

# Road Information Gathering and Sharing during Disasters Using Probe Vehicles

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Although road information sharing is vital in disaster response, recent breakthroughs in information and communication technology have not yet resolved this important problem.

In this study, the existing situation and problems encountered in road information sharing are overviewed. We discuss the characteristics and possible uses of probe vehicle data. Probe vehicle data provides information about roads that are likely to remain available. The travel time is numerically simulated with and without the sharing of road closure information among vehicles. The simulation results indicate that the probe vehicle data can be effectively used to gather regional information about available roads, and for reducing the travel time during disasters.

**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.

Previous researches on utilizing probe vehicle data have mainly focused on sampling technique of the data in non-disaster time by comparison between simulation results and field data. The objectives were to estimate reliable travel time ([1], [2]), to generate traffic condition information ([3], [4]), or to develop incident detection model ([5], [6]) and irregular congestion detection model [7]. On the other hand, large scale demonstration experiments were executed ([8], [9]) to point out problems in commercialization, and afterward several commercial services have been started. An in-car information service on faster and smoother routes started in 2003 [10], and another service for providing slip information to avoid accidents on icy roads started in 2008 [11]. Although probe vehicle data have been utilized to solve various problems as mentioned above, there were not any studies to grasp available roads and road closures promptly during large-scaled disasters such as major earthquakes.

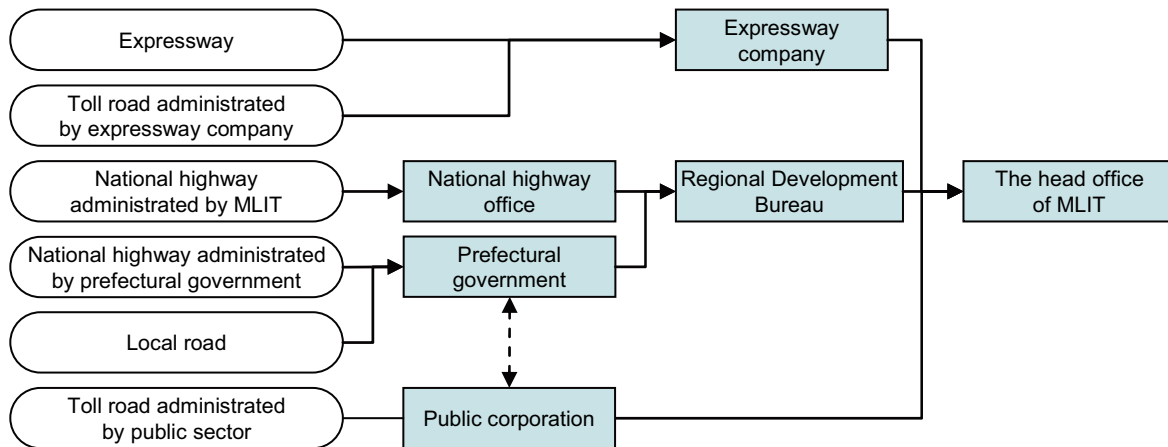
Within several days after an occurrence of a disaster, it is required that vehicles are ensured to arrive at their destinations by sharing information on available road in real-time. Unlike in normal times, a precise estimation of travel time is not required, but instead to avoid encountering road closures and following diversion is demanded.

In preliminary simulation studies, we evaluate the possibilities of information gathering on available roads read from probe vehicle trajectories, and of travel time reduction by sharing road closure information gathered by probe vehicles in a disaster.

## 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 by 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 the earthquake. During disasters, road



**Fig. 1 System for road information collection on road administrators**

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 regulation information of major roads.

The Japan Road Traffic Information Center (JARTIC) [12] 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 regulation.

The Vehicle Information and Communication System (VICS) [13] 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 regulation information is gathered through facsimiles and e-mails whose structures are not standardized. Subsequently, the traffic regulation sections are drawn onto a paper map.

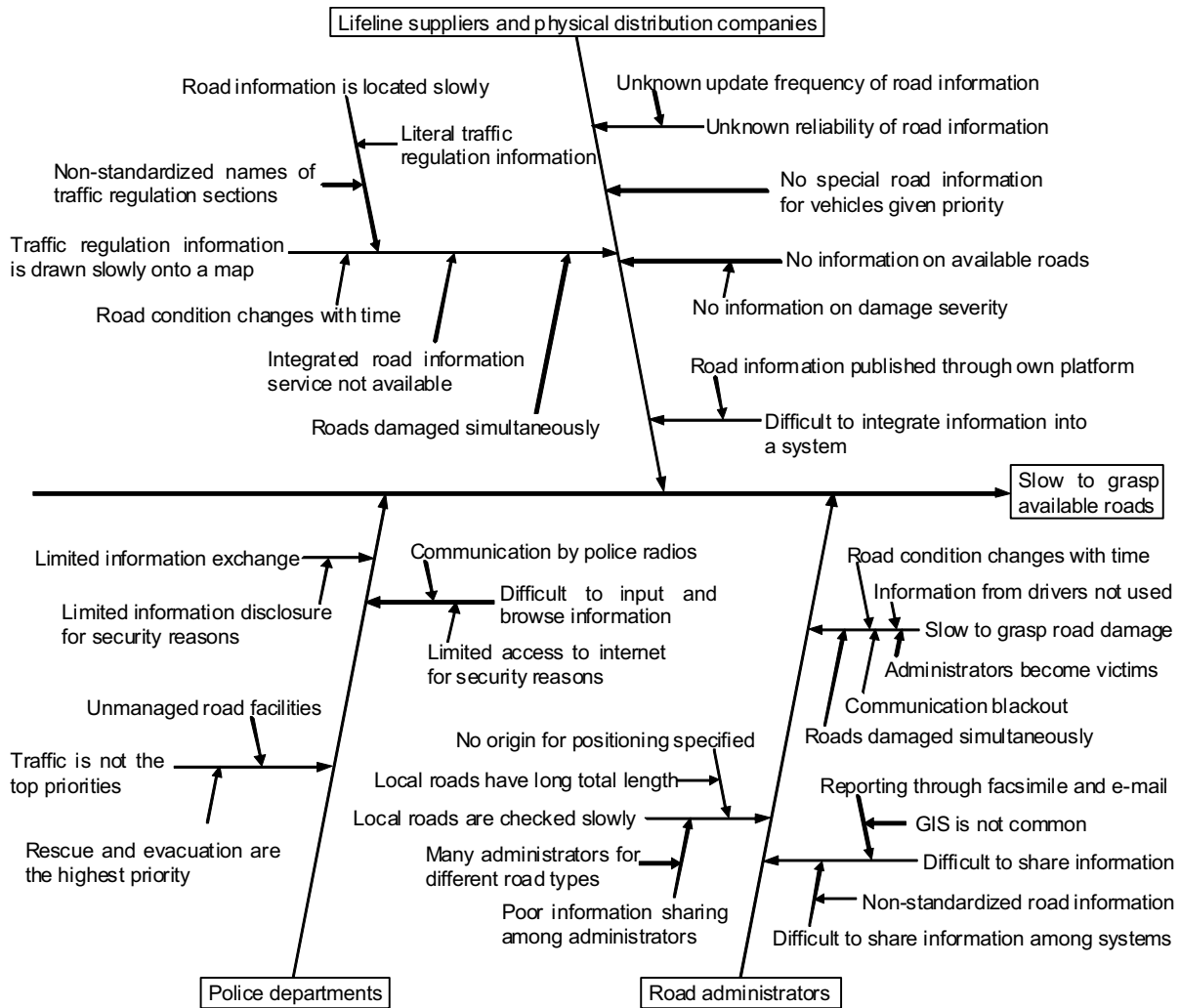


Fig. 2 Cause-and-effect diagram of road information sharing problems

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

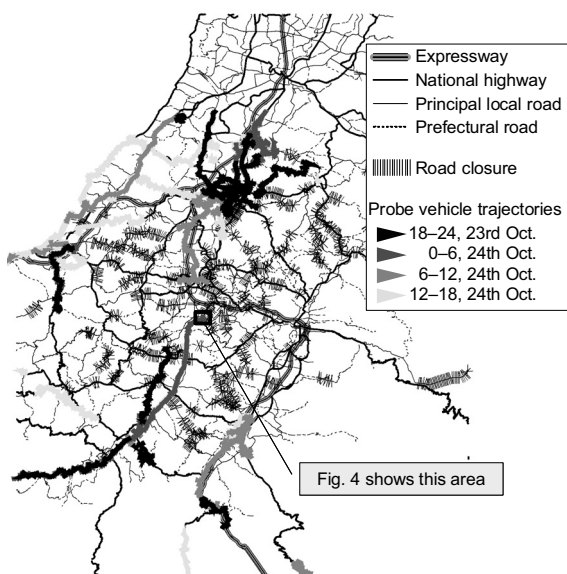
Based on these interview results, the road information sharing problems are structured in a cause-and-effect diagram [14], as shown in Fig. 2. Fig. 2 indicates several points. First, lifeline suppliers and physical distribution companies require updated road information, but such information is not available in disasters. Second, road administrators can not gather road information rapidly because road administrators and contracted construction company for patrol are suffered due to disasters. Third, Police departments are not familiar with information sharing with the other organizations for security reason. Since lifesaving activities become the most urgent and crucial thing for police department in large-scale disasters, police can not concentrate on traffic issue. To solve the above problems, we propose road information gathering and sharing using probe vehicles. In large-scale disasters, a prompt

execution of road patrol is quite hard by road administrators and police. Passed road information read from trajectories of probe vehicles shows the road availability when the vehicle passed, though safety of the road is not secured. In an emergency phase of lack of road information, utilization of probe vehicle data is expected to become very effective.

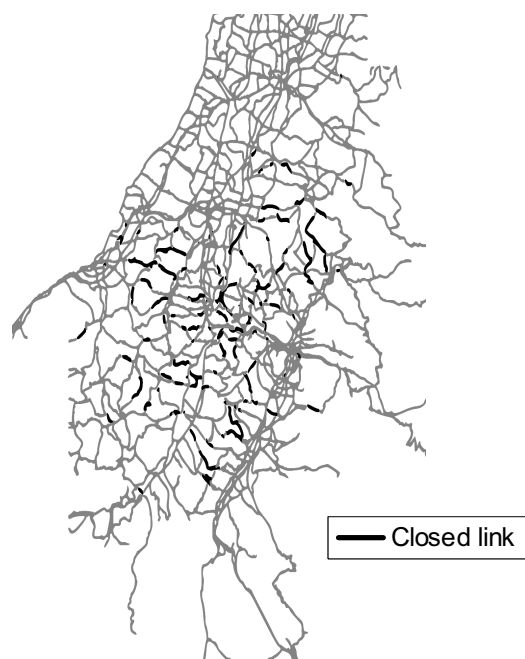
The important points that must be considered for effectively sharing road information are as follows: (1) rapid checks for road availability and (2) providing prompt access to road information. The sharing of probe vehicle data is proposed in order to solve the first problem described above.

#### 4. Example of probe vehicle data in a disaster

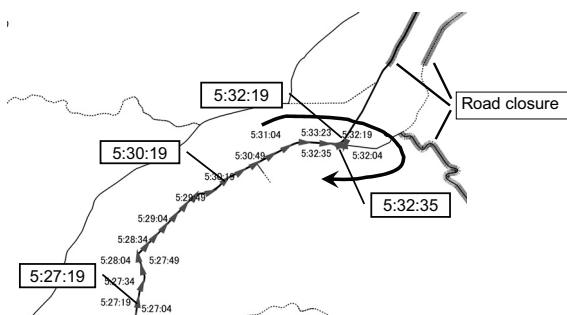
Fig. 3 shows the positions of probe vehicles every six hours for the first 24 hours after the occurrence of the 2004 Mid Niigata Prefecture Earthquake. The short vertical lines indicate road closures that were enforced



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



**Fig. 5** Road network of Niigata Chuetsu region



**Fig. 4** Trajectory of a car turned around before road closures (Oct. 24, 2004)

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 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 judgement which road is available. For all peoples such as rescue crews travelling to the suffered area, this information contributes better judgement 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.

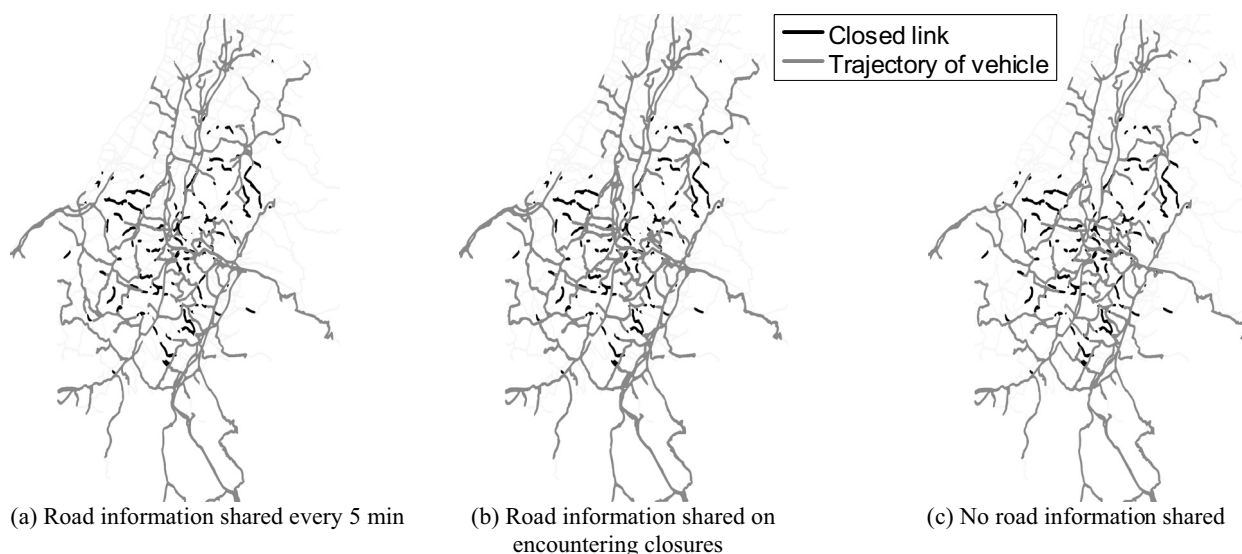
## 5. Preliminary numerical simulation of road information gathering and reduction in travel time

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.



**Fig. 6 Examples of simulated trajectories (100 vehicles)**

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:

$$R_k = \frac{\sum \ell_i}{\sum L_i} \quad (1)$$

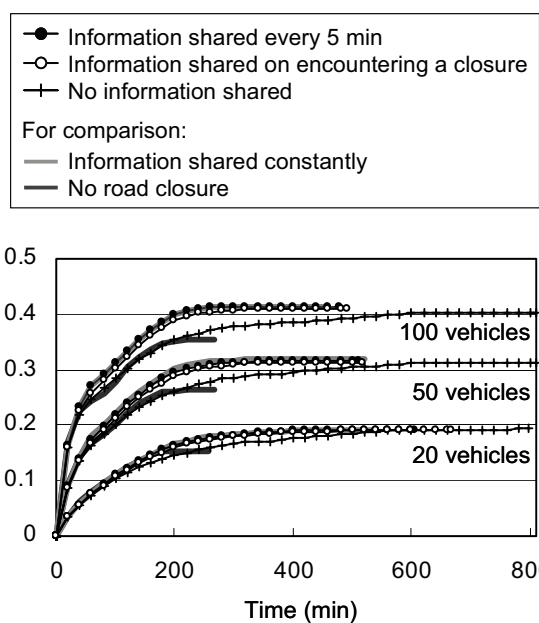
where

$\ell_i$ : 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.

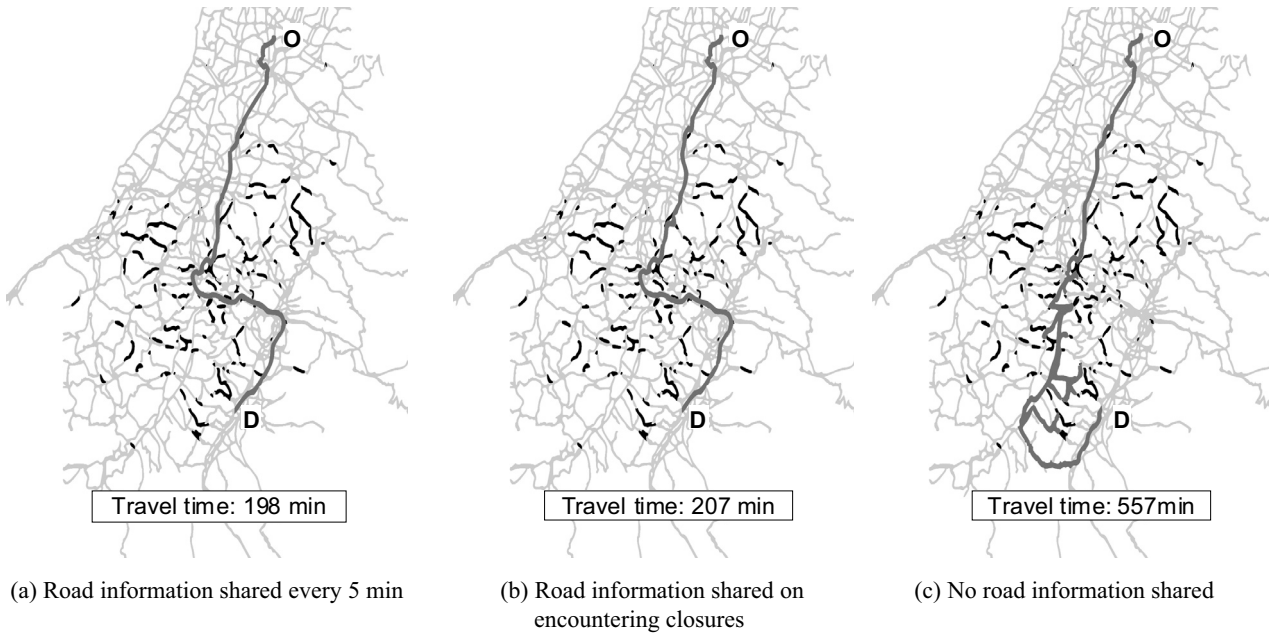
- (i) Vehicles simultaneously share road closure information obtained during driving every 5 minutes via the data server, and search for a new shortest path. If a vehicle encounters a road closure, the closure is added to that vehicle's database, and a new shortest path is searched.
- (ii) When vehicles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



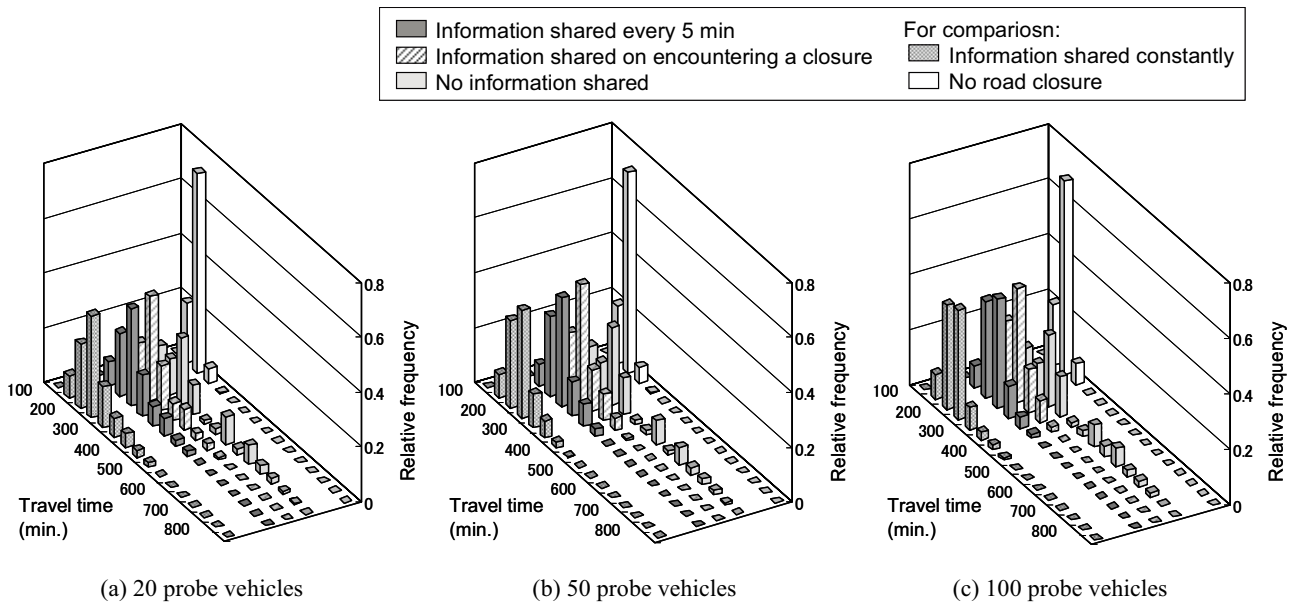
**Fig. 7 Time histories of average rate of known available road  $R_k$**

In the 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



**Fig. 8** Examples of simulated trajectories (One vehicle selected from Fig. 6)



**Fig. 9** Normalized histogram of travel time

used in order to calculate the shortest path to the destination.

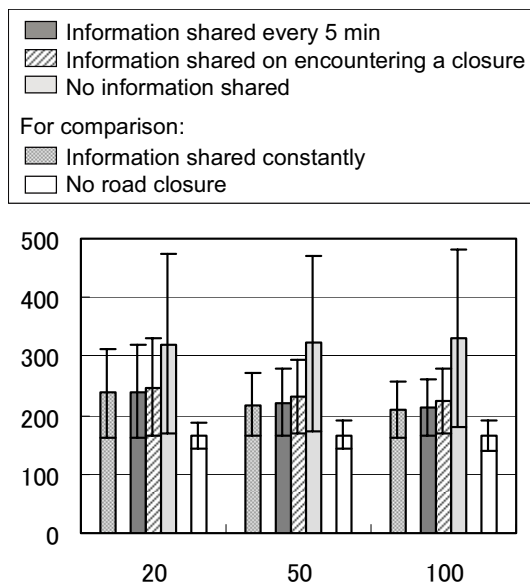
Vehicles drive a linear distance of 50 km at an average speed of 30 km/h. The journeys of 20, 50, and 100 vehicles are simulated. All the vehicles start at the same time in one simulation case. A hundred pairs of origins and destinations are randomly selected, and the travel times and rates of known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

## 5.2. Results of numerical simulation

### 5.2.1. Available road information gathering.

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. 7, 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 of the case that all vehicles constantly share the





**Fig. 10 Comparison of mean value and variation of travel time**  
(Error bars represent standard deviation)

information, and those of the case 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  $R_k$ .

When road closure information is shared, higher rates of known available roads  $R_k$  were obtained compared to the cases without information sharing (**Fig. 7**). But this is not always true, and an example of such a case is discussed in [15]. In this literature, simpler road network is used, and  $R_k$  converged to lower values when road closure information is shared in contrast to **Fig. 7**. This can be explained as follows; when a shortest path search is retried by a vehicle that received new road closure information, a possibility of getting a diversion that no other vehicle has already passed through is higher in a more complex road network.

Furthermore,  $R_k$  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. Even in the cases without road closure information sharing, rates of known available roads  $R_k$  will gradually converge to its maximum values, because diversions will eventually searched and passed through by the vehicles.

### 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. 6**. The trajectories with and without road closure information sharing are found to be remarkably different. In this example, a travel time of 557 minutes when road closure information is not shared is reduced to 198

minutes when it is shared every 5 minutes, and to 207 minutes when it is shared on encountering road closures.

Travel time reductions of the vehicles in the simulations are summarized as normalized histograms shown in **Fig. 9**. The deviation of the travel time is small when any road closure does not exist, because linear distance between the origin and the destination of each vehicle is constant. On the other hand, when some road closure exist and the road closure information is not shared, the deviation becomes larger, as vehicles that need more than 2.5 times of the average travel time account for 20% of all the vehicles. The number of such vehicles, which require longer travel times, is significantly reduced when the road closure information is shared, and it is further reduced as the total number of vehicles increase.

The average travel time is also reduced, as shown in **Fig. 10**. This figure shows that an average travel time of 330 minutes when road closure information is not shared is reduced by the 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. The information sharing of five minutes interval or longer seems to be effective, while to share information constantly may not be realistic unless the communication cost is significantly reduced. **Fig. 10** also shows that the travel time deviation to the longer side is reduced when the road closure information is shared.

## 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 main results obtained from the numerical simulations can be summarized as follows:

- 1) The available roads were readily recognizable when the trajectories obtained from the vehicles were superimposed on a map.

- 2) The sharing of road closure information marginally affects the total length of the available roads that is recognized.
- 3) The simulated travel times of individual vehicle were shortened when the road closure information derived from the probe vehicle data was shared among the vehicles. The deviation of the travel time to the longer side is also reduced.

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.

In the actual operations, vehicle trajectories do not ensure that the roads passed through 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

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