A Route Guidance Method for Vehicles to Improve Driver's Experienced Delay Against Traffic Congestion

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Abstract. The increase of the city population and the number of vehicles brought heavy traffic jam in many cities. To reduce traffic congestion is one of the important tasks in order to reduce economic loss as well as the environmental pollution. Several solutions to mitigate the traffic congestion has been proposed so far, but in most cases they try to optimize whole traffic in the area, and a few treats the route guidance methods when the traffic jam occurs. Once a traffic jam takes place, we hope to clear the jam immediately by means of changing paths of some vehicles. Several studies tackle this problem. However, they enforce vehicles located very close to the traffic jam to change their paths, which results in large delay due to inefficient detour paths. This not only fails to persuade the vehicle drivers to change their paths, but also causes another traffic jam on the detour paths. In this paper, based on the observation that some vehicles often have alternative paths to avoid congested road segments with similar taking time, we propose a new route guidance method that offers vehicles better alternative paths with which the time to reach their destinations would be minimized. Through evaluation, we demonstrated that the proposed method significantly reduces the traveling time of vehicles while clearing the traffic jam within the same time duration.

Keywords: Vehicular congestion avoidance · Intelligent transportation system · Dynamic Route Guidance System · SUMO

1 Introduction

In recent years, the increase of the city population and the number of vehicles causes traffic congestion in large cities, which is one of the serious social problems [1]. According to a study [3], the annual traffic congestion loss in Japan is about 3.81 billion person-hours, which corresponds to as much as 12 trillion JPY in the monetary value. Also, the traffic congestion causes environmental problems [2].

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For example, serious PM2.5 air pollution occurred in Beijing, China, in which PM2.5 particles caused by vehicle accounts for about 20% [4]. Reducing traffic congestions would reduce both the economical and environmental problems, and is strongly desired in many major cities in the world.

On the other hand, from the driver's point of view, delay in arrival time due to traffic congestion is the matter to be considered. If the traveling time of the vehicle is reduced by alleviating the traffic congestion, their time loss would be minimized. In minimizing economical loss due to traffic congestion, not only considering the total optimization, but also considering loss of individuals is important because people satisfaction would be one of the key evaluation items in reducing traffic congestion.

Currently, a method called DRGS (Dynamic Route Guidance System) [5] is attracting attention as a mean for reducing loss from traffic congestion. In DRGS, we can monitor traffic conditions with RSU (Road Side Unit), which is communication terminals installed on the side of the road, and when a traffic congestion occurs, the system adaptively guide a part of vehicles to change their routes to optimize traffic to reduce congestion.

Several DRGS studies proposed route guidance systems that change the route of vehicles running close to the congested road to reduce the traffic congestion [6–8]. However, in most cases, the invoked delay for vehicles in arrival time due to route guidance is significantly large because the offered routes are changed largely and are not good for the drivers of vehicles. Besides, in this case, even when the driver of each vehicle is advised to change the route by the system, they would not possibly change their route because they do not satisfy the offered routes. As a result, the DRGS systems may not work well as the system designer expected, the performance of the systems to reduce traffic congestion would be disappointed. Our idea for this problem is that, if the location of a vehicle is relatively far from the congested road, there will be an alternative route with smaller loss in time, i.e., with higher satisfaction, with higher probability. If we make route guidance that prioritizes the arrival delay, we would achieve both high performance in traffic congestion mitigation (i.e., minimizing time to mitigate congestion), and driver's satisfaction (i.e., minimizing the arrival time delay).

In this paper, we assume that RSU are installed on all the main roads and intersections in the target area so that the traffic conditions can be grasped completely. When a traffic congestion occurs, each RSU detects a congested road based on vehicle density and speed on the road, and the central server computes a feasible route guidance plan to eliminate the traffic congestion that cares for the arrival delay of each detouring vehicle. By controlling the traffic with this rerouting plan, the arrival delay of each vehicle is significantly reduced and the traffic congestion is eliminated by appropriately reducing vehicles injecting to the congested road. As a result of evaluating the proposed method with a well-known traffic flow simulator SUMO, the proposed method is proved to reduce traffic congestion with a smaller average arrival delay than existing methods.

The remainder of this paper is organized as follows. In Sect. 2, we describe the outline of DRGS, its related work, and its problems. In Sect. 3, we describe the proposed method. In Sect. 4, we evaluate the proposed method with traffic flow simulator SUMO. In Sect. 5, we describe the discussion about our method, and finally in Sect. 6 we conclude our study.

2 Related Work

DRGS is a system that obtains the traffic information on roads and provides advised routes to vehicles to achieve optimized traffic control. The main objective of DRGS systems is to reduce traffic congestion so that DRGS systems compute a traffic arrangement plan and guide a part of vehicles with the offered paths in order to mitigate traffic congestion in the minimum time delay.

There is a solid body of the literature in optimizing traffic conditions as vehicular routing problems. However, most of those does not catch up with the current situation where major vehicle movements can be measured as is done by companies such as Google [9] or TomTom [10]. Consequently, major vehicle routing problems treats optimal paths for a single or a small number of vehicles, or pre-planning of large number of vehicles to optimize the traffic conditions [11]. These kinds of studies are not practical in the current situation because they cannot treat dynamic occurrence of traffic congestions in the current transportation systems, nor controlling routes of vehicles to mitigate the congestions. However, recently, there are some practical studies that aims at local solution, i.e., they propose to detect traffic congestion and guide a part of vehicles to avoid it to mitigate the congestion.

Souza et al. [6] proposed a DRGS called CHIMERA (Congestion avoidance througH a traffIc classification MEchanism and a Re-routing Algorithm), which improves the overall spatial utilization of a road network and reduces the average vehicle traveling costs by avoiding vehicles from getting stuck in traffic congestion. It assumes that all vehicles provide their information (i.e., vehicleID, current position, planned route, and destination) to a central entity via mobile communication such as 4G and LTE. CHIMERA has two main phases; The first one is congestion detection and traffic classification, and the second one is route suggestion. In the first process, traffic congestion is detected from the classification results of traffic conditions using k-Nearest Neighbor (kNN) classifier. In the second process, CHIMERA computes alternative routes for all the target vehicles based on probabilistic k-Shortest Paths. By distributing vehicles to multiple routes according to the probabilistic distribution, the possibility of generating new traffic congestion is reduced.

Pan et al. [7] proposed a centralized system to obtain the vehicle speed and density in real time in order to detect traffic congestions. Once a congestion is detected, vehicles are rerouted based on rerouting strategies such as DSP (Dynamic Shortest Path), AR*(A* Shortest Path With Repulsion), RkSP (Random k-Shortest Path), EBkSP (Entropy Balanced k-Shortest Paths) and FBkSP (Flow Balanced k-Shortest Path). Here, DSP is a classical rerouting strategy, which computes the routes with the smallest travel time. However, there is a shortcoming that the new rerouting paths would cause a new congestion in another spot with high probability. AR* is a rerouting strategy, which takes into account the results of route guidance by other vehicles. By reflecting the results of other vehicles' route guidance when calculating the detour route for vehicles, it is difficult for vehicles to concentrate on a particular detour route. However, AR* cannot control traffic on detour routes with high accuracy because it dose not directly take the traffic capacity of the detour routes into account. RkSP randomly chooses a path among k-shortest paths to balance traffic. Although this strategy reduces the possibility of creating congestion in another spot, the traveling time of each vehicle is not much cared about and so far from optimal. EBkSP is the same as RkSP in that k-shortest paths are computed, but different in that the best paths in terms of entropy is selected among k paths. As a result, EBkSP provides more load-balanced traffic distribution than RkSP. FBkSP computes k-shortest paths and calculates the traffic volume of all road segments in the area. When providing a route to each vehicle, FBkSP chooses a path that leads to better balance in traffic volumes among roads. Different from EBkSP, which chooses paths based on entropy, FBkSP directly considers traffic load balancing so that more effective path selection is possible.

The above methods [6,7] would be the representative conventional methods to solve the problems we are targeting on, and have been chosen as comparison methods in many related papers. However, these do not directly take the arrival delay of each vehicle into account. Although the strategy that detouring vehicles located very close to the congested point may reduce the time to resolve the traffic congestion, it enforces individual vehicles to increase largely the traveling delay, and so reduces their satisfaction. Furthermore, because the vehicles close to the congested road is detoured, the traffic volume on the around roads would be easily raised due to detouring traffic, resulting in another congestion around there. In our strategy, it is possible to care for individual satisfaction of drivers while mitigating congestion within the same time scale. To the best of our knowledge, our method is the first route guidance method to mitigates traffic congestion that explicitly considers the time delay experienced by the detoured vehicles.

Shen et al. [8] proposed a DRGS system called NRR (Next Road Rerouting) that considers the feasibility of the system. It focuses on reducing computational cost and system implementation cost. NRR is assumed to be deployed as a software plug-in for SCATS [12], which has already been in use at more than 37,000 intersections in 27 countries. Extending an existing system would considerably reduce the introduction cost. When NRR detects a congested road, it guides the vehicles around it. Specifically, instead of calculating the detour paths to the destinations of vehicles, NRR just calculates the alternative road segment that each vehicle should follow next regardless of their destinations. After following the guidance, each vehicle travels to the destination based on its own VNS (Vehicular Navigation System) [13]. Since the functions of NRR in route guidance is limited, the calculation cost of the entire system can be reduced. However, this method has the similar problem to [6,7] because the vehicles at close to the congested road are detoured.

Our contributions are that proposed method can prevent secondary traffic congestion on detour routes and that it can plan detours considering the burden on drivers. The proposed method calculates how much allowable traffic for each road using the traffic information collected by RSUs. Using this information, it is possible to calculate the detour traffic volume with a certain degree of accuracy. In this way, we can systematically prevent secondary congestion on the detour routes and optimize traffic flow by maximizing the use of the detour routes. In the route planning, we minimize total travel time of all vehicles in target area using an original algorithm that prioritizes reducing the load on drivers during detours, i.e., the delay in destination arrival time due to route guidance. In the following section, we describe the proposed method in detail.

3 Proposed Method

Due to traffic congestion, the time for each vehicle to reach its destination is significantly increased. Our purpose is to mitigate traffic congestion while minimizing the arrival delay of all vehicles. In related work, route guidance is applied to vehicles located close to the congested road. Although the strategy detouring vehicles close to the congested point may reduce the time to mitigate the traffic congestion, it tends to increase the total traveling delay of vehicles. Our method estimates the arrival delay to reach the destination when a vehicle is guided to bypass a congested road at intersection. Then it guides the vehicle to the detour path with the smaller arrival delay. As a result, it is possible to mitigate the traffic congestion while minimizing the arrival delay of each vehicle to its destination. In our proposal, the traffic information necessary for detour plan is acquired by RSUs and aggregated in a central server. When the central server detects traffic congestion based on the aggregated information, it calculates the rerouting table for alleviating congestion and guides each vehicle along the routing plan. For example, it is assumed that the traffic jam occurs as shown in Fig. 1. Suppose that route guidance at point X of the delay in destination arrival time is 10 min, and route guidance at point Y of the delay in destination arrival time is 5 min. In this case, the total travel time of all vehicles can be reduced by guiding the route at point Y rather than at point X. Therefore, the proposed method eliminates traffic congestion by preferentially diverting vehicles that enter point Y.

The details of our method are described as follows. In Sect. 3.1, the notation used in our method is provided. In Sect. 3.2, we describe the method to construct the rerouting table. The rerouting table manages detour routes to guide vehicles, and enables us to judge which detour paths should be activated according to the magnitude of the occurring traffic congestion. In Sect. 3.3, we explains the algorithm to control vehicles based on the rerouting table.

3.1 Notation

A directed and weighted graph $G = (I, R)$ represents the road network, where I is the set of intersections, R is the set of road segments, $S \subset I$ is the set

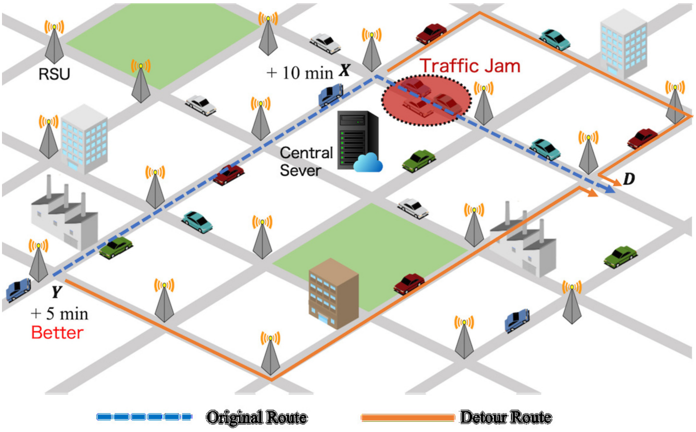


Fig. 1. Overview of Our Method

of sources and $D \subset I$ is the set of destinations of vehicles. $w(\cdot)$ is a function that represents the weight of the road segment. Specifically, $w(r)$ is a positive integer representing the weight for road segment $r \in R$. For a source $s \in S$ and a destination $d \in D$, $P_{(s,d)}$ represents the shortest path from s to d under the weight function $w(\cdot)$. $B_{(s,d)}$ represents the detour path from s to d defined as the shortest path under the weighting function $w(\cdot)$ in the road network $G' = (I, R - P_{(s,d)})$, where $P_{(s,d)}$ also represents the set of road segments included in $P_{(s,d)}$. Namely, $B_{(s,d)}$ is the shortest path from s to d in G that is edge-disjoint to $P_{(s,d)}$. For route P, $w(P)$ is the weight of P defined as the sum of the weights of all road segments included in P, i.e., $w(P) = \Sigma_{r \in P} w(r)$. $C^{diff}_{(s,d)}$ represents the difference in weight between the shortest path and the detour path from s to d, where $C^{diff}_{(s,d)} = w(B_{(s,d)}) - w(P_{(s,d)})$.

V is a set of vehicles existing in the road network. V^{avg}_{len} is the average vehicle length, and g_{min} is the minimum distance between two vehicles. For road segment r, len_r is the segment length and $lane_r$ is the number of lanes, and n^t_r is the number of vehicles on road r at time t. The vehicle density of r at time t is expressed as follows

$$K^t_r = \frac{n^t_r}{len_r}. \tag{1}$$

The maximum number of vehicles that can exist on r is $n^{max}_r = \frac{len_r}{V^{avg}_{len} + g_{min}} \times lane_r$. The maximum vehicle density of r is given as

$$K^{max}_r = \frac{n^{max}_r}{len_r}. \tag{2}$$

At time t, when the ratio of vehicle density to the maximum vehicle density of road r exceeds a predefined threshold δ, i.e., $\frac{K^t_r}{K^{max}_r} \geq \delta$, r is regarded as congested road.

The traffic volume on road r is defined as the number of vehicles passing r per unit time as follows

$$F_r^t = \nu_r^t \times K_r^t, \tag{3}$$

where ν_r^t represents the average speed of vehicles on road segment r at time t.

In this study, the state where no traffic congestion occurs is called the steady-state. ν_r^{std} represents the vehicle speed on the road segment r in the steady-state. The traffic capacity of road segment r is defined as

$$F_r^{cap} = \nu_r^{std} \times \delta K_r^{max}. \tag{4}$$

$F_r^{cap} - F_r^t$ is called the allowable traffic volume of r.

Assume that, at time t, the shortest path $P_{(s,d)}$ from intersection $s \in S$ to $d \in D$ passes through road segment r, and the congestion is detected at r. If we consider to guide vehicles that travels from s to d to bypass on $B_{(s,d)}$, the allowable traffic volume for $B_{(s,d)}$ is defined as

$$A_{(s,d)}^t = \min_{r \in B_{(s,d)}} (F_r^{cap} - F_r^t). \tag{5}$$

Therefore, we can guide the vehicles heading for the intersection d at the intersection s to the detour route $B_{(s,d)}$ up to the upper limit $A_{(s,d)}^t$.

3.2 Reroute Planning

Measuring Traffic Volume in Steady State. The digital road map of the target area is obtained in advance, i.e., we can obtain not only $G = (I, R)$ but also the road length len_r and the number of lanes $lane_r$ on each road $r \in R$. It is assumed that the traffic condition is always measured by RSUs installed beside the roads, i.e., RSUs can obtain the average vehicle speed ν_r^t, the number of vehicles n_t^r and traffic volume F_r^t on each road segment r at any time t. It is also assumed that each vehicle has original route given by its own VNS and the route is transmitted to the server through RSUs.

The steady state represents the state in which vehicles are traveling stably without congestion. Assuming that a certain time t is the steady state, the number of vehicles on each road n_{std}^r, travel speed v_{std}^r, and traffic volume F_{std}^r at that time can be measured by RSU. In this study, the steady state is used as the goal state to reduce the traffic volume on the road when it is congested, and to estimate the allowable additional traffic volume on each road in detour route. Surely, in reality, the road traffic condition differs depending on the time. However, under the condition that there is no traffic jam, it is recommended to obtain each value of the steady state by measuring the road traffic during the relatively congested of the day and the road traffic state updated at regular intervals.

Rerouting Table. The rerouting table essentially represents the priority of intersections to apply route guidance, and is calculated based on the steady-state

Table 1. Rerouting table

Priority $L_{(s,d)}$	Source intersection $s \in S$	Destination intersection $d \in D$	Arrival delay $C^{diff}_{(s,d)}[min]$	Traffic volume guided $E_{(s,d)}$[/min]	Cumulative $X_{(s,d)}$[/min]
1	s_1	d_1	3	26	26
2	s_2	d_2	3	28	54
3	s_1	d_2	6	25	79
4	s_3	d_1	8	21	100
5	s_1	d_3	8	34	134
6	s_4	d_2	9	31	165
7	s_3	d_4	11	14	179
:	:	:	:	:	:
:	:	:	:	:	:
j-1	s_7	d_{12}	31	$E_{(s_7,d_{12})}$	$X_{(s_7,d_{12})}$
j	s_{14}	d_5	33	$E_{(s_{14},d_5)}$	$X_{(s_{14},d_5)}$
:	:	:	:	:	:

traffic volume when traffic congestion on road segment r is detected. As shown in Table 1, rerouting table consists of priority $L_{(s,d)}$, source intersections $s \in S$, destination intersections $d \in D$, arrival delay $C^{diff}_{(s,d)}$, traffic volume to guide $E_{(s,d)}$, and $X_{(s,d)}$ where $X_{(s,d)}$ is the cumulative value of $E_{(s,d)}$. The priority $L_{(s,d)}$ is a positive integer sequentially assigned in the ascending order of $C^{diff}_{(s,d)}$. We also write $L_{(s,d)}$ as L_u where u is a pair of intersections $s \in S$ and $d \in D$. Similarly, we also write the traffic volume to guide as $E_u(= E_{(s,d)})$, and the cumulative value of E_u as $X_u(= X_{(s,d)})$. X_u is the sum of $E_{u'}$ for all intersection pairs u' whose priority is L_u or less.

When congestion on road segment r is detected at time t, we reduce the traffic volume injecting to road r to eliminate the traffic congestion on road r. The traffic volume required to reduce traffic congestion is expressed as follows

$$F^{exc}_r = F^{std}_r - F^t_r. \quad (6)$$

Where F^{std}_r is the traffic volume on road r in steady-state, F^t_r is the traffic volume on road r at time t. We consider that the congestion will be resolved by guiding vehicles passing through the road r to the detour path by βF^{exc}_r, where β is the congestion expansion factor $\beta \geq 1$ introduced to take into consideration the expansion of congestion in near future.

In order to mitigate the congestion on road r, the pairs of intersections (s, d) to apply guidance are selected in the ascending order of priority in the rerouting table. The criteria to select the intersection pairs to apply in the rerouting table is as follows

$$\alpha X_u \geq \beta F^{exc}_r, \quad (7)$$

where α is the probability of guided vehicles to follow route guidance. If the cumulative value of traffic that avoid r (i.e., αX_u) exceeds the traffic volume to be reduced (i.e., βF^{exc}_r), the congestion on road r will be eliminated before long. If the minimum value of the priority that fulfills Eq. (7) is j (remember that j determines X_u), route guidance with the priority less than or equal to j is applied to guide vehicles.

For instance, assume that $F_r^{exc} = 85$, $\alpha = 0.7$, $\beta = 1.3$. If route guidance is applied up to the sixth line in Table 1 (i.e., $j = 6$), $\alpha X_u = 115.5$ vehicles per unit time will change their paths to avoid the congested road r. Since the traffic volume that will avoid r exceeds $\beta F_r^{exc} = 110.5$, the congestion will be eliminated by the route guidance with these six intersection pairs.

Constructing Rerouting Table. The rerouting table is constructed by the following procedure, where U^{all} is the set of all the intersection pairs in the target area.

(1) The pair of intersections $u = (s, d) \in U^{all}$ is extracted in the ascending order of C_u^{diff}.
(2) If $r \notin P_u$, skip u and proceed to the next pair of intersections.
(3) If there is an intersection pair $u' = (x, d)$ in the rerouting table where $P_u \subset P_{u'}$, skip u and proceed to the next intersection pair.
(4) The allowable traffic volume A_u for the detour path in the steady state is set to the guiding traffic volume E_u (i.e., $E_u = A_u$), and add the corresponding entry to the rerouting table. (L is incremented by one every time an entry is added.)
(5) We update $A_{u'}$ for all $u' \in U$ with the values assuming that the traffic volume E_u is bypassed for u. If the detour traffic volumeE_u is $E_u = 0$, proceed to the next pair of intersections without adding the entry for intersection pair u to the rerouting table.

In steps (1) and (2), all intersection pairs included in U^{all} are looped in the increasing order of C_u^{diff}.

Step (3) is a process to avoid guiding a single vehicle multiple times. Suppose two intersection pairs with the same destination $u_1 = (s_1, d)$ and $u_2 = (s_2, d)$. Then, assume P_{u_1} is included in P_{u_2} (i.e., $P_{u_1} \subset P_{u_2}$). (Here, note that P_{u_1} and P_{u_2} are the shortest paths between two intersections, so that they are either completely edge disjoint, or one is included in the other.) In this case, if $C_{u_2}^{diff} > C_{u_1}^{diff}$, the vehicle guided with u_2 at s_2 is again guided with u_1 at s_1. If planning the detour at intersection s_2, the traffic volume flowing into intersection s_1 will change. Then, the detour at intersection s_2 is contradictory the traffic volume flowing into intersection s_1. Therefore, in this case, route guidance for u_2 is not applied. As a result, the intersection pair u_2, which has the same destination as the intersection pairs u_1 with the smallest arrival delay (i.e., $C_{u_1}^{diff}$), is not included in the rerouting table.

In step (4), for each pair of intersections, the traffic volume to guide the detour path is determined based on the road capacity.

In step (5), since the traffic volume on each road changes as a result of route guidance, the allowable traffic volume for each intersection pair is updated. To update the allowable traffic volume in step (5), follow the procedure below.

(a) For each road segment $r' \in P_u$, subtract E_u from $F_{r'}^{std}$.
(b) For each road segment $r' \in B_u$, add E_u to $F_{r'}^{std}$.
(c) Update A_u^{std} for every intersection pair $u \in U^{all}$.

As shown in Step (5), our method does not provide route guidance when the traffic capacity of the detour route cannot be secured, in order to prevent congestion on the detour route. For severe congestion that cannot be solved only at the intersections where the traffic capacity of the detour route can be secured, the proposed method conducts the route guidance at them and allows the congestion to resolve naturally.

3.3 Rerouting Algorithm

This section describes the procedure for providing routes to vehicles based on the rerouting table created in Sect. 3.2. First, if congestion at road segment r is detected at time t, the current excessing traffic volume of road r is calculated, i.e., $F_r^{exc} = F_r^{std} - F_r^t$. Each vehicle has its own destination $d \in D$, and its own shortest path. The source intersection s and the destination intersection d are acquired from every vehicle v. At this time, it is assumed that the RSU can communicate with the vehicle at each intersection. After finding the intersection pair $u = (s, d)$ of each vehicle v, if the priority of u is equal to or less than j (j is the minimum value of the priority that fulfills Eq. (7)), the detour path B_u is provided to v for route guidance. The vehicles guided to the detour path are expected to change the route with probability α, and does not change with the probability $1 - \alpha$.

4 Evaluation

The purpose of the evaluation is to confirm that the proposed method can reduce the average travel time of the rerouted vehicles compared to conventional methods, and alleviate the traffic congestion. As a scenario, we regulate traffic on a road segment at a certain time t in the steady state to invoke traffic congestion. After that, using our method, we reduce the number of vehicles heading to the congested road by applying the route guidance and evaluate the efficiency in relieving the congestion. The performance of our method is compared with the case of no route guidance, and with the route guidance methods DSP, RkSP, EBkSP, FBkSP and AR* used in [7]. We believe these are the most representative methods in this field of study. The criteria for evaluation are the average travel time of the vehicles to which route guidance are applied, and the number of guided vehicles. The details of the evaluation are described as follows. We show the evaluation method in Sect. 4.1 and the evaluation results in Sect. 4.2.

4.1 Method

We use the well-known traffic flow simulator SUMO (Simulation for Urban MObility) [14] for evaluation. SUMO is a simulator widely used in the field of ITS

(Intelligent Transportation System). A mobility model that considers collisions with other vehicles and traffic signals is implemented, and realistic mobility can be generated. We obtained the road map of Osaka city from OpenStreetMap [15] for a real road network. From the map, small roads were removed to extract the main roads in order to avoid small or narrow roads to be used in route guidance.

As a result of the preprocessing, the road network has 66 intersections and 241 road segments connected to the intersections. Traffic signal is installed at every intersection and the time for one cycle of the signal is set to 120 s. Each vehicle has the departing point and the destination point as the edge of the road network. Vehicles are generated at regular time interval. The traffic volume is defined based on a official survey [16]. In [16], the traffic volume per 12 h for each road is described, and the traffic volume in the simulation is determined based on the values. The total number of vehicles generated within the simulation time was 21607. In addition, since the traffic volume for each destination is not described in [16], the traffic volume from the source to the destination is fairly defined as the following steps.

(1) For each source point $s \in S$, the traffic volume $\mathcal{T}_d (d \in D)$ for all destination intersections and its total sum $\Sigma_{d \in D} \mathcal{T}_d$ are calculated.
(2) The traffic volume ratio $p_{(s,d)}$ from each source point $s \in S$ to all destinations $d \in D$ is calculated from (1). Specifically, $p_{(s,d)} = \frac{\mathcal{T}_d}{\Sigma \mathcal{T}_d}$.
(3) The traffic volume to each destination $\mathcal{T}_{(s,d)}$ is calculated by using the traffic volume at the intersection of source point $\mathcal{T}_s (s \in S)$ and the ratio $p_{(s,d)}$. Specifically, $\mathcal{T}_{(s,d)} = \mathcal{T}_s \times p_{(s,d)}$.

In order to calculate the traffic volume in steady-state, we performed a preliminary simulation with SUMO using the above traffic volume. The simulation time for calculating the steady-state traffic volume was 10800 s. After calculating the traffic volume in the steady state, we set a cause of traffic congestion at a road segment to evaluate our method. The simulation time was 10800 s. The congested road is chosen from one of the most crowded roads in the steady state. To invoke congestion, we restricted 1 out of 3 lanes at the road. The time at which this traffic control was applied was 4200 s past from the beginning time of the simulation. To control the traffic, we use TraCI (Traffic Control Interface) [17]. TraCI allows traffic management in cooperation with SUMO in run-time during simulation. Moreover, it provides access and control simulation objects, and enables us to change their behavior. The time interval for detecting congestion is 300 s, the threshold δ for determining whether a road is congested or not is 0.7. The ratio of drivers following route guidance was set to $\alpha = 0.7$, and the traffic congestion expansion factor was set to $\beta = 1.3$. We summarize the simulation settings as shown in Table 2.

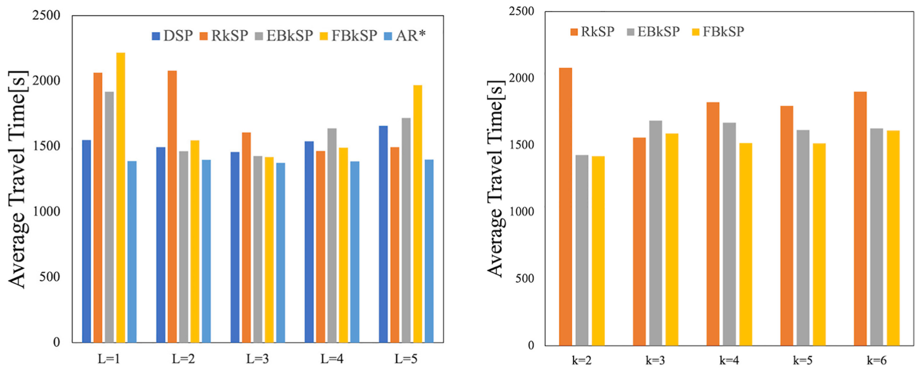
4.2 Result

First, we show the results of preliminary results in Fig. 2(a)(b). In this evaluation, we determine the parameters k and L of the conventional methods to apply in

Table 2. Simulation setting

Item	Description
Simulator	SUMO
Target area	Osaka city (only main roads)
Simulation time	10800 s
The time for one cycle of signal	120 s
Maximum speed of vehicle	60 km/h
Total number of vehicles	21607
Time interval for detecting congestion	300 s
Time to start traffic regulation	4200 s
δ	0.7
α	0.7
β	1.3

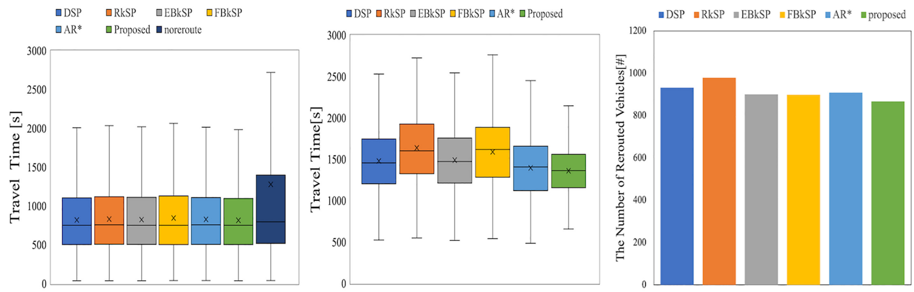
the main comparison, where k is the number of paths computed in k-shortest paths computation, and l is the maximum distance of vehicles from the congested road to apply route guidance. The distance between two road segments is defined as the number of road segments to reach, so distance between the neighboring roads are 1. Namely, if $L = 1$, only vehicles on the road neighboring the congested road are guided for the detour routes in the conventional methods. In Fig. 2(a), we show the results in which L is varied while k is fixed with 2. For all the conventional methods, $L = 3$ marks the best performance. This is because of the trade-off where small L would provide inefficient detour path whereas large L would invoke redundant detouring of vehicles. In Fig. 2(b), we show the results



(a) Result of L with $k = 2$ **(b)** Result of k with $L = 3$

Fig. 2. Results of preliminary evaluation

with several values of k under $L = 3$, which shows that $k = 2$ is the best for conventional methods. Note that DSP and AR* do not appear here because DSP and AR* do not have parameter k. This is because too many paths enforce vehicles to use less quality paths. From the results, we set $k = 2$ and $L = 3$ for the conventional methods in the main evaluation.



(a) Average travel time of all vehicles **(b)** Average travel time of rerouted vehicles **(c)** The number of rerouted vehicles

Fig. 3. Evaluation results

In Fig. 3(a) shows the travel time of all vehicles in the main simulation. Here, *noreroute* is the case where no route guidance methods are applied. We see that all guidance methods are far better than *noreroute* case, meaning that route guidance methods work effectively to mitigate traffic congestion. Next, in Fig. 3(b), we see the travel time of the rerouted vehicles only. We see that the average travel time of proposed method has the best performance among those four. Specifically, since the average travel time of steady-state results is about 800 s, the rerouted vehicle in the proposed method takes about 550 s in addition to the usual travel time in the steady state. In contrast, DSP, EBkSP and FBkSP takes additional 700–800 s, AR* takes additional 650 s, and RkSP takes additional 850 s. Furthermore, the variation of the travel time is the smallest in the proposed method. In Fig. 3(c), we see that the number of rerouted vehicles are almost the same among those four methods (rather, the proposed method is slightly smaller than the others). Note that 800 vehicles are about 4% of all vehicles appeared in the simulation. Consequently, we now see that the total traveling time of all rerouting vehicles are the smallest in the proposed method. From above, we conclude that the proposed method outperforms the conventional methods.

5 Discussion

The evaluation results show that the proposed method can reduce the travel time compared to the other methods. In the literature [7], which proposed a comparison method, the evaluation was also conducted from the viewpoint of computational complexity. However, we did not evaluate the computation time. The reason is that the assumptions of the proposed method and the comparison method are different, so the computation time cannot be compared. In addition, considering the practical aspect, we judged that the computation cost is not an issue. In [7], it is assumed that the calculation of routes is performed for each vehicle. On the other hand, in the proposed method, the detour is calculated not for each vehicle but for each intersection. In other words, the unit of calculation is different, so simple comparison is not possible. Our method assumes that the rerouting table is calculated on a central server in the cloud. In this way, When the computation is performed at the central server, the route calculation for each intersection pair can be performed in parallel, so it is considered that a sufficient number of parallel computers should be available for actual operation. For the map of Osaka City used in the evaluation, we performed route calculations for all intersection pairs using the Dijkstra algorithm 241 times, corresponding to the number of road segments connected to the intersection. Then the computation time was about 3 s on a desktop PC equipped with an 8th generation Intel i5.

From the evaluation, we showed that the proposed method can be applied to solve a single traffic jam. However, the proposed method cannot deal with multiple congestion occurring at the same time. Therefore, it is necessary to develop the method to solve multiple congestion problems simultaneously in the future. On the other hand, we believe that it is also important to deal with a single traffic jam. For example, our method can be applied to traffic jams caused by accidents. By expanding the target area, the possibility of accidents occurring simultaneously in multiple locations increases, but it is not very high. Also, if the number of vehicles traveling in a particular area increases, the possibility of multiple congestion occurring at the same time increases. However, if another traffic jam occurs as a result of vehicles in the surrounding area changing their routes in response to the first traffic jam, it is thought that solving the original traffic jam first will result in the gradual resolution of the traffic jams derived from it. In summary, while it is important to consider ways to solve multiple congestion problems at the same time, there are situations in which methods that address a single congestion problem can be effective.

6 Conclusion

In this paper, we proposed a route guidance method that are aware of the arrival delay to the destinations when vehicles bypass a congested road. Specifically, for each intersection, we care the difference in travel time between the shortest path and the detour path. The intersection pair with the smaller difference between the primary shortest path and the detour path is given the priority in applying route guidance. This enables us to reduce traffic congestion while suppressing the arrival delay to the destinations. In this study, we evaluated the efficiency of the proposed method to alleviate a congestion when it occurred in a part of the target area. We compared the proposed method with the no-reroute guidance case and the conventional methods. As a result, it was clarified that the proposed method reduces the average travel time of all vehicles that followed route guidance. Additionally, compared to the conventional methods whose parameters k and l should be optimally determined in advance, the proposed method does not need for this calibration to mark the best performance. From the above, we showed that our method is useful in the situation where a road is congested due to a sudden accident, and outperforms the conventional methods. Extensive evaluation in various scenarios would be one of the important future work.

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