Road Information Sharing Using Probe Vehicle Data in Disasters

Y. Hada[1], N. Kodama[2], T. Suzuki[3] and K. Meguro[4]

[1] *Research Fellow, Institute of Industrial Science, The University of Tokyo, Japan*
[2] *Assistant Professor, Waseda Institute for Advanced Study, Waseda University, Japan*
[3] *Professor, Interdisciplinary Graduate School of Medical and Engineering, University of Yamanashi, Japan*
[4] *Professor, Institute of Industrial Science, The University of Tokyo, Japan*
Email: haday@iis.u-tokyo.ac.jp

ABSTRACT :
Road information sharing is vital in disaster response, but it still remains today a significant problem in spite of the recent breakthrough of information and communication technology.
In this study, we overview the present situation and structure problems on road information sharing. Two main problems are as follows: i) how to gather the information about which road can be used and ii) how to share the information among different disaster information systems used in the authorities concerned.
We propose road information sharing using probe vehicle data to solve the first problem. The characteristics and the possible use of the GIS plotted probe vehicle data in past disasters are discussed. The probe vehicle data provide information to decide which road are likely to remain available at the time, and also where the vehicle turned around, that indicates the road might not be available.
The travel time of individual car trips are numerically simulated with and without road information sharing among the cars. The reductions of the travel time depend on numbers of probe cars and road closures. The simulation results indicate that the probe vehicle data can be effectively used to reduce the travel time in a time of disaster, and to gather regional information on available roads.

KEYWORDS:
Probe vehicle, Road information, Information sharing, Disaster response

1. INTRODUCTION

Sharing traffic and road information is essential for effective disaster response. Despite the remarkable progress made recently in the fields of information and communication technology, there is currently no generally accepted solution for this problem.
Here, we examine the current status and problems faced in sharing traffic and road closure information. We also propose and evaluate a new method for sharing information about road closures using probe vehicle data. The probe vehicles have been practically employed in the transportation field as a means of gathering information such as speed and direction from cars that are currently available

2. CURRENT STATUS OF INFORMATION SHARING DURING DISASTERS

In this chapter, we present an overview of the schemes currently used for sharing road information and information content. Most of the existing schemes are limited to major roads.
The Ministry of Land, Infrastructure and Transport (MLIT), Government of Japan, monitors the damage and availability of roads. Fig. 1 shows a system for road information collection on road administrators in Japan. Road information grasped each road administrators is reported to higher organizations in the way shown in Fig. 1, finally is collected by the head office of MLIT. In large scale disasters it takes much time on road information collections. Based on the interview investigation about road information collection in the 2004 Mid Niigata Prefecture Earthquake to National Highway and Risk Management Division of MLIT, collected all road regulation information (more than 200 regulations executed) is drawn on to a map 3 days later the occurrence of

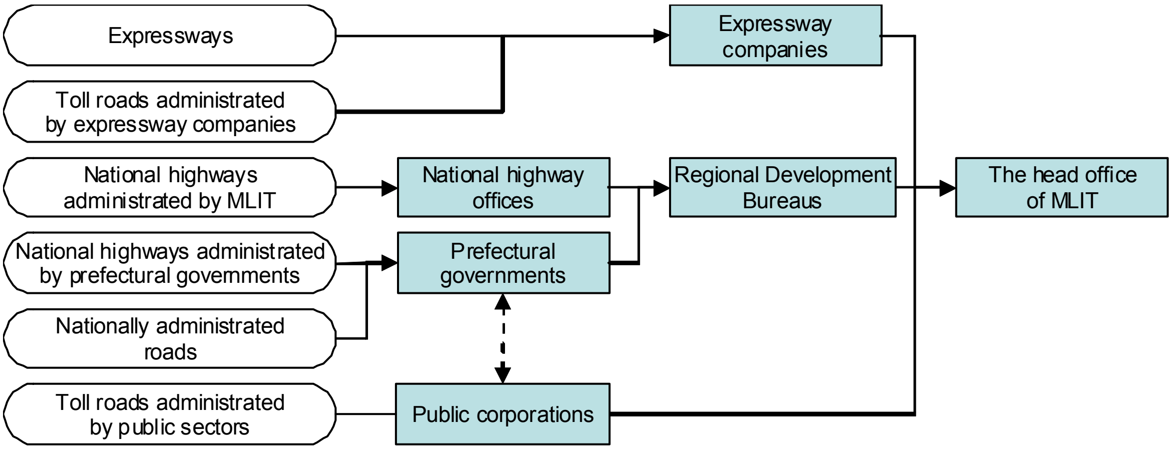


Fig. 1 System for road information collection on road administrators

the earthquake. During disasters, road information is provided through the Internet and electric bulletin boards installed above the roads. The tabular information provided on their web site includes road closures and traffic control information of major roads.
The Japan Road Traffic Information Center (JARTIC) provides information gathering and distribution services delegated by traffic administrators and road authorities such as the National Police Agency and MLIT. Traffic and road information is widely distributed through radio, television, and the Internet. The tabular graphical traffic information provided on the JARTIC web site includes the route name, section and direction, cause of traffic, and details regarding traffic control.
The Vehicle Information and Communication System (VICS) transmits literal graphical traffic information to the in-car navigation system. Drivers can acquire real-time traffic information, as well as other information such as vehicle speed, travelling time, accidents, roadwork, speed limits, lane closures, and car parks. Approximately 70,000 km out of a total road length of 330,000 km of major roads are covered.

3. PROBLEMS FACED IN SHARING TRAFFIC AND ROAD CLOSURE INFORMATION

Road information about both the disaster site and its surrounding areas is required for interregional rescues and backups during disasters. This implies that several road administrators are expected to share their road information. We structure the problems faced in road information sharing during disasters to road users and administrators through interview analysis.

3.1. Lifeline suppliers and physical distribution companies

(i) It is difficult to locate the exact position from literal road or traffic information.
(ii) A lack of information about road availability and damage severity was experienced.
(iii) Road information could not be obtained in a timely manner while driving in the areas affected by the disaster.
(iv) No special road information is provided to emergency vehicles, although they are given priority.
(v) Reliability, update frequency, and last update time of information were not available.
(vi) Sharing of road information and coordinated sources of information are required.

3.2. Road administrators

(i) Traffic regulation sections cannot be exactly located because their names are not standardized.
(ii) Regional road information that is required for finding a diversion is not shared.
(iii) An integrated road information service is not available during disasters.
(iv) The total length of the local roads is so long that it cannot be supervised by an administrator in a short time

span.

(v) An information system is required to gather road information from local residents and drivers, and to share and provide it.

3.3. Police departments

(i) Traffic control information is gathered through facsimiles and e-mails whose structures are not standardized. Subsequently, the traffic control sections are drawn onto a paper map.

(ii) High priorities are given to rescue operations, followed by disaster prevention and evacuation guidance; road information is vital in such situations.

Based on these interview results, the road information sharing problems are structured in a cause-and-effect diagram (Ishikawa, 1986), as shown in Fig. 2. The important points that must be considered for effectively sharing road information are as follows: (1) rapid checks for road availability and (2) providing prompt access to road information. The sharing of probe vehicle data, which is explained in the following section, is proposed in order to solve the first problem described above.

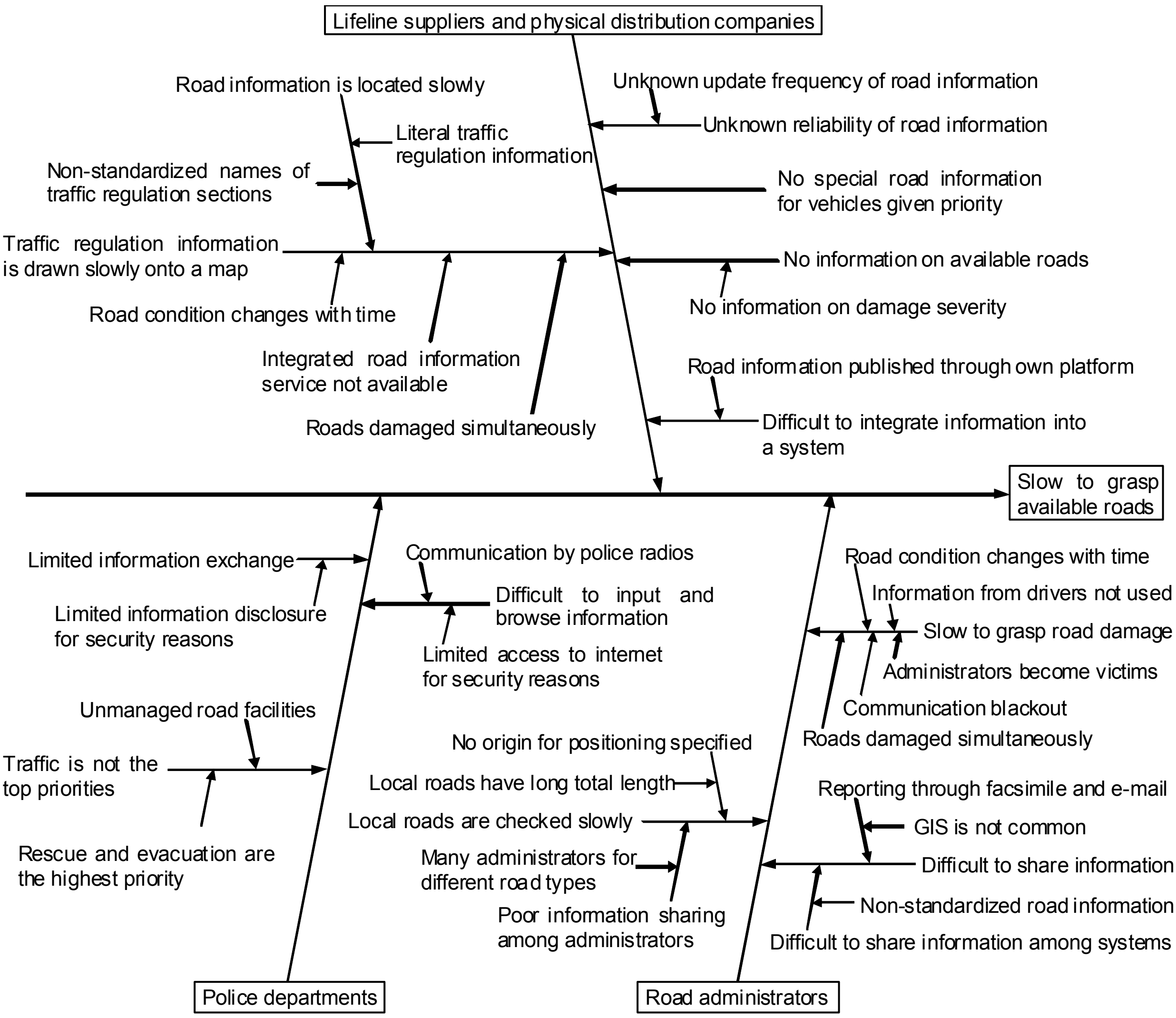


Fig. 2 Cause-and-effect diagram of road information sharing problems

4. EXAMPLE OF PROBE VEHICLE DATA IN DISASTERS

Fig. 3 shows the positions of probe vehicles every six hours after the occurrence of the 2004 Mid Niigata Prefecture Earthquake until the end of the next day. The short red lines indicate road closures that were enforced during that period. The trajectory records of some vehicles indicate that they were within the road closure sections; this occurred because these vehicles travelled in these sections before they were closed, or the literal information interpreted the length of the road closure to be longer than its actual length on the map. Since the number of probe vehicles was not enough, most of roads are not travelled by probe vehicles. Suppose that the

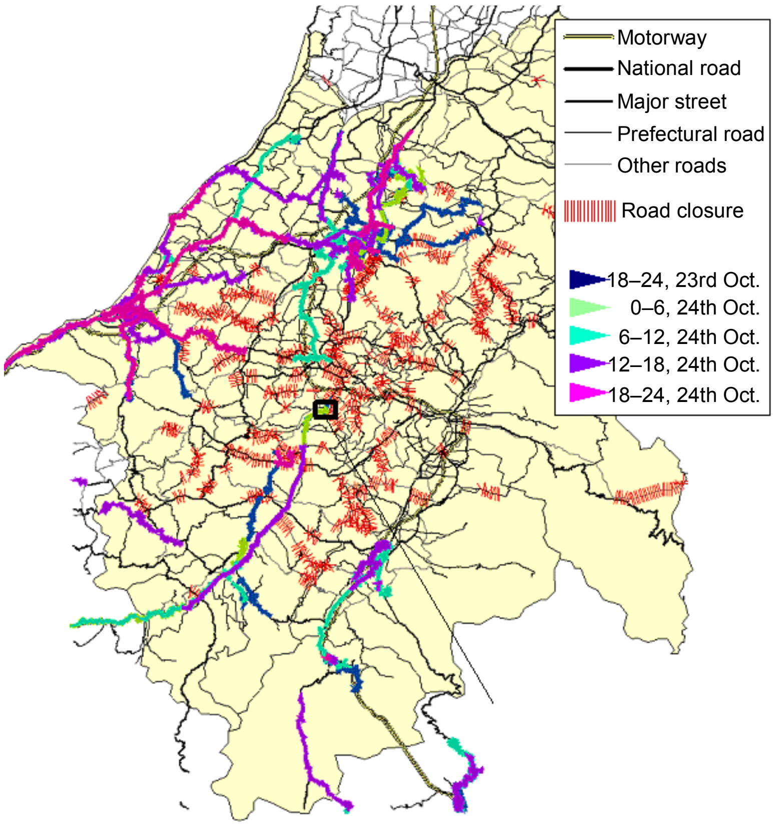


Fig. 3 Probe vehicle trajectories after the 2004 Mid Niigata Prefecture Earthquake

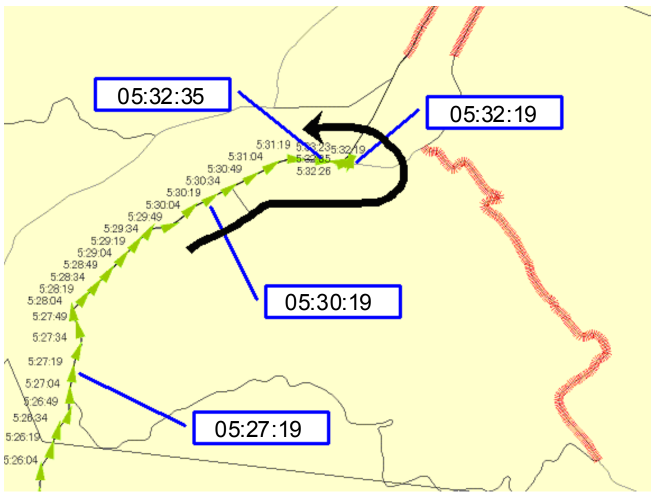


Fig. 4 Trajectory of a car turned around before road closures

number of probe vehicles is much enough to cover all roads and probe vehicles information can be gathered in real-time. Trajectories of probe vehicles can be utilized for judgments which road is available. For all peoples such as rescue crews travelling to the suffered area, this information contributes better judgments on the selection of the route to the destination in an emergency phase of lack of road information.
Fig. 4 shows the trajectory of a vehicle that turned around before the road closures. If the cause of a car turned can be discriminated road closures from the others such as just stopping by a convenience store on the opposite direction, road closure points can be detected automatically.

5. PRELIMINARY NUMERICAL SIMULATION

It is vital for prompt and effective disaster response to gather information on available roads as well as road closures. In this chapter, the information gathered on available roads by combining the trajectories of probe vehicles is numerically simulated. The travel time saved by sharing the road closure information is also discussed.

5.1. Outline of numerical simulation

In the simulation, probe cars travel in a road network of the Niigata Chuetsu region, as shown in Fig. 5. The network includes approximately 7,500 links and its total length is around 4,240 km. The black links indicate road closures approximately thirty hours after the occurrence of the 2004 Mid Niigata Prefecture Earthquake. Each vehicle is equipped with a car navigation system that processes the probe data. The vehicles move on the shortest paths to their destinations and avoid using closed links. All vehicles gather road closure information (link ID) during transit and shared this information among each other. It is assumed that the road closure information is obtained from the trajectory analysis of the probe vehicles or through direct data input to the car navigation device by the drivers.
Here, we compare the travel times and rates of the known available roads with and without road closure information sharing. The rate of known available roads R_k is defined as follows:

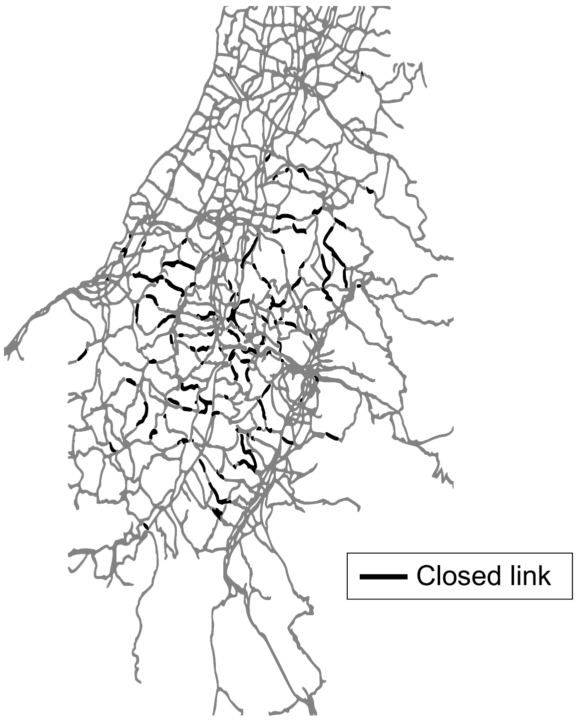


Fig. 5 Road network of Niigata Chuetsu region

$$R_k = \frac{\sum \ell_i}{\sum L_i} \tag{5.1}$$

where

ℓ_i : Length of available link that was used by at least one vehicle

L_i : Length of available link

At the beginning of the simulation, every vehicle searches for the shortest path to its destination without the use of road closure information, and then it begins travelling. The vehicles share the road closure information while they travel according to the following rules.

(i) Vehicles simultaneously share road closure information obtained during driving every 5 min via the data server, and search for a new shortest path. If a vehicle encounters a road closure, the closure is added to that vehicle's database, and a new shortest path is searched.

(ii) When vehicles encounter a closure, they upload the road closure information gathered during driving and download the known road closure information uploaded by other vehicles. Subsequently, the shortest paths are updated.

(iii) Road closure information is not shared. If a vehicle encounters a road closure, it is added to that vehicle's database, and a new shortest path is searched.

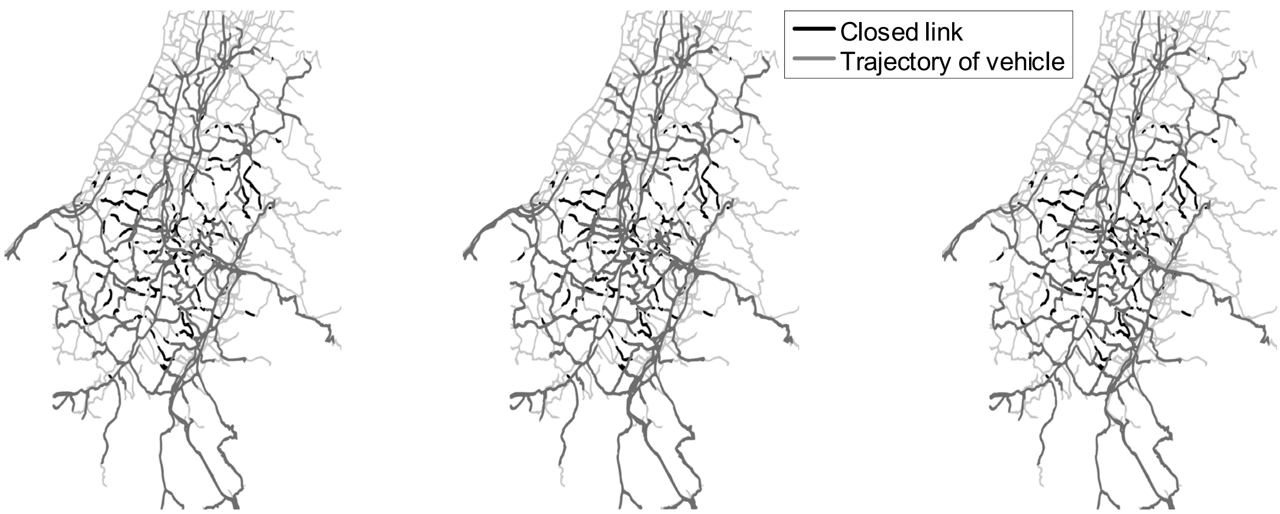
In rules (i) and (ii), the information sharing frequencies are selected so as to avoid excessive communication cost.

Here, we do not consider heavy traffic in order to discuss the primary effect of information sharing on road information gathering and reducing the travel time. The road closures are not supposed to change during the entire simulation time, and consequently the probe vehicle data once gathered is valid until a simulation comes to an end. If an ever-changing road condition is assumed, only the latest probe vehicle data should be used in order to calculate the shortest path to the destination.

Vehicles drive a linear distance of 50 km at an average speed of 30 km/h. The journeys of 20, 50, and 100 vehicles are simulated. A hundred pairs of origins and destinations are randomly selected, and the travel times and rates of known available roads R_k are calculated.

5.2. Results of numerical simulation

5.2.1. Available road information gathering



(a) Road information shared every 5 min (b) Road information shared on encountering closures (c) No road information shared

Fig. 6 Examples of simulated trajectories (100 vehicles)

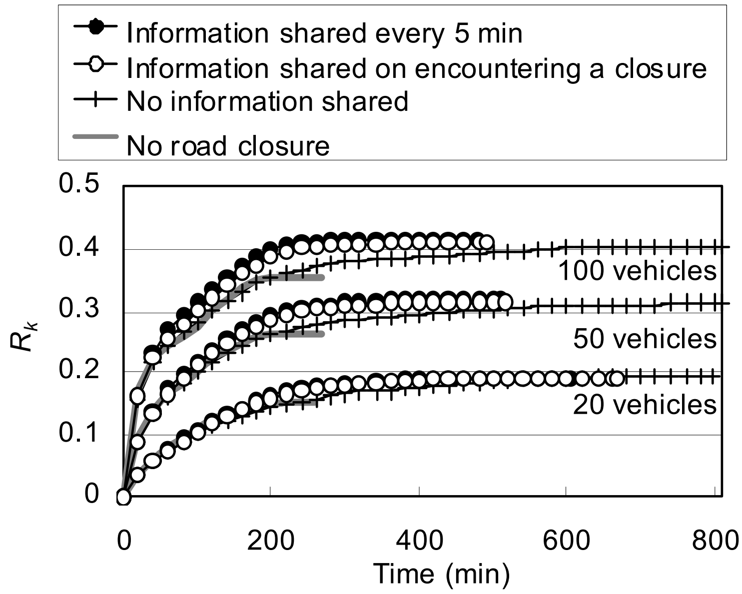


Fig. 7 Time histories of average rate of known available road R_k

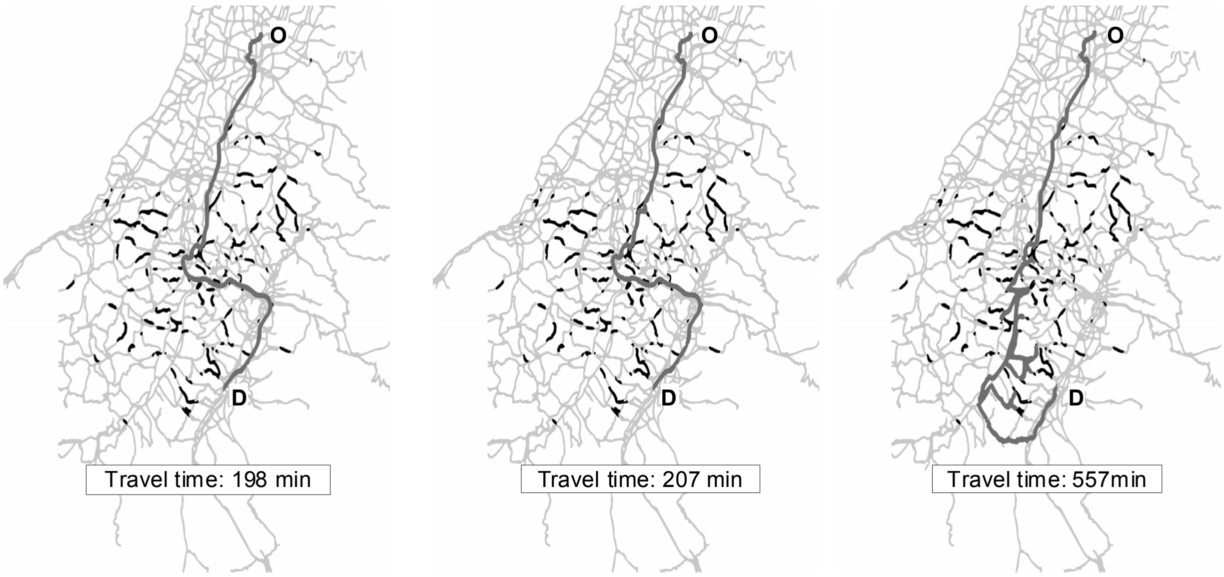
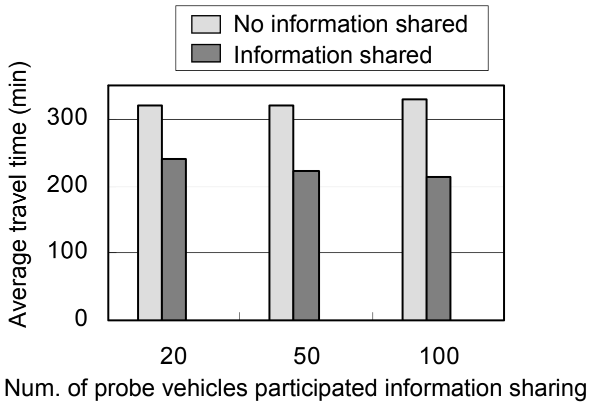


Fig. 8 Examples of simulated trajectories (One vehicle selected from Fig. 5)

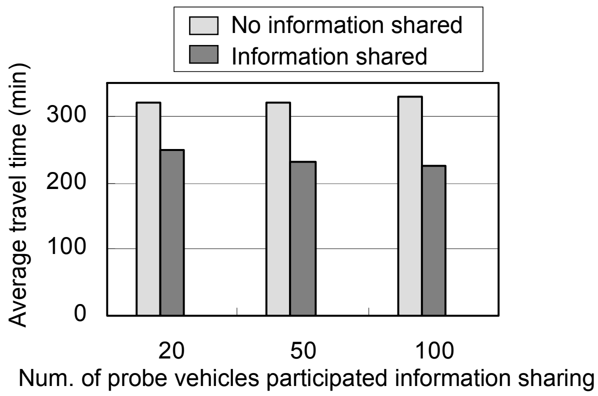
As an example of the simulation results, the trajectories of 100 vehicles are shown in Fig. 6. The layout of the available roads can be instantly recognized. These figures show the results of the three information sharing schemes mentioned in 5.1; however, there is no significant difference among them. In Fig. 6, the same phenomena is shown in time histories of R_k, which implies that the information sharing schemes have no significant influence on R_k saturation values of 0.2, 0.3, and 0.4 for 20, 50, and 100 vehicles, respectively. The results without road closure are also shown for comparison in Fig. 7. R_k saturates with time because the number of vehicles that have arrived at destinations increases and fewer vehicles contribute to the increase in R_k. Further, R_k saturates earlier as the number of total vehicles increases because of an increase in the possibility of other vehicles discovering the road closures on the shortest path of one vehicle.

5.2.2. Travel time reduction

Fig. 8 shows the trajectories of one vehicle selected from among those of the hundred vehicles shown in Fig. 5. The trajectories with and without road closure information sharing are found to be remarkably different. In this example, a travel time of 557 min when road closure information is not shared is reduced to 198 min when it is



(a) Road information shared every 5 min



(b) Road information shared on encountering closures

Fig. 9 Reduction of average travel time by road closure information sharing

shared every 5 min, and to 207 min when it is shared on encountering road closures.
The average travel time is also reduced, as shown in Fig. 9. This figure shows that an average travel time of 330 min when road closure information is not shared is reduced by the sharing of road closure information sharing. The reduction becomes more significant as the number of vehicles increase, and in the case of 100 vehicles, the average travel time reduces by 30%. The difference between the information sharing schemes has no significant influence on the rate of reduction in average travel times.

6. CONCLUSION

We overviewed the problems encountered in sharing traffic and road information during disasters from the viewpoint of an interview investigation, and structured these problems in a cause-and-effect diagram.
The important points to effectively share road information are as follows: (1) rapid checks for road availability and (2) providing prompt access to road information. We proposed probe vehicle data sharing to resolve the first problem. The actual probe vehicle data in a disaster was introduced and its effectiveness in disaster response was presented.
Vehicle trajectories on a real road network with road closures were numerically simulated. In the simulations, heavy traffic is not considered because its effect on road information gathering and reduction in travel time is coupled with that of information sharing.
The available roads were readily recognizable when the trajectories obtained from the vehicles were superimposed on a map. The simulated travel times of individual vehicle journeys were shortened when the road

closure information derived from the probe vehicle data was shared among the vehicles. The sharing of road closure information marginally affects the total length of the available roads that is recognized.
The simulation results indicate that the sharing of probe vehicle data can allow for information on available roads in a wide area to be gathered rapidly, and effectively reduce travel times of vehicles being driven in a disaster site, including the travel time of the disaster response authorities.
Vehicle trajectories do not ensure that the roads travelled by the vehicles are safe, and therefore the trajectory information should be shared with an understanding of its characteristics. Appropriate use of this information can enable prompt and effective disaster response.

7. ACKNOWLEDGMENTS

We are thankful to Prof. Masao Kuwahara, the University of Tokyo, for providing advice and suggestions. We also extend special thanks to Honda Motor Co., Ltd. for providing us with probe vehicle data.
This study was supported by the Ministry of Education, Culture, Sports, Science and Technology (MEXT), Japan.

REFERENCES

Ishikawa K.(1986), "Guide to Quality Control", 2nd Revised Edition, Asian Productivity Organization
Japan Road Traffic Information Center web site (http://www.jartic.or.jp/, in Japanese).
Road Bureau, The Ministry of Land, Infrastructure and Transport, "Monitoring of traffic congestion - deployment of probe cars -", ITS Handbook Japan 2002-2003 (http://www.its.go.jp/ITS/2002HBook/section4/4-9e.html).
Vehicle Information and Communication System Center web site (http://www.vics.or.jp/english/).