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Graphical Route Information Panel and Macroscopic Simulation based Investigation of its Control Benefits

GAN HongCheng, WANG Qing, FAN BingQuan

***Abstract*—A recent effort to control urban freeway network and alleviate congestion is using graphical route information panels (GRIPs). This paper first introduces function and location of GRIPs for the urban freeway network in Shanghai, China. Second, it deals with the information display method of GRIP; Then, it proposes a macroscopic traffic flow model based simulation platform for investigating control benefits of GRIP. The simulation platform combines Papageorgiou's METANET model with the GRIP influence model. Next, control benefits of GRIP in terms of re-current congestion alleviation were examined on a hypothetical freeway network through a case study. Simulation results indicate that GRIP have a positive potential of reducing re-current congestions and facilitate more efficient use of road infrastructures. Last, Concluding remarks are given.**

I. INTRODUCTION

DURING the past decade, road authorities in many metropolitan cities have been making efforts to alleviate congestion in freeway networks through developing traffic information and route guidance systems to assist drivers in making more informed decisions about route choice and en-route diversion. A more recent one of these efforts is to use graphical route information panel (GRIP) [1]-[7]. GRIP uses graphical information (i.e. color-coded level of service) to represent current traffic conditions of a particular area within the road network to convey traffic messages instead of text. GRIP is used to help drivers make better route choice with regards to current road traffic conditions.

Till now, however, only a few countries have applied the GRIP technology in traffic management [1]-[7]. In China, GRIPs were introduced to urban freeway traffic management for the first time through an intelligent transportation system (ITS) pilot project in Shanghai in 2003 [1][2][7]. GRIPs in Shanghai contain two types: Network-Level Guidance Signs and Road Section Signs. The pictures of these two types of GRIPs are given in Fig. 1.

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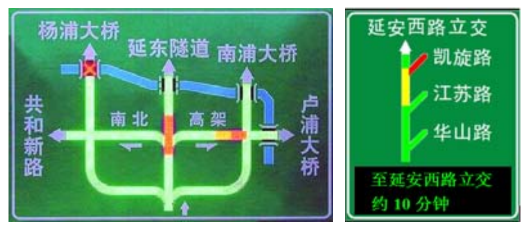
GAN Hongcheng, PhD, associate professor, is with Department of Transportation Engineering of University of Shanghai for Science and Technology, Shanghai, China (86-21-55273759; e-mail: hongchenggan@126.com).

WANG Qing, assistant professor, is with the Department of Information Management of the Shanghai Finance University, Shanghai, China.

FAN Bingquan, professor, is with Department of Transportation Engineering of University of Shanghai for Science and Technology, Shanghai, China.

After the ITS pilot project, the Shanghai road authority has installed more GRIPs in both urban and suburban areas. GRIPs have also been applied in some other cities in China. The interest in installing GRIPs in China now is very high.
The increasing popularity of GRIP has naturally promoted researchers' interests in the study of GRIP benefits. However, due to the short history of GRIP application and human's limited knowledge of travel behavior in response to GRIP information [7]-[10], it is now difficult to accurately model and quantify the potential benefits of GRIPs, e.g. in terms of travel time reduction, safety improvement, and fuel/emission reduction.



(a) (b)

Fig. 1. GRIPs in Shanghai. (a) Network-Level Guidance Signs (b) Road Section Signs

This paper first introduces the function and location of GRIPs in shanghai and the information display method of GRIP, then it uses a macroscopic traffic flow model based simulation approach to investigate control benefits of GRIP through a case study.

II. A BRIEF INTRODUCTION OF SHANGHAI'S GRIP

A. Function and Location of GRIP in Shanghai

The GRIPs on urban freeways in Shanghai are key components of the advanced traveler information system for the shanghai urban freeway network (ATIS-F) [1][2][7], and they are controlled by the traffic management center (TMC) for the urban freeway network. ATIS-F is composed of four variable message signs (VMS) categories: network-level guidance signs, road section signs, entrance condition signs, and traditional VMS.

Network-level guidance signs (see Fig. 1 (a)), are installed on the urban freeway upstream of the key decision point, e.g. freeway -to- freeway interchanges, bridges, and tunnels. They provide graphical route information, i.e. a real-time, color-coded LOS map, to help drivers make better route choice decisions and avoid congestion. Road Section Signs (see Fig. 1

(b)), are installed on the urban freeway upstream of the key off-ramp. The displayed information consists of two parts: a color-coded LOS map of the downstream urban freeway section (covering 2 or 3 off-ramps), and text information describing traffic conditions. They are used to help drivers make informed off-ramp selection decisions and avoid congestion. Entrance Condition Signs, are installed on the surface street in the proximity of the on-ramp, and provide text information about the on-ramp status (open/queued/closed). They help motorists decide in advance whether to use expressways or not. Traditional VMS are installed on the urban freeway upstream of the decision point of minor importance, and provide text information on traffic conditions.

B. Information display method of GRIP

Basic philosophy of the layout of GRIP follows. (1) The layout should be concise, easy to understand, creditable, and confirm to human ergonomics. (2) Road map deformations that greatly distort the driver's sense of distance should be avoided. (3) The displayed network should take into account the OD characteristics of the GRIP location and cover as wide a region as possible. (4) Commonality among different items such as maps, texts, symbols and legends should be achieved. (5) Last, but not the least, the panel size should not be too large due to manufacture, operational and maintenance costs.

VMS (including GRIP) can be conventionally classified in three categories: light-reflecting, light-emitting and hybrid. Hybrid signs which combine static display with Light-Emitting Diode (LED) technology [1][7][11] are used. This can reduce costs in situations when part of a message will be changed. The panel of GRIP includes two parts: the static component and the dynamic component.

1) The static component: The static component includes background and other items such as border, driver's current location arrow, place/road names, route shape border, and route direction arrow. They are displayed by reflective sheet for static signs. The shape, color, dimensions, legends, borders and illumination or retro reflectivity confirm to the national standards for static signs.

2) The dynamic component: The dynamic component is used to display the level of service map composed of LED rows. The LOS display principle for GRIP is described as follows: First, the freeway network is divided into links that are usually the roadways between two key decision points. A link usually includes several on-ramps and off-ramps. For the simplicity of the LOS map, on-ramps and off-ramps are not displayed on network-level guidance signs, and only off-ramps are displayed on road section signs. Second, a link is further divided into several segments according to a certain segmentation approach. A segment is the smallest unit that a driver can see while traveling on the road and is represented by a number of LED dot rows. Third, three levels of service are defined to describe a segment's traffic condition: "free-flow" (green), "crowded" (yellow), and "congested" (red). For more details and discussions about various segmentation approaches, we refer to [1][7][11].

III. The Macroscopic Traffic Flow Model Based Simulation Platform for GRIP Benefit Evaluation

Sufficiently accurate macroscopic mathematical models of freeway traffic are needed for testing control strategies via simulation [12][13][14]. We present a macroscopic model based simulation platform for investigating control benefits of the GRIP. The widely used METANET model [14]-[16] was chosen to establish the simulation platform. METANET is suitable for free flow, critical and congested traffic conditions, and has been widely used in freeway traffic modeling, control, simulation [16]-[29]. It was validated using real freeway traffic data in Shanghai. The simulation platform consists of two components: the METANET model and the GRIP influence model.

A. The METANET component

We only give a brief introduction of METANET for the self-containedness of this paper. For more details about the model, we refer to [14]-[16].

The freeway network is represented as a directed graph whereby the links of the graph represent freeway stretches. Each stretch has uniform characteristics, i.e. no on-/off- ramps and no major changes in geometry. The nodes of the graph are placed at locations where a major change in road geometry occurs, as well as at junctions, on-ramps, and off-ramps. The time and space arguments are discretized. The discrete time step is denoted by *T*. A freeway link m is divided into N_m segments, with the length of each segment Δ_m and the number of lanes λ_m. Each segment *i* of each link m at each time instant *t=kT* is characterized by macroscopic variables **traffic density** $\rho_{m,i}(k)$ (veh/km/lane), **mean speed** $v_{m,i}(k)$ (km/h), and **traffic volume** $q_{m,i}(k)$ (veh/h). For a multi-destination network, **partial density** $\rho_{m,i,j}(k)$ and **composition rate** $\gamma_{m,i,j}(k)$ are defined, where $j \in J_m$ and J_m is the set of destinations reachable via link m.

Traffic variables for segment *i* of each link m at each time step k are calculated by the following equations

$$\rho_{m,i,j}(k+1) = \rho_{m,i,j}(k) + (T/\lambda_m\Delta_m)[\gamma_{m,i-1,j}(k)q_{m,i-1}(k) - \gamma_{m,i,j}(k)q_{m,i}(k)] \quad (1)$$

$$\forall j \in J_m$$

$$q_{m,i}(k) = \rho_{m,i}(k)v_{m,i}(k)\lambda_m \quad (2)$$

$$v_{m,i}(k+1)=v_{m,i}(k)+\frac{T}{\tau}[V_{fund}(\rho_{m,i}(k))-v_{m,i}(k)]$$

$$+\frac{T}{\Delta_m}\cdot v_{m,i}(k)\cdot[v_{m,i-1}(k)-v_{m,i}(k)] \quad (3)$$

$$-\frac{\nu\cdot T}{\tau\cdot\Delta_m}\cdot\frac{\rho_{m,i+1}(k)-\rho_{m,i}(k)}{\rho_{m,i}(k)+\kappa}$$

$$V_{fund}(\rho_{m,i}(k))=v_{f,m}\exp(-\frac{1}{a_m}(\frac{\rho_{m,i}(k)}{\rho_{cr,m}})^{a_m}) \quad (4)$$

where $v_{f,m}$, $\rho_{cr,m}$ are free flow speed and critical density per lane, respectively, of link *m,* while a_m is a parameter of the fundamental diagram (Eq. (4)) of link m. τ , ν , and κ are global parameters. To consider the speed decrease caused by merging and weaving phenomena, Eq. (3) is modified as suggested by Papageorgiou et al. [12][13].

Traffic enters a node n through a number of input links and is distributed to a number of output links according to the following equations

$$Q_{n,j}(k)=\sum_{\mu\in I_n}q_{\mu,N_\mu}(k)\gamma_{\mu,N_\mu,j}(k) \qquad \forall(n,j) \quad (5)$$

$$q_{m,0}(k)=\sum_{j\in J_m}\beta^m_{n,j}(k)Q_{n,j}(k) \qquad \forall m\in O_n \quad (6)$$

$$\gamma_{m,0,j}(k)=\beta^m_{n,j}Q_{n,j}(k)/q_{m,0}(k) \qquad \forall m\in O_n,\forall j\in J_m \quad (7)$$

where I_n is set of links entering node *n*, O_n is the set of links leaving node *n*. $Q_{n,j}(k)$ is total traffic volume entering node *n* at period *k* that is destined to destination *j*. The splitting rate $\beta^m_{n,j}(k)$ is the portion of $Q_{n,j}(k)$ which leaves node *n* at period *k* through link $m\in O_n$. $q_{m,0}(k)$ and $\gamma_{m,0,j}(k)$ are used in Eq. (1) for *i=1*.

The queue evolution at origins of the network is described by the following equations

$$w_{o,j}(k+1)=w_{o,j}(k)+ T[\theta_{o,j}(k)d_o(k)-\gamma_{o,j}(k)q_o(k)] \quad (8)$$

$$q_o(k)=\min\{d_o(k)+w_o(k)/T, Q_o\min\{1,(\rho_{\max}-\rho_{\mu,1}(k))/(\rho_{\max}-\rho_{cr,\mu})\} \quad (9)$$

where d_o (veh/h) is the demand at *o*, $w_{o,j}$ is the partial queues with destination *j* in the queue length w_o (veh), $\theta_{o,j}$ is the portion of the demand originating in *o* and having *j* as its destination, q_o is the outflow allowed to enter the mainstream, $\rho_{\max}$ is maximum density. Q_o is the capacity of origin (veh/h).

In order to calculate $v_{m,1}(k+1)$ and $\rho_{m,N_m}(k+1)$ in Eq. (3), $\rho_{m,N_m+1}(k)$ and $v_{m,0}(k)$ are calculated according to the following equations

$$\rho_{m,N_m+1}(k)=\sum_{\mu\in O_n}\rho^2_{\mu,1}(k)/\sum_{\mu\in O_n}\rho_{\mu,1}(k) \quad (10)$$

$$v_{m,0}(k)=\sum_{\mu\in I_n}v_{\mu,N_\mu}(k)q_{\mu,N_\mu}(k)/\sum_{\mu\in I_n}q_{\mu,N_\mu}(k) \quad (11)$$

In METANET, it is assumed route guidance for traffic departing from node n and leaving for destination j is deployed by variable direction signs or on-board equipment, thus leading to following relation between the ordered splitting rate $\beta^m_{G,n,j}(k)$ (calculated by the control strategy) and $\beta^m_{n,j}(k)$

$$\beta^m_{n,j}=(1-\varepsilon)\beta^m_{N,n,j}+\beta^m_{G,n,j}\varepsilon \quad (12)$$

where ε ($0\le\varepsilon\le1$) is drivers' compliance rate and $\beta^m_{N,n,j}$ (called nominal splitting rate) is the portion of vehicles that take the main route in absence of any route recommendations. $\beta^m_{G,n,j}$ will take the value in {0, 1} or [0, 1].

B. The GRIP influence model component

In contrast to prescriptive route recommendation, GRIP message is descriptive. Therefore, for bifurcation nodes with GRIP, Eq. (12) is replaced by the following equation

$$\beta^m_{n,j}(k)=f_\beta(\beta^m_{N,n,j},LOS_{n,j}(\mathrm{k}),\xi(\mathrm{k})) \quad (13)$$

where $f_\beta(\cdot)$ is a function which maps the currently posted GRIP message to $\beta^m_{n,j}(k)$; $LOS_{n,j}(\mathrm{k})$ represents the displayed LOS information related to the particular sub-network connecting node n and destination j at time step k; $\xi(\mathrm{k})$ represents the un-modeled random disturbance which influencing the splitting rate. Since human's current knowledge of drivers' route choice response to GRIP information is very limited [7]-[9], it is almost impossible to explicitly give a mathematical expression of $f_\beta(\cdot)$. Even if a satisfactory functional relation between the GRIP message and the splitting rate can be obtained, it certainly depends, both on the network and location of bifurcation at hand, and on drivers' general (aggregate) altitudes towards and preferences for GRIP. For the present time, we can at best derive some empirical logics that relate GRIP messages with splitting rates for the network under consideration through properly conducted driver surveys (e.g. questionnaires, route choice simulator based surveys).

IV. GRIP BENEFIT EVALUATION-A CASE STUDY

A. Simulation Scenario and Network Description

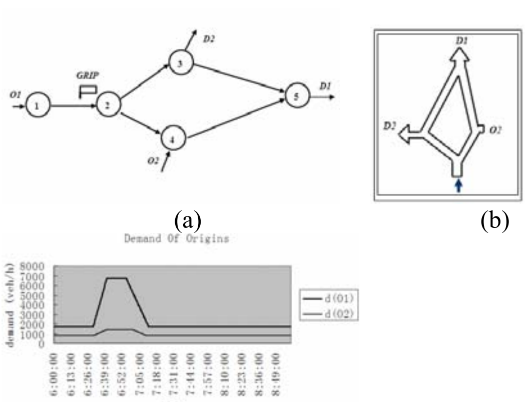
To investigate network-level GRIP impacts regarding congestion alleviation and network performance improvement, a hypothetical test network equipped with a GRIP is considered. The network contains two origins (O1 and O2) and two destinations (D1 and D2), and is similar to some real-world networks connecting suburban areas with central shanghai (Fig. 2 (a)). The GRIP is located at the network's main bifurcation (node 2).

Links (1-2), (2-4), (4-5), (2-3), (3-5) are 4km, 3km, 9km, 5km, and 9km respectively, and have 4, 2, 2, 2, 2, and 2 lanes respectively. For the bifurcation (node 2), we define "2-4-5" to be the main route and "2-3-5" the alternate route. All links are divided into segments with the length of 0.5 km. The Shanghai-style GRIP panel for node 2 is schematically presented in Fig. 2 (b). The characteristics of the network and model parameters' values are listed below.

τ =20/3600h, δ =35veh/km/lane, ν =60km^2/h, $\rho_{\max}$ =180veh/km/lane, $\rho_{cr,m}$ =33.5veh/km/lane, a_m =1.636, $v_{f,m}$ =110km/h, T=10/3600h, Q_{o1} =8000veh/h, Q_{o2} =1500veh/h.

The utilized values for $v_{f,m}$, $\rho_{cr,m}$, and a_m result in a freeway link capacity of 2000veh/h/lane which reflects real world observations of urban freeway links in Shanghai.

Trapezoidal demands similar to typical demands during peak hours in Shanghai are used for the origins of the network (Fig.2 (c)). It is assumed that 65% of the drivers destined to D1 take the main route while the others take the alternative route, i.e. $\beta_{2,D1}^{2-4}$ =0.65, to approximate UE under the non-peak period. It is also assumed that 95% of the demand in O1 have D1 as their destination, while 5% of the demand in O1 have D2 as their destination, i.e. $\theta_{O1,D1}$ =0.95 and $\theta_{O1,D2}$ =0.05.These values remain constant over the entire simulation time horizon. The simulated time period starts from 6:00 AM to 9:00 AM, to ensure a time period long enough for our GRIP impact evaluation.



(c)

Fig. 2 Simulation Scenario and Network Description (a) A hypothetical freeway network equipped with a GRIP; (b) Schematic presentation of Shanghai style GRIP; (c) Demands of O1 and O2

B. The no-GRIP case

When no GRIP is applied, congestion appears at the main route, downstream of the origin O2 (as shown by Fig. 3 (a)), during the peak hour. Due to mainstream congestion downstream of O2, a long queue formed at O2 during the peak period, with its duration time being about 28 minutes (6:45 AM - 7:13 AM) (Fig.3 (b)). The congestion downstream of O2 forms a bottleneck, generating shock waves propagating backward all the way to link (1-2) which also suffers from congested conditions (as shown in Fig.3 (c) and Fig.3 (d)). Congestion in link (1-2) also affects the traffic conditions in the alternate route because it results in smaller outflow volume towards the alternative route, leading to underutilization of the alternate route's capacity (see Fig.3 (e) and Fig.3(f)). These above phenomena are common in reality and are characteristic of observations of re-current congestions in Shanghai. The total time spent (TTS) (total travel time + total waiting time) is 2577.76 veh*h.

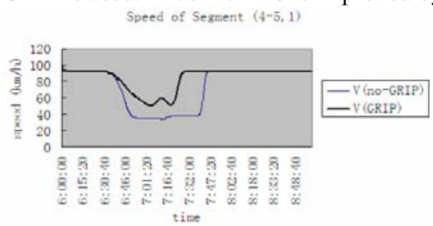
To facilitate more visually clear demonstration of the network traffic conditions, a snapshot of the global network traffic condition are given by Fig.4. The snapshot is for time instance 7:11 AM, indicating that congestion wave of the bottleneck has propagated to Link (1-2) and the network is reaching a terribly bad operating condition. In Fig.4, the white color represents the non-congestion state, while the black color represents the congestion state.

C. The with-GRIP case

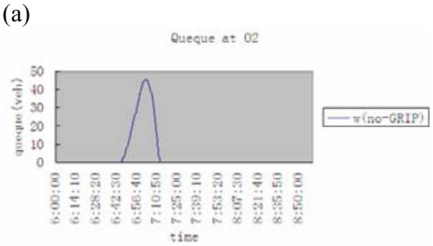
GRIP can influence route choice decisions of those drivers destined to D1. Obviously the route choice of the drivers that are not destined to D1 can not be influenced by GRIP. For the network in our study, we hypothesize the trajectory of the splitting rate $\beta_{n,j}^{m}(k)$ (as depicted Fig.5) resulting from disseminating GRIP information, based on the preliminary research results of our previous studies investigating drivers' route choice response to GRIP [7]-[9].

The simulation results follow. Due to traffic diversion at the bifurcation node resulting from the GRIP information dissemination, the main route doesn't encounter severe congestion. The segments downstream of the on-ramp O2 which are influenced by on-ramp flows still operate in non-congestion regime in peak hours (see Fig.3 (a)). There are no queues at O2, indicating that vehicles enter the mainstream without delay in peak hours. Link (1-2) operates at the free flow level (Fig.3 (c)), ensuring a longer duration of high volume at node 2 (as shown in Fig.3 (d)). Moreover, congestion did not occur on the alternate route (as shown in Fig.3 (e)), although the alternate route accommodates larger flow as compared to the no-GRIP case. The outflow of the whole network is depicted in Fig.3 (g). It can be seen that the network maintains a higher outflow during the peak hours compared to the no-GRIP case. The early increase of the total outflow is reflected in the improvement of the TTS which reduces to 2197.35 veh*h when

GRIP is used. Thus the TTS is improved by 14.76 %.



(a)



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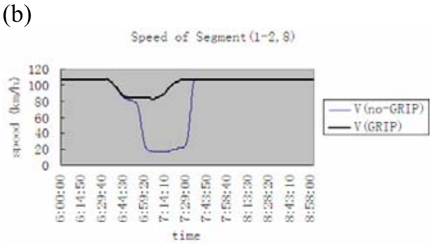

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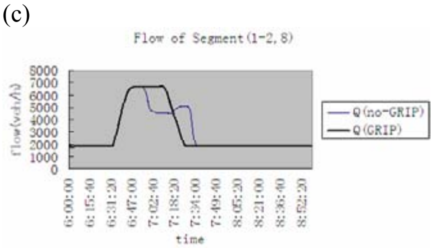

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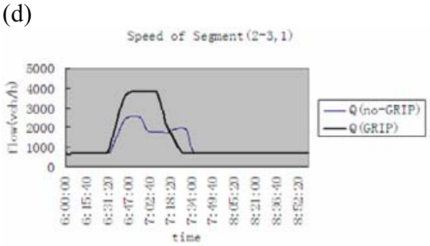
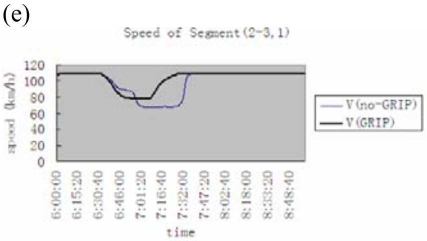
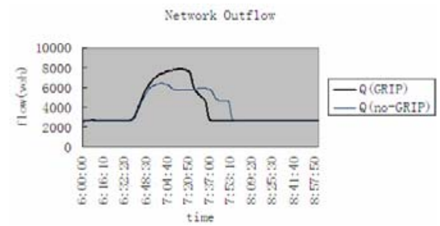


(e)



(f)



(g)

Fig. 3 Simulation results for the no-GRIP case and the with-GRIP case. (a) speed at segment 1 of Link (4-5); (b) queues at O2; (c) speed at segment 8 of Link (1-2); (d) Flow at segment 8 of Link (1-2); (e) Flow at segment 1 of Link (2-3); (f) speed at segment 1 of Link (2-3); (g) total outflow of the network

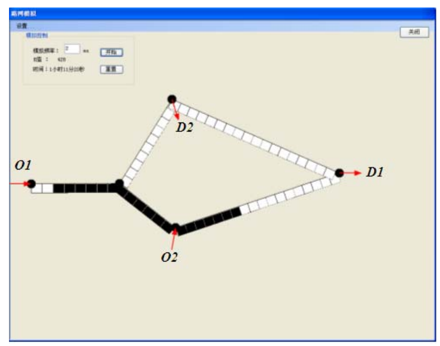


Fig. 4 Snapshot of 7:11 AM for global network traffic condition

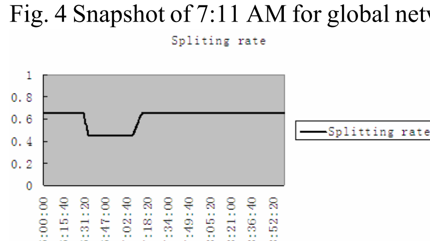


Fig. 5 The trajectory of splitting rate under the GRIP scenario

V. Concluding Remarks

GRIP, a new collective information provision technology, has obtained more attention by the transportation community internationally. This paper deals with the two kinds of GRIP (i.e. network-level guidance signs and road section signs) in Shanghai, China, focusing on the function, installing location, and level of service map display method of them. It moreover proposes a macroscopic simulation approach to investigate control benefits of GRIP. Simulation on a hypothetical freeway network shows high efficiency of GRIP in terms of alleviating recurrent peak hour congestion.

However, research about drivers' travel behavior in response to GRIP and network-level impacts of GRIP on traffic conditions are still in its infant stage. Further behavioral studies should be conducted to explore the relation between diversion behavior and GRIP information and derive behaviorally sound mathematical functions for the GRIP influence model component (Eq. 13). It is hoped that more research about GRIP will be inspired by the work of this paper.

ACKNOWLEDGEMENT

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