually, average travel time for all cases converge in the same manner as average travel times for trip BC.

Cumulative numbers of ordinary vehicles arriving at their destinations are measured over time in traffic simulations for all the information sharing cases. In this paper, the cumulative curves for basic and sharing cases are shown in Figure-6. Since average travel time for each case is calculated over 5 traffic simulations, 5 cumulative curves are shown for each case. In either case growth rates of cumulative curves dramatically declines in course of time, which indicates that overall traffic flow is severely disrupted by the traffic congestion induced by earthquake event. Sharing case presumably helps ordinary vehicles flow more efficiently than basic case since the growth rate of the cumulative curve for sharing case drops at higher level than that for basic case.

(2) 80% of the Traffic Demand Assumed in (1) and 10% Installation Rate of VICS

Since overall traffic flow is heavily disrupted in the traffic demand above, traffic simulation is conducted for 80% of the demand. Average travel times for trips BC and CA are shown in Figures-7. Average travel times for sharing and priority cases are smaller than that for basic case. While average travel time for priority case almost rises up to that for basic case 60 minutes after the earthquake event, average travel time for sharing case is smaller than those for other cases for almost two hours after the event. The characteristics of average travel time computed for the reduced traffic demand is similar to that for the traffic demand assumed in (1). As shown in Figure-8, growth rates of cumulative curves for reduced traffic demand dramatically declines as well as the cumulative curves illustrated in (1).

(3) 80% of the Traffic Demand Assumed in (1) and 80% Installation Rate of VICS

80% of the traffic demand employed in (1) and 80% installation rate of VICS are assumed for traffic simulations. In this assumption installation rate of VICS is enhanced as compared with the rates above. This assumption corresponds to facilitating further immediate information sharing, since more ordinary vehicles don’t have to stop by car information boards to obtain disrupted road information and update congested road information. Figures-9 illustrate the average travel times for trips BC and CA. As shown in the figures, average travel time for sharing case is smaller than those for the other cases continuously over time. It is also smaller than average travel time for the sharing case assumed in (2). Figure-10 illustrates growth rates of cumulative curves measured in sharing case under the reduced traffic demand and enhanced installation rate of VICS. As shown in the figure, all the growth rates do not decline. Thus, all the simulated traffics do not fall into congested states to such an extent to be almost stopped.

As described in the above, in the case traffic demand is reduced and high installation rate of VICS is assumed in traffic simulation, average travel time for sharing case is smaller than those for priority and basic cases. In terms of traffic flow, reduced traffic demand in traffic simulation corresponds to redundant traffic capacity of road network. High installation rate of VICS corresponds to immediate information sharing since latest traffic information can be obtained immediately from VICS. Based on the simulations, it is recognized that emergency activities are facilitated by immediately providing disrupted road information not only to emergency vehicles but also ordinary vehicles. The effectivity of immediate information sharing is enhanced by road network redundancy and further immediate sharing.

Summary

Dynamic traffic simulations are conducted under variously assumed post-earthquake information sharing cases. Effectivities of the information sharing cases are discussed in terms of facilitating emergency activities. Based on the traffic simulations, it is recognized that emergency activities are facilitated by providing information immediately to both of emergency vehicles and ordinary vehicles. The immediate information sharing not only facilitates the emergency activities but also rationalize overall traffic flow. The simulations conducted under variously assumed traffic conditions indicate that the effectivity of immediate information sharing is enhanced by road network redundancy and further immediate information sharing.

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References

1) Sakai, J., et al.: “Real-time earthquake damage detection system for bridge structures”, Proceedings of the 23rd US-Japan Bridge Engineering Workshop, 2007

2) Traffic Simulation Committee, Japan Society of Traffic Engineers, "Standard Verification Process for Traffic Flow Simulation Model", 2002
3) Kuwahara, M., et al.:" Development of Dynamic Traffic Simulation Model for Urban Expressways", Traffic Engineering vel.28.4, 1993

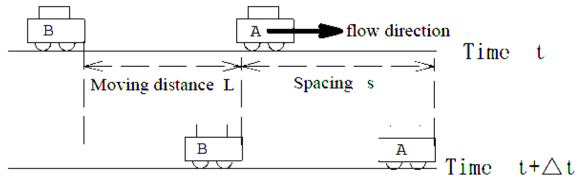


Figure-1 Car Following Model [Kuwahara, et al., 1993]

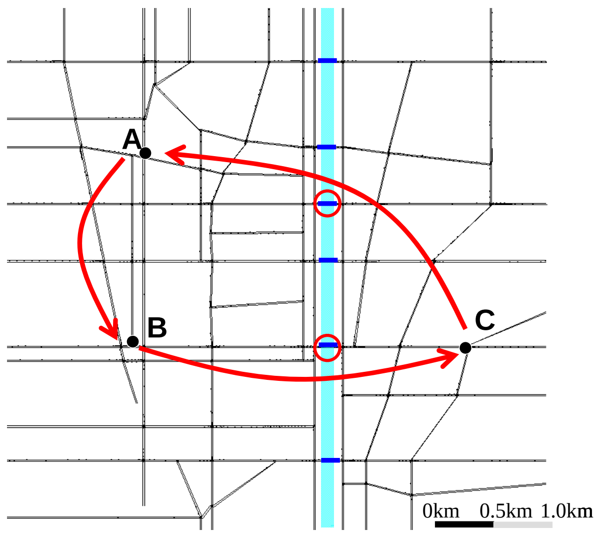


Figure-2 Road Network for Traffic Simulation

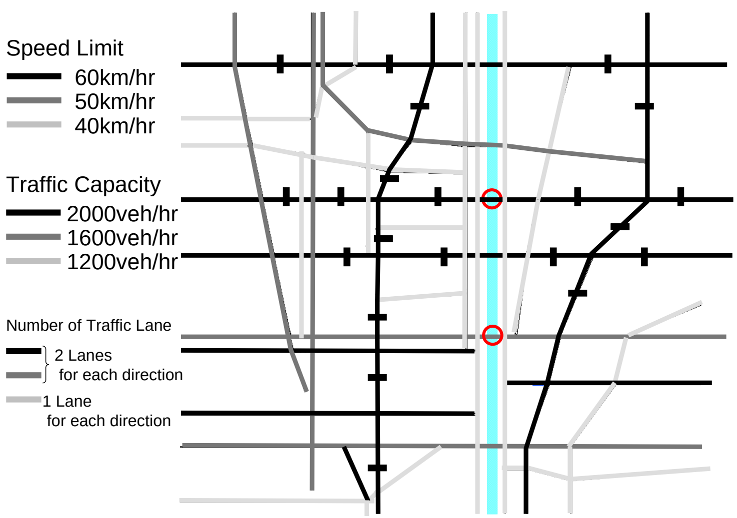


Figure-3 Characteristics of the Road Network

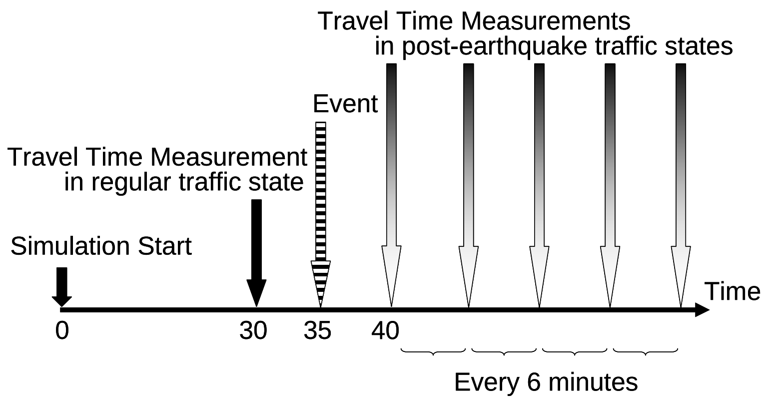
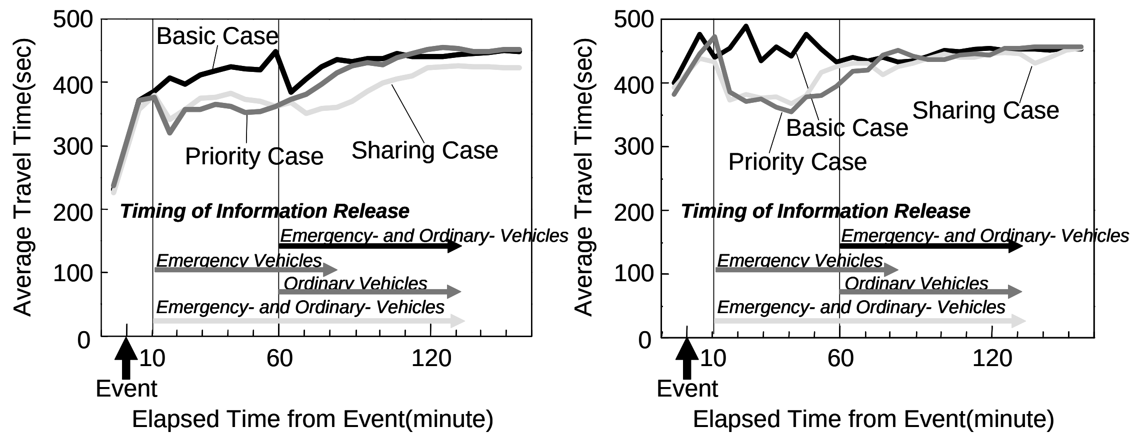


Figure-4 Time History of Assumed Events in Traffic Simulation



(a) Trip BC
(b) Trip CA

Figure-5 Relatively High Traffic Demand and 10% Installation Rate of VICS

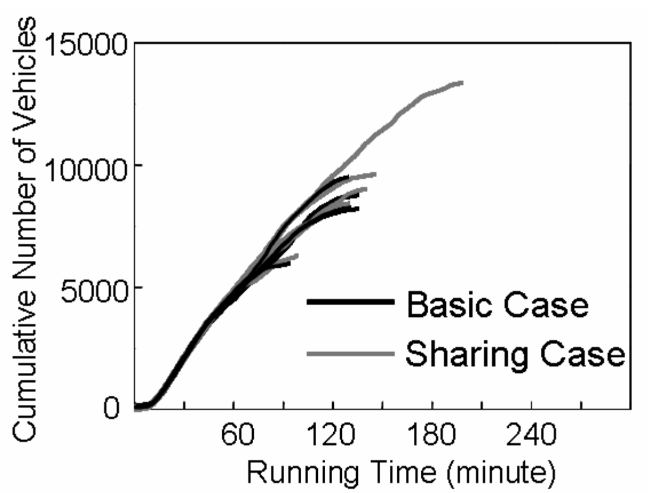
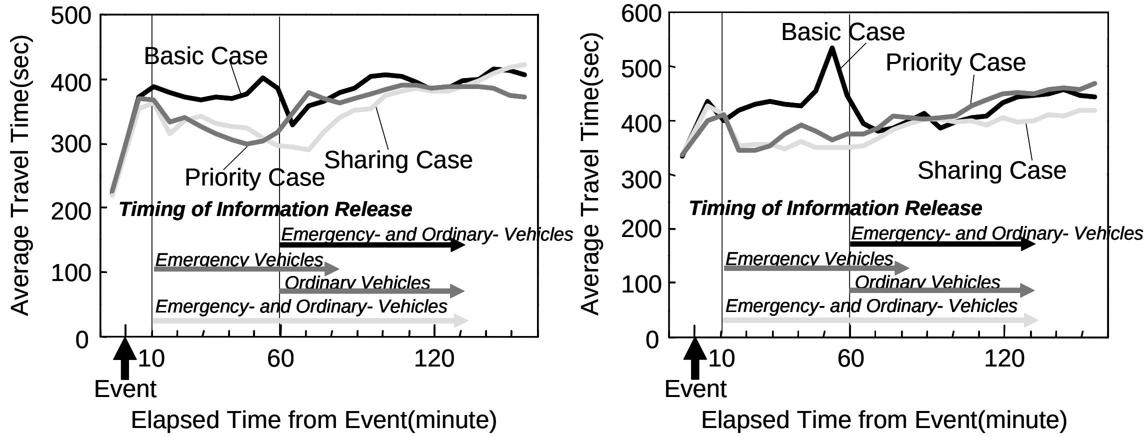


Figure-6 Cumulative Number of Ordinary Vehicles Arriving at their Destinations



(a) Trip BC (b) Trip CA

Figure-7 80% of the Originally Assumed Traffic Demand and 10% Installation Rate of VICS

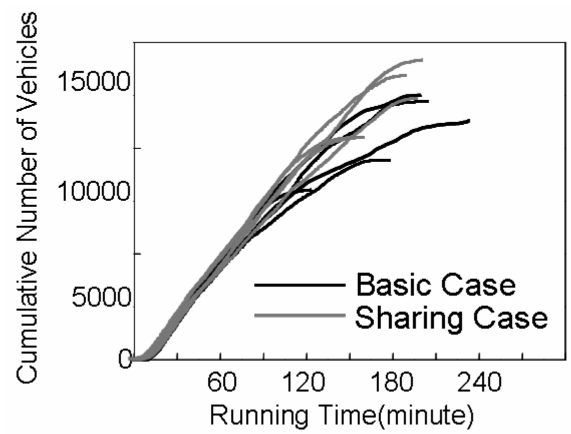
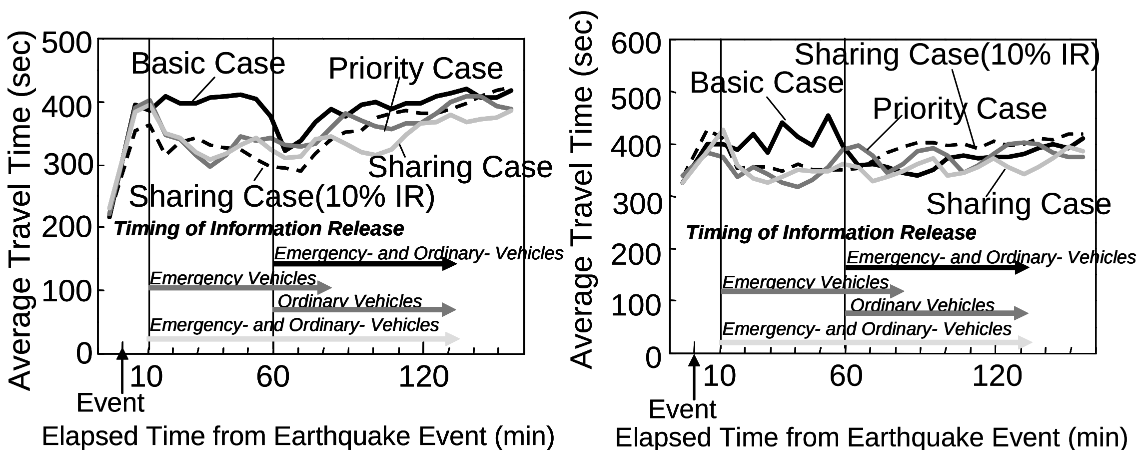


Figure-8 Cumulative Number of Ordinary Vehicles Arriving at Their Destinations



(a) Trip BC (b) Trip CA

Figure-9 80% of the Originally Assumed Traffic Demand and 10% Installation Rate of VICS

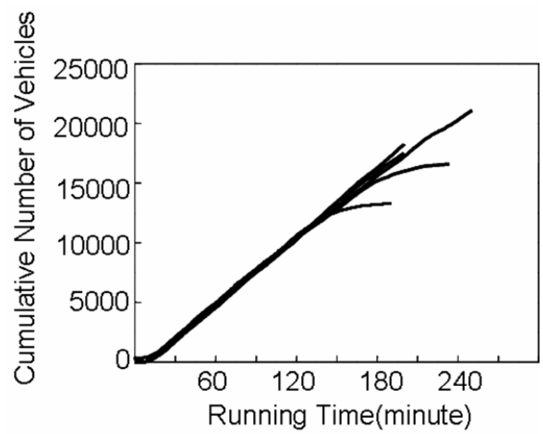


Figure-10 Cumulative Number of Ordinary Vehicles Arriving at Their Destinations

Appendix: Verification Examples of the Developed Traffic Simulation Program

1) Propagation Rates of Backward- and Forward- Waves

As shown in the above picture of Figure-11, simple road section with bottleneck on downstream side is formed. The traffic demand changes over time from 700 to 1400 veh/hr and declines back to 700 veh/hr.

Traffic congestion is induced on the upstream side of the bottleneck as the traffic volume of 1400 veh/hr arrives at the bottleneck and the traffic transition propagates upstream as backward wave. As traffic demand decreases back to 700 veh/hr, the back end of the traffic queue begins to move forward to bottleneck as forward wave. As shown in Figure-11, several observational points are installed along the road section and numbers of vehicles passing through the points are counted so that propagations of the backward- and forward- waves can be recognized. The upper picture of Figure-12 shows cumulative number of traffic volume passing each point. The inclination changes of the cumulative curves indicate the observationally recognized propagation of backward- and forward- waves.

On the other hand, as shown in Figure-13, backward- and forward- wave propagation rates can be determined theoretically from flow-density curve derived from the assumed traffic demand. Based on the theoretically derived propagation rates, traffic condition transition diagram on upstream side of the bottleneck is prepared as shown in the lower picture of Figure-12. The circles in the figure indicate the backward- and forward- wave propagations passing through each observational point. The theoretically derived circles are overlapped on the observed cumulative curves in the upper picture of Figure-12. The circles agree well with the inclination changes of the cumulative curves.

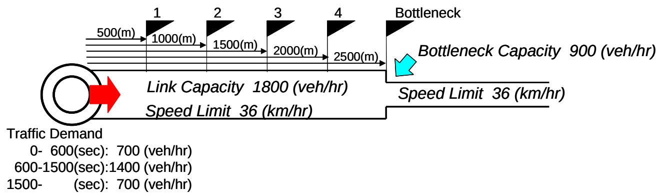


Figure-11 Road Section Developed for Propagation Rate Verification

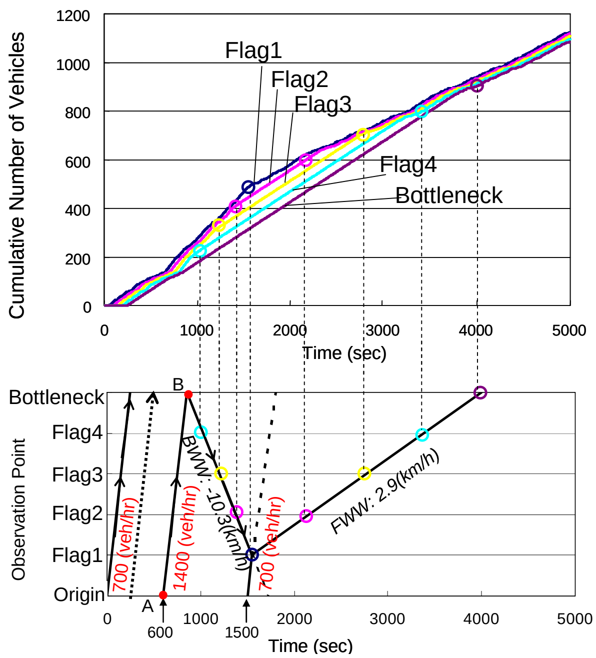


Figure-12 Backward- and Forward- Wave Propagations

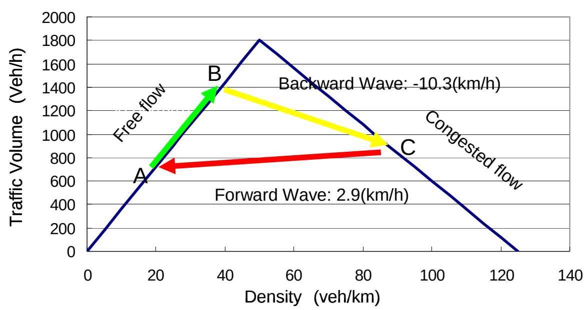


Figure-13 Theoretical Propagation Rates of BW and FW Waves

2) Number of Right Turn Through Vehicles

In order to verify right-turn capacity, a road network with a signalized intersection is formed as shown in Figure-14. Number of right turn through vehicles against various number of straight through opposing vehicles are counted in simulations and compared with the right-turn capacity calculation equation (2) of the Japan Society of Traffic Engineers. Various parameters set for the verification example below are shown in Figure-15. Traffic simulation is conducted under variously assumed numbers of opposing straight through traffic.

The observed numbers of right-turn vehicles against various numbers of opposing straight through vehicles agree well with the equation (2) as shown in Figure-15.

$$SR = 1800\,f\,(SG - qC)/(S - q)C + 3600K/C \qquad (2)$$

where:

SR : Capacity of an exclusive right-turn lane [veh/hr]

S : Saturation flow rate at approach of opposing straight through traffic [veh/effective green one hour]

q : Volume at the approach of opposing straight through traffic [veh/hr]

C : Cycle length [sec]

G : Effective green time [sec]

K : Number of vehicles that can be discharged at change of signal [veh/cycle]

f : Gap acceptance probability determined from the following relationship

$f =$ 1.00 ($q = 0$), 0.81 ($q = 200$),
0.65 ($q = 400$), 0.54 ($q = 600$),
0.45 ($q = 800$), 0.37 ($q = 1000$),
0.0 ($q > 1000$), Interpolation for median q value

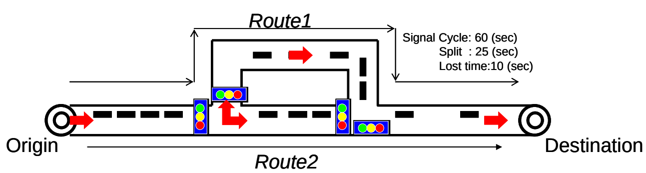


Figure-14 Road Network Developed for Verification of Route Choice Function

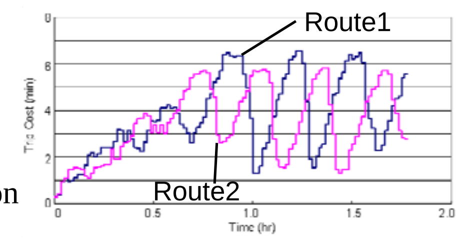


Figure-15 Travel Times for Routes1 & 2

3) Optimal Route Choice Function

A road network with two routes is formed as shown in Figure-16. Figure-17 shows travel time variation over time for the two routes. As shown in the figure, travel times for the two routes oscillate opposite each other. Since the oscillations indicate that more vehicles tend to choose the route with shorter travel times, it is ascertained that the route choice function performs as expected.

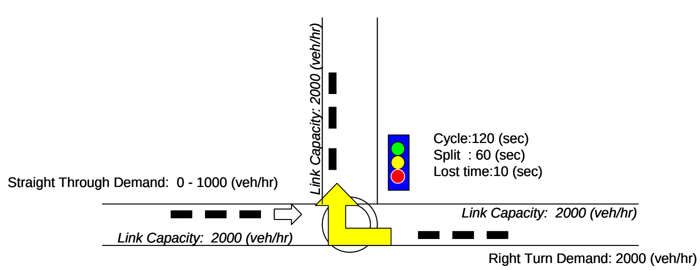


Figure-16 Verification Road Network for Number of Right-turn Through Vehicles

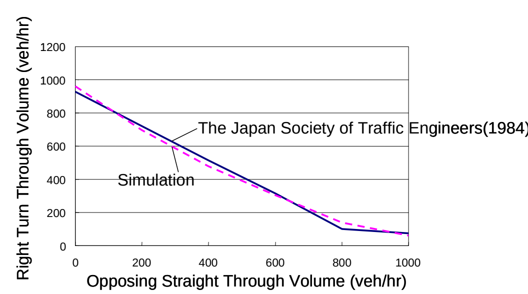


Figure-17 Right-turn Through Volume