Smooth Traffic Flow with a Cooperative Car Navigation System

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ABSTRACT

With maturation of ubiquitous computing technology, it has become feasible to design new systems to improve our urban life. In this paper, we introduce a new application for car navigation in a city. Every car navigation system in operation today has the current position of the vehicle, the destination, and the currently chosen route to the destination. If vehicles in a city could share this information, they could use traffic information to globally plan semi-optimal routes for each vehicle. Thus, we propose a cooperative car navigation system with route information sharing (RIS). In the RIS system, each vehicle transmits route information (current position, destination, and route to the destination) to a route information server, which estimates future traffic congestion using this information and feeds its estimate back to each vehicle. Each vehicle uses the estimation to re-plan their route. This cycle is then repeated. Our multiagent simulation confirmed the effectiveness of the proposed RIS system. The average travel time of drivers using the RIS system is substantially shorter than the time of drivers who chose shortest distance or simple shortest time estimates. Moreover, as the number of RIS users increases, the total amount of traffic congestion in the city decreases.

Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems; I.6 [**Simulation and Modeling**]: Miscellaneous; H.4.2 [**Information Systems Applications**]: Types of SystemsDecision support

General Terms

Design

Keywords

traffic congestion, car navigation, information sharing

1. INTRODUCTION

With maturation of ubiquitous computing technology, particularly with advances in positioning and telecommunications systems, we are now in a position to design advanced assist systems for many aspects of our lives. However, most of the research we've seen to date has focused on aspects of supporting a single person. Multiagent technology has not been tied to ubiquitous computing, except in a small number of studies [20]. We believe a mass user support system [7, 8] would have a large impact on society. The new concept would benefit not only society as a whole but would also benefit individuals. In particular, Nakashima [11] has focused on technologies that might enhance urban social life, especially transportation support systems. With ubiquitous computing and multiagent technologies, a new "dial-a-ride" system [12] and a new car navigation system [17, 18] have been proposed. This paper reports on our recent multiagent simulation demonstrating the effectiveness of a new kind of car navigation system.

Many researchers have been trying to design better navigation systems, by examining the variety of traffic information available [1, 6, 14]. However, previous research efforts have revealed that individually optimizing performance with only traffic congestion information is difficult [10, 15, 19]. A navigation system recommends the route for the shortest estimated travel time based on the current state of traffic congestion. However, if other drivers, using the same information, simultaneously choose the same route, traffic would become concentrated on the new route.

Although active queue management algorithms for TCP traffic, e.g., random early detection (RED) [3], are similar to city traffic management, these algorithms are unsuitable for traffic flow in road transportation systems for two reasons.

One is a physical constraint: dropping vehicles like packets in TCP traffic is impossible. The other is a social constraint: such algorithms are problematic from the standpoint of fairness because the utilities of the vehicles that are randomly dropped (or stopped) suffer a big loss.

Car navigation systems were originally designed as electronic enhancements of maps automatically indicating the current position of the vehicle and a route to the destination. Japan roads now support the second generation of car navigation systems connected to VICS (Vehicle Information and Communication System, http://www.vics.or.jp/english/ index.html). This new system can download traffic information and display it on the map. The system uses the information to avoid congested routes when it plans a route. What we suggest in this paper is yet another generation of car navigation systems [21]. VICS measures traffic volume with sensors located on roadsides, e.g., radar, optical, and ultrasonic vehicle detectors and CCTV (closed circuit television) cameras. The gathered information is transmitted using infrared beacon, radio wave beacon, and FM multiplex broadcasting. Each car just receives information from VICS, but does not return any.

If a car could transmit information by using a mobile phone or other short-range communication, we believe that we could design a far better navigation system. Every car navigation system in operation today has the current position of the vehicle, the destination, and the currently chosen route to the destination. If vehicles in a city could share this information, they could use traffic information to globally plan semi-optimal routes for each vehicle. Our idea is thus a cooperative car navigation system with route information sharing (RIS). In the RIS system, each vehicle transmits route information (current position, destination, and route to the destination) to a route information server, which uses this information to estimate future traffic congestion and feeds its estimate back to each vehicle. Each vehicle then uses the estimation to re-plan its route. This cycle of gathering information, estimating congestion, and planning a route is repeated many times.

The main purpose of this paper is to report the results of simulations demonstrating the validity of our idea. In particular, the simulation showed the average travel time is substantially shorter when drivers use the RIS mechanism. Moreover, as the number of RIS users increases, the total amount of traffic congestion of the city decreases.

Before we go into the details of the simulation, let us suggest a further capability of the idea presented here. Estimated traffic volume based on gathered route information can be used in many other ways. One of the simple usages is to reflect it in the timing of traffic signals. We can increase the green light time of the traffic signals that are expected to receive more traffic. Traffic lanes may also be dynamically changed. By connecting many systems in a city in a cooperative way, we can increase the physical capacity of the city's infrastructure.

To implement our idea as an actual service, the anonymity of drivers must be ensured. It is not a good idea to broadcast your destination to other drivers. That means the information exchange with the route information server must be anonymous. Systems designed for anonymous auctions [9] are able to guarantee such anonymity.

2. TRAFFIC FLOW MODEL

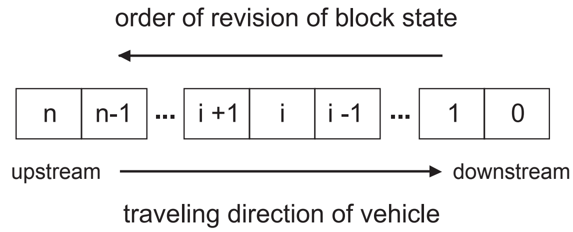

Figure 1: Direction of vehicle movement and revision of blocks

We constructed a simple traffic flow model to examine the interdependence between traffic congestion as macro phenomena and route choice of individual drivers as micro behavior. Therefore, we did not consider the following factors: traffic signals (e.g., stopping at red lights), waiting for oncoming cars when turning at intersections, turn lanes, multiple lanes, passing, blind allies; and U-turns in lanes, not at intersections.

Our traffic flow model designates a road between intersections as a link. It is divided into several blocks. The block length is equal to the distance that a vehicle runs at the free flow speed of V_f of the link during one simulation step. After link division, an order is assigned to each block from downstream to upstream. Concerning the block assigned to be the i-th, we define K_i as the density of block i, L_i as the length of block i, N_i as the number of the vehicles in block i, and V_i as the feasible speed of vehicles in block i. K_i is the division of N_i by L_i. In block i, V_i is revised based on Greenshield's V-K relationship as follows:

$$V_i = V_f(1 - \frac{K_i}{K_{jam}}), \qquad (1)$$

where K_{jam} is the traffic jam density. The density signifies the minimum density that prevents vehicles in a traffic jam from moving. In our simulation, we set these coefficients as $V_f = 13.89$ and $K_{jam} = 0.14$.

The process of the flow calculation between neighboring blocks i and $i+1$ is as follows. At every step, the speed of vehicles in each block is revised according to the V-K relationship. The vehicles then move forward based on this speed. The vehicles' movement is processed from downstream to upstream, as shown in Figure 1. Depending on V_i, vehicle j can move forward. When vehicle j moves from block $i+1$ to block i, its speed changes from V_{i+1} to V_i. If K_i exceeds the jam density K_{jam}, no vehicles can move into block i from block $i+1$. After j_1 in front of vehicle j_2 moves, if j_1 is within a distance that allows j_2 to move forward at V_i, j_2 approaches j_1 to the minimum distance between them. Although j_2 has sufficient speed to advance, it must remain behind j_1. At the next step in block i, when V_i is revised based on K_i, vehicles can accelerate or slow down to V_i immediately, regardless of the speed in the last step.

3. ROUTE CHOICE MECHANISMS

To examine the proposed mechanism, we compared it with two other route choice mechanisms. These other mechanisms are well known and easy to understand because they seek routes minimizing the travel distance or travel time.

3.1 Shortest Distance Route

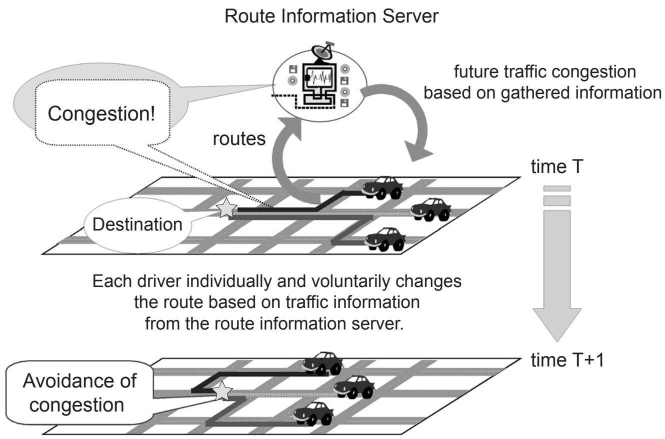

Figure 2: Outline of route information sharing

Drivers searching for the shortest distance route (SD) select a route on a map without using information on traffic congestion. That is, SD drivers simply select the shortest distance route from their respective origin to their destination, and don't consider traffic congestion at all.

3.2 Shortest Time Route

Drivers searching for the shortest time route (ST) decide a route with information on the current levels of traffic congestion. Their choice will thus vary based not only on map information, but also on congestion information on the entire network, as would be obtained from a traffic information center (e.g., a VICS Center) via vehicle equipment.

A traffic information center measures the current traffic density of all blocks, and calculates the expected travel time of each link by estimating the time spent on a link in light of the current traffic density. A traffic information center calculates expected travel time ETT_l of link l as follows.

1. Feasible speed $V_{i,l}$ on block i in l is calculated based on the V-K relationship with traffic density $K_{i,l}$.
2. Passage time $PT_{i,l}$ of block i in l is calculated based on length $L_{i,l}$ and speed $V_{i,l}$ on block i in l.
3. Expected travel time ETT_l of link l is calculated as

$$ETT_l = \Sigma^{k}_{0 \leq k < n} PT_{k,l}, \tag{2}$$

   where n is the number of blocks in l.

The expected travel time is transmitted to all ST drivers at every simulation step. ST drivers search for the shortest route in terms of the expected travel times from their current position to their destination at every intersection.

3.3 Shortest Time Route with Route Information Sharing

Drivers searching for the shortest time route by using route information sharing (RIS) base their selection on information sent from a route information server. Moreover, RIS drivers transmit route information (current position, destination, and route to the destination) to the route information server. The route information server then estimates future traffic congestion levels based on this route information and transmits the estimate to the RIS drivers. The RIS drivers use the estimate to revise their route at every intersection. The route information server only provides traffic information to the RIS drivers, but does not plan the routes of drivers. Each RIS driver plans its route based on information sent from the route information server. Figure 2 shows the outline of route information sharing mechanism.

The route information sharing procedure between RIS drivers and the route information server is as follows.

1. RIS drivers search for the shortest route in terms of expected travel time from their origins to their destinations. They transmit their route information to the route information server.
2. The route information server collects route information from all RIS drivers, and uses it to assign a passage weight for each RIS driver to a link. The passage weight indicates the degree of accuracy with which an RIS driver will pass through the link in the future. Passage weight $PW_{j,l}$ of RIS driver j to link l is calculated as follows.
   (a) If j's route passes through p links from the current position to a destination, the links are assigned numbers in ascending order from the destination to the driver's current position.
   (b) The order of each link is divided by p, and it is regarded as the passage weight of the link. (For example, $1/p$ is assigned the link including the destination, and 1 (=p/p) is assigned to the link including the current position.)
3. The route information server calculates the total passage weight of each link based on the passage weight of each link. Total passage weight means the accumulated [means the sum of the??] passage weights of all RIS drivers. Total passage weight TPW_l of link l is calculated as

$$TPW_l = \Sigma^{k}_{k \in RIS} PW_{k,l}, \tag{3}$$

   where RIS is the set of RIS drivers.
4. The route information server calculates the prospective traffic volume of each link based on the total passage weight and the expected travel time. Prospective traffic volume PTV_l of link l is calculated as

$$PTV_l = ETT_l \times (TPW_l + \alpha), \tag{4}$$

   where α is a positive constant. (In our simulation, we set α to 1.0.)
5. The prospective traffic volume is transmitted from the route information server to all RIS drivers. The RIS drivers revise the shortest route in the prospective traffic volume and again transmit route information to the route information server when they reach the next intersection.
6. Processes 2 $\sim$ 5 are repeated.

Figure 3 shows an example of calculating total passage weight. Driver 1 has a route through six links 6, 5, 4, 3, 2, 1, from the current position on link 6 to the destination on link 1. Based on the current position, destination, and route

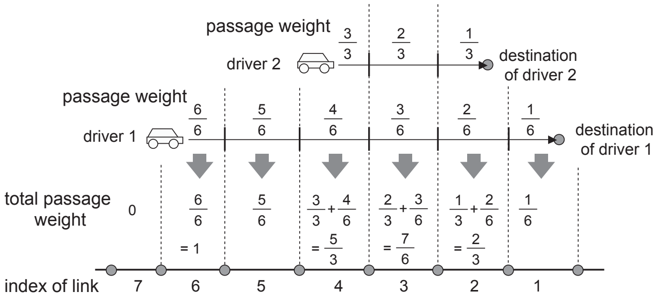

Figure 3: Sample calculation of total passage weight

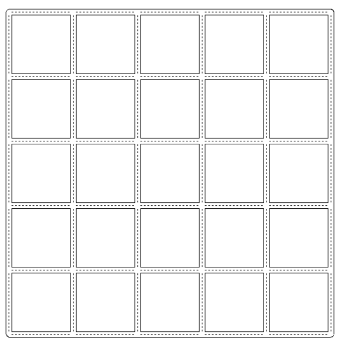

Figure 4: Lattice network

of driver 1, the passage weights for links 1 to 7 of driver 1 are

$$\begin{aligned}&PW_{1,1} = 1/6, PW_{1,2} = 2/6, PW_{1,3} = 3/6,\\ &PW_{1,4} = 4/6, PW_{1,5} = 5/6, PW_{1,6} = 6/6,\\ &PW_{1,7} = 0.\end{aligned} \quad (5)$$

Driver 2 has a route through three links 4, 3, 2, from the current position on link 4 to the destination on link 2. Similarly, the passage weights of links 1 to 7 of driver 2 are:

$$\begin{aligned}&PW_{2,1} = 1/3, PW_{2,2} = 1/3, PW_{2,3} = 2/3,\\ &PW_{2,4} = 3/3, PW_{2,1} = PW_{2,5} = PW_{2,6} = PW_{2,7} = 0.\end{aligned} \quad (6)$$

Given the passage weights for links 1 to 7 of drivers 1 and 2, the total passage weights of link 1 to 7 are:

$$\begin{aligned}&TPW_1 = 1/6, TPW_2 = 2/3, TPW_3 = 7/6,\\ &TPW_4 = 5/3, TPW_5 = 5/6, TPW_6 = 1,\\ &TPW_7 = 0.\end{aligned} \quad (7)$$

4. MULTIAGENT SIMULATION

4.1 Simulation Settings

To evaluate the RIS mechanism, we performed a multiagent simulation using the three route choice mechanisms for which the ratio of ST and RIS drivers varied from ST:RIS = 0.8:0 to ST:RIS = 0:0.8, and the ratio of the SD drivers was fixed at 0.2. This setting was based on an estimation that car navigation systems and traffic information services will be more easily accessible for many drivers in the near future.

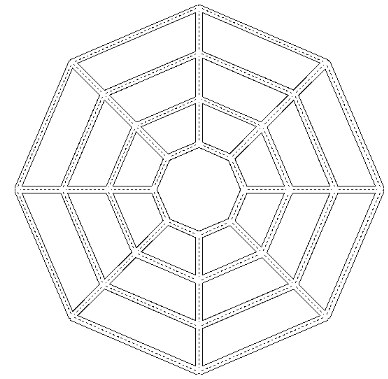

Figure 5: Radial and ring network

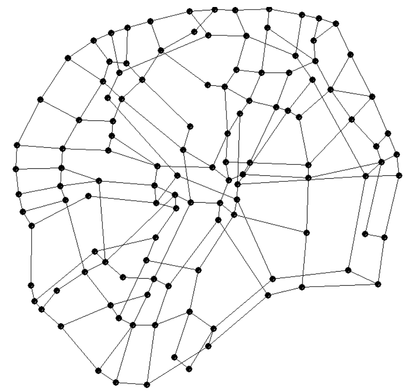

Figure 6: Tokyo network

Furthermore, We evaluated the effectiveness of the RIS mechanism on three different road networks: a lattice network, a radial and ring network, the network around the city of Tokyo (see Figures 4, 5, and 6 and also Table 1). In particular, the Tokyo network matches the structure of the main trunk roads and expressways within the 8 km centered on the Imperial Palace in Tokyo, Japan. In these road networks, all blocks in a link have the same capacity.

The origin and destination of a vehicle are assigned randomly to any block on any link. After reaching its destination, the vehicle is removed from the network.

The number of vehicles to a capacity of traffic systems influences the effect of traffic information systems for shorting travel time. The effect of traffic information systems can be classified into following three cases according to the number of vehicles

- Case 1. The number of vehicles is few compared with the capacity of a traffic system. Without traffic information systems, each vehicle can move from an origin to a destination at shortest travel time by choosing the shortest distance route.
- Case 2. The number of vehicles is within range of the capacity of a traffic system. The concentration of certain vehicles causes traffic congestion, and their travel time should be lengthened. If vehicles can avoid traffic congestion, their travel time can be shortened.

Table 1: Settings of three networks

	lattice	radial and ring	Tokyo
Number of nodes	36	32	120
Number of links	60	56	200
Number of blocks	1,200	1,168	4,034

Table 2: Number of vehicles generated in one step

	lattice	radial and ring	Tokyo
N_{gen}	40, 45	30, 35	55, 65

Therefore, it is easy to observe the effect of traffic information system.

- Case3. The number of vehicles exceeds the capacity of a traffic system. Because traffic congestion is caused in any routes, the route choice based on traffic information cannot have great influence to shorten travel time.

It is desirable that the effect of the RIS mechanism is examined under general traffic conditions. In our simulation, we apply the number of vehicles in a traffic system belonging to Case 2 because this is most realistic traffic situation in the three cases.

Vehicles are generated every simulation step, until the amount of vehicles reaches 25,000. Table 2 lists the numbers of vehicles generated in one step N_{gen}. Based on our preliminary simulation results, it was confirmed that the number of vehicles generated in one step in table 2 belongs to Case 2. N_{gen} of each network realizes a traffic situation in which roads are not vacant, yet a deadlock does not occur.

4.2 Simulation Results

We were particularly interested in the transition of the average travel time of each mechanism as the ratio of RIS drivers increased.

The travel time of each driver was normalized by the ideal travel time to compare the results the different road networks and different sets of vehicle origins and destinations. The ideal travel time is the time required from origin to destination when a driver passes through the shortest distance route at free flow speed. The travel time is thus defined as the ratio of the actual travel time to the ideal travel time.

Figures 7 to 12 show the simulation results averaging 30 trials. In these graphs, the horizontal axis is the ratio of RIS drivers and the vertical axis is the average travel time using each mechanism. The ratio of RIS drivers among all drivers is denoted as R_{RIS}. The average travel times of the SD, ST, and RIS drivers are denoted as $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$.

Figure 7 shows the average travel time with $N_{gen} = 40$ in the lattice network. The average travel times of the three types decreased irregularly as R_{RIS} increased. In particular, $\overline{T}_{SD}$ at $R_{RIS} = 0.2$ was longer than that at $R_{RIS} = 0.3$ as R_{RIS} increased. Similarly, $\overline{T}_{SD}$ at $R_{RIS} = 0.8$ was longer than $\overline{T}_{SD}$ at $R_{RIS} = 0.7$. The average travel times were ranked in ascending order as $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$. For $R_{RIS} = 0.5$ or more, there was only a marginal difference between $\overline{T}_{ST}$ and $\overline{T}_{RIS}$.

Figure 8 shows the average travel time with $N_{gen} = 45$ in the lattice network. The average times of all three types

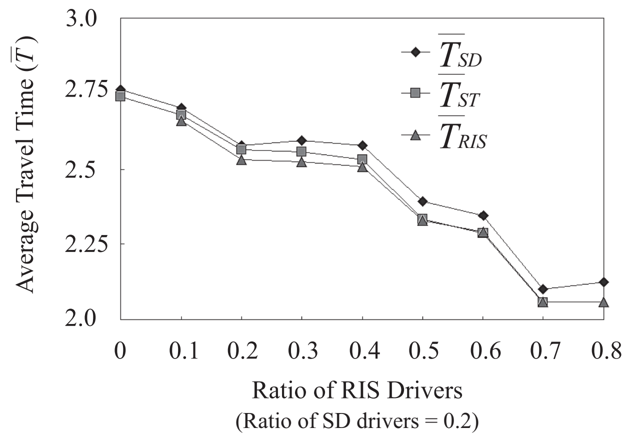

Figure 7: Average travel time with $N_{gen} = 40$ in the lattice network

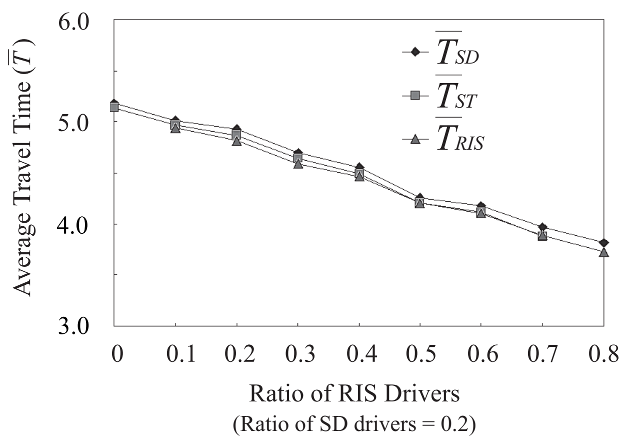

Figure 8: Average travel time with $N_{gen} = 45$ in the lattice network

decreased monotonically as R_{RIS} increased, and they were always ranked in ascending order as $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$. In all cases of R_{RIS} , there was only marginal differences among them.

Figures 9 and 10 show the average travel time with $N_{gen} = 40$ and with $N_{gen} = 45$ in the radial and ring network. In both cases, the average times of all three types decreased monotonically as R_{RIS} increased and were ranked in ascending order as $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$. There was only a marginal difference between $\overline{T}_{ST}$, and $\overline{T}_{RIS}$. Only in the case with $N_{gen} = 35$ at $R_{RIS} = 0.7$ was $\overline{T}_{ST}$ longer than $\overline{T}_{RIS}$.

Figure 11 shows the average travel time with $N_{gen} = 55$ in the Tokyo network. Except at $R_{RIS} = 0.3$, the average times of all three types decreased monotonically as R_{RIS} increased and were ranked in ascending order as $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$. In all cases of R_{RIS}, there were only marginal differences between $\overline{T}_{ST}$ and $\overline{T}_{RIS}$.

Figure 12 shows the average travel time with $N_{gen} = 65$ in the Tokyo network. The average times of all three types decreased substantially as R_{RIS} increased. $\overline{T}_{SD}$ increased

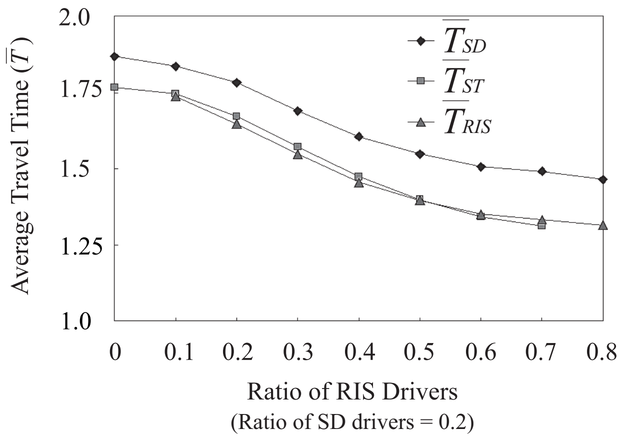

Figure 9: Average travel time with $N_{gen} = 30$ in the radial and ring network

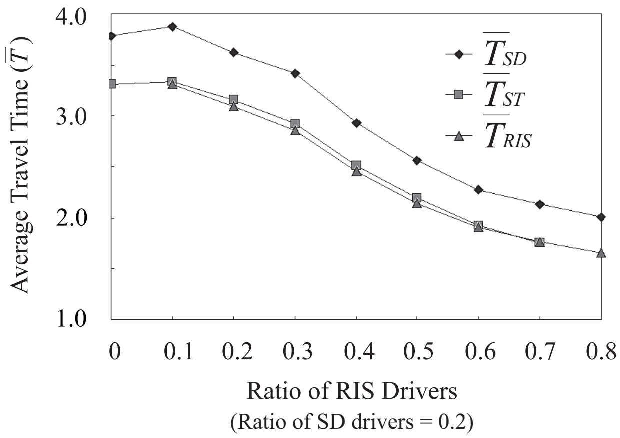

Figure 10: Average travel time with $N_{gen} = 35$ in the radial and ring network

at $R_{RIS} = 0.2, 0.3$, and 0.6 as R_{RIS} increased. $\overline{T}_{ST}$ at $R_{RIS} = 0.2$ and $\overline{T}_{RIS}$ at $R_{RIS} = 0.6$ increased slightly. The average times were ranked in ascending order as $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$. At $R_{RIS} = 0.6$ and 0.7, $\overline{T}_{ST}$ was shorter than $\overline{T}_{RIS}$.

5. DISCUSSION

5.1 Evaluation of RIS System

First, we discuss the effectiveness of the RIS mechanism from the viewpoint of whether it promotes individual incentive and social acceptability. Individual incentive means an incentive by which a driver would switch from using the other navigation mechanisms to the RIS mechanism. Here it is significant that the traffic efficiency of the RIS drivers is always higher than that of drivers using the other mechanisms we simulated. Social acceptability means the acceptability of the RIS mechanism to promote its popularity. Here it is notable that as the number of RIS drivers increases, their traffic efficiency improves.

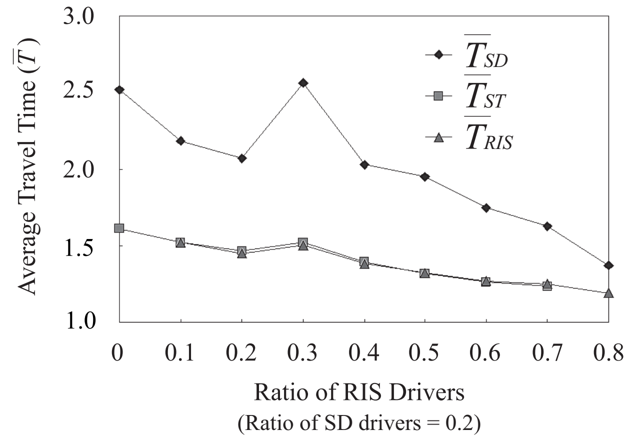

Figure 11: Average travel time with $N_{gen} = 55$ in the Tokyo network

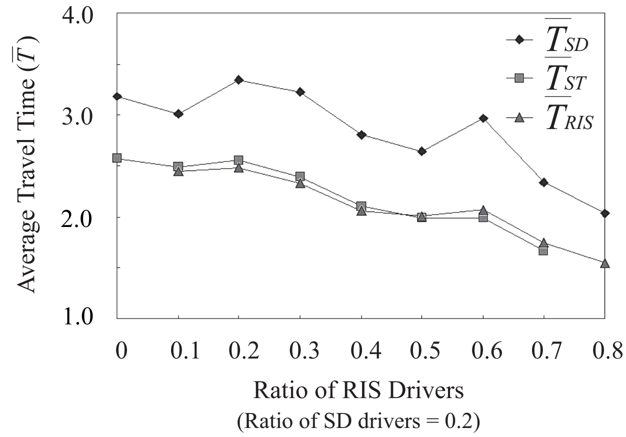

Figure 12: Average travel time with $N_{gen} = 65$ in the Tokyo network

Our simulation showed that $\overline{T}_{RIS}$ was always shorter than the other average times. Therefore, of the RIS system seems to promote individual incentive in the lattice network.

Individual incentive was also promoted in the radial and ring network and the Tokyo network, because $\overline{T}_{RIS}$ was shorter than the other times except that $\overline{T}_{RIS}$ was slightly longer than $\overline{T}_{ST}$ in the case of $N_{gen} = 35$ at $R_{RIS} = 0.7$ in the radial and ring network, and in the case of $N_{gen} = 65$ at $R_{RIS} = 0.6$ and 0.7 in the Tokyo network.

In the lattice and the radial and ring networks, our method promoted social acceptability because $\overline{T}_{RIS}$ decreased monotonically as R_{RIS} increased. In the Tokyo network, social acceptability was substantially promoted because $\overline{T}_{RIS}$ increased slightly as R_{RIS} increased only in the case of $N_{gen} = 65$ at $R_{RIS} = 0.6$.

It follows from these results that the RIS mechanism can a realize shorter travel time than other mechanisms, and that the travel time of the RIS drivers decreases as the number of RIS drivers increases. Moreover, the results confirm the RIS mechanism's effectiveness in promoting both individual incentive and social acceptability.

Many previous researches asserted only individual incentive of their proposed traffic information system at certain diffusion rate of them. However, the effect of traffic information systems significantly depends on its diffusion rate. In our research, we introduced social acceptability as another index estimating whether an information system can spread or not. Furthermore, we examine the effect of our proposed RIS system from the point of view of social acceptability, and confirm that the RIS system satisfied social acceptability. Previous research revealed that traffic Information systems providing current congestion status doesn't satisfy social acceptability (and partly satisfy individual incentive) [10, 15, 19]. Therefore, the result that the RIS system satisfied both individual incentive and social acceptability is significantly valuable.

5.2 Influence of Network Structure

Next, we discuss the different tendencies of effect of the RIS mechanism in the three networks.

5.2.1 Lattice network

In the lattice network, the SD drivers did not seriously concentrate on the central links because they had a number of shortest routes to choose from randomly. Traffic congestion caused by the SD drivers tended to occur suddenly on any link. Therefore, under these circumstances, the ST and RIS drivers had more difficulty in preliminarily avoiding congested links, and were often caught in traffic congestion. Accordingly, the differences among $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$ were small. Because the ST and RIS drivers were often involved in the traffic congestion caused by the ST drivers, $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$ decreased slightly irregularly for $N_{gen} = 40$. Furthermore, when the congestion on a link was caused by the SD drivers, traffic congestion often occurred on other links because the ST drivers concentrated on links other than the ones affected by SD drivers. Therefore, $\overline{T}_{SD}$, $\overline{T}_{ST}$, and $\overline{T}_{RIS}$ decreased overall because this kind of traffic congestion decreased as R_{RIS} increased.

5.2.2 Radial and ring network

In the radial and ring network, the SD driver had only one or two shortest routes of the same distance. Because these shortest distance routes statistically tended to pass through the innermost ring when the origin and destination were assigned randomly on the entire map, the SD drivers tended to concentrate at the innermost ring. The ST and RIS drivers could avoid congestion occurring on the innermost ring. Therefore, in the radial and ring network, $\overline{T}_{SD}$ was longer than $\overline{T}_{ST}$ and $\overline{T}_{RIS}$. However, by avoiding the innermost ring and concentrating on vacant links, the ST drivers often caused congestion on the second and third innermost ring. Furthermore, the RIS drivers did not cause such traffic congestion on the second- and third-innermost rings. Therefore, $\overline{T}_{RIS}$ decreased monotonically as R_{RIS} increased.

5.2.3 Tokyo network

In the Tokyo network, the SD drivers often concentrated on certain links in the center of the network because its structure is similar to the radial and ring network. The SD drivers often caused traffic congestion at the center of the network regardless of the ratio of the RIS drivers. The ST and RIS drivers could avoid traffic congestion in the center. Therefore, $\overline{T}_{SD}$ was much longer than $\overline{T}_{ST}$ and $\overline{T}_{RIS}$. Furthermore, a certain distribution of origins and destinations of the ST drivers frequently caused traffic congestion on links besides those at the center because the asymmetric structure of the Tokyo network naturally had bottlenecks. When such traffic congestion occurred suddenly, some of the ST and RIS drivers became involved in traffic congestion. Therefore, $\overline{T}_{RIS}$ decreased irregularly as R_{RIS} increased. However, many ST and RIS drivers could avoid this traffic congestion. Actually, $\overline{T}_{ST}$ and $\overline{T}_{RIS}$ did not increase like $\overline{T}_{SD}$, although $\overline{T}_{ST}$ significantly increased in the case of $N_{gen} = 55$ at $R_{RIS} = 0.3$ and the case of $N_{gen} = 65$ at $R_{RIS} = 0.6$.

5.3 Realization of an RIS System

Finally, we discuss the RIS system as it might be implemented in actual services. To develop the RIS system, we must first consider its system architecture. For instance at the beginning of this paper, we suggested direct communication between the RIS drivers and the route information server via long-distance communication, e.g., mobile phone. However, if we were to apply such an RIS system on a huge road network like the one in the Tokyo metropolitan area (with millions of cars on the roads), direct communication by phone would be impossible because the route information server could not deal with the heavy communication traffic. Instead of phones, we are considering using traffic signals as relay stations [2]. In this architecture, traffic signals would collect route information from the RIS drivers, and transmit it to the route information server on a dedicated high-speed line.

Recently, DSRC (dedicated short range communication) [5] and infrared beacons [13] have been developed as short-distance two-way communications for the intelligent transport system (ITS). These technologies have already been put to practical use. Thus, the RIS system could easily use them for communication between vehicles and traffic signals. Moreover, by connecting the traffic signal system with the RIS system, the prospective traffic volume could be used to to control traffic signals.

Now let us briefly discuss anonymity in the RIS system. The RIS mechanism offers advantages in terms of anonymity. In this mechanism, the route information server must know route information, the current position, the destination, and the route to the destination of each RIS driver to calculate the prospective traffic volume. However, the route information server does not need to know which RIS driver passes through the route. Therefore, if the techniques of anonymous auction [9] are applied, we can ensure anonymity in the RIS system.

Furthermore, security of the route information server collecting route information also has to be guaranteed. ETC (electric toll collection) has been applied to a part of expressways as a new payment method of expressway toll through credit card [22]. [1] Thus, basic technology for secure telecommunication system dealing with personal information has already developed.

[1]This system enables drivers with on-board unit for ETC to automatically pay tolls without stopping the car at tollgates. The ETC roadside equipment is mounted on overhead gantries or in the pavement that allows vehicles to be charged while they proceed at highway speeds.

6. CONCLUSION

We proposed a cooperative car navigation system with route information sharing (RIS). For the evaluation, we constructed a simple traffic flow model using multiagent modeling. Three types of route choice were compared in a simulation: the shortest distance route (SD), the shortest time route (ST), and the shortest time route with route information sharing (RIS).

The simulations were of a lattice network, a radial and ring network, and the network around Tokyo. The simulation results confirmed that the RIS mechanism promoted i) drivers' individual incentive to switch to using it: the average travel time of the RIS drivers was always shorter than those of drivers using the other choice mechanisms, and ii) social acceptability: the travel time of RIS drivers became shorter as the percentage of RIS drivers increased. Moreover, the results showed that the network structure influenced the effectiveness of the RIS mechanism.

Finally, the paper discussed how the RIS mechanism might be implemented with traffic signals linked to a route information server.

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