Proposal of information provision to probe vehicles based on distribution of link travel time that tends to have two peaks

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Abstract. In most cities, traffic congestion is a primary problem that must be tackled. Traffic control/operation systems based on information gathered from probe vehicles have attracted a lot of attention. In this paper, we examine provision of travel information to eliminate traffic jams. Although it is conventional to provide the mean of historical accumulated data, we introduce the 25th percentile and 75th percentile values because a distribution of link travel time tends to have two peaks. As a result, the proposed method reduced travel time of vehicles compared with the conventional method.

Keywords: Traffic management, Probe car, Intelligent Transport System

1 Introduction

Automobile traffic jams have become a major problem in many cities of the world. In Japan, an increase in vehicle emissions and time loss due to traffic congestion have also become significant problems. As a solution to these problems, information collected from probe vehicles is attracting attention. In this research, we assume an environment in which information of the travel time of a vehicle in the past can be obtained, vehicles can communicate mutually, and vehicles can share traffic conditions to reduce the travel time of all vehicles. Thus, we propose a method of providing information to a probe vehicle for reducing travel time of regular vehicles, and show the effectiveness of the proposed method by simulation experiments.

In this research, we focus on how a distribution of link travel time tends to have two peaks for historical accumulated data of travel time of the vehicle. In addition to the mean of historical accumulated data of the link travel time, using the 25th percentile value and 75th percentile value of historical accumulated data, we perform path finding and give information to the probe vehicle. Furthermore, to demonstrate that the proposed method of this research is effective, we implement traffic flow simulation based on the cell transmission model[1][2], and we perform vehicle movement simulation of the conventional method and proposed method. We use travel time of the vehicle, which has also been used in conventional research, for the effect analysis of information provided to the probe vehicle. In addition, we examine the difference between the time taken to move in the simulation and travel time to the destination that is expected from the historical accumulated data of the vehicle.

The remainder of this paper is organized as follows. Background and purpose of this research are presented in chapter 2, and the distribution of link travel time having two peaks is discussed in chapter 3. We describe the proposed information provision method in chapter 4, the vehicle simulation in chapter 5, and the effectiveness of the proposed method, along with future work in chapter 6.

2 Background and purpose

In this chapter, we describe the background and purpose of this research. Personal vehicles have become an essential means of transportation for many people. However, there are many problems we must solve; for example, decline in economic efficiency due to traffic congestion, global environmental degradation such as global warming and air pollution, and many traffic accidents. Transportation and traffic account for about 20% of carbon dioxide emissions in Japan, and of that, vehicles account for about 90%[3]. Figure 1 is a diagram showing the relationship between carbon dioxide emissions and the running speed of a vehicle. Because we can see that the carbon dioxide emissions from the vehicle decrease when running speed of the vehicle increases, we must decrease carbon dioxide emissions by eliminating traffic congestion, and increasing the running speed of the vehicle. Also, there are approximately 5 billion hours per year in time lost to congestion in Japan, and the economic loss is 11 trillion yen. Problems caused by traffic congestion have clearly become serious in Japan, as in many other parts of the world, and it is necessary to resolve these issues.

In addition to the promotion of next-generation vehicles such as electric cars as a way to solve these problems, traffic operation and management measures by Intelligent Transport Systems (ITS), such as providing path information and road pricing, have attracted attention. The number of vehicles with vehicle perception and navigation systems (probe vehicles) is increasing, and technology of information collection and provision has also advanced in route search information. Further, from the historical accumulated data collected from the probe vehicle, it is observed that a distribution of link travel time tends to have two peaks.

About providing information to the probe vehicle, Kanamori et al.[4] simulated providing information to a probe vehicle using not only the historical accumulated data collected from the probe vehicle but also predicting the traffic situation. Morikawa et al.[5] simulated providing information to a probe vehicle using the number of right and left turns in the path to the destination, in addition to the historical accumulated data collected from the probe vehicle.

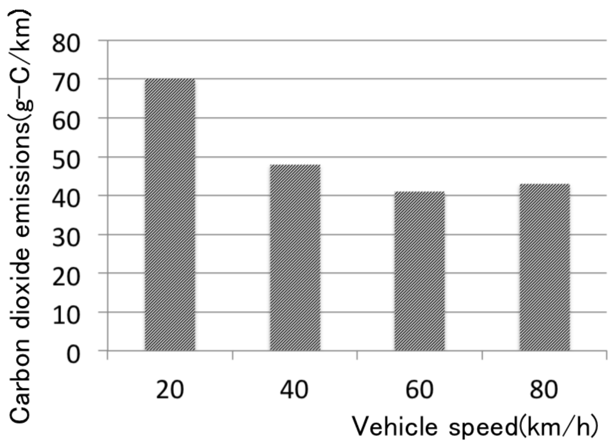

Fig. 1. Relationship between carbon dioxide emissions and running speed of vehicle

In researches of Kanamori et al. and Morikawa et al., they simulated providing information that uses the mean of historical accumulated data collected from probe vehicles, and searches for a route to a destination.

The purpose of this research is to propose a method to use historical accumulated data focusing on the distribution of link travel time, which tends to have two peaks, and reducing travel link time of vehicles in the simulation.

3 Distribution of link travel time

In this section, we discuss how a distribution of link travel time tends to have two peaks. Link travel time of the vehicle described in this research is the time to travel from one intersection to another.

Figure 2 shows example of distribution of link travel time. It is observed that a distribution of link travel time tends to have two peaks when the vehicles pass through the intersection, and simulations that reproduce a distribution of link travel time have been researched[6].

The cause of the link travel time of the vehicle having two peaks is, for example, a traffic signal. When the vehicle passes through an intersection, a considerable difference occurs because the vehicle stops at the signal or doesn't stop. In previous research, they didn't consider that a distribution of link travel time tends to have two peaks; instead, they used the mean value of the link travel time collected from the probe vehicle.

4 Information provision to probe vehicles

In this chapter, we provide a detailed description of the method of information provision to the probe vehicle in this research. As usage of the historical accu-

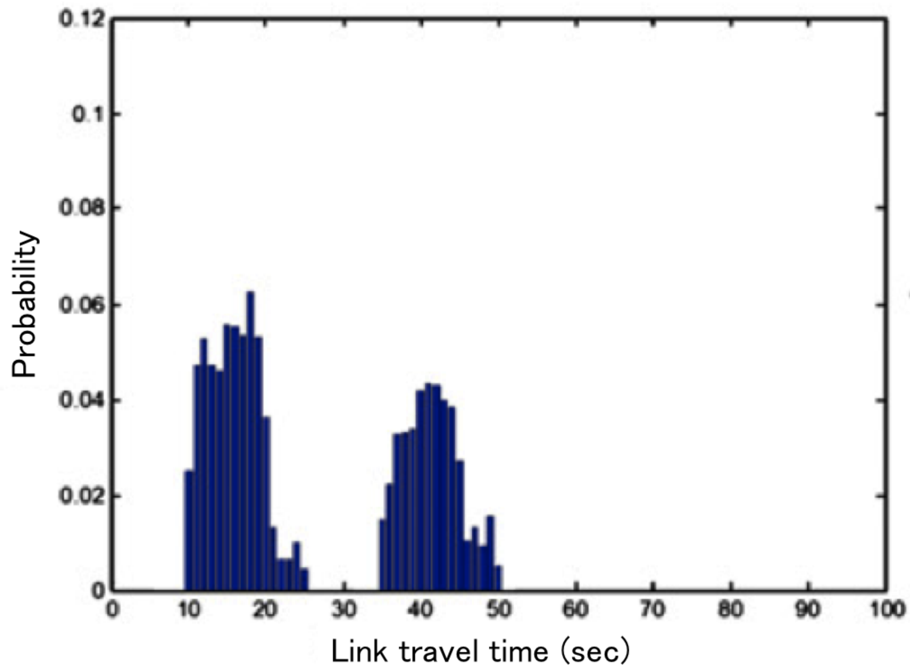

Fig. 2. Distribution of link travel time

mulated data of link travel time for searching the route to the destination, in addition to a conventional method to provide the mean of historical accumulated data of the travel time, we introduce provisions of the 25th percentile value and 75th percentile value of historical accumulated data of the travel time in this research.

Probe vehicle assumed in this paper is sending information of link travel time and receiving information of path to destination with least travel time. Information of path to destination with least travel time is predicted by link travel time collected from probe vehicle.

In this experiment, we use the data of the 25th percentile and 75th percentile values of the historical accumulated data of link travel time. To decide which value we will use in this research, we conduct a preliminary experiment. First, we used only the 25th percentile value of the historical accumulated data in the information-providing simulation. Second, we used only the 75th percentile value of the historical accumulated data in the information-providing simulation. We compared the mean of historical accumulated data of the link travel time with 25th percentile and 75th percentile values regarding the travel time of the vehicle. In this research, assuming the differences of factors such as the number of intersections passed through depending on the travel distance of the vehicle, we compare the mean value, 25th percentile and 75th percentile values by travel distance of each vehicle.

We set the travel distance of vehicles using the 25th percentile or 75th percentile values in the simulation, and conduct information provision simulation using the 25th percentile and 75th percentile values for searching the route to the destination.

5 Simulation for evaluation

5.1 Settings of simulation

We use the data of Kichijoji and Mitaka that are provided in the traffic simulation clearing house as a road network used for the evaluation experiment in this research. The traffic simulation clearing house[7] is an institution providing various data for validation. The network is composed of 57 nodes and 137 links. Vehicles in the simulation number about 17,000 units, and approximately 50% are probe vehicles in this experiment. Further, in order to accumulate link travel time for the vehicles to be used for route search, the simulation was repeated about 30 times. Figure 3 is a network diagram from Kichijoji and Mitaka that is used for the simulation in this research.

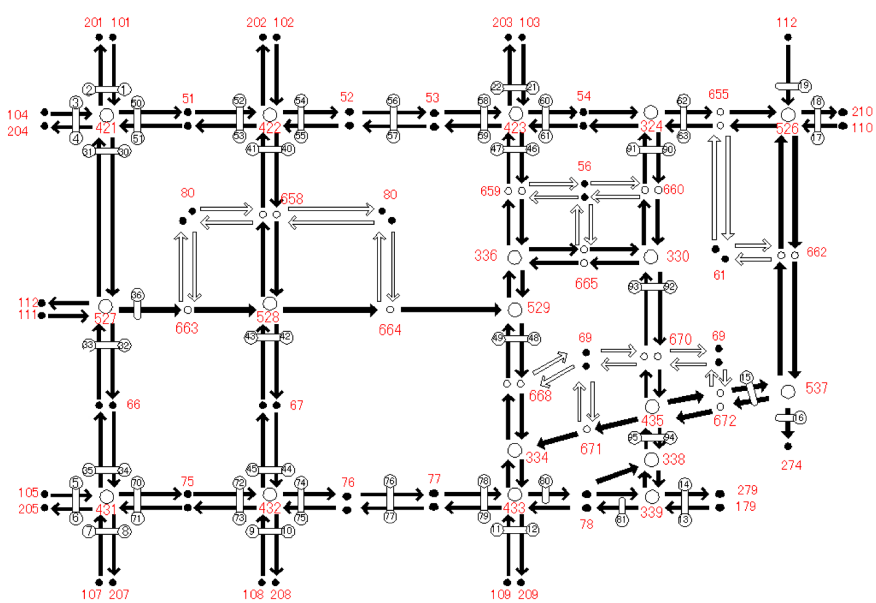

Fig. 3. Network of Kichijoji and Mitaka

Table 1 shows survey contents collected by Kichijoji and Mitaka. Investigation time is set to a high-traffic period.

Since the investigation data contain the times each vehicle entered and exited the network, we can obtain the travel time to the destination of each vehicle.

Table 1. Details of survey of Kichijoji and Mitaka

investigation time	AM 7:00 AM 10:00
target area	Mitaka and Musashino, Tokyo
observation points	70
target vehicle	four wheel vehicles
survey contents	passage time
	vehicle number
	car model(bus, taxi, and other)

5.2 Traffic flow simulation

In this research, we implemented a traffic flow simulation based on the cell transmission model, in which the repeatability of travel time is high and we can control the route choice of the vehicle in the simulation. The cell transmission model is a model that divides the network links into cells and controls the movement of vehicles by the density of vehicles in a cell.

$$y_i(t) = min\{ n_{i-1}(t), Q_i(t), N_i(t) - n_i(t)\} \tag{1}$$

- $y_i(t)$: number of vehicles moving to the cell of index i at time t
- $Q_i(t)$: maximum number of vehicles that can flow into the cell of index i at time t
- $N_i(t)$: maximum number of vehicles in the cell of index i at time t
- $n_i(t)$: number of vehicles in the cell of index i at time t

Equation (1) represents the number of vehicles to move between cells on the cell transmission model. The number of vehicles that can move to the next cell is determined by the smallest number of the following: number of vehicles in the present cell, the amount of empty space in the next cell, or maximum number of vehicles that can flow into the next cell. Equation (2) represents traffic flow rate.

$$q = k * v \tag{2}$$

- q: traffic flow rate in the cell.
- k: vehicle density in the cell.

- v: vehicle speed in the cell.

Traffic flow rate can be calculated from the vehicle speed and vehicle density in the cell. There are many equations that can calculate the vehicle speed from the density. In this research, we use the formula of Green Shields[8] to calculate the traffic flow rate.

The traffic flow simulation implemented in this research uses a data set of network and departure time, departure point, destination point, and whether the vehicle is a probe vehicle. To verify the reproducibility of the traffic flow simulation, we compare ours with the traffic flow simulation based on the cellular automata model[9][10] regarding a coefficient of simple linear regression and root mean square of the travel time of the vehicle. The cellular automata model is a discrete model and is easy to implement. In the experiments, root mean square being close to 0 and a coefficient of simple linear regression being close to 1 represents that the reproducibility of vehicle travel time is high.

Table 2. Comparison of cellular automata model and cell transmission model for reproducibility of travel time

model	root mean square	coefficient of simple linear regression
cell transmission	2.029	0.835
cellular automata	3.502	0.339

Table 2 shows the results of a comparison of the coefficient of simple linear regression and the root mean square regarding the simulation based on the cellular automata model and the cell transmission model. Table 2 shows that the reproducibility of the travel time in the simulation based on the cell transmission model is greater than that of the cellular automata model from the values of both the coefficient of simple linear regression and the root mean square.

Traffic flow simulation that reproduces a distribution of link travel time tending to have two peaks is required for information provision and shows the effectiveness of proposed method.

Figure 4 shows that the passage number and travel times of the vehicles on one link in the network when we simulated movement of the vehicles using the Kichijoji and Mitaka data set on traffic flow simulation. As Figure 4 shows, it was confirmed that it is possible to reproduce a distribution of link travel time tending to have two peaks in the traffic flow simulation implemented in this research.

5.3 Experimental result

Difference of the travel time for each distance of vehicles We show the comparison results regarding the travel time of vehicles between using the

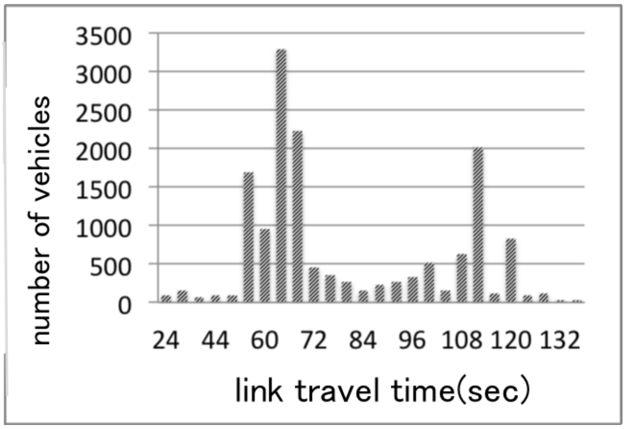

Fig. 4. Traffic volumes and travel time of the vehicles at a certain link in the simulation

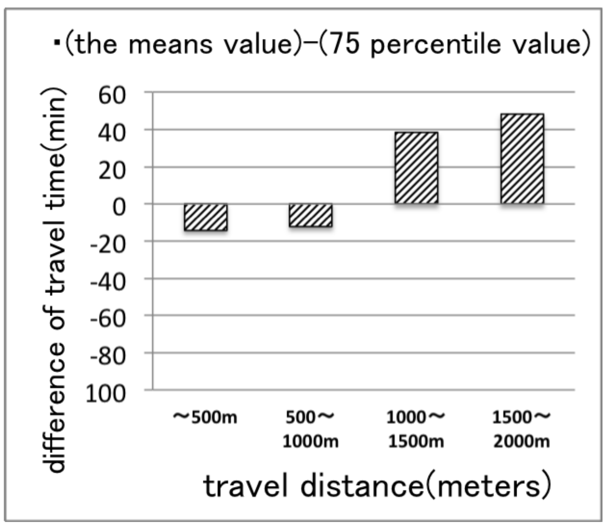

Fig. 5. Difference in travel time of vehicles between using the mean value and 75th percentile value for route search by travel distance of vehicles

mean value, 25th percentile value and 75th percentile value of the historical accumulated data of the link travel time.

Figures 5 and 6 show difference of travel time between using the mean, 25th percentile value, and 75th percentile value for route search by travel distance of vehicle. The value of the graph subtracts the travel time when using 75th percentile and 25th percentile values from the travel time in case of using the mean value. As the value of the graph is large, it represents that the travel time

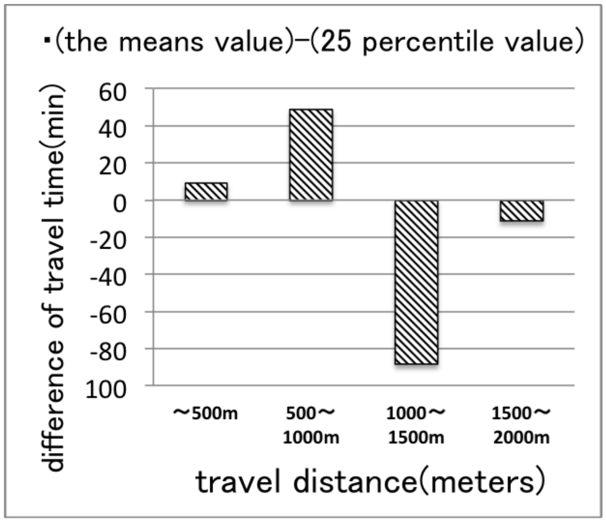

Fig. 6. Difference in travel time of vehicles between using the mean value and 25th percentile value for route search by travel distance of vehicles

of vehicles using the mean value is more than the travel time of vehicles using the 25th percentile value and 75th percentile value. In Figure 5, the travel time of vehicles using the 75th percentile value is less than that using the mean value regarding vehicles that travel distances of 1,000 meters or more. On the other hand, in Figure 6, the travel time of vehicles using the 25th percentile value is less than that using the mean value regarding vehicles that travel distances of 1,000 meters or less.

Proposed method and evaluation In this research, we proposed that vehicles whose travel distance is 1,000 meters or less perform a route search using the 25th percentile value of historical accumulated data, and vehicles whose travel distance is 1,000 meters or more perform a route search using the 75th percentile value of historical accumulated data. The effect analysis is the total travel time of all vehicles in the simulation.

Figure 7 shows the result of the simulation experiment in each case. Values in the graph of Figure 7 show the total travel time of all vehicles in each case. We describe setting of each case. There is no probe vehicle in case 1; that is, vehicles do not change their routes in repetition. The probe vehicles search for the route using mean value in case 2, 25th percentile value in case 3, and 75th percentile value in case 4 as link cost. We use the proposed method in case 5.

As shown in the graph of Figure 7, using both 25th percentile value and 75th percentile value of historical accumulated data reduced the travel time of all vehicles most.

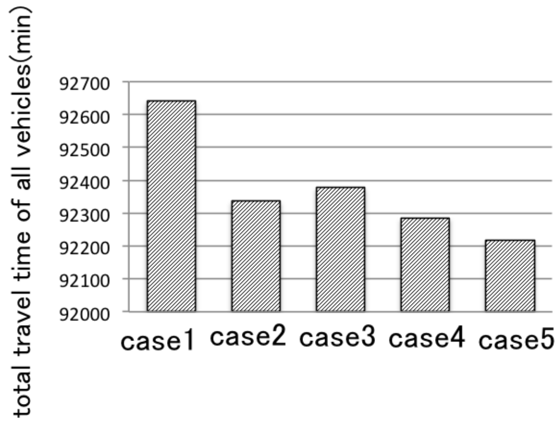

Fig. 7. Total travel time of all vehicles in each information provision

6 Conclusion and future work

In this research, we presented background information about the problems caused by the increasing number of vehicles on the road, such as economic losses and environmental degradation. Also, the number of probe vehicles has increased in recent years, and the distribution of link travel time tends to have two peaks. Next, we proposed information provision based on a distribution of link travel time tending to have two peaks. In the experimental simulation, as the information provision to the probe vehicle, we proposed using both the 25th percentile and 75th percentile values as a function of travel distance of a vehicle. We demonstrated that the proposed method reduced the travel time of all vehicles compared with the conventional method.

In future work, we will simulate a large network. In this experiment, since we used a small network data set, it is necessary to test a larger network to confirm that the proposed method is effective.

The information method proposed in this research used travel distance of the vehicles; it is also necessary to use such factors as the departure time of the vehicles in future research.

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