A Novel Dynamic En-route Decision Real-Time Route Guidance Scheme in Intelligent Transportation Systems

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***Abstract*—In an intelligence transportation system (ITS), to increase traffic efficiency, a number of dynamic route guidance schemes have been designed to assist drivers in determining the optimal route for their travels. In order to determine optimal routes, it is critical to effectively predict the traffic condition of roads along the guided routes based on real-time traffic information to mitigate traffic congestion and improve traffic efficiency. In this paper, we propose a *Dynamic En-route Decision real-time Route guidance (DEDR)* scheme to effectively mitigate road congestion caused by the sudden increase of vehicles and reduce travel time. Particularly, DEDR considers real-time traffic information generation and transmission. Based on the shared traffic information, DEDR introduces *Trust Probability* to predict traffic conditions and dynamically en-route determine alternative optimal routes. In addition, DEDR considers multiple metrics to comprehensively assess traffic conditions and drivers can determine optimal route with individual preference of these metrics during travel. DEDR also considers effects of external factors (e.g., bad weather, incidents, etc.) on traffic conditions. Through a combination of extensive theoretical analysis and simulation experiments, our data shows that DEDR can greatly increase the efficiency of an ITS in terms of great time efficiency and balancing efficiency in comparison with existing schemes.**

***Keywords*—Intelligence transportation systems, Dynamic route Guidance Systems, Real-time traffic information, En-route guided route decision.**

I. Introduction

An intelligence transportation system (ITS) uses modern information, communication, computing, and control technologies to make transportation systems more reliable, efficient and secure [10], [16]. ITS is a typical example of cyber-physical systems, which integrates transportation management and control systems supported by modern networking computing and communication techniques [7], [2], [6]. In the US and many other countries, the modernization of ITS is vital to reduce traffic congestion and to increase road capacity. The development of ITS has received renewed attention recently [21], [22], [8].

As one critical goal of ITS, informing drivers about optimal routes from the initial locations to the destinations with a low traffic congestion and a great road capacity is essential for ITS. To achieve this goal, a number of static and dynamic route guidance schemes have been developed in the recently past to assist drivers in determining optimal routes [13], [3], [19], [14], [5], [28], [11], [18], [1], [12], [23], [26], [29], [17], [20]. Most static route guidance schemes focus on finding the shortest path from the initial location to the destination with the shortest static distance or the smallest static travel time [19]. Without considering real-time traffic information, static route guidance schemes cannot see the traffic conditions of the transportation system and cannot effectively mitigate road congestion.

With the advance of modern sensor and communication technology, there has been a considerable number of efforts on dynamic route guidance schemes, which can provide drivers with optimal routes by using real-time traffic information [13], [3], [14], [5], [28], [11], [18], [1], [12], [23], [26], [29], [17], [20], [27]. Nonetheless, most of these dynamic route guidance schemes do not consider the generation and transmission of real-time traffic information in an ITS. Some existing dynamic route guidance schemes also collect real-time traffic information and determine optimal routes, but do not effectively predict the traffic condition of roads along the guided routes using real-time traffic information during travel to mitigate traffic congestion. In this case, some roads would suffer from traffic congestion due to suddenly increases of vehicles on these roads, where traffic conditions are great before these vehicles depart and becomes bad when vehicles enter these roads. In addition, few efforts have considered the effects of external factors (e.g., weather, incidents, etc.) on determining optimal routes for drivers. Therefore, this calls for an effective dynamic route guidance scheme, which can dynamically and effectively predict the traffic condition of roads along the guided routes by considering both real-time traffic information and external factors and determine alternative guided routes to mitigate traffic congestion and improve traffic efficiency based on predicted traffic conditions.

In this paper, we propose a novel dynamic en-route decision real-time route guidance scheme (also called DEDR) for an

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ITS, which can dynamically, en-route, adjust the optimal route from its current location to the destination during travel. Our proposed scheme can effectively mitigate road congestion raised by the sudden increase of vehicles on a road and can also minimize the amount of time spent traveling, and achieve traffic balance in an ITS. During travel, DEDR can dynamically determine whether the current guided route remains the optimal route from the current location to the destination and can, en-route, predict traffic conditions of roads along guided route and determine an alternative optimal route for drivers based on real-time traffic information. Particularly, DEDR first considers the generation and transmission process of real-time traffic condition information. Based on the generated and shared traffic information, DEDR introduces *Trust Probability* to declare the probability of determining whether the current guided route remains the optimal route to the destination. In our scheme, the current guided route will not be considered as the optimal route and the alterative optimal route will be determined when the *Trust Probability* of the current guided route under real-time traffic conditions is lower than a pre-defined threshold. In addition, DEDR considers metrics (e.g., travel time, and vehicle density) to comprehensively assess traffic conditions. DEDR can adaptively determine the optimal route with drivers' individual preference by using these metrics during travel. DEDR also considers the effects of external factors (e.g., weather, incidents, etc.) on determining the optimal route and formalizes external factors as travel time delay when the optimal route is determined. Therefore, DEDR can, en-route, dynamically adjust the optimal route from current location to the destination during travel by considering both real-time traffic information and external factors, leading to the reduction of road congestion and the increase of traffic efficiency.

Through a combination of both theoretical analysis and simulation experiments, we evaluate the effectiveness of DEDR in comparison with the shortest distance route guidance scheme (SDRG), the shortest time route guidance scheme (STRG) and the dynamic real-time route guidance scheme (RTRG) in terms of time efficiency and balance efficiency. STRG, SDRG and RTRG represent the shortest path scheme [25], [9], [24] with weight as static travel time, travel distance and dynamic real-time travel time, respectively. Our data shows that DEDR achieves better performance than existing schemes. For example, the average travel time of DEDR is always less than that of existing schemes. When 3000 vehicles travel in ITS, the average travel time of DEDR is $152s$, which is $459.5s$, $221.2s$ and $51.1s$ less than that of SDRG, STRG and RTRG, respectively. In addition, DEDR can achieve great traffic balance and the maximum number of jammed roads is 10, which is less than 34 of SDRG, 31 of STRG, and 23 of RTRG, respectively. That shows that DEDR can achieve better traffic balance than existing schemes. Our evaluation data shows that DEDR can effectively mitigate road congestion and improve traffic efficiency in comparison with existing schemes.

The remainder of the paper is organized as follows: We introduce system models in Section II. We present our proposed scheme in Section III. We analyze the effectiveness of our proposed in Section IV. In Section V, we show experimental results to validate our findings. We conclude this paper in Section VI, respectively.

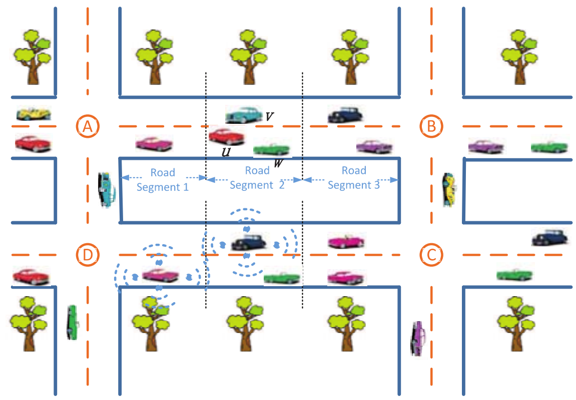

Fig. 1. System model of intelligence transportation systems

II. SYSTEM MODEL

The objective of an ITS is to provide services to support efficient transport and traffic management. Route guidance system (RGS), considered as one of the key components in an ITS, and is used to improve the safety of transportation, reduce travel time and road congestion and enhance traffic efficiency. RGS can inform drivers of real-time traffic conditions, and provide drivers optimal routes from their initial locations to their destinations before their departure as well as during travel. In addition, RGS can inform travelers external factors on their guided route (e.g., bad weather, incidents, etc.).

Generally speaking, in an ITS, each vehicle is deployed with a global positioning system (GPS), sensors, and a wireless communication device. The GPS is used to determine the current position of vehicle during while traveling, and sensors are used to measure operation parameters of vehicle (e.g., speed, fuel consumption, and others). The wireless communication device is used to share the real-time traffic information measured on a vehicle with the other vehicles on the road. One critical service of an ITS is the information interaction among vehicles. The shared real-time traffic information can effectively guide vehicles to determine and alter the optimal route from its current location to the destination during travel.

We consider that each road or street is divided into several segments with a fixed length. We assume that each road or street has a unique road ID and each segment of the road has a unique segment ID. As shown in Fig. 1, road Rd_{AB} is divided into three segments, denoted as $segment_1$, $segment_2$ and $segment_3$, respectively. Note that, road Rd_{AB} is not equal to road Rd_{BA}. Road Rd_{AB} represents the road that vehicles can only travel from position A to B and road Rd_{BA} represents the road that vehicle can only travel from position B to A. In

Fig. 1, vehicle v travels in $segment_2$ of Rd_{BA} and vehicle u and w travel in $segment_2$ of Rd_{AB}, respectively.

The vehicles that travel in the same segment are organized as a cluster and the vehicle that is the closest to the center of segment is considered to be cluster-head. Obviously, the members of a cluster will change as vehicles move and cluster-head will also change as vehicles move. Vehicles in the same cluster measure real-time traffic conditions (e.g., travel speed, fuel consumption, vehicle density, incidents, and others) associated with their current segment and sent the measured traffic information to the cluster-head vehicle within the same segment via wireless communication. After receiving measured traffic information from cluster members, the cluster-head vehicle aggregates the received traffic information and forms the real-time traffic information message for its segment and shares this message with other cluster-head vehicles within the neighboring road segments. Fig. 1 shows the example of our system model. Here, vehicles u and w that travel in $segment_2$ of Rd_{AB} can organize a cluster. Vehicle w can be considered as a cluster-head because it is closer to the center of $segment_2$ of Rd_{AB} in comparison with vehicle u. Hence, vehicle w can aggregate the real-time traffic information of $segment_2$ of Rd_{AB} measured by vehicle u and itself and share the formed traffic information message with the neighboring cluster-heads through wireless communications.

Note that, the cluster-head vehicle can not only form the real-time traffic information message for its own road segment, but also can forward the received real-time traffic information messages transmitted from other road segments. In this way, the real-time traffic conditions of a certain position can be quickly propagated through the vehicular network without relying on a fixed infrastructure, which normally incurs a high cost. We also assume that all vehicles are always steered as quickly as possible to reduce travel time and improve traffic efficiency. To simplify our analysis, we focus on one lane in each road or street. Nonetheless, because in multi-lane roads different lanes have different driving diversions in intersections, the scenario with multi-lane in each road or street can be easily extended by our proposed scheme.

All notations used in this paper are shown in Table I

TABLE I
NOTATION

T :	Slot time.
t :	Time interval.
Rd :	Road or street ID.
Sg_{Rd} :	Segment ID of road Rd.
$Sd_T^{Sg_{Rd}}$:	travel speed in segment Sg_{Rd} at time T.
$Tr_T^{Sg_{Rd}}$:	Travel time needed to pass segment Sg_{Rd} in time T.
W_{Rd} :	Wide of road Rd.
L_{Rd} :	Length of road Rd.
$L^{Sg_{Rd}}$:	Length of segment Sg_{Rd}.
Num_T^{Rd} :	The number of vehicles that travel on segment Sg_{Rd} at time T.
$Den_T^{Sg_{Rd}}$:	Vehicle density of segment Sg_{Rd} at time T.
Pin_T^{Rd} :	The number of vehicles that entry road Rd at time T.
$Pout_T^{Rd}$:	The number of vehicles that leave road Rd at time T.
$Inc_T^{Sg_{Rd}}$:	The effect degree of incidence in segment Sg_{Rd} at time T.
$Wea_T^{Sg_{Rd}}$:	The effect degree of weather in segment Sg_{Rd} at time T.
u, v, w :	Vehicle ID.
V_u :	Travel speed of vehicle u.
f :	Rolling resistance coefficient.
g_e :	Engine fuel Consumption.
ρ :	Fuel density.
P_e :	Engine consumption power.
r :	Wheel radius.
i_g :	Transmission gear ratio.
i_o :	Main reducer transmission ratio.
n_e :	Engine speed corresponding to the transmission gear ratio.
TP_T^{Rd} :	The trust probability of road Rd at time T.
Φ :	The pre-defined trust threshold.
α, γ :	Individual preference factor of travel time and vehicle density, respectively.

III. Our Approach

In this section, we first present the basic idea of our approach and then detail the key components.

A. Basic Idea

The basic idea of our scheme is described below. In DEDR, the vehicles measure real-time traffic information of current positions through the deployed GPS and sensors and share the measured traffic information through wireless communication networks. Vehicles traveling on the same road segment can be organized as a cluster and the vehicle that remains closest to the center of this segment is considered as the temporary cluster-head and is responsible for aggregating the received traffic information shared by local cluster members. The cluster-head then forms the real-time traffic information message for its segment and shares this formed message with cluster-head vehicles in other segments. In addition, a cluster-head vehicle can forward the received traffic information message from other segments and share the received message with its local cluster members. In this way, the real-time traffic information message of a segment can be quickly propagated through the vehicular network.

When a vehicle receives the traffic information messages of roads included in its current guided route, DEDR assists the vehicle in predicting *Trust Probability (TP)* of these roads and determines whether the TP of the current guided route is lower than the pre-defined acceptable threshold Φ. If it is lower, DEDR will, en-route, determine an alternative optimal route with a higher TP from the current location to the destination based on the received real-time traffic information from the other segments. In this way, DEDR can en-route determine and alter its real-time optimal route from the current location to the destination, reducing the traffic congestion, which could raised by a suddenly increasing the number of vehicles on a road.

DEDR considers two different metrics, which include both travel time and vehicle density, to comprehensively assess the TP of each road segment and successfully determining the optimal routes with considering drivers' individual preference of these metrics. Based on different individual preference, time efficiency and balance efficiency can be greatly achieved by DEDR. In addition, external factors (e.g., weather, incidents, etc.) are considered in DEDR when determining optimal routes to increase the traffic efficiency.

Our proposed approach consists of the following key components: (i) *Real-time traffic information measurement* is used to sense and measure the required traffic information based on the current traffic conditions, (ii) *Real-time traffic information message generation and propagation* is used to form the traffic information messages and share the formed message with other vehicles, (iii) *Determination of traffic states* is used to determine the *Trust Probability* of all road segments, and (iv) *En-route route alteration and decision* is used to, en-route, determine and alter the real-time optimal route from the current position to the destination during travel. In the following, we present these key components in detail.

B. Real-time traffic information measurement

Again, we assume that vehicles traveling in an ITS are deployed with GPS, sensor nodes and wireless communication device and these devices can be used to determine the current location of vehicles, and measure the operation parameters as well as traffic condition information while interacting with other vehicles. The *real-time traffic information measurement* of DEDR consists of four steps, including *vehicle initialization*, *operation parameters measurement*, *road state measurement*, and *measurement aggregation and sharing*, which will be discussed in detail below.

1) Step 1: vehicle initialization: In our scheme, each vehicle is assigned with a vehicle ID, which can be the license plate number of this vehicle, denoted as u in our paper. Before the vehicle departs, DEDR determines the current location of vehicle u through the deployed GPS, denoted as SN_u, and the traveler inputs the destination in DEDR, denoted as DN_u, and individual metrics preference factors, α and γ for travel time and vehicle density during travel, respectively.

In this stage, DEDR only collects the information, including vehicle ID, current position, destination and preference setting and stores them in its memory. After collecting the information, DEDR determines an initial optimal route from its current position to the destination based on the preference setting for the traveler. Then, the vehicle travels along using the initially settled optimal route. The detailed route determination process will be described in subsections III-D and III-E.

2) Step 2: operation parameters measurement: In this stage, DEDR measures and collects operation parameters by sensors deployed on vehicle u during travel, including the current slot time T, vehicle average speed V_u at time T, vehicle rolling resistance coefficient f_u, vehicle engine fuel consumption ge_u, fuel density ρ, vehicle engine consumption power Pe_u, vehicle engine speed ne_u, vehicle transmission gear ratio i_{gu}, and vehicle main reduced transmission ratio i_{ou}. DEDR stores these parameters in memory and these parameters can be used to determine the real-time traffic condition of current position and determine the total travel time and fuel consumption economy when travelers complete the travel.

3) Step 3: road state measurement: In this stage, DEDR measures the road state of current vehicle traveling position (e.g., road ID Rd, road segment ID Sg_{Rd}, wide of road W_{Rd}, length of road L_{Rd}, the effect degree of incidence $Inc^{Sg_{Rd}}$, and the effect degree of weather $Wea^{Sg_{Rd}}$). These road state measurements will be used in the assessment of real-time traffic conditions. In addition, DEDR measures the distance from current vehicle position to the center of the current segment Sg_{Rd}. The distance (denoted as $Ds_u^{Sg_{Rd}}$) is used to determine the cluster-head vehicle in this segment cluster.

4) Step 4: measurement aggregation and sharing: In this stage, vehicle u aggregates the measurement obtained from *Step 2* and *Step 3* and generates the local traffic information report r_u, which is constructed by

$$\begin{aligned} r_u = (u|T|Rd|Sg_{Rd}|V_u|W_{Rd}|L_{Rd} \\ |Inc^{Sg_{Rd}}|Wea^{Sg_{Rd}}|Ds_u^{Sg_{Rd}}) , \end{aligned} \tag{1}$$

where $|$ is denoted as the connect operation and other notations are defined in Table I.

After generating the local traffic information report r_u, vehicle u shares the report r_u through wireless communication networks and receives the traffic information report of other vehicles in the same segment Sg_{Rd},

$$u \rightarrow * : r_u, \tag{2}$$

$$* \rightarrow u : r_*, \tag{3}$$

where $*$ represents other vehicles in the same segment as vehicle u.

C. Real-time Traffic Information Message Generation and Propagation

In our scheme, a road is divided into multiple segments with fixed length and vehicles in the same segment are organized as a cluster. Cluster members jointly measure and generate real-time traffic conditions associated with their current segment. Generated traffic condition information is also shared with vehicles in other segments through wireless communications. In this way, the real-time traffic information of roads and segments can be quickly propagated over the network. This stage consists of three steps, including *cluster organization*, *traffic information message generation*, and *traffic information message propagation*, which will be described below.

1) Cluster organization: In our scheme, the traffic conditions of one segment are measured by vehicles in that segment, which is organized as a cluster. Those vehicles communicate with each other through wireless communication networks and share a local traffic information report r. After receiving the traffic information reports from the other vehicles within the same segment, vehicle, denoted as u, determine whether it is closest to the center of current segment by comparing $Ds_u^{Sg_{Rd}}$ and $Ds_*^{Sg_{Rd}}$ of other vehicles. If vehicle u is the closest one, u is considered as the cluster-head of current segment. Otherwise, the closest one, denoted as v can be selected by comparing $Ds_*^{Sg_{Rd}}$ and vehicle v is notified as a cluster-head, and the segment ID is selected as cluster ID. Note that, because of vehicle movement, cluster members and cluster heads of segments will be changed over time.

2) Traffic information message generation: After receiving all traffic information reports generated by cluster member vehicles, the designated cluster-head aggregates reports r_* and merges the real-time traffic information into an integrated traffic information message (TIM) associated with the current segment at time T. In our scheme, two types of traffic information message are considered, including normal TIM and exigence TIM, respectively.

Normal TIM is used to show real-time traffic conditions of current segment in the normal case and is formed by,

$$NR_T^{Sg_{Rd}} = \Big(T|Rd|Sg_{Rd}|W_{Rd}|L_{Rd}|Sd_T^{Sg_{Rd}} \\ |Num_T^{Sg_{Rd}}|Den_T^{Sg_{Rd}}\Big), \tag{4}$$

where $|$ is denoted as the connection operation and $Num_T^{Sg_{Rd}}$ is the total number of vehicles in this segment, which can be computed by counting the number of received traffic information reports of cluster-head. $Den_T^{Sg_{Rd}}$ represents the vehicle density of this segment at time T, which can be derived by

$$Den_T^{Sg_{Rd}} = \frac{Num_T^{Sg_{Rd}}}{W_{Rd} \cdot L_{Sg_{Rd}}}. \tag{5}$$

$Sd_T^{Sg_{Rd}}$ is the speed that vehicles in this segment can achieve at time T, which can be obtained by

$$Sd_T^{Sg_{Rd}} = \frac{1}{Num_T^{Sg_{Rd}}} \cdot \sum V_*. \tag{6}$$

Exigence TIM is used to inform the exigent traffic condition information (e.g., bad weather, incidents, and others). Exigent TIM can be formed by

$$ER_T^{Sg_{Rd}} = \Big(T|Rd|Sg_{Rd}|Wea_T^{Sg_{Rd}}|Inc_T^{Sg_{Rd}}|Delay\Big), \tag{7}$$

where $Wea_T^{Sg_{Rd}}$ and $Inc_T^{Sg_{Rd}}$ represent the effect degree of bad weather and incidents, respectively. The effect degree includes the number of lane reductions, the vehicle pass, and so on. $Delay$ represents the remaining time delay caused by bad weather and incidents (i.e., the time taken to recover the traffic conditions).

3) Traffic information message propagation: In our scheme, both normal and exigent traffic information messages of different segments will be flooded by cluster-head vehicles in corresponding segments. In this way, the communication and computation overhead can be reduced, energy can be saved, and the throughput capacity of vehicular networks can be increased as well.

After generating normal TIM $NR_T^{Sg_{Rd}}$ and exigent TIM $ER_T^{Sg_{Rd}}$, the cluster-head vehicle broadcasts the information to all cluster-head vehicles in neighboring segments. Note that the normal TIM is broadcast once by the cluster-head in each time slot and exigent TIM is broadcasted only if the weather becomes bad or incident occurs.

The cluster-head vehicle in one segment can also serve as the relay nodes to receive and forward TIMs of other segments. When a cluster-head vehicle receives a TIM from other segments, it determines whether roads and the segment in which TIM is generated is part of current guided route. If so, the cluster-head vehicle first stores the received TIM in memory and then forwards the TIM to its nearby neighboring cluster-head vehicles. Otherwise, the cluster-head vehicle only forwards the received TIM. In this way, DEDR can quickly propagate the TIM of a road segment over the vehicular network and make all vehicles in an ITS can receive and use the real-time traffic information to assess traffic conditions of target roads and segments. In this way, our approach does not rely on a fixed infrastructure that is normally costly to deploy. The stored TIM can be used to assess traffic conditions of roads and segments, which the vehicle will go and pass in next step of DEDR.

D. Determination of traffic states

Based on the received and stored normal traffic information messages of target roads and segments, DEDR can help vehicles to assess and predict traffic conditions of the roads and segments that vehicles will go and pass. In our scheme, two metrics are considered for the assessment and prediction the traffic conditions on the roads, including *travel time (TT)* and *vehicle density (VD)*. The description of mentioned three metrics is shown in Appendix A of our technical report [15], which is available online. In the following, *Trust Probability (TP)* is introduced to determine the traffic states of ITS.

1) Traffic conditions determination: According to the aforementioned analysis, we can find that the number of vehicles and the speed that vehicles can achieve in segment $Sg_{Rd_i}^j$ at time T_j is very important to assess and predict traffic conditions of $Sg_{Rd_i}^j$ at time T_j in terms of TT and VD. In our scheme, the TIMs of segment $Sg_{Rd_i}^j$ and its neighboring segments generated at time T_l are used to predict traffic conditions at time T_j. DEDR introduces *Trust Probability (TP)* to measure the predicted traffic conditions. The definition of *Trust Probability (TP)* is described in Definition 1.

Definition 1: ***Trust Probability (TP)*** is defined as the probability that the traffic conditions of a segment at time T_j is no worse than the traffic condition of the segment at current time T_l as time goes on, where T_j is larger than T_l.

TP represents the probability that traffic condition of a segment in time T_j is not worse than the previous traffic condition of the segment. Take metric TT as an example, the TP of segment $Sg_{Rd_i}^j$ at time T_j can be derived by

$$TP_{T_j}^{Sg_{Rd_i}^j} = P(Tr_{T_j}^{Sg_{Rd_i}^j} \le Tr_{T_l}^{Sg_{Rd_i}^j}) = P(Sd_{T_j}^{Sg_{Rd_i}^j} \ge Sd_{T_l}^{Sg_{Rd_i}^j}), \tag{8}$$

where T_l represents current time slot and other notations are defined in Table I. Based on the definition, TP of a segment is not constant and will change over time as the traffic conditions of the segment change. In addition, TP of a segment in different time slots will be different.

Based on the analysis shown in the last subsection, the key problem of assessing and predicting traffic conditions (i.e., TP) of segment is to predict the possible vehicle speed that vehicles can move on the segment. In the transportation system, vehicle speed is dependent on the vehicle density of the current segment of road. For a segment of a road, the following three types of density threshold should be considered: *unimpeded density*, *stable density*, and *jammed density*, denoted as K_p, K_s and K_m, respectively. The unimpeded density represents the maximum density, in which vehicle speed can achieve the limited speed of the segment or road, stable density represents the interim density, in which vehicles can pass the segment with stable speed, and the jammed density represents the minimum density, in which vehicles only can stay static because of traffic jammed. Based on the fastest limited speed of segment and operation parameters of vehicles, K_p and K_m of segment can be derived by

$$K_p = \frac{1}{\frac{\left(Sd_{HL}^{Sg_{Rd_i}^j}\right)^2}{2a_d} + b \cdot Sd_{HL}^{Sg_{Rd_i}^j} + c}, \tag{9}$$

$$K_m = \frac{1}{c}, \tag{10}$$

where $Sd_{HL}^{Sg_{Rd_i}^j}$ is the fastest limited speed of segment $Sg_{Rd_i}^j$, and a, b and c are operation parameters, in which a_d is the vehicle braking deceleration, b is the response time, and c is the total length of vehicle length and save braking distance, respectively. K_s relies on the driver's operation habits and can be only obtained by observation.

Based on the rand-size relationship among real-time vehicle density, K_p, K_s and K_m, the real-time vehicle speed of a segment can be formed by Equations (11) $\sim$ (14). The detailed description of determining vehicle speed is shown in Appendix B of our technical report [15].

$$Sd_{T_j}^{Sg_{Rd_i}^j} = Sd_{HL}^{Sg_{Rd_i}^j}, \qquad \left(Den_{T_j}^{Sg_{Rd_i}^j} < K_p\right) \tag{11}$$

$$Den_{T_j}^{Sg_{Rd_i}^j} = \frac{1}{a \cdot \left(Sd_{T_j}^{Sg_{Rd_i}^j}\right)^2 + b \cdot Sd_{T_j}^{Sg_{Rd_i}^j} + c}, \quad \left(K_p < Den_{T_j}^{Sg_{Rd_i}^j} < K_s\right) \tag{12}$$

$$Den_{T_j}^{Sg_{Rd_i}^j} = \frac{1}{b \cdot Sd_{T_j}^{Sg_{Rd_i}^j} + c}, \qquad \left(K_s < Den_{T_j}^{Sg_{Rd_i}^j} < K_m\right). \tag{13}$$

$$Sd_{T_j}^{Sg_{Rd_i}^j} = 0, \qquad \left(Den_{T_j}^{Sg_{Rd_i}^j} > K_m\right). \tag{14}$$

Therefore, to predict the vehicle speed on a road in a time slot, the number of vehicles on the road is required to be predicted first. The number of vehicles on a road Rd_i in the next time T_j can be derived by

$$Num_{T_j}^{Rd_i} = \sum_{k=1}^{m} Num_{T_l}^{Sg_{Rd_i}^k} + Pin_{T_j}^{Rd_i} - Pout_{T_j}^{Rd_i}, \tag{15}$$

where T_l is the current time and is equal to $(T_j - 1)$, $Num_{T_l}^{Sg_{Rd_i}^k}$ is the number of vehicle in each segment of road Rd_i, $Pin_{T_j}^{Rd_i}$ is the number of vehicles, which will enter road Rd_i, and $Pout_{T_j}^{Rd_i}$ is the number of vehicles, which will leave road Rd_i at time T_j. As $Num_{T_l}^{Sg_{Rd_i}^k}$ can be obtained by the normal traffic information messages of $Sg_{Rd_i}^k$ at time T_l, we only need to determine $Pin_{T_j}^{Rd_i}$ and $Pout_{T_j}^{Rd_i}$.

For a road that includes a road-head and a road-tail, a vehicle can only be steered from road-head to road-tail or enters the road from road-head and leave the road from road-tail. In our scheme, we assume that only vehicles in the last segment of a road should leave road in the next time. Therefore, $Pout_{T_j}^{Rd_i}$ and $Pin_{T_j}^{Rd_i}$ can be formed by

$$Pout_{T_j}^{Rd_i} = Num_{T_l}^{Sg_{Rd_i}^{last}}, \tag{16}$$

$$Pin_{T_j}^{Rd_i} = \theta \cdot \sum_{x \in \mathbb{N}_{Rd_i}} Num_{T_l}^{Sg_{Rd_x}^{last}}, \tag{17}$$

where Rd_x represents neighboring roads of Rd_i and connects to road-head of Rd_i, $Sg_{Rd_x}^{last}$ represents the last segment of road Rd_x, and θ is the percentage of vehicles, which enter into Rd_i and vehicle, which leaves Rd_x, respectively. All parameters in Equations (16) and (17), except θ can be obtained by the real-time traffic information message at time T_l. Therefore, θ is determined by the vehicle density of road Rd_i at time T_l and can be derived by

$$\theta = \begin{cases} \dfrac{L_{Rd_i} \cdot W_{Rd_i} \cdot K_p - Num_{T_l}^{Rd_i} + Num_{T_l}^{Sg_{Rd_i}^m}}{\sum_{x \in \mathbb{N}_{Rd_i}} Num_{T_l}^{Sg_{Rd_x}^{last}}} & \left(Den_{T_l}^{Rd_i} \le K_p\right) \\ \dfrac{Num_{T_l}^{Sg_{Rd_i}^m}}{\sum_{x \in \mathbb{N}_{Rd_i}} Num_{T_l}^{Sg_{Rd_x}^{last}}} & \left(Den_{T_l}^{Rd_i} > K_p\right) \end{cases} \tag{18}$$

where $Num_{T_l}^{Rd_i}$ is the total number of vehicles in road Rd_i and is equal to the sum of vehicles in all segments of Rd_i. Equation (18) represents that if vehicle density in road Rd_i is smaller than unimpeded density of Rd_i, the vehicle density of Rd_i in the next time slot can achieve unimpeded density without affecting traffic conditions of Rd_i. Otherwise, the entering number of vehicles must be no more than the leaving number of vehicles to keep traffic conditions of road Rd_i.

Recall that T_j is the next time slot of time T_l, i.e., $T_j = T_l + 1$. Therefore, we can use the real-time traffic information message at time T_l to predict traffic conditions at time T_j. According to the aforementioned analysis, we can find that no matter which metric (including travel time, vehicle density, etc.) is used to assess traffic conditions, the number of vehicles is the key parameter. All metrics of a road, including travel time and vehicle density, will turn worse as the number of vehicles is increased on the road.

Based on the definition of *Trust Probability (TP)* in Definition 1 and Equation (8), $TP_{T_j}^{Sg_{Rd_i}^j}$ is defined as the probability that the vehicle speed at time T_j is slower than that at time T_l.

According to the relationship between vehicle speed and vehicle density analyzed in Equations (11)∼(14), vehicle speed is monotone non-increasing with vehicle density. Therefore, $TP_{T_j}^{Sg_{Rd_i}^j}$ can also be considered as the probability that the number of vehicles that enter road at next time T_j is no more than the number of vehicles that leave this road at current time T_l.

Note that, there should be too many segments in the current guided route in a long route. To reduce computation and communication overhead, in this paper we only choose TP of road, denoted as $TP_{T_j}^{Rd_i}$, to represents TP of all segments in the road. In our scheme, we assume that vehicles in the last segment of a road must be left this road at the current time, and vehicles in the last segment of a road have equal probability to enter any one of neighboring roads connected to current road. Therefore, $TP_{T_j}^{Rd_i}$ can be represented as

$$\begin{aligned} TP_{T_j}^{Rd_i} =& P(Pin_{T_j}^{Rd_i} \leq Pout_{T_j}^{Rd_i}) \\ =& \sum_{n=0}^{Pout_{T_j}^{Rd_i}} C^n_{\left(\sum_{x\in\mathbb{N}_{Rd_i}} Num_{T_j}^{Sg_{Rd_x}^{last}}\right)} \left(\frac{1}{|\mathbb{N}_{Rd_i}|}\right)^n \\ & \cdot \left(1-\frac{1}{|\mathbb{N}_{Rd_i}|}\right)^{\left(\sum_{x\in\mathbb{N}_{Rd_i}} Num_{T_j}^{Sg_{Rd_x}^{last}} - n\right)}, \end{aligned} \tag{19}$$

where $\frac{1}{|\mathbb{N}_{Rd_i}|}$ is the number of neighboring roads that are connected to the road-head of road Rd_i and $Pout_{T_j}^{Rd_i}$ can be obtained by Equation (16).

Note that, Equation (19) considers the case where the number of vehicles, which may enter road Rd_i, is larger than the number of vehicles, which would leave the road Rd_i. When the number of vehicles, which may enter road Rd_i, is smaller than the number of leaving vehicles, $TP_{T_j}^{Sg_{Rd_i}^j}$ can be considered as 100%. This is because the number of entering vehicles in road Rd_i will be always smaller than that of leaving vehicles even if all vehicles in the last segment of all neighboring roads of Rd_i enter into road Rd_i.

$TP_{T_j}^{Sg_{Rd_i}^j}$ can effectively reflect the probability that real-time traffic conditions are not worse than the previous traffic condition. The use of $TP_{T_j}^{Sg_{Rd_i}^j}$ can effectively help travelers to, en-route, decide the alterative optimal route to the destination when traffic conditions of current guided route worsens and the current guided route is degenerated to a non-optimal route. The detailed process of en-route route alteration and decision is described in Section III-E below.

E. En-route Route Alteration and Decision

In this section, we describe the detailed process en-route route alteration and decision of DEDR, which considers the metrics including *travel time (TT)* and *vehicle density (VD)*.

1) Route Alteration and Decision with Single Metric: Assuming that vehicle u is steered along the current guided route to the destination, and the current guided route is denoted as $\{Rd_1, Rd_2, \cdots, Rd_n\}$. When vehicle u receives the real-time traffic information messages (TIMs) of roads in the current guided route at the current time T_l, DEDR predicts time slots that vehicle u enters each road of the current guided route, based on the real-time vehicle speed. For example, the time slot that vehicle u enters road Rd_i can be formed by

$$T_i = T_l + \frac{L_{Rd_1} - L_{passed}}{Sd_{T_l}^{Rd_1}} + \sum_{x=2}^{i-1} \frac{L_{Rd_x}}{Sd_{T_l}^{Rd_x}}, \tag{20}$$

where Rd_1 is the current road on which vehicle u is steered on, T_l is the current time slot, L_{passed} is the length that vehicle u has been steered on road Rd_1, and $Sd_{T_l}^{Rd_x}$ is the real-time vehicle speed on road Rd_x. Note that, the vehicle speed of a road is equal to the average vehicle speed of all segments divided in the road. All these parameters can be obtained from TIMs.

After obtaining the predicted time slots that vehicle u enters each road in the current guided route, DEDR predicts the traffic conditions of each road in corresponding time slots, i.e, *Trust Probability (TP)*. Based on Equation (19), DEDR can predict ***TP*** of a road in the next time slot through analyzing real-time TIM in the current time slot. Through the iteration method, DEDR can obtain the ***TP*** of a road in a latter time slot based on TIMs in the current time slot. That is, for the current guided route $\{Rd_1, Rd_2, \cdots, Rd_n\}$, DEDR can predict and determine corresponding ***TP*** of these road, which is denoted as $\{TP_{T_2}^{Rd_2}, TP_{T_{Rd_3}}^{3}, \cdots, TP_{T_n}^{Rd_n}\}$.

As traffic conditions of roads in the current guided route are relevant, the TP of the current guided route can be obtained by the product of TP of all roads, which is formed by

$$TP_{current} = \prod_{x=2}^{n} TP_{T_x}^{Rd_x}. \tag{21}$$

After obtaining the $TP_{current}$, DEDR determines whether the current guided route remains an optimal one from its current location to the destination by comparing $TP_{current}$ with the pre-defined trust threshold, denoted as Φ. If $TP_{current}$ is not smaller than Φ, the current guided route remains the optimal one. Otherwise, the current guided route is considered to be a non-optimal route. As the traffic conditions change over time, an alternative optimal route is needed.

To determine the alterative optimal route, DEDR considers two metrics to assess traffic conditions, including *travel time (TT)* and *vehicle density (VD)*.

Considering *travel time (TT)* as a metric to assess traffic conditions, the predicted TT of current guided route can be formed by

$$TT_{current} = \sum_{x=2}^{n} \frac{L_{Rd_x}}{Sd_{T_l}^{Rd_x} \cdot TP_{T_x}^{Rd_x}}. \tag{22}$$

DEDR can also determine an alternative optimal route by using floyd shortest distance method [24], [4] by considering the weight as travel time. The travel time TT_{alter} of alterative optimal route, denoted as $\{Rd_1, Rd_2^*, \cdots, Rd_n^*\}$, should be smaller than $TT_{current}$, where TT_{alter} can be obtained through the same way in Equation (22). After obtaining an alternative optimal, vehicle u will be steered along the alterative optimal route.

Considering *vehicle density (VD)* to assess traffic conditions, the predicted VD of the current guided route can be derived in the same way as the derivation of TT, which can be formed by

$$VD_{current} = \sum_{x=2}^{n} \frac{Den_{T_l}^{Rd_x}}{TP_{T_x}^{Rd_x}} = \sum_{x=2}^{n} \frac{Num_{T_l}^{Rd_x}}{L_{Rd_x} \cdot W_{Rd_x} \cdot TP_{T_x}^{Rd_x}}. \tag{23}$$

In these cases, DEDR can also determine an alternative optimal route by using floyd's shortest distance method by considering the weight as vehicle density, based on real-time TIMs of related roads.

Note that DEDR can not only assess traffic conditions with one metric, but also assess traffic conditions with considering multi-metrics simultaneously and determine the optimal route with drivers' individual preference of these metrics during travel. The detailed process of route alteration and decision with combined metrics is described in Appendix C of our technical report [15].

All of the above mentioned is en-route route alteration and determination when vehicles receive the normal traffic information message (TIM). Recall that there is also another message in our scheme, namely exigent traffic information message (TIM) discussed in Section III-C2, which is used to inform the exigent traffic conditions (e.g., bad weather, incidents, and others). Exigent TIM can inform drivers the remaining time delay raised by bad weather and incidents (i.e., the time to restore the traffic conditions). When drivers receive the exigent TIM, if the current time is before the restored time, the weight of this road is considered as infinity. Otherwise, the traffic conditions of the road are considered to be restored and the traffic conditions can be reset to the initial value until the fresh normal TIM of road is received by the vehicles. Based on the obtained weight of road, DEDR can, en-route, determine and alter the optimal route in the same way as it receives the normal TIM.

Based on received normal TIM and exigent TIM, DEDR can effectively, en-route, determine the traffic conditions of guided route and alter optimal route when traffic conditions worsen, which can effectively mitigate the sudden traffic congestion. In fact, a sudden traffic congestion could be raised by the sudden increase of vehicles on some roads. For example, if vehicles cannot collect real-time traffic information or alter guided route based on the real-time traffic information during travel, the road whose traffic conditions are considered to be great and selected as a part of the guided route by many vehicles may be congested when these vehicles enter this road and cause the vehicle density on this road that has suddenly increased. Because DEDR can, en-route, measure and collect real-time traffic information and, en-route, alter optimal routes to destinations when traffic conditions worsen, DEDR can effectively mitigate sudden traffic congestion raised by the suddenly increase of vehicles on a road. In addition, DEDR can also achieve travel time reduction and traffic load balance by considering different traffic metrics to assess traffic conditions.

IV. Analysis

We now analyze the performance of our proposed scheme to guide travels. The performance metrics include: (i) *time efficiency* is defined as the ratio of the travel time of the expected shortest route and the travel time of DEDR, and (ii) *balance efficiency* is defined as the probability of vehicle shunt. Note that, recall the workflow of DEDR, the communication and computation overhead is acceptable, because each vehicle can measure traffic information by using the deployed GPS and the generated and forwarded messages only include the limited traffic parameters. In addition, vehicles are randomly selected as cluster-head, achieving low average computation and communication overhead of DEDR. Therefore, in our analysis, we only focus on the efficiency performance of DEDR.

A. Time Efficiency

In an ITS, each road has its own parameters, including the length and the width of road, the limited speed of road, and the lane number of road, and others. To simplify our analysis, we only consider that one lane in each road in our scheme and our analysis can be extended to multiple lanes in each road. Based on the length and the limited speed of a road, the smallest time to driving over the road can be obtained. With the smallest time as weight, the expected travel time and the expected shortest route from the initial location to the destination can be obtained by the shortest distance scheme (e.g., Floyd [24], [4] and Dijkstra [25], [9]), which can be denoted as TT_{total}^{exp}, $\{Rd_1^{exp}, Rd_2^{exp}, \cdots, Rd_n^{exp},\}$, respectively.

In DEDR, when the travel is completed, the traveled route from the initial location to the destination based on DEDR can also be obtained, which can be denoted as $\{Rd_1^{DEDR}, Rd_2^{DEDR}, \cdots, Rd_m^{DEDR}\}$. The time that is used to drive over each road can also be concluded. The total travel time of DEDR can be formalized by

$$TT_{total}^{DEDR} = \frac{Rd_1^{DEDR}}{Sd_{T_1}^{Rd_1^{DEDR}}} + \frac{Rd_2^{DEDR}}{Sd_{T_2}^{Rd_2^{DEDR}}} + \cdots + \frac{Rd_m^{DEDR}}{Sd_{T_m}^{Rd_m^{DEDR}}}, \tag{24}$$

where $Sd_{T_1}^{Rd_1^{DEDR}}$ is the average speed when vehicle traveled on the road Rd_1^{DEDR}.

In our analysis, we consider the *time efficiency* of DEDR in the following three traffic cases: (i) light traffic, (ii) moderate traffic, and (iii) heavy traffic.

Case 1: light traffic. In this case, a few vehicles are steered on the road, and the average vehicle speed on all roads is currently moving the speed limit set on these roads. Then, the expected route $\{\{Rd_1^{exp}, Rd_2^{exp}, \cdots, Rd_n^{exp},\}\}$ is the best route from the initial position to the destination, and the expected time TT_{total}^{exp} is the time to complete travel with limited speeds. Note that, the core idea of DEDR is to determine traffic conditions and the route is determined by the shortest distance scheme (e.g., Floyd and Dijkstra). Hence, the guided route determined by DEDR in this case should be equal to the expected route $\{Rd_1^{exp}, Rd_2^{exp}, \cdots, Rd_n^{exp},\}$. This is because traffic conditions of all roads are great and the guided route is not required to alter during travel. Hence, the travel time of DEDR is equal to the expected smallest time, i.e., $TT_{total}^{DEDR} = TT_{total}^{exp}$ and the *time efficiency* of DEDR is

$$P_{TE}^{DEDR} = \frac{TT_{total}^{exp}}{TT_{total}^{DEDR}} = 1. \tag{25}$$

Case 2: moderate traffic. In this case, there is a moderate number of vehicles are driving on the roads and some roads may show traffic congestions. Thus, the expected time can be formalized by

$$TT_{total}^{exp} = \frac{L_{Rd_1^{exp}}}{Sd_{T_1}^{Rd_1^{exp}}} + \frac{L_{Rd_2^{exp}}}{Sd_{T_2}^{Rd_2^{exp}}} + \cdots + \frac{L_{Rd_n^{exp}}}{Sd_{T_n}^{Rd_n^{exp}}}. \tag{26}$$

The initial guided route obtained by DEDR is also considered to be the expected route. The *Trust Probability (TP)* of each road in the expected route is concluded en-route and the TP of the expected route can be obtained as well. If the TP of expected route is larger than the pre-defined threshold Φ, the vehicle remains steered along the expected route. Otherwise, vehicle is steered on road Rd_i, and the TP of all rest roads in the expected route is less than Φ. Then, DEDR determines an alternative optimal route, denoted as $\{Rd_i^{DEDR}, Rd_{i+1}^{DEDR}, \cdots, Rd_m^{DEDR}\}$, in which the travel time of the alternative route should be conformed to

$$\sum_{x=i}^{m} \frac{L_{Rd_x^{DEDR}}}{Sd_{T_x}^{Rd_x^{DEDR}} \cdot TP_{T_x}^{Rd_x^{DEDR}}} < \sum_{y=i}^{n} \frac{L_{Rd_y^{exp}}}{Sd_{T_y}^{Rd_y^{exp}} \cdot TP_{T_y}^{Rd_y^{exp}}}. \tag{27}$$

Based on the basic idea of DEDR, the predicted travel time of a road in an alternative route can be formalized by

$$TT_{Rd_x^{DEDR}}^{DEDR} = \frac{L_{Rd_x^{DEDR}}}{Sd_{T_x}^{Rd_x^{DEDR}} \cdot TP_{T_x}^{Rd_x^{DEDR}}}. \tag{28}$$

Therefore, based on Equations (27) and (28), we have

$$\begin{aligned} TT_{total}^{DEDR} =& TT_{passed} + \sum_{x=i}^{m} TT_{Rd_x^{DEDR}}^{DEDR} \\ <& TT_{passed} + \sum_{y=i}^{n} TT_{Rd_y^{exp}}^{exp} \\ =& TT_{total}^{exp}. \end{aligned} \tag{29}$$

Also, the *time efficiency* of DEDR for this case is

$$P_{TE}^{DEDR} = \frac{TT_{total}^{exp}}{TT_{total}^{DEDR}} > 1. \tag{30}$$

Case 3: heavy traffic. In this case, a large number of vehicles currently driving on roads and most of the roads are showing traffic congestion. As most of roads are congested, DEDR cannot choose an alternative route, in which the TP of alternative route is larger than the pre-defined threshold Φ. Hence, vehicles should be steered along the expected route and the travel time of DEDR is equal to the expected travel time, and the *time efficiency* of DEDR should be "1".

Note that, **Case 1** and **Case 3** will occur in an ITS with a low probability because of the increasing number of vehicles, while also factoring in road construction. Due to this, the traffic conditions, most of the time, can be represented by **Case 2**. Hence, DEDR can achieve greater *time efficiency* in an ITS and assist travelers in saving travel time in comparison to existing route guidance schemes.

B. Balance Efficiency

DEDR can also achieve vehicles shunting during travel. Assuming that the expected route from the initial location to the destination can be denoted as $\{Rd_1^{exp}, Rd_2^{exp}, \cdots, Rd_n^{exp},\}$. When the number of vehicles on the expected route is small, DEDR will not alter the route and will steer vehicles along with the expected route. When vehicles are steered on road Rd_i^{exp} and the traffic conditions of the expected route become worse when traffic congestion occurs on the expected route, DEDR will determine an alternative route from the road Rd_i to the destination. The alternative route can be denoted as $\{Rd_i^{DEDR}, Rd_{i+1}^{DEDR}, \cdots, Rd_m^{DEDR}\}$. Based on the basic idea of DEDR, the predicted travel time of alternative route should be smaller than that of the expected route, i.e., conforming to Equation (29).

Note that, the alternative route can be determined if and only if the criteria stated in Equation (29) can be achieved. Therefore, there could be no alternative route from its current location to the destination existing in an ITS under the current traffic conditions. That means that there could be only one route from its current location to the destination existing in an ITS or other routes are also congested under real-time traffic conditions. In this case, as vehicle shunting cannot increase traffic capacity, there is no need to shunt vehicles.

If alternative routes exist, DEDR can shunt vehicles from its current guided route to the alternative route with a probability, given by

$$P_{BE}^{DEDR} = \frac{|Route_{Alter}|}{|Route_{Total}|}, \tag{31}$$

where, $|Route_{Alter}|$ and $|Route_{Total}|$ represent the number of existing alternative routes and the number of total routes from the current location to the destination.

In an area, the number of total routes from one location to another location should be constant and the number of alternative routes changes as the traffic conditions change over time. Based on Equation (31), DEDR can shunt vehicles to alternative routes with a greater probability when the traffic capacity of the current guided route is low. As the number of vehicles shunted to alternative routes is increased, the number of alternative routes can be decreased as the traffic capacity of altered routes become worse and the traffic capacity of the current guided route can be increased. Until the number of alternative routes approaches zero or the traffic capacity of the current guided route is restored, DEDR stops vehicles shunting. Hence, when traffic congestion exists in the current

Fig. 2. Part of traffic map of Xi'an in China

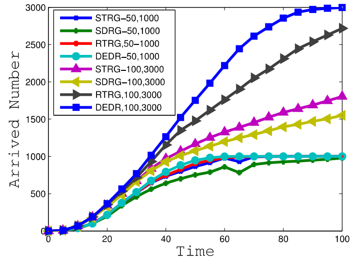

Fig. 3. Arrived number versus time

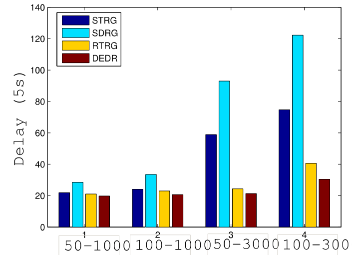

Fig. 4. Average delay

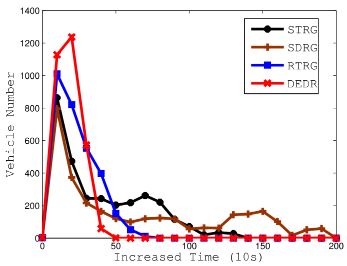

Fig. 5. Vehicles number versus increased time

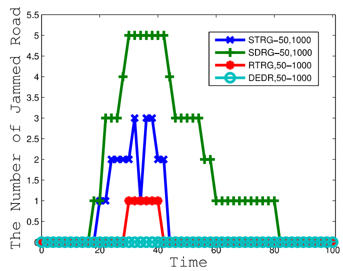

Fig. 6. Jammed number of road versus time (vehicle increasing ratio as 50 per time slot)

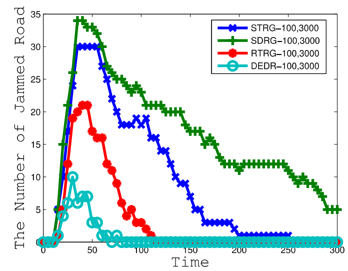

Fig. 7. Jammed number of road vs. time (vehicle increasing ratio as 100 per time slot)

guided route, DEDR can effectively determine alternative routes and achieve traffic balance.

In the above analysis, *balance efficiency* is evaluated using *travel time (TT)* as a metric to determine routes in DEDR. When the route is determined by other metrics (e.g., *vehicle density (VD)*, etc.), the *balance efficiency* of DEDR can also be applied in the same way and desirable *balance efficiency* can be achieved.

V. Performance Evaluation

In this section, we will show the simulation results of DEDR in comparison with the shortest distance route guidance scheme (SDRG), the shortest time route guidance scheme (STRG), and the real-time route guidance scheme (RTRG) in terms of time efficiency and balance efficiency as we stated in Section IV. Note that STRG and SDRG belong to the shortest path scheme (e.g., Dijkstra [25], [9] and Floyd [24]) with weight as static travel time and static distance, respectively. RTRG is a shortest path scheme with weight as dynamic real-time travel time. STRG, SDRG and RTRG can effectively show the efficiency of static and dynamic route guidance schemes.

A. Evaluation Setup

We conduct performance evaluation based on a simplified version of partial traffic map of Xi'an city in China, shown in Fig. 2. We select major intersections as nodes in the topology. The backbone of the traffic line is based on the connection between these nodes. The 45 intersections are selected as simulation objects, in which 73 traffic lines are included, as shown in Fig. 2.

The data sets used for the simulation consists of road distance and the limited speed of each road in Fig. 2, respectively. These two data sets can be easily obtained by the traffic map of Xi'an. To simplify our evaluation, we consider that all roads in Fig. 2 have a dual carriageway and only one lane existing in each direction. Based on the basic idea of DEDR, each road is divided into several segments with a fixed segment length of $50m$. In each evaluation, a number of vehicles are randomly selected to join in the transportation system and the maximum number of vehicles that can be included in our simulation is 3000. The initial location and destination of a vehicle are randomly selected from 45 nodes in Fig. 2. Each of the vehicles in our evaluation can not only measure and send local real-time traffic condition information, but also receive and forward the real-time traffic conditions information of other locations.

As we stated in previous sections, we define several metrics to measure the effectiveness of our proposed scheme. The *time efficiency* is evaluated by the consumed time that vehicles complete travel. The balance efficiency is evaluated by the vehicle density of all roads when vehicles are steered on roads with different route guidance schemes. We also evaluate the number of jammed roads to demonstrate the *balance efficiency* of evaluated schemes. In our evaluation, the performance of DEDR is not only evaluated by assessing traffic condition with single metric, but is also evaluated by assessing traffic conditions with travelers' individual preference of multiple metrics. To obtained the operation parameters of vehicles, $YC6L260-40$ engine is chosen as an example in our experiments. In addition, the pre-defined trust probability threshold

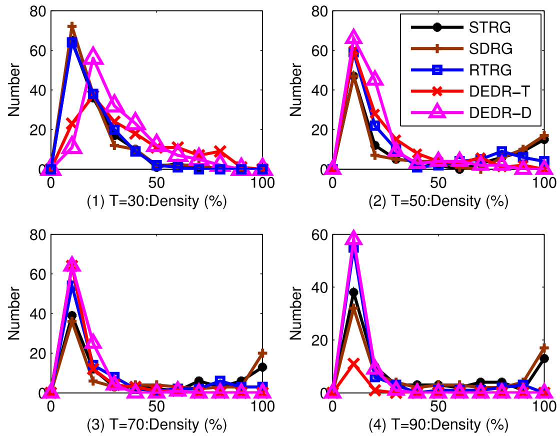

Fig. 8. Vehicles number versus vehicle density

is 50% in our evaluation. All simulations in this paper are completed by Matlab.

B. Evaluation Results

In the following, we show the evaluation results.

1) Time Efficiency: Fig. 3 illustrates the number of vehicles increasing as the time passes when travel time is used as a metric to assess traffic conditions. As we can see, Fig. 3 shows that the arrived number of vehicles with DEDR is always larger than the number of vehicles when other route guidance schemes are used. This indicates that given the same traffic condition, DEDR could effectively reduce the travel time of vehicles. For example, when 3000 vehicles are traveling in an ITS, all vehicles with DEDR can complete their travels during 90 time slots, while in the same condition, only 2600, 1500 and 1700 vehicles complete their travels with RTRG, SDRG and STRG respectively.

Fig. 4 shows the average delay of all vehicles with different route guidance schemes. The average delay is equal to the time difference between the expected shortest time and the consumed time. As Fig. 4 shown, no matter the traffic conditions in each situation, DEDR can always achieve the lowest average time delay in comparison with other schemes. Fig. 5 shows the number of vehicles that complete their travels with increased travel time. From the figure, in DEDR, the increased time of most vehicles is 30 time slots and no vehicle's increased time is larger than 50 time slots. While, in RTRG, SDRG and STRG, there also exists a large number of vehicles whose increased time is more than 50. Hence, DEDR can effectively reduce the travel time in comparison with RTRG, SDRG and STRG and achieve great *time efficiency*.

2) Balance Efficiency: Fig. 6 and Fig. 7 show the number of jammed roads in an ITS as the time passes. As we can see from the figure, when the number of vehicles that join an ITS in each time slot is low (say 50 per time slot in our evaluation setting), the number of jammed roads in DEDR can be zero, i.e., no road is congested. While, under the same condition, the highest number of jammed roads in RTRG, SDRG and STRG are 1, 5 and 3, respectively. When the increasing ratio of vehicle numbers is high (say 100 per time slot in our evaluation setting), the highest number of jammed road in DEDR, RTRG, SDRG and STRG are 10, 23, 34 and 30, respectively. Hence, DEDR can effectively mitigate traffic congestions in an ITS.

Fig. 8 shows the number of roads with different vehicle densities. Note that, DEDR-T means that vehicle uses DEDR with travel time (TT) to assess traffic conditions and DEDR-D means that a vehicle uses DEDR with vehicle density (VD) to assess traffic conditions. In Fig. 8, if density is equal to 100%, it means that the road is jammed. As we can see, in the initial stage, as shown in Fig. 8 (1), no road is jammed in an ITS no matter which route guidance scheme is used. As the time passes, as shown in Fig. 8 (2), (3) and (4), the vehicle density of most roads in DEDR (including both DEDR-T and DEDR-D) are only 20% of the jammed density of these roads, while the vehicle density of most roads in other schemes is not balanced because a number of jammed roads exists with these schemes. Based on Fig. 6, Fig. 7 and Fig. 8, we can see that DEDR can effectively balance traffic and achieve great *balance efficiency*.

VI. Conclusion

In this paper, we proposed a novel scheme, which can effectively mitigate traffic congestions and improve the traffic efficiency of an ITS. Particularly, DEDR adopts *Trust Probability (TP)* to assess real-time traffic conditions with multiple metrics and en-route alter the optimal route from current location to the destination during travel. DEDR can assess real-time traffic condition with multiple metrics and determine the optimal route, achieving travel time reduction and traffic balance. DEDR considers both real-time traffic information generation and vehicle route guidance control, which are essential to ITS. Through a combination of both theoretical analysis and simulation experiments, our data shows that our scheme achieves better traffic efficiency in terms of time efficiency and balance efficiency in comparison with existing schemes.

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