Research on optimization and evaluation method of the car following model based on SUMO application test scenario

Qianjing Sun[1] and Yong Wang[2] and Lingqiu Zeng[2] and Qingwen Han[3,4] and Qinglong Xie[5] and Lei Ye[3] and Fukun Xie[2]

***Abstract*— In terms of V2X (Vehicle to Everything) testing and evaluation, HIL (Hardware-in-the-loop) simulation has become an indispensable technology. In the research of HIL testing, it is necessary to use micro-traffic simulation software to build scenarios and simulate traffic objects to meet the testing requirements of complex traffic scenarios for the IOV (Internet of Vehicles). However, the performance of the micro-simulation model deadly influences simulation accuracy. Hence, in this paper, an improved micro-simulation model is constructed on basis of the Krauss model, and an application test scheme is designed. Simulation results show that the improved model solves the problem of acceleration changing abruptly, and improves the effectiveness and practicability of the V2X in-loop test.**

I. INTRODUCTION

With the development of the connected and automated vehicle (CAV) technology, both academics and industries agree that a validity testing and verification procedure is needed to support CAV industrialization progress.

In the past few years, a number of field test schemes have been proposed to evaluate the application performance of CAVs. Although field test is useful and necessary, it is frequently criticized for its high expense and time consuming[1]. On the other hand, virtual simulation test means test in a virtual environment, from simulated sensors, vehicle dynamic model and controller, virtual driver, to simulated comprehensive traffic environment[2]. The function modules are tested by software in the loop (SIL), hardware in the loop (HIL), vehicles in the loop (VEHIL), or mixed simulation methods[3]. It is fast and able to simulate any scene, but it can't verify the real effect.

The Digital Twin (DT) consists of a digital representation of physical systems, knowns as Physical Twin (PT), able to run simulations of the system lifecycle and actuate reflecting synchronously with PT [4], and is considered as a new test approach for CAV. In [5], the authors use real-world driving data to construct DT test scenarios. In our previous work[6], a DT based autonomous driving test approach is proposed. Moreover, in [7], we design an in-chamber CAV test scheme to implement V2X related tests, which include both the communication test and application test. In 2020, we design a DT based in-chamber test system, which uses SUMO to realize dynamic scenario generation, and is planned to be deployed at CAERI (China Automotive Engineering Research Institute). Obviously, the effectiveness of DT based in-chamber test largely depends on the rationality of DT scenarios, which should meet the requirement of continuity in space and time[8]. Hence, the realistic vehicle mobility model [9] should be considered.

In general, the vehicle mobility model could be divided into three catalogs: macroscopic mobility model [10], mesoscopic model, and microscopic mobility model [11]. Here we focus on the microscopic mobility model, which is more suitable for CAV applications test. As a sort of typical microscopic mobility model, the car-following model could denote the behavior relationship between the vehicle and the preceding vehicle and becomes an interesting point in the SUMO simulation process.

In the study of the car-following model, the German scholar, Krauss S, proposes the original Krauss following model based on the safe velocity model [12], but the accelerations of the front and rear cars in the model are equal. Tobias Mayer et al. improve the original Krauss model on the basis of SUMO's original Krauss model, taking into account the different accelerations of the front and rear cars [13], but the model believes that the acceleration reached the maximum instantaneously, which is inconsistent with the actual driving behavior. Cui et al. compare various car-following models on the SUMO platform and find that the Krauss model has better control performance for a single vehicle than other models [14]. Han et al. propose a new model of the gradual process of vehicle deceleration on the basis of the original Krauss model [15]. But the new model does not consider the different accelerations of the front and rear vehicles and the calculation of the gradual process is not accurate enough. On the basis of the safe distance between vehicles, Parker [16] first proposes a model based on the expected safe distance between vehicles, which can well reflect the changes of leading and following vehicle's velocity. In this paper, based on the Krauss model, the influence of the velocity of the following car on the following state and the problem of acceleration changing abruptly in the following model are considered. Moreover, we analyze the braking process of the vehicle and consider the dynamic time headway, and optimize the Krauss model to make the simulation scenario

[1] State Key Laboratory of Vehicle NVH and Safety Technology, Chongqing, 401122 China sunqianjing@caeri.com.cn
[2] College of Computer Science, Chongqing University, Chongqing, 400044 China. wangyong202133@126.com, zenglq@cqu.edu.cn, 20174317@cqu.edu.cn
[3] School of Microelectronics and Communication Engineering, Chongqing University, Chongqing, 400044 China. hqw@cqu.edu.cn, Yelei@cqu.edu.cn
[4] Chongqing Key Laboratory of Space Information Network and Intelligent Information Fusion, Chongqing, 400044 China hqw@cqu.edu.cn
[5] College of Mechanical and Vehicle Engineering, Chongqing University, Chongqing, 400044 China xql@cqu.edu.cn

Manuscript 500 submitted to 2021 32nd IEEE Intelligent Vehicles Symposium (IV). Received April 13, 2021.

more reasonable.

The rest of this paper is structured as follows. Section II introduces the HIL testbed and the construction of test scenarios in SUMO. The improved model based on the Krauss model is provided in Section III. Then experimental simulation and result analysis are presented in Section IV. Finally, the conclusion is given in Section V.

II. PRELMINARIES

A. DT based in-chamber test system

The architecture of the proposed DT based in-chamber test system is shown in Fig.1.

The proposed system includes three key components, which are scenario generator, communication node matrix, and EMC tester.

- Traffic Scenario generator

All test cases should follow corresponding specifications, such as SAE 2945, and are generated by a scenario generator. Obviously, key factors, such as road network, traffic feature, and inter-vehicle relationships, should be considered in the traffic scenarios generating process, which is implemented by SUMO.

- Communication node matrix

The communication node matrix, which includes forty OBUs (on-board unit) and three RSUs (Road Side Unit), generates a corresponding message according to the output of the Scenario generator. DUTs (device under test), such as V2X component and vehicle, collect messages and trigger a specific response.

- EMC tester

EMC tester is used to evaluate the operating performance of the vehicle equipped with the DUT under a circumstance of high power radio radiation [17].

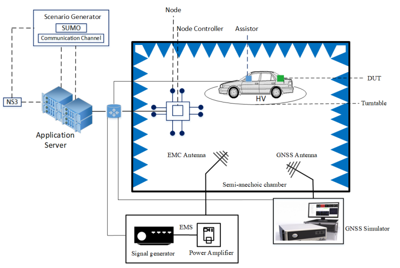


Fig. 1: The architecture of DT based in-chamber test system

The corresponding test procedure is set as follows;

Step 1: Test Case selection

Here, two processes should be considered, the one is EMC scenario selection, while the other is traffic scenario selection.

According to the EMC scenario definition, the EMC signal generator generates a predefined frequency sweeping signal and radiates it from the radiating antenna.

Traffic scenario is selected according to application definition.

Step 2: Traffic scenario injection

Traffic scenario generator output simulation RVs' data, such as vehicle type, GPS information, cruising velocity, lane information, etc., and inject it to GNSS simulator and communication node matrix. The communication node matrix generates corresponding data packets, which will be sent via the DSRC/PC5 interface.

Step3: Data collect and analyze

DUTs receive the packet and trigger specific warning progress. Both communication performance parameters and application response information of DUTs are sent to the application server via CAN BUS. Moreover, communication performance parameters of the communication node matrix are sent to the application server via ethernet. The data analysis process is done by the application server.

B. Traffic scenario generation

As mentioned earlier, in the proposed system, all traffic scenarios are generated by SUMO. The generation progress includes three key points, as described as follows.

- Road network generation

Here the OpenStreetMap map tool is employed to collect real traffic road information, including road topology, traffic light, lanes, intersections, and generate a road network information map, which could be compiled and used by SUMO simulator.

- Vehicle information generation

Vehicle driving information, such as vehicle type, GPS information, cruising velocity, lane information, cruising velocity, acceleration, etc., is employed to generate routing files.

- Scenarios control progress

To fulfill scenario control, we design a TraCI background block, which is developed by python.

The collaborative interaction between SUMO and TraCI, which includes four steps, is shown in Fig.3 and described as follows;

Step 1: The initial scenario, which is generated by SUMO, is injected into TraCI backend to construct the target test case.

Step 2: Traci backend feeds back the operation detail of node matrix, such as simulated vehicle trajectory, cruising velocity, etc. to SUMO.

Step 3: According to the feedback information, SUMO executes the scenario adjusting process, and updates the scenario parameters.

Step 4: Updated scenario is injected to TraCI backend to update test case.

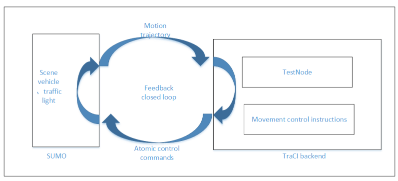


Fig. 2: Scenario control in simulation

Manuscript 500 submitted to 2021 32nd IEEE Intelligent Vehicles Symposium (IV). Received April 13, 2021.

III. IMPROVEMENT OF KRAUSS MODEL

A. Krauss model

The Krauss model, proposed by German scholar Krauss S, is a microscopic, space-continuous, collision-free car-following model. According to the theory of relative motion, the constrained condition of collision avoidance of two vehicles is denoted by a parameter, safe velocity, which is defined as follows,

$$v_{safe} = v_l(t) + \frac{g(t) - v_l(t) * \Gamma}{\frac{v_l(t)+v_f(t)}{2b} + \Gamma} \tag{1}$$

where $v_l(t)$ is the velocity of the leading vehicle on time moment t, $g(t)$ is headway distance, b is the maximum deceleration of the vehicle, while Γ is the driver response time (about 1s).

To ensure the usability of the car-following model, vehicle desired velocity is defined as follows,

$$v_{des} = min[v_{max}, v + a * t, v_{safe}] \tag{2}$$

where t is time-stepping of simulation, v_{max} is the velocity limit of the corresponding road section.

It is true that the Krauss model could express vehicle driving status, however, there are still some problems in the simulation process. Firstly, although the Krauss model employs headway distance and leading vehicle velocity of the current moment to calculate v_{safe}, the influence of current following vehicle velocity is not considered. Then, the following vehicle may hardly catch up v_{des} value smoothly and presents a velocity steeping change phenomime, which is not allowed in the simulation process. Secondly, the Krauss model is designed to avoid the collision. It only considers the deceleration scene, and is hard to express actual traffic characteristics.

Hence, in this paper, we improve the Krauss model in three aspects. Firstly, we modify the definition of v_{safe}. Secondly, according to the modified definition of v_{safe}, a deceleration model is constructed. Thirdly, the acceleration model and acceleration/deceleration conversion model are proposed.

B. Improved Krauss model

In Krauss model, safety following distance is defined as,

$$D_f + 0.5 \leqslant D_l + g(t) \tag{3}$$

where D_l is the position of the leading vehicle, while D_f is the position of the following vehicle, $g(t)$ is the headway distance between the leading vehicle and the following vehicle. 0.5 is the threshold value of safety distance.

Considering the influence of following vehicle's velocity, we define safety following distance as,

$$D_f + 0.5 \leqslant D_l + T * v_f \tag{4}$$

where T is dynamic time headway and v_f is following the car's velocity.

Based on Equ. (4), we construct the deceleration model, acceleration model, and acceleration/deceleration conversion model as follows.

- Deceleration model

Obviously, deceleration progress is related to braking progress, which is denoted in Fig.3.

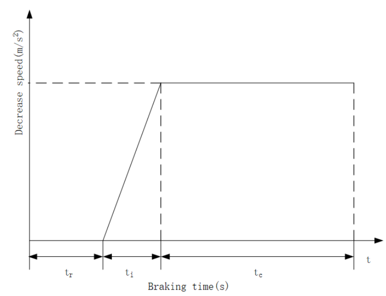


Fig. 3: The variation of deceleration

As shown in Fig.3, the braking progress of the following vehicle includes three phases, which are the driver's reaction phase, brake down phase, and braking phase. On the other hand, the braking progress of the leading vehicle includes only two phases, the brake down phase, and the braking phase. All three phases are explained as follows.

Phase 1: Driver's reaction phase

There is no deceleration occurring in this phase. Then the real-time position of the following vehicle is,

$$D_r = v_0 t_r \tag{5}$$

where t_r is the driver's reaction time, v_0 is the following vehicle's velocity. Here we assume that the following vehicle in motion is with constant velocity.

Phase 2: Brake down phase

In this phase, deceleration increase almost linearly over time. Then, the real-time position of the following vehicle is

$$D_i = \int_0^{t_i} (v_0 - \frac{b_{max}}{2t_i} t^2) d_t = v_0 t_i - \frac{b_{max} {t_i}^2}{6} \tag{6}$$

where b_{max} is the maximum deceleration of the following vehicle.

Phase 3: Braking phase

In this phase, deceleration is a constant value. The real-time position of the following vehicle is

$$D_c = \frac{(v_0 - \frac{b_{max}}{2} t_i)^2 - 0^2}{2b_{max}} = \frac{v_0^2}{2b_{max}} - \frac{v_0 t_i}{2} + \frac{b_{max} {t_i}^2}{8} \tag{7}$$

Then for the whole braking progress, the real-time position of the following vehicle is

$$\begin{aligned} D_f =& D_r + D_i + D_c = v_{safe} t_r + \frac{1}{2} v_{safe} t_{fi} + \frac{{v_{safe}}^2}{2b_{max}} \\ & - \frac{b_{max} {t_{fi}}^2}{24} \approx v_{safe}(t_r + \frac{1}{2} t_{fi}) + \frac{{v_{safe}}^2}{2b_{max}} \end{aligned} \tag{8}$$

where t_{fi} is the duration time of following vehicles brake down phase.

On the other hand, for the whole braking progress, the real-time position of the leading vehicle is

$$\begin{aligned} D_l = D_i + D_c = & \frac{1}{2} v_l t_{li} + \frac{{v_l}^2}{2a_{max}} - \frac{a_{max} {t_{li}}^2}{24} \\ \approx & \frac{1}{2} v_l t_{li} + \frac{{v_l}^2}{2a_{max}} \end{aligned} \tag{9}$$

Manuscript 500 submitted to 2021 32nd IEEE Intelligent Vehicles Symposium (IV).
Received April 13, 2021.

where a_{max} is the maximum deceleration of leading vehicle and t_{li} is the duration time of leading vehicle's brake down phase.

Here we assume that the duration time of both the leading vehicle and following vehicle's brake down phase are the same, then,

$$t_i = t_{li} = t_{fi} \tag{10}$$

Safe velocity is calculated as,

$$v_{safe} = \sqrt{b^2(t_r + \frac{1}{2}t_i)^2 - b(1 - v_l t_i - \frac{{v_l}^2}{a} - 2T * v_f)} - b(t_r + \frac{t_i}{2}) \tag{11}$$

Then using Equ. (2), we can calculate the desired velocity.

- Acceleration model

Here we employ integral theory to calculate acceleration distance to get a smooth acceleration process.

Acceleration distance is calculated by

$$D(v) = \int_{v_0}^{v_m} \frac{v_m - v}{a} d_v \tag{12}$$

where v_0 is current velocity, v_m is the target velocity, a is acceleration.

With the derivation of acceleration distance, the acceleration time is obtained,

$$T = \frac{d_{D(v)}}{d_v} = \frac{d}{d_v}\int_{v_0}^{v_m} \frac{v_m - v}{a} d_v = \frac{(v_m - v_0)^2}{2a} \tag{13}$$

In acceleration progress, a restricted condition of the safety car-following model is that the velocity difference between the leading and following vehicles must greater than or equal to the speed calculated based on safety distance, then

$$v_l - v_f \geqslant \frac{v_l t_r - T * v_f}{\frac{v_{safe}}{a} + t_r} \tag{14}$$

According to Equ. (12) and Equ. (13), we can get the maximum safe velocity of acceleration car-following model,

$$v_{safe} = v_l + \frac{\frac{(v_m - v_0)^2}{2a} * v_f - v_l * t_r}{\frac{v_l + v_f}{2a} + t_r} \tag{15}$$

Then using Equ. (2), we can calculate the desired velocity.

- Acceleration/deceleration conversion model

Acceleration/deceleration progress is shown in Fig.4.

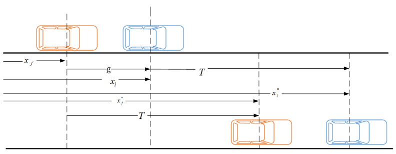


Fig. 4: Schematic diagram of car following

As shown in Fig.4, the initial position of the following car is x_f , x_l is the initial position of the leading vehicle, and g is the distance between the two vehicles.

From time t to time $t+T$, the position of the following vehicle could be denoted as

$$v_l^* = x_l + v_l * T \tag{16}$$

The position of leading vehicle is

$$v_f^* = x_f + v_f * T \tag{17}$$

Then the distance between the two vehicles is calculated as

$$D^* = v_l^* - v_f^* = x_l - x_f + (v_l - v_f) * T \tag{18}$$

The initial distance between two vehicles is

$$D = x_l - x_f \tag{19}$$

Note here, if v_f is greater than v_l, an acceleration status should be changed to deceleration, and the converse is also true.

IV. SIMULATION AND RESULT ANALYSIS

A. *Microscopic traffic simulation*

1) Simulation setup: Here we take a vehicle following scene as an example to construct the SUMO simulation scenario, as shown in Fig. 5.

Fig. 5: vehicle following scene

Corresponding road and vehicle parameters are set in TABLE I.

TABLE I: Microscopic simulation parameters

Parameter	Value
Road length	$1000m$
Number of lanes	4
Vehicle's number	2
Vehicle's length	$5m$
Vehicle's width	$1.8m$
Vehicle's maximum velocity	$22.22m/s$
Vehicle's maximum acceleration	$3m/s^2$
Vehicle's maximum deceleration	$4.5m/s^2$
Driver proficiency	1
Driver reaction time	$1s$

Simulation progress includes three steps,

Step 1: Set leading vehicle's initial position as the center point of the road section, and its cruising trajectory parallels to the centerline of the road. Leading vehicles cruising direction is as same as the following vehicle.

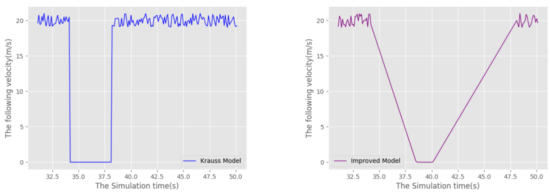
Step 2: Both leading vehicle and following vehicle accelerate slowly. If the following vehicle's velocity reaches about $20m/s$, the experiment should start. Here the acceleration value is a random number between 0 and 1.

Step 3: Leading vehicle decelerates by its maximum deceleration. Then the following vehicle decelerates. When the velocity of both vehicles decreases as low as 0, the leading vehicle accelerates slowly. Then the following vehicle accelerates either. When the velocity of both vehicles increases as high as $20m/s$, the experiment ends.

Manuscript 500 submitted to 2021 32nd IEEE Intelligent Vehicles Symposium (IV).
Received April 13, 2021.

2) Simulation Design and Result Analysis: The microscopic scene selects the velocity of the following vehicle and the probability of velocity steep change as the evaluation index. Here the original Krauss model and the improved model are used as a contrast to verify the effectiveness of the proposed model.

The velocity change of the following vehicle is shown in Fig. 6.



(a) Krauss model (b) improved model

Fig. 6: Velocity curves

As shown in Fig. 6, the velocity curve of the proposed model is relatively smoother than that of the original Krauss model, which solves the problem of velocity steep change.

Here we define the probability of velocity steep change as

$$p = (m+1)/(n+2) \tag{20}$$

where m is steep change event frequency, while n is the simulation times. Corresponding calculation results are listed in TABLE II.

TABLE II: Calculation results

Model	Simulation times	Steep change event frequency	Steep probability
Krauss	100	85	0.843
Improved Krauss model	100	11	0.117

As shown in Table II, comparing with the original Krauss model, the proposed model presents a low steep probability; then solves the velocity steep change problem.

B. Macroscopic traffic simulation

To display the performance of SUMO based simulation, here we select a crossroad scenario, Three Gorges Branch Road and Shapingba Station North Road, Chongqing, China, as an example.

1) Simulation setup: The simulation scenario is shown in Fig.7. As shown in Fig.7, each entrance of the intersection has 3 lanes, which are left turn lane, go straight lane, and right turn lane. 24-hour traffic data of October 21, 2020 are used to calculate traffic flow per hour, which is shown in Table III.

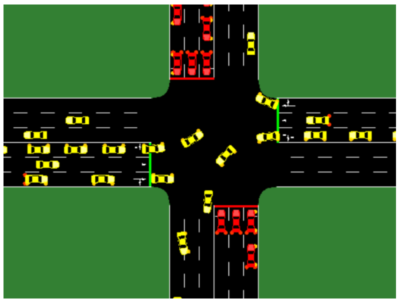


Fig. 7: Crossroads scenario

TABLE III: Summary of traffic data (unit: vehicles/h)

Entrance	Turn left	Go straight	Turn right	Total
Northern entrance	313	449	236	998
Southern entrance	227	1104	159	1540
Western entrance	117	511	46	674
Eastern entrance	135	509	251	895

Corresponding simulation parameters are listed in Table IV.

TABLE IV: Macroscopic simulation parameters

Parameter	Value
Simulation scenario's area(m^2)	$2700 * 1700$
Car-following model	improved model/Krauss
Vehicle's number	895
Simulation time	24h

2) Simulation Design and Result Analysis: Here travel time, average vehicle density, road occupancy rate, average waiting time, and average velocity are selected as the evaluation index. Simulation results for the Krauss model and proposed model are shown in Table V and Table VI.

TABLE V: Simulation results of Krauss model

Entrance	travel time (s)	Average vehicle density	Road occupancy rate	Average waiting time (s)	Average velocity (m/s)
Northern entrance	46.36	40.59	6.09	25.355	4.97
Southern entrance	41.79	37.10	5.57	25.225	4.45
Western entrance	46.15	33.07	4.96	20.956	5.00
Eastern entrance	47.89	39.43	5.91	25.267	4.81

TABLE VI: Simulation results of improved Krauss model

Entrance	travel time (s)	Average vehicle density	Road occupancy rate	Average waiting time (s)	Average velocity (m/s)
Northern entrance	43.01	37.73	5.66	18.493	5.36
Southern entrance	44.64	32.02	4.80	16.342	5.16
Western entrance	41.68	29.94	4.49	14.346	5.53
Eastern entrance	42.96	35.44	5.32	16.986	5.37

Manuscript 500 submitted to 2021 32nd IEEE Intelligent Vehicles Symposium (IV).
Received April 13, 2021.

As shown in Table 5 and Table 6, compared with the original model, the travel time, average vehicle density, road occupancy rate, average waiting time of the improved model have been significantly reduced, and the vehicle velocity has been significantly increased.

3) Example of test: Based on the proposed method, a DT based in-chamber test system is designed according to the demand of CAERI. The real-time results in the test system are shown in Fig.8.

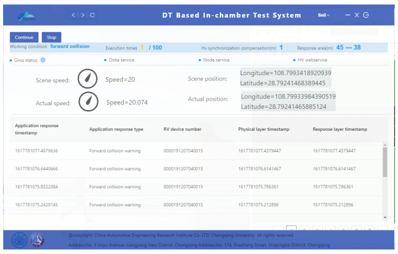


Fig. 8: Real-time results in the test system

As shown in Fig. 8, the figure on the right side shows the forward collision scene simulated by SUMO. The figure on the left side shows the application response in the test task.

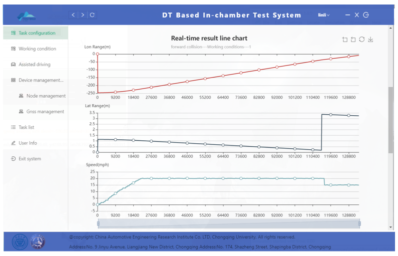


Fig. 9: The test results of a test task

In addition, a test report is generated for each test procedure, as shown in Fig. 9. The test report includes corresponding information, such as relative longitude, the relative latitude of the front and rear cars, and the speed of the following car.

V. CONCLUSION

To match the requirement of V2X oriented test, in this paper, we design test procedures and explain the corresponding scenario control process. Moreover, to improve the reliability of simulation, we define safety following distance, which considers not only the distance between the leading and following vehicle but also following vehicle's velocity. Then an improved Krauss model, which includes the deceleration model, acceleration model, and acceleration/deceleration conversion model is proposed. Simulation results show that the proposed model could reduce the probability of velocity steep change and perform a smooth vehicle following effect. A test system is designed to support the in-chamber V2X test, and a test example is given.

In our future work, we should consider communication interference and optimize SUMO's lane-changing model, to match the demand of the V2X application test.

ACKNOWLEDGMENT

This research is supported by the National Nature Science Foundation of China under Project No.61601066 and the Open Research Fund of State Key Laboratory of Vehicle NVH and Safety Technology under Grant No.NVHSKL-202113.

REFERENCES

[1] E. Zhang and N. Masoud, "V2XSim: A V2X Simulator for Connected and Automated Vehicle Environment Simulation," in 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), 20-23 Sept. 2020 2020, pp. 1-6, doi: 10.1109/ITSC45102.2020.9294660.

[2] A. M. Ivanov and S. S. Shadrin, "Development of autonomous vehicles' testing system," in Materials Science and Engineering Conference Series, 2018.

[3] W. L. Huang, K. Wang, Y. Lv, and F. H. Zhu, "Autonomous vehicles testing methods review," in IEEE International Conference on Intelligent Transportation Systems, 2016.

[4] V. Souza, R. Cruz, W. Silva, S. Lins, and V. Lucena, "A Digital Twin Architecture Based on the Industrial Internet of Things Technologies," in 2019 IEEE International Conference on Consumer Electronics (ICCE), 11-13 Jan. 2019 2019, pp. 1-2, doi: 10.1109/ICCE.2019.8662081.

[5] D. Zhao and H. Peng, "From the Lab to the Street: Solving the Challenge of Accelerating Automated Vehicle Testing," 07/15 2017.

[6] Y. Ge, Y. Wang, R. Yu, Q. Han, and Y. Chen, "Demo:Research on test method of autonomous driving based on digital twin," in 2019 IEEE Vehicular Networking Conference (VNC), 4-6 Dec. 2019 2019, pp. 1-2, doi: 10.1109/VNC48660.2019.9062813.

[7] J. Lei, S. Chen, L. Zeng, F. Liu, K. Zhu, and J. Liu, "In-Chamber V2X Oriented Test Scheme for Connected Vehicles," in 2019 IEEE Intelligent Vehicles Symposium (IV), 9-12 June 2019 2019, pp. 1-6, doi: 10.1109/IVS.2019.8814263.

[8] D. J. Fremont et al., "Formal Scenario-Based Testing of Autonomous Vehicles: From Simulation to the Real World," in 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), 20-23 Sept. 2020, pp. 1-8, doi: 10.1109/ITSC45102.2020.9294368.

[9] C. Jing and W. Tengfei, "Research on simulation technology of vehicular ad hoc networks based on mobility model," Journal of Huazhong University of Science and Technology (Natural Science Edition), 2013.

[10] F. A. Silva, A. Boukerche, T. R. Silva, L. B. Ruiz, and A. A. Loureiro, "A novel macroscopic mobility model for vehicular networks," Computer Networks, vol. 79, pp. 188-202, 2015.

[11] M.-A. Lbre, F. Le Moul, and E. Mnard, "On the importance of real data for microscopic urban vehicular mobility trace," in 2015 14th International Conference on ITS Telecommunications (ITST), 2015: IEEE, pp. 22-26.

[12] S. Krau, P. Wagner, and C. Gawron, "Metastable states in a microscopic model of traffic flow," Physical Review E, vol. 55, no. 5, p. 5597, 1997.

[13] "SUMO User Documentation," [Online]. http://sumo-sim.org/userdoc/, February.2021.

[14] C. U. I. Ju-fu, H. U. Ben-xu, X. I. A. Hui, C. Fei, and Chengxiangguo, "Comparative Analysis of Simulation of Multi-Car-following Models under SUMO Platform," Journal of ChongQing University. [Online]. Available: cqdxzren/article/abstract/zk-201911006.

[15] G.-h. Han, X.-r. Chen, Y. Yu, and Y.-q. Li, "A study of microscopic traffic simulation based on sumo platform," computer engineering and science, vol. 34, no. 7, pp. 195-198, 2012.

[16] M. Parker, "The effect of heavy goods vehicles and following behaviour on capacity at motorway roadwork sites," Traffic engineering and control, vol. 37, no. 9, pp. 524-531, 1996.

[17] Q. Han, J. Lei, L. Zeng, Y. Tang, J. Liu, and L. Chen, "EMC Test for Connected Vehicles and Communication Terminals," in 2018 IEEE Intelligent Vehicles Symposium (IV), 26-30 June 2018 2018, pp. 55-60, doi: 10.1109/IVS.2018.8500418.

Manuscript 500 submitted to 2021 32nd IEEE Intelligent Vehicles Symposium (IV).
Received April 13, 2021.