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Evaluations of Driving Safety with Increasing Connected Vehicles on the Expressway: A Simulation-Driven Research

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Abstract. Connected vehicles will gradually become important participants of expressways in the future. However, evaluations for driving safety when there are increasing connected vehicles on expressways are not sufficient. To address the issue, this research makes driving safety evaluations of ramp merging and vehicle following under low-visibility events, two typical V2X scenarios on expressways, through a SUMO simulation approach. The simulation is carried out based on the topology map of the Changtai Expressway, one of the leading V2X demonstration projects in China. Three indicators, namely 'Number of Decelerations', 'Average Speed', and 'Number of Abnormal Acceleration', are continually analyzed to evaluate driving safety on the expressway. The results show that the number of decelerations and abnormal acceleration generally decreases while the average travel speed gradually rises when the market share of connected vehicles grows. Therefore, the safety evaluation indicators perform better under a higher share of connected vehicles, which is encouraging in developing V2X on expressways.

Keywords. Evaluation of driving safety, connected vehicle, SUMO simulation

1. Introduction

Connected vehicles on expressways can receive various information that promote safety, including warnings for approaching vehicles, road conditions, etc. However, evaluations for driving safety when there are increasing connected vehicles on expressways are not sufficient. This is mainly due to the following points. First, the scale of expressways with intelligent roadside facilities is still insufficient and cannot support field tests for a certain amount of connected vehicles. Second, the market share of connected vehicles is relatively low at present, therefore, researchers cannot make real safety test on expressways under an increasing share of connected vehicles. In this context, it is necessary to utilize the V2X simulation to evaluate the driving safety of all the vehicles on expressways while the market share of connected vehicles continually increases.

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The basis of traffic simulation is its built-in simulation models and the corresponding parameters. Under the V2X context, it is vital to consider real-time information exchange and processing among vehicles and infrastructures when designing simulation models and parameters [1,2]. In this research, we manage to make the V2X simulation based on SUMO, the simulation tool which supports sensor suite and V2X models [3-6].

The remainder of this paper is structured as follows: In section 2 we make a brief description of the research context and the dataset. In section 3, we describe the procedures for making driving safety evaluations using SUMO simulation. In section 4, we discuss the evaluation results. We make conclusions for this study in the last section.

2. Research Context and Dataset

Jiangsu Province, located in the east of China, is one of the most developed regions in the country. The expressway density and V2X development of Jiangsu are the top among all the provinces in China. In this context, we choose Changtai Expressway, a major V2X demonstration construction project crossing the Yangtze River in Jiangsu Province, as the research site. Particularly, the section with a mileage of 37km is selected, including the river-spanning bridge and the link road.

Since the construction of the Changtai Expressway has not been completed, we collect the equipment layout plan of the Changtai Expressway as the base map of the simulation. In addition, the input data of the simulation are referred as the traffic flow data from the surrounding expressway. Elements of data collection are listed in table 1:

Table 1. Elements of data collection.

Elements	Unit
Distance between RSU	m
RSU information transmission frequency	s
Traffic volume (2 directions)	Veh/h
Ratio of cars to freights	/

3. Methodologies

In this research, we make the driving safety evaluation framework of connected vehicles on the Changtai expressway in Jiangsu Province based on SUMO. Detailed procedures are as follows:

Procedure 1: Import the existing road network topology of Changtai Expressway through the open-source map database OpenStreetMap, as is shown in figure 1.

Figure 1. Road topology of Changtai Expressway in OpenStreetMap.

Procedure 2: Build the V2X vehicle simulation environment by importing data to SUMO as in table 1.

Procedure 3: Specify the driving mechanism of the connected vehicles in the V2X simulation. Basically, connected vehicles drive according to the predetermined route and strictly comply with the driving regulations on the expressway. It should be noted that connected vehicles always keep a certain safe following distance from the previous vehicle. In each simulation step, connected vehicles receive various traffic information within a sensing and communication range. Based on the received information, connected vehicles make three types of decisions, namely driving control, driving assistance, and navigation.

To be precise, driving control occurs only when there is an emergency and the connected vehicle has to take action immediately to avoid an accident. In the V2X simulation, connected vehicles receive the driving condition of the vehicle in front (left front, front, right front) through the Traci interface. When the front vehicle abruptly stops or changes lanes, the driving system will directly decelerate based on the driving control algorithm, regardless of the driver's operation.

Driving assistance serves the whole driving process to improve driving safety and efficiency. For this function, we set a parameter, drivers' compliance rate with assistance, to represent the proportion of drivers complying with different kinds of driving assistance. In the V2X simulation, connected vehicles receive information from other connected vehicles and RSU through the Traci interface. Some basic driving assistance is provided according to the received information, including suggestions for acceleration, deceleration, lane changes as well as warnings for low visibility and slippery roads.

Navigation mainly generates driving routes in advance according to the received traffic condition information and the current traffic control strategies. For this function, we set a parameter, drivers' compliance rate with navigation, to represent the proportion of drivers complying with the recommended navigation routes. In the V2X simulation, connected vehicles receive information and provide navigation service through the Traci interface, which is the same as the driving assistance function.

Parameters related to the driving mechanism of the connected vehicles in the V2X simulation are shown in table 2:

Table 2. V2X simulation parameters.

Parameter	Unit
Simulation Time	s
V2V sensing and communication range	m
Lane change durations	s
Drivers' compliance rate with driving assistance	%
Drivers' compliance rate with navigation	%

Procedure 4: Build typical scenarios associated with driving safety by SUMO, and further select indicators to evaluate driving safety of the connected vehicles with an increasing market share. In this research, we choose *'Number of Decelerations'*, *'Average Speed'*, and *'Number of Abnormal Acceleration'* as the safety evaluation indicators.

4. Results and Discussion

We make the V2X simulation based on SUMO using traffic data from surrounding expressways in Jiangsu and map data of the Changtai Expressway from OpenStreetMap. We choose warnings of ramp merging, as well as vehicle following when low-visibility events occur, as the studied typical scenarios. The simulation parameters are set as in table 3.

Table 3. Value of the simulation parameters.

Parameter	Value
Simulation Time	4800s
V2V sensing and communication range	300m
Lane change durations	3s
Drivers' compliance rate with driving assistance	80%
Drivers' compliance rate with navigation	50%

(1) Ramp merging.

For the scenario of ramp merging, we make the following simulation settings: All the common vehicles are expected to decelerate 200 meters ahead of the ramp in response to an unpredictable ramp status. However, connected vehicles can receive a warning if the vehicle next lane will reach the ramp earlier or at the same time, as shown in figure 2.

Figure 2. Rendering of ramp merging warnings.

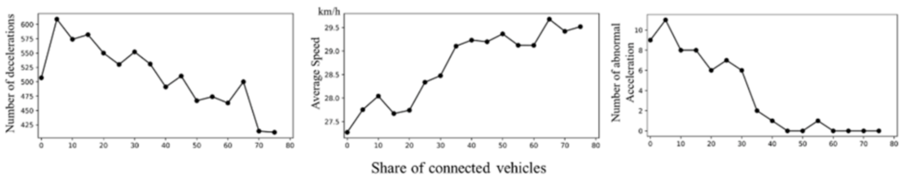

Figure 3. Simulation results of the ramp merging scenario.

The simulation results of the three safety evaluation indicators for ramp merging are shown in figure 3. It can be concluded that as the share of connected vehicles rises from 0% to 80%, there is an obvious decrease in the number of decelerations and abnormal acceleration. In addition, the average speed of the vehicles in the ramp gradually increases. In general, the three indicators perform better with a higher share of connected vehicles for this scenario.

(2) Vehicle following under low-visibility events

For the scenario of vehicle following under low-visibility events, the environment visibilities in the simulation are set below 50 meters. In this context, connected vehicles receive warnings of the surrounding vehicles using V2V and V2X communications to compensate for visibility, as shown in figure 4.

Figure 4. Rendering of vehicle following under low-visibility events.

The simulation results of the three safety evaluation indicators for vehicle following under low-visibility events are shown in figure 5. It is clear that when the occupation of connected vehicles increases from 0% to 80%, there is a significant decrease in the number of decelerations and abnormal acceleration of all the vehicles under low-visibility events. The downward trend becomes steeper when the share reaches 30%. In addition, there is a steady rise in average speed. As a whole, the three indicators perform better with a higher share of connected vehicles for this scenario.

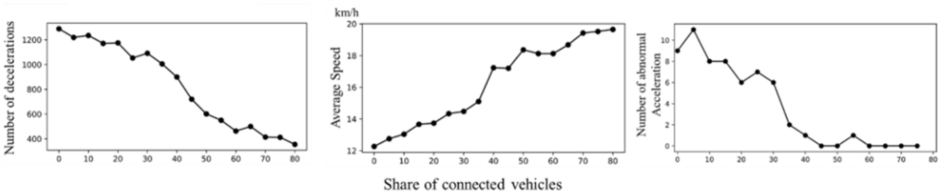

Figure 5. Simulation results of the vehicle following under low-visibility events scenario.

5. Conclusion

This research innovatively evaluates driving safety on expressways with increasing connected vehicles through a SUMO simulation approach. We select the Changtai Expressway, one of the leading V2X demonstration projects in China, as the research site. Ramp merging and vehicle following under low-visibility events, two typical application scenarios of connected vehicles, are built by the Traci interface of SUMO to make the evaluation.

We analyze three typical indicators, *'Number of Decelerations'*, *'Average Speed'*, and *'Number of Abnormal Acceleration'*, to evaluate driving safety on the expressway when there is an increasing share of connected vehicles. It turns out that the indicators perform better under both scenarios when there is a higher share of connected vehicles. This is encouraging in the development of V2X on expressways.

There are also some limitations of this research. In future studies, more V2X scenarios are supposed to be included in the simulation research to verify the study results. Furthermore, we should carry out quantitative comparisons between different simulation tools to choose the one with the best performance.

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