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Traffic guidance measures based on vehicle-road cooperation under accident conditions

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Abstract: When an accident occurs in a certain section of the expressway network, the traffic demand on the road cannot be met, and the travel efficiency of the expressway is greatly reduced. In this environment, appropriate induction measures can not only alleviate traffic congestion, but also ensure the minimum range of indirect impact of the accident. In the process of developing to the pure autonomous driving stage, the mixed driving of manually driven vehicles and autonomous vehicles is an essential stage, in this stage, when a traffic accident occurs, more efficient guidance measures need to be studied. In this paper, the OMNeT++ simulation framework and SUMO road simulation model are used to simulate how to induce traffic accidents in expressway sections based on vehicle-road cooperation. According to the simulation results, the induction scheme was evaluated and analyzed from the aspects of easing traffic congestion and improving traffic efficiency. The results show that the combined induction measures can effectively alleviate the congestion caused by the accident and improve the traffic efficiency.

1. Introduction

When a traffic accident occurs at a certain section of the road network, the traffic capacity of the accident point suddenly declines, and it cannot meet the upstream traffic demand, resulting in traffic congestion, resulting in increased travel time of the section. If the traffic accident is serious, the traffic congestion will extend to the adjacent highway, and in serious cases, it will lead to traffic paralysis of the regional highway network, greatly increasing people's travel time. The overall efficiency of the road network operation has dropped sharply. In order to reduce the negative impact of traffic accidents, people should not only prevent traffic accidents, but also implement effective traffic guidance quickly after the accident according to the accident situation and road network traffic conditions, so as to reduce the impact of accidents on road network traffic and maintain a high level of road network operation efficiency. Driven by the current computer technology and communication technology, the traditional automobile industry can communicate between vehicles and between vehicles and infrastructure through the installation of sensor equipment and communication equipment on the vehicle, forming an intelligent networked vehicle, which can bring people more comfortable and safe services. It can also alleviate the negative impact of traffic accidents faster and better. With the rapid development of communication technology and transportation technology, vehicle-road collaboration technology in the field of intelligent transportation has become an important research direction for the development of countries around the world, and based on this technology, it is an important means to solve traffic safety and traffic efficiency in various countries [1]. All developed countries have carried out a number of studies in the field of vehicle-road collaboration, including the CVIS and PreVENT projects in Europe and the VVI and CICAS projects in the United States [2,3]. From 2001 to 2010, a lot of research has been carried out in the aspects of vehicle navigation, vehicle operation safety state monitoring and early warning, vehicle safety driving assistance system, driver status recognition, traffic information collection, etc., and various traffic technologies under the environment of vehicle networking have been basically mastered. In the driving assistance system, the research results of vehicle distance warning and lane departure warning are obtained. In terms of traffic information service and management, research achievements such as electronic information plate, intelligent bus system and vehicle navigation system have been achieved [4]. It can be predicted that the vehicle composition of trafic in the future will inevitably be a mixture of human-driven vehicles and autonomous vehicles [5]. Various problems faced by urban trafic in the past, such as trafic safety and road congestion, are expected to be solved with the help of various advantages of autonomous vehicles. Therefore, it is necessary to study accident induction measures in the case of autonomous vehicles mixed in.

There is currently limited research on accident induction measures in the case of autonomous driving vehicles mixed in, many studies have demonstrated the potential of autonomous vehicles (AVs) to enhance road capacity[6-9]. However, it has been suggested that significant improvements in road capacity will only occur when a certain threshold of AV penetration is reached.

Werf et al. utilized the Monte Carlo method, a statistical simulation technique, to examine the impact of AVs on highway traffic capacity using two models, namely ACC(Adaptive Cruise Control) and CACC(Cooperative Adaptive Cruise Control). They conducted sensitivity analyses on various parameters within these models. The findings indicated that with a time headway of 1 second in ACC, road capacity could reach 30%. However, when the time headway increased to 1.4 seconds, the capacity decreased[10]. Similarly, Jones and Philips emphasized in their study that traffic flow improvements would only be noticeable when the penetration rate of ACC or CACC autonomous vehicles on the road reached 40% [11]. Calvert et al. conducted an experiment on a 19 km long, 3-lane highway, and the results demonstrated that traffic flow improvements were only observed when the penetration rate of self-driving vehicles exceeded 70%. However, there was a slight decrease in traffic flow when the penetration rate reached 80% [12]. Tientrakool et al. discovered that road capacity could be enhanced only when the penetration rate of CACC autonomous vehicles exceeded 85% [13].

OMNeT++ supports a variety of wireless communication network modeling, such as wireless sensor network modeling, queuing network modeling, communication protocol modeling, and vehicle networking modeling combined with other software. In this experiment, OMNeT++ simulation framework and SUMO road simulation model are selected for simulation, but the two pieces of software do not connect with each other, so a communication simulator Veins is required to connect the two pieces of software. Veins (Veins: Vehicles in Network Simulation) [14] is a kind of simulation run car networking environment of open source framework. Veins performs its simulation based on two mature simulators, the network simulation simulator OMNeT++ and the road traffic simulator SUMO, and then conducts simulation experiments through the Traci module.

Based on expressway ramp confluence, this experiment discusses how to induce downstream accidents from the perspective of the overall operating efficiency of the road network. Through the research, we hope to reduce the impact of traffic accidents on road network traffic and improve the operation efficiency of highway network.

2. Simulation Description and Available Data

In this study, the Beijing-Harbin expressway section with one on-ramp and one off-ramp in Beijing is selected as the object, as shown in Figure 1, 2. In Figure 1, the arrow direction is the direction of traffic flow. The main road is lane 1, lane 2 and lane 3 from top to bottom, and the detector is arranged at three locations, namely, interweaving zone, before the on-ramp and upstream section of the road, for the purpose of flow statistics. The detectors at the three positions divide the road into three zones from right to left, which are zones one, two, and three. The accident point was set at the downstream of the road, 150m away from the exit. Only cars were considered as vehicle types in this study. The exit ramp was set to be closed before the simulation began, and no vehicles were allowed to exit from the exit ramp.During the simulation run, we obtained detailed traffic-operation parameters, including:

The number of vehicles, average speed, and time occupancy (collected by loop detector);

The individual vehicle speed, space occupancy, and vehicle-lane-change rate (collected by radar detector);

In summary, for the studied road sections, we ensured that sufficient detailed data were obtained for analysis to present a wide range of traffic conditions.

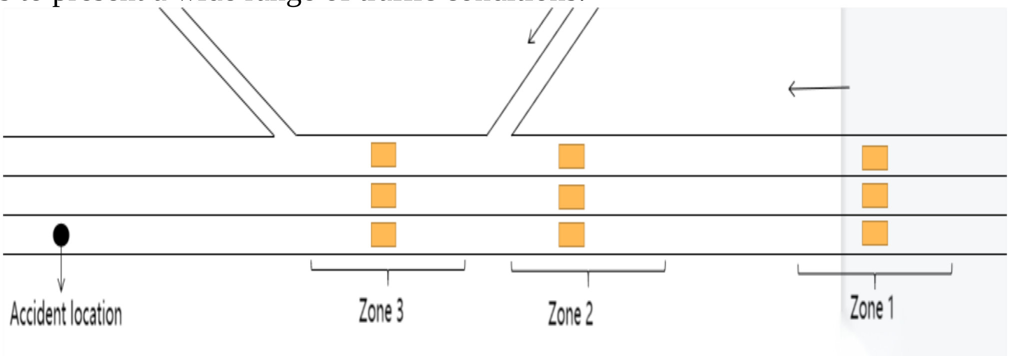

Figure 1: Ramp-convergence scenario.

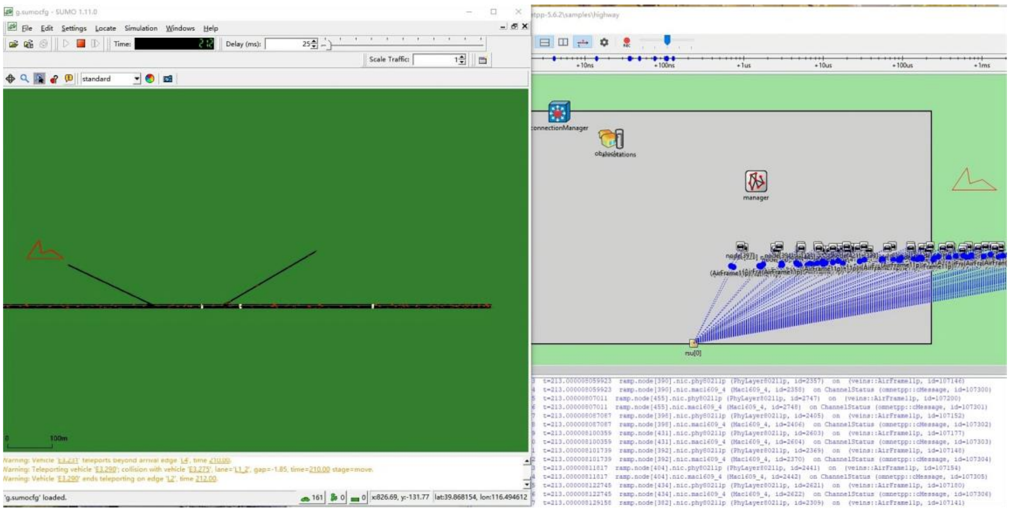

Figure 2: SUMO-- OMNET++ running.

In this study, the Wiedemann 99 and CACC models were used as the car-following models in the freeway-ramp-merging scene, with the driving-behavior parameters adjusted according to the actual driving situation. When the default simulation value is selected, it becomes difficult for the vehicle to change lanes and enter the main line. However, making lane changes too easy often results in smaller time-to-vehicle distances, leading to a higher number of vehicle collisions. Thus, finding an appropriate balance between lane-changing behavior and the car-following model is crucial. The main parameter for adjusting the car-following model during this process was CC1 (desired headway).

3. Comprehensive analysis of Mixed Traffic of dual Vehicles

Chinese law stipulates that the maximum speed limit of freeways should not exceed 120 km/h.Therefore, the maximum speed limit for all vehicles is 120km/h. In the experiment to study the induced measures after an accident, two different induced measures were proposed, namely opening the exit ramp, and the best scheme to alleviate the upstream road congestion was explored by comparing the situation without imposing any measures. To study the road-traffic conditions under different conditions of main-road flow, according to the service level of the basic sections of freeways in our country and the maximum service traffic volume of grades 2 to 4. Considering the actual situation of expressways, this section has increased the types of vehicles on the road, from the original consideration of only cars to the comprehensive analysis of cars and trucks, and trucks account for 10% of all vehicles on the road. In addition, the inducement was changed so that all CACC vehicles on the road were removed from the exit ramp after the accident. The flow rate is set to 1000veh/h on ramp and 6000veh/h on main line. The proportion of CACC vehicles increased from 0% to 100%, each increase of 10%, a total of 11 flow Settings for vehicles on the road are shown in Table 1.

Table 1: Simulation traffic setting (veh/h)

Flow Setting scheme	W99		CACC	
	Ramp	Main road	Ramp	Main road
1	1000	6000	0	0
2	900	5400	100	600
3	800	4800	200	1200
4	700	4200	300	1800
5	600	3600	400	2400
6	500	3000	500	3000
7	400	2400	600	3600
8	300	1800	700	4200
9	200	1200	800	4800
10	100	600	900	5400
11	0	0	1000	6000

(1)Average flow Analysis

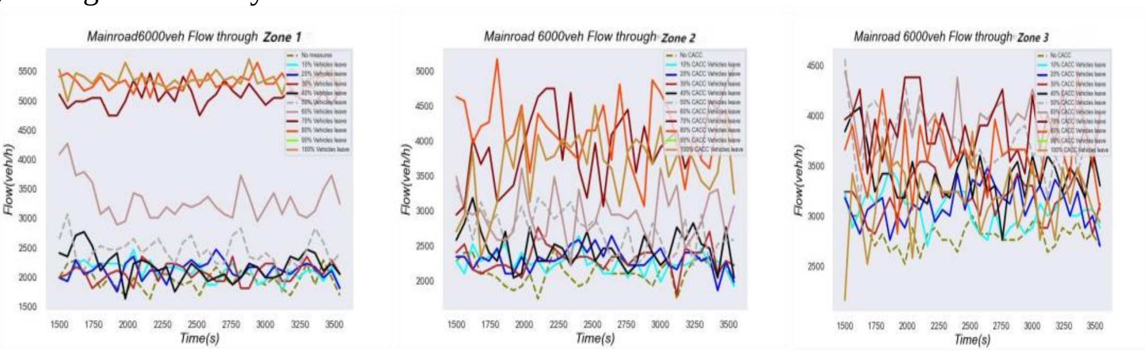

Figure 3: Average flow of Zone 1, 2, 3

Table 2: Average flow of Zone 1, 2, 3(veh/h)

Zone	No measures	10% vehicles departure	20% vehicles departure	30% vehicles departure	40% vehicles departure	50% vehicles departure
1	1942	2081	2103	2064	2175	2438
2	2105	2253	2304	2307	2451	2722
3	2810	3050	3117	3185	3410	3765
Zone	-	60% vehicles departure	70% vehicles departure	80% vehicles departure	90% vehicles departure	100% vehicles departure
1	-	3298	5059	5306	5362	5362
2	-	2930	3945	4113	3639	3639
3	-	3931	3876	3621	3170	3170

The traffic flow of three different zones is shown in Figure 3 and Table 2, zone 1 is at the upstream of the road, where an accident has the greatest impact on the traffic flow. When the proportion of CACC vehicles on the road is small, it can be seen from the chart that the road traffic flow is very low. However, after the proportion of CACC vehicles on the road exceeds 70%, all of them are driven off the exit ramp after the accident. Traffic through region I remains high; zones 2 and 3 are close to the exit ramp, most CACC vehicles leaving the road will cause the queuing phenomenon on the main road, and vehicles are more congested, so the traffic flow through this zone has decreased.

(2)Analysis of average speed

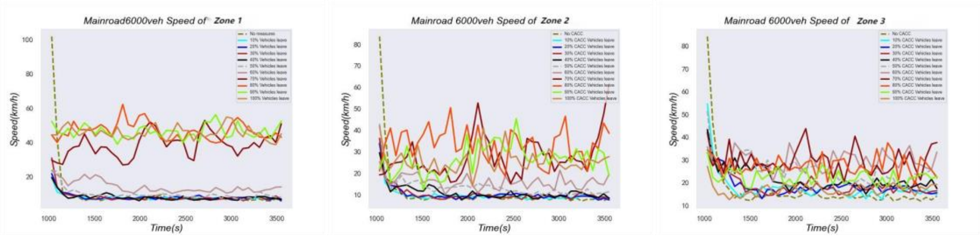

Figure 4: Average speed of Zone 1, 2, 3

Table 3: Average speed of Zone 1, 2, 3(km/h)

Zone	No measures	10% vehicles departure	20% vehicles departure	30% vehicles departure	40% vehicles departure	50% vehicles departure
1	10.20	7.82	8.05	8.14	7.98	9.61
2	11.06	9.78	10.12	10.28	10.91	13.32
3	16.46	17.77	18.59	18.88	21.64	25.30
Zone	-	60% vehicles departure	70% vehicles departure	80% vehicles departure	90% vehicles departure	100% vehicles departure
1	-	13.91	38.45	46.53	46.24	45.62
2	-	15.85	27.43	33.11	26.58	25.69
3	-	29.57	29.58	27.32	22.47	16.87

The average speed of three different zones is shown in Figure 4 and Table 3. After the accident, when the CACC vehicles on the road accounted for a relatively small number, the vehicle speed decreased significantly, and there were serious congestion in the three zones. When the CACC vehicles on the road accounted for a relatively large number and some vehicles pulled off the exit ramp, the average vehicle speed increased greatly, which was consistent with the situation of traffic flow response. In zone 2 and zone 3 near the exit ramp, the driving speed is slow due to the queuing of vehicles; When the proportion of CACC vehicles exceeds 50%, the greater the proportion, the faster the driving speed.

(3) Travel time analysis

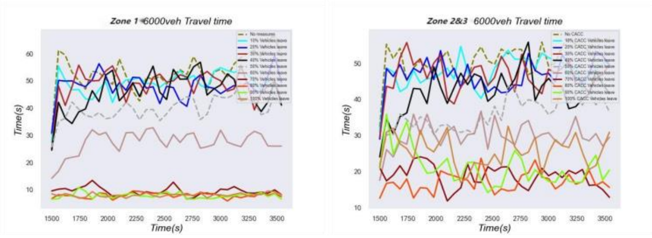

Figure 5: Travel time of Zone 1, 2&3

Table 4: Travel time of Zone 1, 2&3(s)

Zone	No measures	10% vehicles departure	20% vehicles departure	30% vehicles departure	40% vehicles departure	50% vehicles departure
1	53.32	48.83	47.98	48.31	45.53	39.66
2&3	51.15	47.48	46.59	46.27	42.08	35.66
Zone	-	60% vehicles departure	70% vehicles departure	80% vehicles departure	90% vehicles departure	100% vehicles departure
1	-	27.23	9.36	7.86	7.79	8.00
2&3	-	29.75	18.66	17.01	21.10	25.61

The travel time of three different zones is shown in Figure 5 and Table 4, it is consistent with the above, the travel time of zone 2 and zone 3 is calculated together. It can be seen from the chart that in the upstream of the road in zone 1, the travel time through the section is shortened with the increase of the proportion of CACC vehicles, although the departure from the exit ramp has little impact on the driving of the area. For zone 2 and zone 3, the increase in the proportion of CACC vehicles will also shorten the travel time correspondingly, but the queuing phenomenon caused by a large proportion of CACC vehicles leaving the on-ramp will affect the travel time through the section, and the travel time will decrease first and then increase.

4. Discussion and Conclusion

In the case of accidents in the lower reaches of expressways, based on the vehicle-road collaborative environment, this paper analyzes the traffic conditions of vehicles on the road after different induction measures are applied. The research conclusions are as follows: In terms of transportation efficiency, traffic flow, average speed and travel time are selected as indicators to evaluate transportation efficiency. According to the experimental results, after the accident occurred downstream of the main road, when human-driven vehicles and CACC vehicles are mixed, different experiments and different induction measures are adopted to obtain that if only CACC vehicles are allowed to leave after an accident, different results will be obtained in different areas for different mixture ratio of CACC vehicles. The closer the upstream area is and the more CACC vehicles there are, the better the overall road indicators will be if this measure is adopted. However, for areas close to the exit ramp, causing a large proportion of CACC vehicles to leave can actually cause serious congestion.For the implementation of other combined induction measures, repeated experiments are still needed to obtain more practical conclusions. Therefore, the authors of this paper will study the following in the future:

(1) To study on joint guidance measures for heterogeneous traffic flow with ACC and CACC vehicles mixed in.

(2) To study on joint guidance measures for CACC vehicles with a maximum speed limit exceeding 120km/h

(3) Using machine learning methods to refine induction measures.

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