A Control Strategy of Urban Expressway Under CVIS

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***Abstract* — with the rapid development of cooperate vehicle-infra-structure system technologies, vehicle can communicate with each other and road side facilities to provide safety alerts and improve efficiency. This study aiming at improving road safety, efficiency and meanwhile reduce fuel consumption at urban expressway weaving area by a control algorithm base on CVIS. This control algorithm were based on our previous work on driving behavior and divided into three phases, lane changing at upstream base on destination, main road platoon forming and yield to ramp traffic, weaving lane platoon forming and yield to main road exit traffic. The result of evaluation including three aspects, efficiency, safety and fuel consumption, all three show positive improving. Evaluation was developed base on Vissim and C#.**

Keywords: CVIS, urban expressway, weaving area, control algorithm

I. INTRODUCTION

Vehicle Infrastructure Integration of American, or VII is a special agency consist of Federal Highway Administration, AASHTO, state DOT, the alliance of automobile industry, ITS American and other special agencies. Vehicle and road infrastructure integrate based on information and communication technology, an applicable program started since 2005. Japanese Smartway program is sponsored by Japanese government and other 23 enterprises, aiming at improve road infrastructure, improve transport efficiency, develop advanced safety vehicle, or ASV. The European eSafety program is raised by ERTOCO, got approve of Europe Commission and been included in EU action plan. The main content is accelerate the development and integration of traffic safety support system, provide a comprehensive transportation security solutions based on advanced information and communication technology, or ICT. The 2012-2020 intelligent transportation development strategy of China proposed the strategic objectives of intelligent transport system is to build a system can basically adapt to the modern transportation industry development needs, build key technique system, standard system and industry in a cross regional, large-scale integrated intelligent traffic application, collaborative operation way.

On urban road, entrance ramp and exits are quite close to each other, usually less than 200m, sometimes even less than 50m, statistics show that 9 of top 10 congestion in Beijing are located near weaving area. Weaving area and merging area are also high risk and accidents potential area, more than 30% accidents occurred relative to merging on highway in china.

Traditional pre-warning is apply permanent traffic sign tell drivers where the access is and where is the exit, which is in an isolate and passive way and not able to provide real time information and warning based on actual situation. When the application is inadequate or not legible enough, it will failed lead drivers and give them enough and efficient information in time. For a long time, merging research only focus on acceleration lane optimization design and capacity enhancement.

Through mechanism analysis of urban expressway main driving behavior, destination oriented lane changing is the main cause of traffic jam, so find a solution to appropriate guide lane changing and merging control strategy, improve operation efficiency and reduce the traffic conflict at urban expressway weaving area is the main purpose of this study.

On urban road in china, the layouts of entrance and exit often arranged continuously, and the distance between is very close. The most common scenarios are the following situations: entrance first, exit after with another entrance after entrance as shown in figure 1, or entrance first, exit following, connected to another entrance and exit.

Fig.1 exit ramp after entrance weaving with next 2 entrance weaving

II. BEHAVIOR ANALYSIS AND CONTROL DESIGN

The organization of this study is organized as follows. After a general introduction of the basic layouts and character of urban expressway weaving area in section I. section II analysis driving behavior at weaving area and design the basic algorithm concept. Detailed control strategy and simulation is discussed in section III. Section IV summarized simulation results and conclusions, a further study discussion also included in the last part.

There are many researches on merging area control strategy both in china and in other countries. To better describe them, there are some terminology involved shown in Figure 2. According to control objective, control strategies can be divided into four categories, individual vehicle and platoon control, group of vehicle control and string of vehicles. Consecutive vehicles traveling on the same lane are defined as a string of vehicles. A string of vehicles traveling with constant and small gaps between them are defined as platoon, which can be either naturally formed or induced by the control algorithm. Finally, adjacent vehicles on multiple lanes are defined as a group.

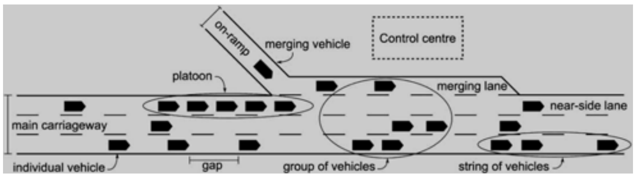

Fig. 2 components of merging control strategy under CVIS

According to the lane where controlled vehicles driving on, control strategies can be divided into main carriageway control and on co ramp control. According to the merging pattern, divided into single vehicle merging and platoon merging.

A. Characteristic of car following behavior in weaving area.

Weaving vehicles must complete lane changing within a limited distance, compared with road section car following distance is not maintain minimum safety distance, car following speed is not likely reach close to desired speed, but in a contrast way, probably longer distance and slow down to wait for an appropriate gap. Weaving vehicles are searching a possibility gap in adjacent lane and adapted to its speed. Sometimes, a full stop waiting for a gap as it cannot find an enough gap in such a short distance. But for non-weaving vehicles, they want to drive in higher speed and narrow gap and eliminate traffic weaving. So, try to eliminate this interference is the first issue to design the control strategy.

B. Behavior characteristics of lane changing in the weaving area.

Weaving vehicles must changing to objective lane, and must complete lane changing within a limited distance. If he did not find appropriate gap, high risk driving behavior like compulsory lane changing, stop and changing, accelerate changing could happen. Therefore, try to solve unsafe behavior problem on main road and on ramp is the other two issues to design control strategies.

C. Design of control strategies

Base on the analysis, weaving area control strategy is divided into three phases. In the first phase, main road vehicles are divided into three categories base on its destination, these vehicles will lead to three dedicated lane under DOLC, destination oriented lane control. In the second phase, the outside lane of main road vehicle form in platoons and yield to ramp vehicle, let ramp vehicle merging in a higher speed and a smooth way under MCPC, main carriageway platoon control. In the third phase, in the weaving lane, the destination is exit vehicle from ramp form in platoons and yield to outside lane of main road whose destination is exit under WLPC, weaving lane platoon control, as shown in figure 3.

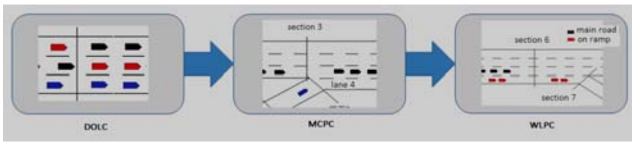

Fig. 3 description of weaving area control strategy

III. CONTROL STRATEGY AND ALGORITM

A. DOLC control

In the first phase, according to the main road vehicle destination, adjust its lane starting from the section 1 as shown in figure 4. If the destination is far away, objective lane is lane 1, if the destination is next exit, objective lane is lane 2, and the destination is this exit objective lane is lane 3. All necessary conflicts between main road vehicles regarding way finding is adjusted before section 1. The area of conflict is reduced, compulsory lane changing, sudden lane changing, continuous lane changing behavior is sharply deduced after section 1. According to previous statistical survey, 65% of the conflict can be reduced at section 3. Vehicle distribution before and after the implementation of DOLC strategy are shown in Figure 4 and 5, the algorithm is shown in figure 6.

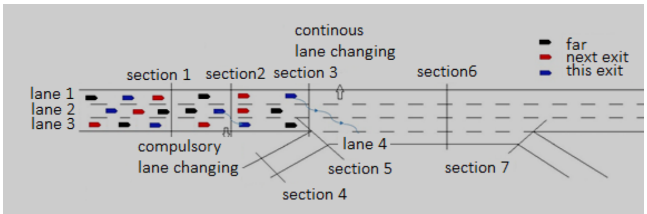

Fig. 4 lane distribution before DOLC control strategy

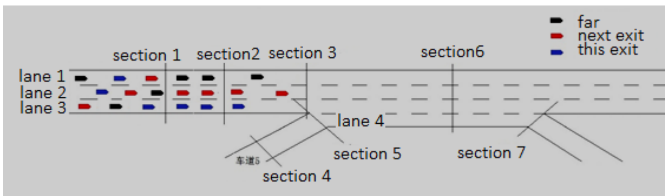

Fig. 5 lane distribution after DOLC control strategy

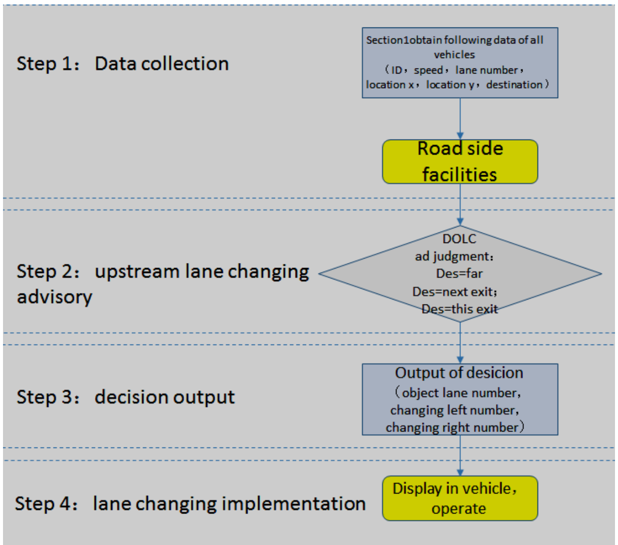

Fig. 5 DOLC control strategy algorithm

B. MCPC control

In the second phase, at Section 3, MCPC control main road vehicles to generate platoon, at the same time platoon yield to vehicles from ramp whose destination is entering main road. At this point of time, vehicles on lane 3 are all going to this exit, they are controlled not allowed to merge to the weaving lane until they travel to section 6.

MCPC consists of 5 steps.

Step 1, data collecting, all vehicles on lane 3 travel across section 2 will collect its status information function , which means ID, speed, accelerate, location x, location y, destination of vehicle respectively. All vehicles on lane 5 travel across section 4 will collect its status function of vehicle.

Step 2, main road platoon forming. Judge if the distance between vehicle and ahead larger than critical value, if yes, then become the leading vehicle, if no, accelerate to chase vehicle ahead until distance between less than critical value. Next vehicle do the same process until all vehicle within backward distance all in platoons. Three key indicators need to be clarified, so an interface is designed to set different values when developing simulation environment. This acceleration other than deceleration in other control will improve efficiency significantly.

Step 3, main road vehicle yield to ramp vehicle. Calculate the time the last rear of platoon passing and the time ramp vehicle rear passing, compare these two. If ramp arrive earlier, then let it pass. If platoon arrive earlier, calculate the speed ramp can pass earlier.

Step 4, decision output. Output of suggestion function to each vehicle on main road and ramp, which means ID, current speed and objective speed.

Step 5, display and implementation.

Vehicle distribution before and after the implementation of MCPC strategy are shown in Figure 7 and 8, the algorithm is shown in figure 9.

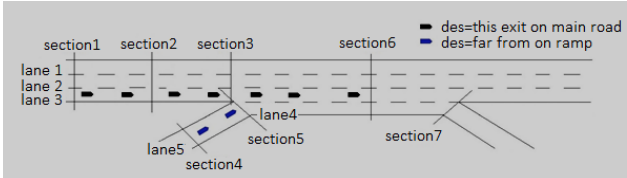

Fig. 7 lane distribution before MCPC control strategy

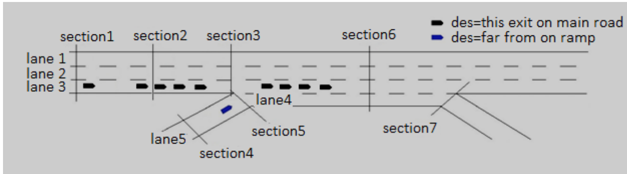

Fig. 8 lane distribution after MCPC control strategy

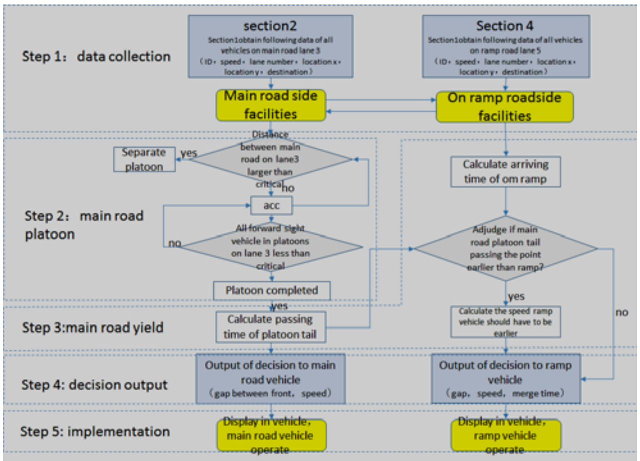

Fig. 9 MCPC control strategy algorithm

C. WLPC control

In the third phase, at Section 6, WLPC control weaving lane vehicles to generate platoon, at the same time weaving lane platoon yield to vehicles from main road lane 3 platoon whose destination is exit. At this point of time, vehicles on lane 3 are all going to this exit, they are controlled prioritized merge to the weaving lane at section 6.

Similarly, WLPC consists of 5 steps. Vehicle distribution before and after the implementation of WLPC strategy are shown in Figure 10 and 11, the algorithm is shown in figure 12.

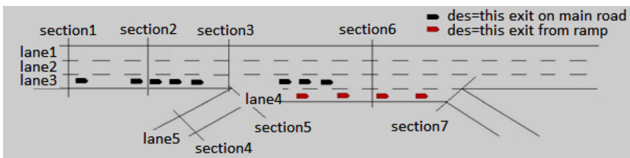

Fig. 10 lane distribution before WLPC control strategy

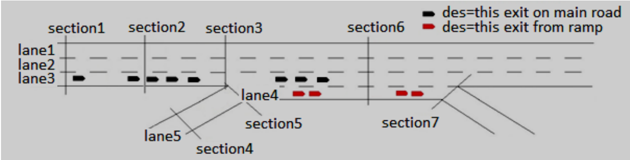

Fig. 11 lane distribution after WLPC control strategy

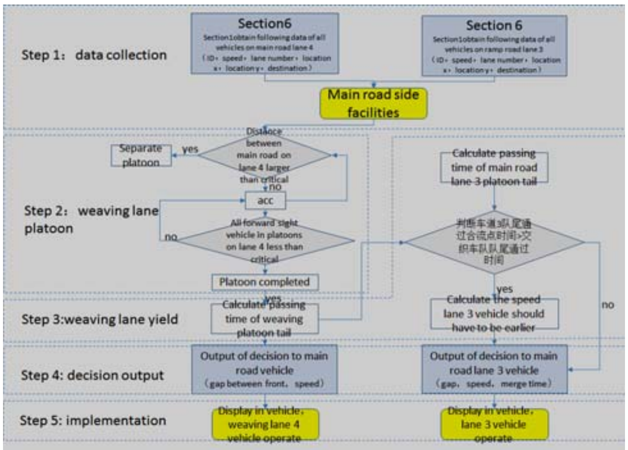

Fig. 12 WLPC control strategy algorithm

IV. Simulation and Conclusion

This study selected the Vissim as fundamental simulation platform, COM as component object model, EDM external driver model, with advanced development, to achieve simulation under the scenario of vehicle networking and automatic driving technology. Specific implementation features including Vehicle platoon forming, automatic driving, and vehicle road communication. Communication module can realize the exchange of information, extraction information of vehicle ID, speed, acceleration, location, time, destination and other information. Can realize control and tracking to upstream vehicle lane change, main road lane change at permission, platoon organization, vehicle longitudinal acceleration. The simulation system is composed of four parts, parameter input, basic Vissim scenario setup, control strategy and advanced driver model development, parameter output, as shown in Figure 13.

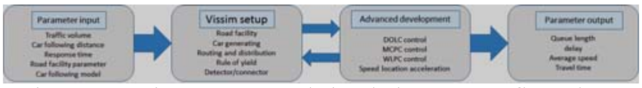

Fig. 13 weaving area control simulation system flow chart

Input main road traffic volume as 3000 veh/h, ramp traffic as 600 veh/h, and run simulation of 3600s. This section analysis the implementation of control strategy, average speed, delay, queue, parking frequency and other indicators were evaluated separately.

A. *Average speed improving*

After the implementation of designed control strategy, average speed of each section were significantly improved. Average speed on main road increased from 16.67km/h to 27.48 km/h, speed increased by 64.8%. For outside lane of main road, whose destination is this exit, average speed increased from 16.9 km/h to19.86 km/h, speed increased by 17.8%. For weaving lane, average speed increased from 17.7 km/h to21.2 km/h, speed increased by 20%. For on ramp vehicle, average speed increased from 29.9 km/h to 48.2 km/h, speed increased by 61%.

B. *Average delay*

After the implementation of the strategy, the delay of each section was significantly reduced. Average delay on main road decreased from 299s to 110s, delay decreased by 63.1%, significantly goes down. For outside lane of main road, whose destination is this exit, average delay decreased from 181s to 155s, delay decreased by 14%. For weaving lane, average delay decreased from 169s to 25s, delay decreased by 85%. For on ramp vehicle, average delay decreased from 3.24s to 0. 25s, delay decreased by 92%.

C. *Average throughput*

After the implementation of the strategy, except weaving lane, the throughput of each section was significantly improved. For main road, average throughput increased from 56.5 veh/100s to 75.4 veh/100s, increased by 33.5%. For outside lane of main road, whose destination is this exit, average throughput increased from 21.2 veh/100s to 26.8 veh/100s, increased by 26.5%. For weaving lane, average throughput decreased from 21.4 veh/100s to 14.4 veh/100s, decreased by 32.8%. For on ramp, average throughput increased from 16 veh/100s to 18.8 veh/100s, increased by 17%.

D. *Average stop*

After the implementation of control strategy, the number of stop vehicle on ramp was significantly reduced. The number of stop vehicles deduced from 7.71 veh/100s to 4.5 veh/100s, reduced by 41%.

E. *Average speed improving*

After the implementation of control strategy, the energy consumption of each section was significantly reduced. The average instantaneous fuel consumption of the main road is changed from 0.47g/s to 0.42g/s, reduced by 9.4%. The average instantaneous fuel consumption of the weaving lane changes from 0.61g/s to 0.49g/s, reduced by 19.89%. On ramp instantaneous fuel consumption is changed from 2.83g/s to 0.71g/s, which is reduced by 75%.

With the popularity of smart car and collaborative environment, more and more control strategy is coming true. Urban road expressway weaving area is a special form of complex merge area, few studies on the related control strategy. The control strategy proposed in this paper can effectively improve the safety, improve efficiency and reduce emissions, but inevitably there are omissions and deficiencies, in many aspects need further study.

This paper assume loading rate and comply rate as 100 percent. When the loading rate and compliance rate for a certain proportion, the implementation of the strategy needs

DOI 10.2013/IJSSST.a.17.06.06 ISSN: 1473-804x online, 1473-8031 print

to be further studied. As driving behavior is not only affected by the upstream traffic organization, downstream traffic organization will influence exit the vehicle operation efficiency as well, the implementation of the strategy needs to be further studied.

In this paper, passenger car is the main traffic, but due to the different dynamic performance of large vehicles, need a larger space and gap, need further study. The applicability of the same strategy under different traffic conditions, different traffic components and different length of weaving section need to be discussed in further research.

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