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On-road i-Vics Management for Blockage of Abreast Low Speed Vehicles near Signalized Intersections

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***Abstract*— Driving at velocity much lower than the speed limit greatly restraints the movements of the followers, resulting in considerable waste of road resource every day. When two slow vehicles are moving abreast on the city road, the result is devastating for their followers. To solve such problem by the idea the i-Vics (intelligent vehicular infrastructure cooperative systems), this paper proposes a dedicated on-road traffic management plan for abreast low speed connected vehicles, especially for scenarios near signalized intersections. The management plan takes three steps to erase the traffic blockage caused by those abreast slow drivers, including detection of abreast slow drivers, appraisal of environmental factors, and traffic guidance notification for all relevant drivers. In the proposed plan, the detection model initially evaluates the whole street and picks out all the abreast low speed vehicles based on the i-Vics. For every blockage target, a appraisal model of the surroundings determines the strategy how to dissolve the traffic blockage, including the feasibility of overtaking, and possibility of passing through the intersection and etc. Finaly, once the dissolving strategy is approved by the appraisal program, the management system sends notification of speed guidance to all relevant drivers to guide them to pass through the signalized intersection within the remaining green time.**

I. INTRODUCTION

A. Background and Motivation

Urban Transportation inefficiency at signalized intersections has always been a concern and this problem is exacerbated while some low-speed vehicles retard the entire traffic. Although driving at velocity much lower than the normal speed limit is ordinary among beginners and cautious drivers. considerable waste of road resource happens every day in the city when an excessively slow car hinders a group of vehicles eager to overtake. Most time the slow car drivers may not hinder deliberately while they do not realize the accumulative queuing drivers behind. The following drivers usually get much angrier when they are coming close to a signalized intersection about to turn red. The situation becomes much more serious when two slow drivers are heading abreast and the followers are impossible to overtake. Such situation usually happens on highway when two HDT (heavy-duty trucks) are heading side by side. Since these moderate speed heavy vehicles have considerablely long bodies, the overtaking process takes a long time for long HDT to separate from each other. In urban trafic system, such situation is uncommon, whereas, much more devastating once happened. Compared to the highway scenario, the length and width of urban roads are relatively short and the car density is much higher. Additionally, the green time is so limited that every driver wishes to avoid stopping at the red-time intersections. However, there is not enough time to dissolve the traffic blockage caused by low speed drivers moving abreast. If the green time runs out unfortunately, those followers will have to wait at the intersection while such prolonged queueing can be precluded. In this paper, the term, traffic blockage, dedicatedly refers to those situation where normal speed vehicles are limited by two low speed vehicles moving abreast and have to decelerate and follow. Fig. 1 illustrates the traffic blockage caused by low-speed vehicles moving abreast.

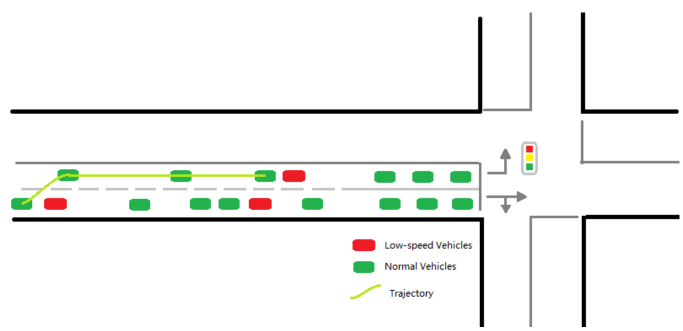

Fig. 1. Traffic blockage caused by slow drivers moving abreast

In order to prevent the formation of traffic blockage and dissolve it, based on the idea of i-Vics (intelligent vehicular infrastructure cooperative systems), we proposed an on-road traffic management system, which consists of three parts: detection, appraisal and guidance. The detection model of abreast low speed vehicles will locate the low speed pairs, which may potentially block the movement of their followers. The appraisal model help evaluate the seriousness of the blockage situation and synthesize various environmental factors to determine the strategy for different blockage situations. Finally, according to strategy, notification traffic guidance assists all the relevant vehicles to move in order and eliminates the blockage in the end. With the powerful help of vehicular networks and connected vehicles[1], this on-road traffic management plan will be able to acquire the

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essential information of detection, aprraisal and guidance and eventually eliminate such traffic blockage.

B. Previous Works

The idea of an advanced traffic management system has been of worldwide researchers' concern for long. N. Myridis (2004) proposed a traffic supervising system named E-a-R (Eye-at-road)[2]. This system is dedicated for traffic safety on low visibility roads, due to curve-figured routes, highlands and fog. F. Terroso-Saenz, and et al. (2012)[3] proposed an approach to traffic congestion detection with complex event processing and VANET (Vehicular Ad hic Networks). They mention the detection of slow vehicles in traffic jam situation.

In a abreast low speed vehicles blockage situation, we made the assumption that all the relevant vehicles assemble a connected cluster, where one of the low-speed vehicle can play as the cluster head and all the other affected vehicles are components. In order to guide those connected vehicles properly and avoid defying the basic rules of VANET communication, we refered to a lot of researchers' expertise. The low-speed blockage vehicles are relative stable and inert, which can be appreciated in the election of cluster head. This stable characteristic of a cluster head is mentioned in Z. Wang and et al. (2008)'s research[4]. W. Liu,and et al. (2017) integrated the dynamic clustering theory into the traffic signal control[5].

In making the strategy for dissolving traffic blockage. We alse refered to many researches' works about overtaking or intelligent lane change assistance. R. Rai, and et al. (2015) design a nonlinear, time-invariant motion planner for lane changing, derived from the Lyapunov-based Control Scheme works[6]. M. Younes, and et al. (2017) proposed a protocol for lane change on highway[7]. As for speed guidance, B. Yang, and et al. (2013) proposed optimization model and a distributed algorithm[8], which can promote the traffic efficiency through speed guidance. Z. Wu, and et al. (2016) presented an integrated control strategy of transit signal priority and speed guidance under the environment of Connected Vehicles[9].

C. Our Contribution

To detect abreast low-speed vehicles precisely from the traffic flow, we proposed an model of low-speed indicator and design an cluster algorithm to connect all the relevant vehicles in one specific blockage zone through the connected vehicular networks. After the establishment of each blockage cluster, the appraisal model will make a dissolving strategy for every cluster by synthesizing all the environmental factors available from the i-Vics. Once the strategy is determined, the traffic guidance notification will take it into action. In our proposed plan, except for essential orders of moving direction (change to left lane or right lane), speed guidance is the main operation.

The rest of this paper is organized as follows. In Section 2, we make some basic assumptions and overview the design of entire on-road i-Vics management systems. Then we respectively illustrate the detection of abreast low speed vehicles in section 3, environment appraisal and strategy making in section 4 and speed guidance notification in section 5. Finally, this paper will be concluded in Section 6.

II. OVERVIEW AND ASSUMPTIONS

The proposed on-road i-Vics management system for abreast low speed vehicles near intersections comprises three steps: detection, appraisal and action.

The detection algorithms of low speed connected vehicles are mainly based on vehicles' motion features. This feature-based algorithm automatically gather all the useful information from the i-Vics and calculate the suspicion of every vehicle on the road by comparing their low speed suspicion value. If this value is lower than a threshold, the vehicle with the value will be considered as a suspicious vehicle of abreast blockage. In the meantime, to check out whether there is(are) low speed car(s) in neighboring lane(s), we combine each vehicle's suspicion value with their current location (e.g. headlights' position). For a road with 2 lanes (the minimum situation), if two low speed vehicles in two different lanes have close ordinates within a threshold, the detection model considers it as a abreast blockage. For a road with $N(N > 2)$ lanes, the blockage situation will be more complicate. Section 3 will discuss multi-lane situations in detail.

According to the blockages provided by the detection step, the appraisal part is proposed to make dissolving strategies for different blockage situations. Environmental factors, including signal status at the next intersection, the current lane space at the blockage zone and the density of vehicles distributing forward, are synthesized into the appraisal model for accurate strategy making. The basic idea of dissolve these blockage is to tear the blockage apart by urging one low speed car to accelerate and still keeping the other at low speed rate. In section 4, we will disscuss this in detail.

After the decomposition of abreast blockage, further arrangement should be implemented to help all relevant vehicles to pass through the next signalized intersection. Speed guidance is an eligible method of traffic guidance notification to help individual drivers to follow the V2X instructions. The detailed speed guidance method will be discussed in section 5.

In this paper, we assume that all the vehicles on the road can be connected and communicate with their neighbors and Road-Side-Unit (RSU). All vehicles are equipped with 360 degree sensors like LiDAR (Light Detection And Ranging) and able to sense the positions of vehicles at lateral lanes. Moreover, the research scenario is established on one road segment with one signalized intersection downstream.

III. DETECTION MODEL

In order to find a blockage zone created by a pair of or several abreast low speed vehicles, it is supposed to locate the positions of all suspicious vehicles at first. A suspicious vehicle refers to a low speed vehicle that is likely to obstruct its followers. Two or even more suspicious vehicles moving abreast will create a blockage for their followers. However, a low speed vehicle is not supposed to be a suspicious one. That is, we cannot judge a suspicious vehicle merely from its speed. Even if the car moves slowly, there will be no negative influence at all if the car is just moving alone and proved as no obstacle for others. To narrow down the search area of suspicious vehicles, various traffic factors should be taken into consideration. Based on vehicles' motion features, including current speed, body length and front & rear space headways, the proposed detection model provides a more accurate way to locate all abreast low speed vehicle blockage.

A. Space Headway Features

Due to the extreme cautiousness on road, typically, a slow driver is keeping a relatively long distance from the front vehicles. Meantime, its followers are closely following the slow driver. Therefore, a suspicious car is with the feature of a relatively long front space headway and a short rear space headway at the same time. Since the space headways can be measured with the help of on-board sensors, it is not a challenge to obtain space headway statistics. Denote the front space headway and the rear space headway as s_f and s_r respectively. Equation (1) shows the ratio of s_f to s_r, denoted as R_s , which is one measurement of low speed vehicles' suspicion.

$$R_s = \frac{s_f}{s_r} \tag{1}$$

For every car on the road, its R_s value will be calculated by on-board arithmetic unit. A bigger R_s value indicates larger suspicion of being a part of abreast blockage. Cars moving normally in a free flow have both long front and rear space headway. Thus, their R_s value will be much smaller than suspicious vehicles'. On the other hand, cars already stuck in traffic jam have a R_s value approximately with 1. They will not be considered as suspicious vehicles of abreast blockage.

B. Speed Features

Since the front space headways drivers try to maintain correlate highly with vehicles' speed, the recognition of suspicious vehicles will be biased from the value of R_s. Thus, speed parameters are taken into consideration. With the help of connected networks and on-board interface, acquiring instant speed is possible. For every vehicle and its front and rear neighbors, denote the speed compound of three vehicles as $V = (v_f, v_m, v_r)$, where v_f, v_m, v_r are the speed of the front, middle and rear vehicle respectively (the middle vehicle is the main entity in this analysis part). The cautiousness of each driver can be measured as a proportion of its front space headway s_f to its ideal safety distance s_0. The safety distance s_0 is defined as the minimum distance a vehicle should maintain when its front neighbor stops suddenly. With a reaction time delay t_d and a deceleration rate a_d, safety distance can be built as:

$$s_0(v_m) = v_m t_d + \frac{v_m^2}{2a_d} \tag{2}$$

For simplicity, take t_d as 1.0 second and a_d as 5 m/s^2. Then the cautiousness of the concerned driver is measured as:

$$C(v_m) = \frac{s_f}{s_0(v_m)} = \frac{2a_d s_f}{2a_d v_m t_d + v_m^2} \tag{3}$$

The value of C is a simple indicator of the concerned driver's cautiousness. A careful driver may keep a long front space headway, which is unnecessary when the speed is at a relatively low level. Thus, a vehilce with both slower speed and larger front space headway will be taken as a cautious driver. Then check then closest behind driver: if the behind dirver is obstructed, its front space headway will be at small level. Note that the front space heaway of the behind driver is the rear space headway of the concerned driver. Similarly, the cautiousness value of the behind driver can be writen as $C(v_r) = s_r/s_0(v_r)$. Then calculate the ratio of $C(v_m)$ to $C(v_r)$, as a measure of the severity of obstruction (shown in Equation 4).

$$R_C = \frac{C_m}{C_r} = \frac{s_f}{s_r} \cdot \frac{2a_d v_r t_d + v_r^2}{2a_d v_m t_d + v_m^2} \tag{4}$$

Compared to the suspicion value R_s in Equation 1, the value of R_C is a speed revision over the front & rear space headway difference. Thus, it is more reasonable to regard a vehicle with high R_C value as a suspicious one of abreast blockage. However, sometimes the R_C value may be wrongly amplified by the volatility of instant speed and the uncapped space headway. Therefore, speed values are treated as mean speed in a short period, and the space headways are with a maximum value of S_{max}, e.g. 50% of road length, and a minimum value of S_{min}, e.g. 100% of body length.

C. Abeast Blockage Detection

In addition to the suspicion value R_C listed above, every vehicles on road is maintaining its own data, which is a tuple with many elements, e.g. horizontal coordinate $X(i)$; lane number $Y(i)$; car body length $l(i)$; speed $v(i)$; front space headway $s_f(i)$; suspicion value $R_C(i)$, denoted as $\alpha_i = \{X(i), Y(i), l(i), v(i), s_f(i), R_C(i), ...\}$.

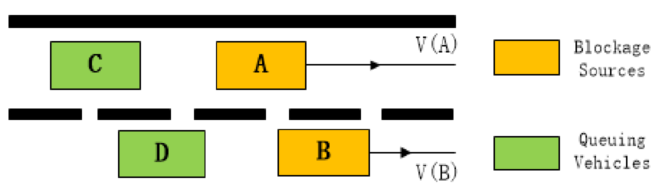

Fig. 2. Abreast blockage in two-lane situation

In two-lane situation (shown in Fig. 2), an abreast blockage happens when a suspicious vehicle A has hindered its follower C and meantime vehicle B at the other lane with similar speed is moving together with A. Therefore, once the blockage is formed, there is no room for followers like vehicle C or D to overtake. When such blockage happens near signalized intersections (at green time), followers like C may unfortunately fail to pass through the intersection within the limited green time.

The detection of abreast blockage has two major steps: (1) find all the suspicious vehicles and their followers (if existed) on each lane; (2) for each suspicious vehicle, check out the conditions on the other lane. In step (1), all the suspicious vehicles on each lane refer to the vehicles with larger R_C value. Thus, according to the order of R_C value, pick up top 10% (the percentage θ depends on congestion severity of the road) of all vehicles on each lane as candidates. For each candidate, check its closest follower's acceleration rate: if the follower is decelerating, then confirm the candidate as a suspicious vehicle. After step (1), each lane j is maintaining a list of confirmed suspicious vehicles $A_S(j)$. For every suspicious vehicle $\alpha_{Sj}(i)$ in $A_S(j)$, check the closet vehicle $\alpha^*(i)$ at the lateral lane with the help of lateral sensor. On board sensors can provide the distance between two vehicles at different lanes and for simplicity, its value can be derived by the Pythagorean theorem:

$$Dist(A,B) = \sqrt{(X(A) - X(B))^2 + w^2} \tag{5}$$

where w is width of one lane. Actually, the horizontal distance $|X(A) - X(B)|$ can be measured by location devices directly. If the accuracy is guaranteed, both measuring method are appropriate to determine the interval between two abreast blockage vehicles.

If the distance between $\alpha_{Sj}(i)$ and $\alpha^*(i)$ is less than a threshold: $Dist(\alpha_{Sj}(i), \alpha^*(i)) < \sqrt{(kl)^2 + w^2}$ (equivalently, horizontal distance is limited with $|X(A) - X(B)| < kl$), and their speed difference is also within a threshold of δ, then confirm $\alpha_{Sj}(i)$ and $\alpha^*(i)$ as a pair of blockage sources $\beta_1(n) = \{\alpha_{Sj}(i), \alpha^*(i)\}$. The algorithm of detection of abreast blockage in two-lane situation is listed below in Algorithm 1.

Multi-lane situation can be treated as several two-lane situation combined together. For a N-lane road ($N > 2$), combine every two neighboring lanes together as a two-lane road: e.g. combine the 1^{st} lane and the 2^{nd} lane as the 1^{st} two-lane road, and combine the $(N-1)^{th}$ lane and the N^{th} lane as the $(N-1)^{th}$ two-lane road. Then apply the detection algorithm above for all $(N-1)$ two-lane road. Then assemble all the output blockage results.

IV. APPRAISAL AND STRATEGY

After locating the exact position of all abreast blockages, the next step is to conduct appraisal of environmental condition for making overtaking strategies. Fig. 3 illustrates the idea of dissolving blockage by urging vehicle B to accelerate and create space for vehicle C's overtaking.

Denote the lane where vehicle A moves as lane-A, and the other as lane-B. In Fig. 3, vehicle C overtake vehicle B from lane-B to lane-A with 1 lane change. However, if vehicle C is following behind vehicle A at lane-A, should vehicle C conduct 2 lane changes?

Algorithm 1 The detection of two-lane abreast blockages.

Input: Vehicle data list: $A = \{\alpha_1, \alpha_2, ...\}$; For each vehicle: $\alpha_i = \{X(i), Y(i), l(i), v(i), s_f(i), R_C(i), ...\}$

Output: all abreast blockages $B = \{\beta_1, \beta_2, ...\}$;

1: Parameters initialization: $\theta = 10\%$, $k = 100\%$, $l = 4.8$ meters, $\delta = 15\%$;
2: Sort the vehicle data list in order of R_C;
3: For each lane (Y=1, 2), pick up top θ of vehicles at the lane as candidates $A_C(1)$ and $A_C(2)$ in order of R_C;
4: For each candidate $\alpha_{C1}(i)$ in the 1^{st} candidate set $A_C(1)$, check its closet follower's speed volatility on the same lane – if the follower is decelerating, then put the candidate $\alpha_{C1}(i)$ into the set of confirmed suspicious vehicles $A_S(1)$;
5: Repeat step 4 for the other candidates set and generate all confirmed suspicion set $A_S(1)$, $A_S(2)$;
6: For every suspicious vehicle $\alpha_{S1}(i)$ in the 1^{st} suspicion set $A_S(1)$, check the closet vehicle $\alpha^*(i)$ at the lateral lane: if $Dist(\alpha_{Sj}(i), \alpha^*(i)) < k \cdot l$ and $\frac{|v_{Sj}(i) - v^*(i)|}{v^*(i)} \cdot 100\% < \delta$, then confirm $\alpha_{Sj}(i)$ and $\alpha^*(i)$ as a pair of blockage sources $\beta_1(n) = \{\alpha_{S1}(i), \alpha^*(i)\}$, composing the blockage set $B_1 = \{\beta_1(1), \beta_1(2), ...\}$;
7: Repeat step 6 for rest suspicion set and generate the other blockage set $B_2 = \{\beta_2(1), \beta_2(2), ...\}$
8: **return** $B = B_1 + B_2$;

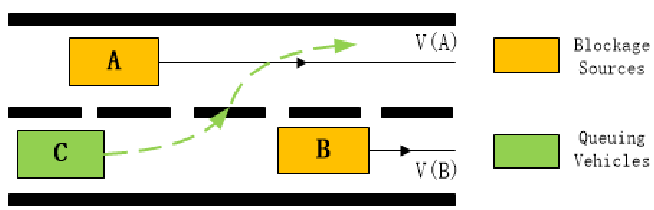

Fig. 3. Dissolve blockage in two-lane situation

According to the detection algorithm in section 3, the horizontal interval between two blockage source vehicles is with k times of average vehicle body length l. If this distance is long enough (e.g. $|X(A) - X(B)| \leqslant l$, L can be 50% average body length) for vehicle A's switch to lane-B while vehicle B accelerate to create more space for A's lane change. Meantime, vehicle C accelerates in lane-A without any lane change and total lane change time is 1 (from vehicle A). A flow diagram of making overtaking strategy is shown in Fig. 5. Generally, the interval $|X(A) - X(B)|$ between two blockage sources and the initial lane of the following

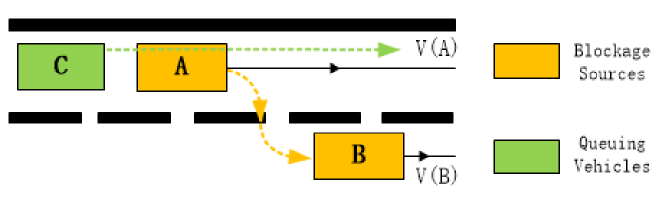

Fig. 4. Another strategy in two-lane situation

vehicle $Y(C)$ determine the overtaking strategy to dissolve the blockage..

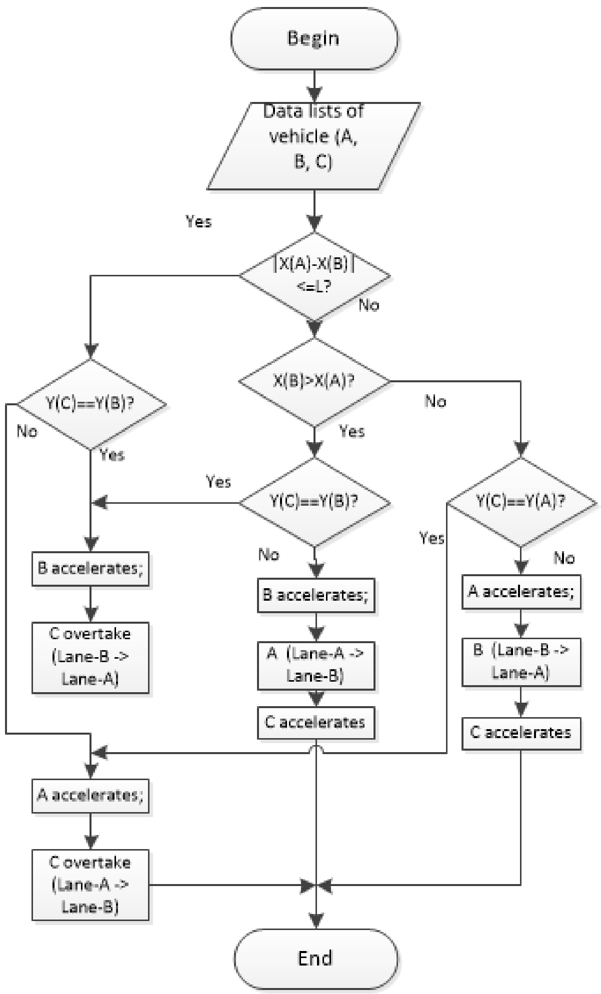

Fig. 5. Flow diagram of making overtaking strategy

V. SPEED GUIDANCE NOTIFICATION

After dissolving all abreast blockages, all relevant vehicles are encouraged to make full use of the remaining green time. Therefore, the last step is to help the vehicle pass the signalized intersection after breaking through an abreast blockage. Since vehicles are close to the lane-change-inhibited zone near the intersection, no lane change (no overtaking as well) should happen during the period of speed guidance. For the i^{th} vehicle α_i (α_1 is the vehicle closest to the intersection), during its acceleration time, the acceleration rate can be simplified as a process with features of climbing-stable-descent in Fig. 6, where $t_0(i)$ is the total acceleration time for vehicle α_i, and $a_0(i)$ is the maximum rate for α_i.

During acceleration time $t_0(i)$, the distance vehicle α_i travelde is $\Delta S_i(t_0) = \int_0^{t_0}\int_0^{t_0} a(i,t)\mathrm{d}t\mathrm{d}t$. Denote the total time cost from vehicle α_i's acceleration to its intersection pass as T_i. Since no overtaking happens during the period of speed guidance and the vehicles near the intersection arrive before vehicles far away, it suits for any $i, j (i < j)$ that

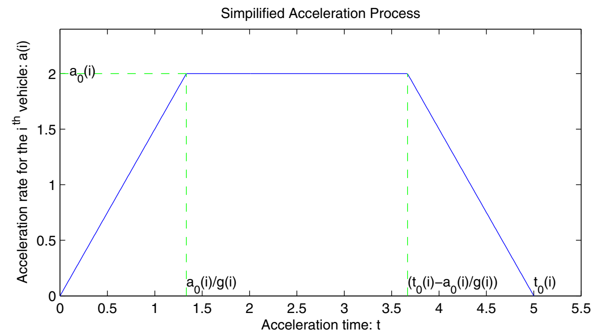

Fig. 6. Simplified Acceleration Process

$T_i < T_j < T_g$, where T_g is the remaining green time. Assume that vehicles move at constant speed after t_0. Then the total travel distance is

$$S_i(T_i) = \Delta S_i + (v_i + \Delta v_i)(T_i - t_0(i)) \qquad (6)$$

where v_i is vehicle α_i's initial speed and Δv_i is the speed increase during acceleration time $t_0(i)$. Denote the distance between vehicle α_i and the intersection as d_i. If α_i pass the intersection successfully, then $S_i(T_i) = d_i$; if not, $S_i(T_i) < d_i$. Additionally, the time headway between every two consecutive arrive time T_i and T_{i+1} should be long enough to guarantee that vehicle α_{i+1} won't collide with vehicle α_i:

$$T_{i+1} - T_i > \frac{l_{i+1}}{v_{i+1} + \Delta v_{i+1}} \qquad (7)$$

where l_{i+1} is the body length of vehicle α_{i+1}. Besides, every vehicle's maximum acceleration rate is capped with $a_{\max}$. Therefore, to guide more vehicles is to find the first vehicle that can't pass through after all front vehicles' acceleration, which is to find the maximum subscript k in the optimization problem below:

$$\max\ k$$
$$s.t.\ \begin{cases} S_i(T_i) = d_i & (i = 1, 2, \cdots, k), \\ S_k(T_k) < d_k & (1 < k \leqslant N), \\ T_i < T_j \leqslant T_g & (1 \leqslant i < j < k), \\ T_{i+1} - T_i > \frac{l_{i+1}}{v_{i+1}+\Delta v_{i+1}} & (i = 1, 2, \cdots, k), \\ a_0(i) < a_{\max} & (i = 1, 2, \cdots, k). \end{cases}$$

All eligible acceleration parameters $a_0(i)$ and $t_0(i)$ can be used as references to help vehicles' acceleration after breaking through abreast blockages.

VI. CONCLUSIONS

In this paper, we proposed an on-road traffic management system dedicated for retardation caused by low-speed vehicles. The proposed system takes three steps to dissolve abreast blockages: detection of suspicious vehicles, appraisal of overtaking condition and guidance notification. The suspicion value R_C is proposed as an index for the operation of detection algorithm. Various environmental factors have been taken into consideration and analysis of overtaking and speed guidance integrate them comprehensively. We select low-speed vehicles as cluster heads and design overtaking strategies and speed guidance recommendation as solutions within clusters. In the future, we are about to build a simulation environment for evaluating the influence of abreast blockages and the performance of our management systems.

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