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Virtual subjective and objective evaluation method of traffic jam assist

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Abstract

The virtual subjective and objective evaluation method is a significant development method to improve the performance of Traffic Jam Assist (TJA). This paper proposed a virtual subjective and objective evaluation method of TJA, including test scenarios and evaluation indices. Firstly, the paper built a virtual test and evaluation platform for intelligent vehicles based on a high-fidelity driving simulator and VTD traffic simulation software. Secondly, the paper proposed an objective evaluation system composed of evaluation indices, 11 test scenarios, and 49 test cases. Thirdly, the paper put forward a subjective evaluation system composed of three indices: acceptance, comfort, and psychological load. Finally, the paper used the platform mentioned above to conduct subjective and objective tests and evaluations of the TJA system that comes from Matlab. Meanwhile, objective and subjective evaluation scoring results were obtained. The evaluation results showed that the subjective and objective evaluation method proposed in this paper can test the objective and subjective performance of the TJA system comprehensively and systematically, which provided a guarantee for the improvement of the TJA system.

Keywords

Traffic jam assist, subjective evaluation, objective evaluation, virtual test platform, driving simulator

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Introduction

Traffic jam assist (TJA) has become the focus of research and development of auto works. TJA allows automated driving in traffic jam situations. The system doesn't change lanes automatically and works up to a speed of 60 km/h.[1] It's an integrated system, which is composed of Stop&Go Adaptive Cruise Control (ACC) and Lane Keeping Assistance (LKA) functions. Due to the complex functions, its control algorithm needs to be tested and verified on more cases and mileages. The virtual subjective and objective evaluation method of TJA is an important method, which can reduce development costs and time.

Many scholars have carried out a lot of research around test evaluation methods and test scenarios. First, some scholars have studied some subjective test evaluation methods of Advanced Driving Assistance System (ADAS). Hoedemaeker and Brookhuis[2] used a driving simulator to evaluate driver behavior with Adaptive Cruise Control systems. Bernsteiner et al.[3] proposed a subjective evaluation method which was correlated with objective results. Piao et al.[4] studied the subjective evaluation method of the acceptance of ACC and carried out user surveys in three European. Hoedemaeker[5] utilized a driving simulator to conduct a purely psychological study on the acceptance of ACC systems. Van Driel et al.[6] used a driving simulator to evaluate human driving behavior and acceptability after using the TJA. Brookhuis et al.[7] completed the subjective evaluation of the driver's acceptability and psychological load of TJA by using the driving simulator. Benmimoun[8] took TJA as an example and proposed a systematic evaluation method based on acceptance, effectiveness, and controllability. Rösener et al.[9] proposed a comprehensive framework for the evaluation of automated driving and completed usefulness and satisfactoriness evaluation of the TJA system. Hof et al.[10] evaluated the mental workload while driving with a congestion assistant. Auricht and Stark[11] introduced a tool which can capture User Experience on the Model-in-the-Loop level. Zhang et al.[12] explored

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factors affecting users' acceptance of automated vehicles and found that initial trust was the most critical factor in promoting a positive attitude toward automated vehicles.

In terms of ADAS objective test evaluation, the test standards or regulations for ACC mainly come from organizations such as ISO,[13,14] SAE.[15] The test focuses on performance tests such as detection distance, target recognition ability, and curve adaptability. Yi et al.[16] performed vehicle tests of a vehicle longitudinal control algorithm for stop-and-go cruise control. Guvenc and Kural[17] developed an ACC evaluation method based on a multiple Driver-in-the-Loop vehicle simulator, which can evaluate and test different ACC systems. Van Aerde and Rakha[18] described a framework for the evaluation of system safety benefits of Adaptive Cruise Control systems. Okamura et al.[19] used a microscopic traffic simulation model to evaluate the impacts of ACC installation on traffic flow. Zhao et al.[20] proposed an accelerated evaluation method to assess the safety performance of automated vehicles.

In the aspect of evaluation scenarios, Tamás et al.[21] tested the control effect of TJA longitudinal following while emergency braking. Dogan et al.[22] used a driving simulator to generate traffic congestion scenarios and test the driver's performance of taking over the TJA system. Auckland et al.[23] carried out subjective evaluations of ACC and LKA in several simple scenarios by offline simulation. Rao et al.[24] studied the longitudinal behavior of TJA vehicles while following a lead vehicle. Chen et al.[25] proposed a novel mixed test environment-based validation method which integrated the virtual and the real-world scenarios with the vehicle in the loop. Klischat and Althoff[26] proposed an approach that automatically generated critical scenarios based on a minimization of the solution space of the vehicle under test. Malayjerdi et al.[27] developed a prototype virtual environment for safety experiment simulations by using point cloud data of the real physical environments. Qiong et al.[28] proposed a platform to conduct rapid development, simulation, and test of ADAS by combining the advantages of rapid prototyping and software development. Tao et al.[29] proposed a virtual assessment framework using a fully automated test case generation method, which was embedded into the continuous development and validation process of LKS. Singh et al.[30] attempted to better understand the basic requirements to successfully test common ADAS algorithms by describing a generalized structure of simulation framework.

Scholars have carried out some studies on the objective test evaluation of ACC and the subjective evaluation of ADAS. But researchers either made a single subjective evaluation or a single objective evaluation. And they only evaluated the longitudinal or lateral performance of TJA in limited test scenarios. The objective test scenarios and subjective evaluation methods of TJA were not comprehensive and systematic. This paper defines standardized and systematic test scenarios, which is composed of 11 test scenarios and 49 test cases. At the same time, this paper provides systematically objective evaluation methods for corresponding scenarios, including evaluation indices and scoring method. It also proposed a subjective test and evaluation method composed of acceptability, comfort, and psychological load.

The rest of the paper is structured as follows. In the next section, the virtual test and evaluation platform is introduced. The "Objective test evaluation method of TJA" section presents 11 test scenarios and objective evaluation method. Then, the subjective test evaluation method of TJA is described in Section "Subjective test evaluation method of TJA." Simulation results and discussion are given in the next section. Finally, the conclusion is presented.

Virtual test and evaluation platform

To realize the virtual subjective and objective evaluation of TJA, the paper built a virtual test platform of intelligent vehicles based on the automobile driving simulator of Jilin University and VTD. As shown in Figure 1, the platform architecture is mainly composed of VTD, the driving simulator, dSPACE, and the tested intelligent vehicle control algorithm. The characteristics of the platform are as follows:

1. High-precision vehicle dynamics model.[31] This paper adopts the vehicle dynamics model researched by the State Key Laboratory of Automobile Simulation and Control of Jilin University. It has been developed for more than 30 years and verified by more than 150 operating conditions, and the model accuracy reaches over 90%. It provides a high-precision vehicle model for intelligent vehicle testing and evaluation.
2. Virtual subjective evaluation environment with high fidelity. As shown in Figure 2, this paper is based on the six degrees of freedom automobile driving simulator of Jilin University, which provides high-fidelity somatosensory, visual perception, auditory perception, force perception, and human-machine interface of the real automobile, thus providing a virtual subjective evaluation environment with high fidelity.
3. Vivid test scenarios. This paper makes full use of the traffic simulation and visual system provided by VTD to provide the evaluators with an almost real driving environment, which is convenient for subjective evaluation of TJA.

Objective test evaluation method of TJA

The function of TJA is to realize longitudinal following and lateral lane keeping of vehicles. The objective

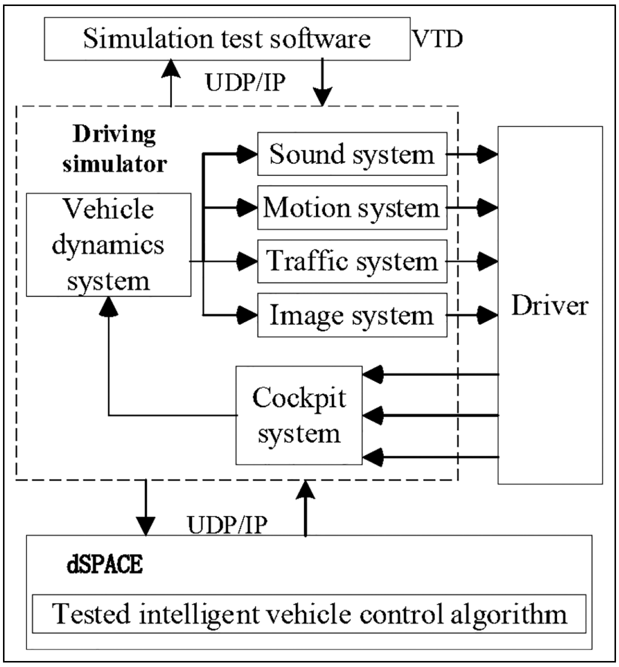

Figure 1. The test platform architecture.

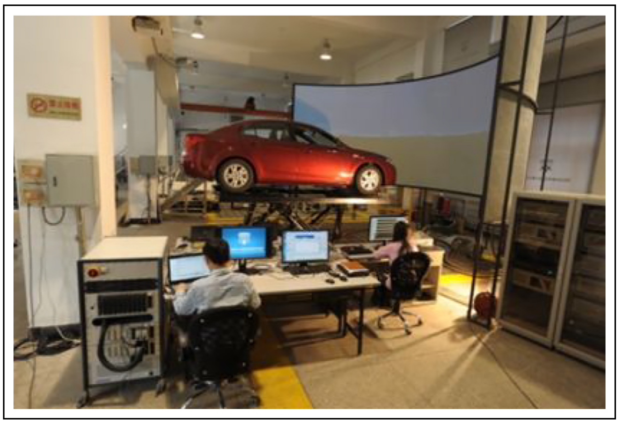

Figure 2. Automobile driving simulator.

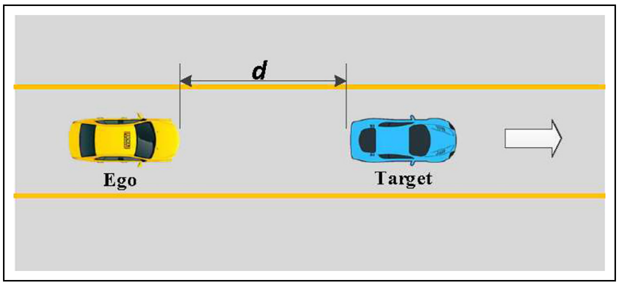

Figure 3. Test scenario of lead vehicle accelerating then decelerating.

evaluation of TJA can be performed from two aspects: longitudinal performance and lateral performance.

The objective test scenarios of the longitudinal performance of TJA are as follows: lead vehicle accelerating then decelerating, lead vehicle emergency braking, lead vehicle cut-out, lead vehicle cut-in with braking and free braking.

The objective test scenarios of the lateral performance of TJA are as follows: lane ahead merging, lane ahead diversion, lane ahead narrowing, lane ahead widening, partial missing of the lane line ahead, and straight road to the curve.

Longitudinal performance evaluation scenarios and test cases

TJA realizes the longitudinal control of vehicles by Stop&Go ACC. The classic ACC control principle is as follows [32]:

$$a_i = a\left[1 - \left(\frac{v_i}{v_0}\right)^{\delta} - \left(\frac{s_i}{s}\right)^2\right] \tag{1}$$

The acceleration a_i is characterized by the maximum acceleration a, the actual speed v_i, the desired speed v_0, the desired distance s_i, the distance to the lead vehicle s, and the free acceleration exponent δ. δ characterizes how the acceleration decreases with velocity ($\delta = 1$ corresponds to a linear decrease while $\delta \to \infty$ denotes a constant acceleration).

$$s_i = s_0 + Tv_i + \frac{v_i \Delta v_i}{2\sqrt{ab}} \tag{2}$$

Besides the jam distance s_0 to the lead vehicle and the actual speed v_i, the desired distance s_i also takes into account the desired time gap T, the velocity difference Δv_i, the maximum acceleration a, and the desired deceleration b. Referring to the research of Kesting,[32] δ is taken as 4 and T is 1.5 s in this paper.

Combined with the control principle of TJA, this paper tests the longitudinal performance of TJA in five test scenarios.

Lead vehicle accelerating then decelerating. In heavy traffic jams, the ego vehicle will follow the target vehicle at low speed, and go and stop frequently. It's to test the control performance of TJA and its ability to avoid collisions in this scenario.

As shown in Figure 3, the ego vehicle and the target vehicle are driving in the center of the same lane. The target vehicle first accelerates to the test speed at 0.12 g, and the cruising speed of the ego vehicle is 10 km/h higher than the test speed of the target vehicle. The following distance d depends on the default following distance of algorithms. As shown in Table 1, the target vehicle decelerates to a stop at a_1 after the ego vehicle follows the target vehicle steadily.

Table 1. Test cases of lead vehicle accelerating then decelerating.

Case	Test speed (km/h)	Deceleration a_1 (g)
1	10	0.3
2	20	0.3
3	30	0.3
4	30	0.6

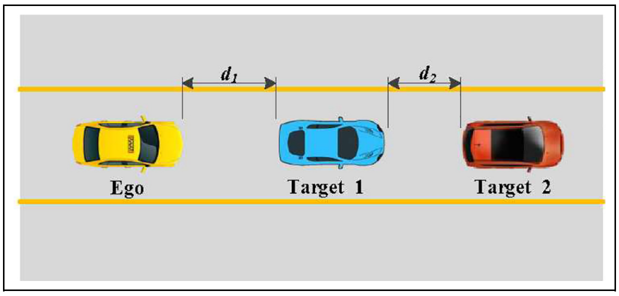

Figure 4. Test scenario of lead vehicle emergency braking.

Lead vehicle emergency braking. When the target vehicle 2 is stationary due to traffic jams, the ego vehicle is following the target vehicle 1. Then the target vehicle 1 will suddenly notice the stationary target vehicle 2 and take emergency braking. It's to test the control performance of TJA and its ability to avoid collisions in this scenario.

As shown in Figure 4, the ego vehicle follows the target vehicle 1 at cruising speed, and cruising speed of the ego vehicle is 10 km/h higher than test speed of the target vehicle 1. The following distance d_1 depends on the default following distance of algorithms. As shown in Table 2, the target vehicle 1 begins braking when the distance between the target vehicle 1 and the target vehicle 2 is d_2.

Lead vehicle cut-out. As shown in Figure 5, a stationary target vehicle 2 will suddenly appear in front of the ego vehicle when the vehicle ahead cuts out. It's to test the control performance of TJA and its ability to avoid collisions in this scenario.

The cruising speed of the ego vehicle is 10 km/h higher than the target vehicle 1. The target vehicle 1 is 100 m away from the lane change point to ensure that the ego vehicle reaches a stable state after activating the TJA system. The target vehicle 1 is accelerated to the test speed shown in Table 3. After the ego vehicle follows the target vehicle 1 at the corresponding cruising speed, the target vehicle 1 begins to cut out. At this time the distance between the target vehicle 1 and the target vehicle 2 is the sum of d_1 and d_2. When the distance between them is d_2, the target vehicle 1 completely enters the right lane. In this paper, d_1 is taken as 11 m, and d_2 is taken as 3 me.

Table 2. Test cases of lead vehicle emergency braking.

Case	Cruising speed (km/h)	Deceleration (g)	Distance d_2 (m)
1	40	0.3	50
2	40	0.6	30
3	60	0.3	100
4	60	0.6	60

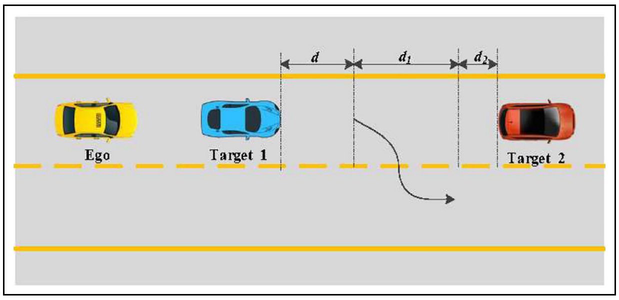

Figure 5. Test scenario of lead vehicle cut-out.

Table 3. Test cases of lead vehicle cut-out.

Case	Cruising speed (km/h)	Test speed (km/h)
1	20	10
2	30	20
3	50	40
4	60	50

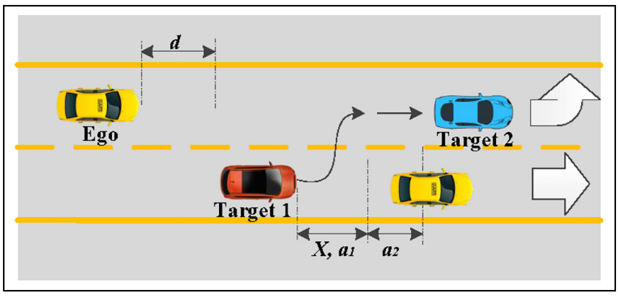

Figure 6. Test scenario of lead vehicle cut-in with braking.

Lead vehicle cut-in with braking. As shown in Figure 6, the target vehicle 1 decelerates to cut into the left lane. When it completes the lane change, the target vehicle 1 will stop. It's to test the control performance of TJA and its ability to avoid collisions in this scenario.

The cruising speed of the ego vehicle is 10 km/h higher than the target vehicle. According to the test cases shown in Table 4, the ego vehicle follows the target vehicle 2. The target vehicle 1 changes lane when the distance from the ego vehicle is d. The distance x during the lane change process is 7.6 m and the deceleration a_1 is according to the test cases. After entering

Table 4. Test cases of lead vehicle cut-in with braking.

Case	Cruising speed (km/h)	Deceleration a_1(g)	Deceleration a_2 (g)
1	20	0.05	0.3
2	40	0.05	0.3
3	40	0.05	0.6
4	60	0.05	0.3
5	60	0.05	0.6
6	60	0.1	0.3
7	60	0.1	0.6

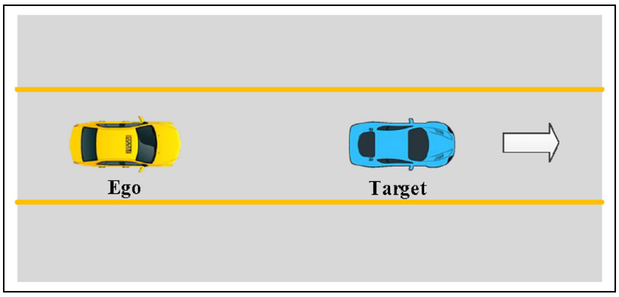

Figure 7. Test scenario of free braking.

the left lane, the target vehicle 1 continues to decelerate at the acceleration a_2. According to the calculation, d is 4.5 m when the test speed is below 40 km/h, and d is 20 m when the test speed is 40 km/h or higher.

Free braking. It's to test the control performance of TJA without emergency braking. As shown in Figure 7, the ego vehicle and the target vehicle are driving in the center of the same lane. The target vehicle is stationary. The ego vehicle approaches the target vehicle from a distance of 200 m to reach the cruising speed of 10, 20, 40, and 60 km/h.

Lateral performance evaluation scenarios and test cases

TJA usually realizes the lateral control of vehicles by LKA. The classic LKA control principle uses the time to line cross (TLC). Besides the lane width, it is also related to the vehicle speed, the heading angle of the vehicle, etc.[33]

Considering that congestion often occurs when lanes change, this paper proposes six test scenarios to test the lateral performance of TJA. In the following test scenarios, cruising speed is set: 10, 20, 40, and 60 km/h.

Lane ahead merging. It's to test the lane keeping ability of TJA when the number of lanes ahead decreases. As shown in Figure 8, the ego vehicle is driving in the center of the left lane. The road changes from a two-lane to a single lane at 100 m. The width of the lane is 3.5 m.

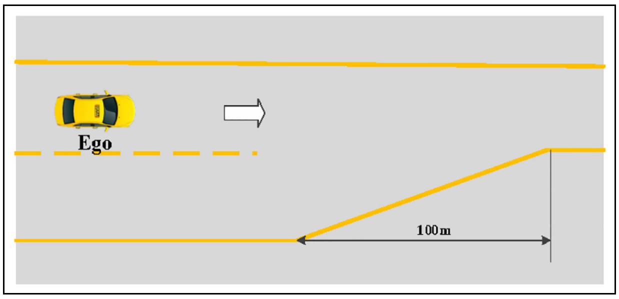

Figure 8. Test scenario of lane ahead merging.

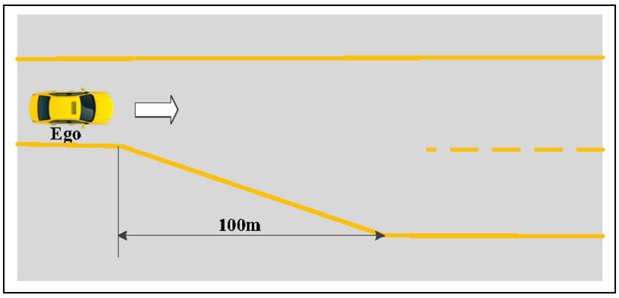

Figure 9. Test scenario of lane ahead diversion.

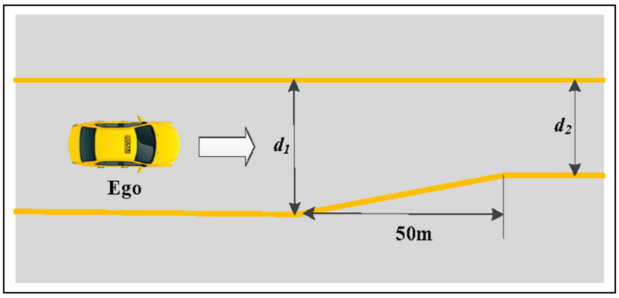

Figure 10. Test scenario of lane ahead narrowing.

Lane ahead diversion. It's to test the ability to reasonably choose a lane ahead and continue to drive in the center when the number of lanes increases. As shown in Figure 9, the ego vehicle is driving in the center. The single lane is changed to a double lane at 100 m.

Lane ahead narrowing. It's to test the ability of the lane keeping after entering the narrow lane from the wide one. As shown in Figure 10, the ego vehicle is driving in the center. The standard lane width d_1 is 3.5 m, and the narrow lane width d_2 at a distance of 50 m is 2.8 m.

Lane ahead widening. It's to test the ability of the lane keeping after entering the wide lane from the narrow one. As shown in Figure 11, the ego vehicle is driving in the center. The standard lane width d_1 is 3.5 m, and the wide lane width d_2 at a distance of 50 m is 6 m.

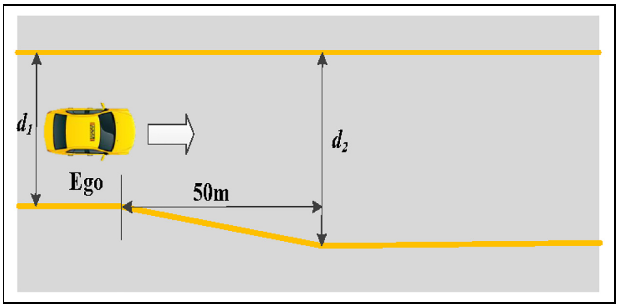

Figure 11. Test scenario of lane ahead widening.

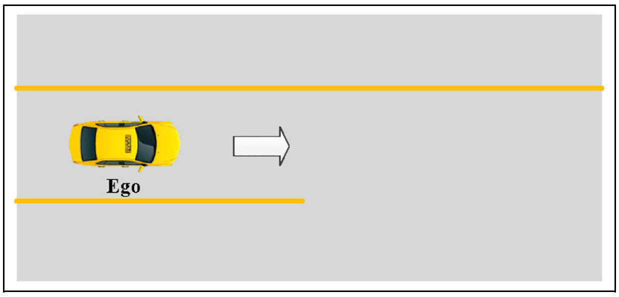

Figure 12. Test scenario of partial missing of lane line ahead.

Partial missing of lane line ahead. It's to test the ability of the lane keeping when partial lane line information ahead is missing. As shown in Figure 12, the ego vehicle is driving in the center, and part of the right lane line ahead is missing.

Straight road to the curve. It's to test the lane keeping ability of TJA in the scenarios of the large curve radius and small curve radius.

As shown in Figure 13, the ego vehicle is driving in the center of the straight road. The straight road is long enough, and the curve is composed of two parts: fixed curvature and variable curvature. The radius of the fixed curvature part is as shown in Table 5. The variable curvature part is the connection between the straight and the fixed curvature, and its purpose is to ensure the smooth transition from the straight segment to the curve. After the ego vehicle reaches the cruising speed in the straight road, it maintains the speed to enter the curve section.

Subjective test evaluation method of TJA

Subjective evaluation is the evaluation of the automobile system from the perspective of physiological and psychological. For ADAS, subjective evaluation is the key to success in the market. According to the subjective evaluation method of automotive electronic systems, this paper divides the subjective evaluation of TJA into acceptance, comfort, and psychological load evaluation.

Table 5. Test cases of straight road to the curve.

Case	Cruising speed (km/h)	Curve radius (meter)
1	10	150
2	20	150
3	40	150
4	40	200
5	60	200
6	60	250

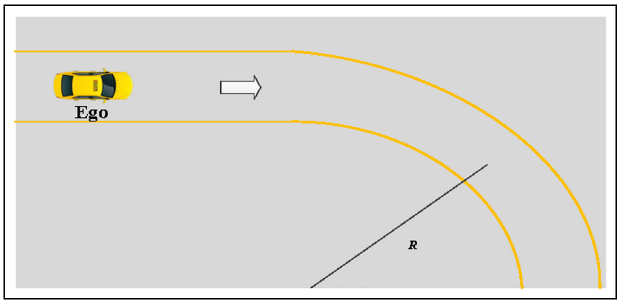

Figure 13. Test scenario of straight road to the curve.

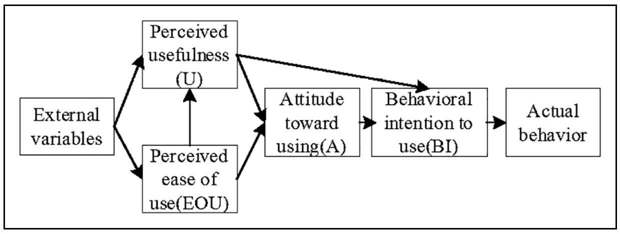

Figure 14. Technology acceptance model.

Acceptance

Currently, there are a variety of models for the evaluation of acceptance. Technology Acceptance Model (TAM) is used widely in the evaluation of a certain technology acceptance. As shown in Figure 14, TAM believes that people's actual behavior can be determined by the person's attitude toward using the system (A), perceived usefulness (U), and ease of use (EOU).[34]

Attitude toward using the system is defined as an individual's positive or negative feelings about using TJA. Usefulness is defined as the prospective user's subjective probability that TJA will increase his or her job performance. Ease of use refers to the degree to which the user expects TJA to be free of effort. Behavioral intention to use is a measure of the strength of one's intention to use TJA.

According to TAM, A is jointly determined by U and EOU, with relative weights statistically estimated by linear regression:

$$A = U + EOU \tag{3}$$

Table 6. Subjective evaluation phenomena.

Index	Evaluation phenomena
Acceptance	1. The ego vehicle collides with the front vehicle; 2. The ego vehicle deviates out of the lane; 3. When braking stops, the distance between the ego vehicle and the vehicle ahead is too small; 4. When braking stops, the distance between the ego vehicle and the vehicle ahead is too large; 5. The ego vehicle is too close to the adjacent lane.
Comfort	1. The ego vehicle can't maintain the cruising speed when cruising; 2. Following the vehicle ahead, the speed of the ego vehicle fluctuates obviously; 3. Obvious setbacks occur during acceleration and deceleration of the ego vehicle; 4. When the ego vehicle is driving in the center of the lane, the tester can feel that the ego vehicle swinging from side to side.
Psychological load	1. The tester should always observe the distance between the ego vehicle and the vehicle ahead, and prepare to take over it in case of collision; 2. The tester should always observe the ego vehicle and prepare to take over it when it deviates from the lane.

Behavioral intention (BI) is viewed as being jointly determined by the person's attitude toward using the system (A) and perceived usefulness (U), with relative weights estimated by regression:

$$BI = A + U \tag{4}$$

Considering that TAM has been verified in the acceptance research of emerging automobile technologies, this paper proposes evaluation content reflecting its work characteristics combining TAM and the application scenarios of TJA. Usefulness is evaluated by using two questions:

1. Whether can the TJA system follow vehicles and keep the lane center in the congested scene?
2. Whether can the TJA system make driving easier and reduce pedals and steering operation fatigue?

Ease of use is also evaluated by using two questions:

1. Whether can the following distance from the lead vehicle make you feel suitable?
2. Whether can you predict the future state of the ego vehicle in the traffic scenarios well?

Comfort

With the development of automobile technology, people's requirements on automobiles are no longer limited to basic performance, such as power performance and economy, but focus on the comfort and pleasure of driving. As an important evaluation criterion, comfort has been paid more and more attention by consumers. The comfort evaluation of TJA in this paper mainly considers longitudinal comfort and lateral comfort. Comfort is evaluated from three aspects:

1. Speed stability: the speed fluctuation degree when the vehicle is following and cruising.
2. Lane center stability: the fluctuation degree of vehicle lateral acceleration.
3. Acceleration stability: the degree of change in acceleration.

Psychological load

Psychological load refers to the number of resources required to process a task.[35] It depends on the task, the situation and the character of the person. Psychological load is mainly used to evaluate how many mental and perceptual activities the operator participates in to achieve a specific task goal, whether the operator needs to pay high attention (such as thinking, decision-making, observation, search, and other activities), and whether the task is simple or complex for the operator.

The subjective scoring method is the most effective way to evaluate the psychological load. After all, the drivers know the degree of their own psychological load best. However, the key of the subjective scoring method is to fully reflect the characteristics of psychological load and make it easy for drivers to express their psychological load.

Subjective evaluation scoring

As shown in Table 6, the subjective evaluation of TJA is evaluated from the three indices: acceptance, comfort, and psychological load.

Acceptance scoring has five types of evaluation phenomenon. When evaluation phenomenon 1 or 2 occurs, it is unacceptable. When any two of evaluation phenomenon 3, 4, and 5 occur, this is unsatisfactory. When any of the evaluation phenomena 3, 4, or 5 occurs, this is acceptable. When there is no evaluation phenomenon, the tester can choose satisfactory or very satisfactory to evaluate the TJA according to personal driving style.

The next step is to evaluate comfort. When four evaluation phenomena all occur, it means very poor. When there are three evaluation phenomena, it means that the comfort is poor. When there are two evaluation phenomena, it means normal. When there is only one evaluation phenomenon, it means that the comfort is good.

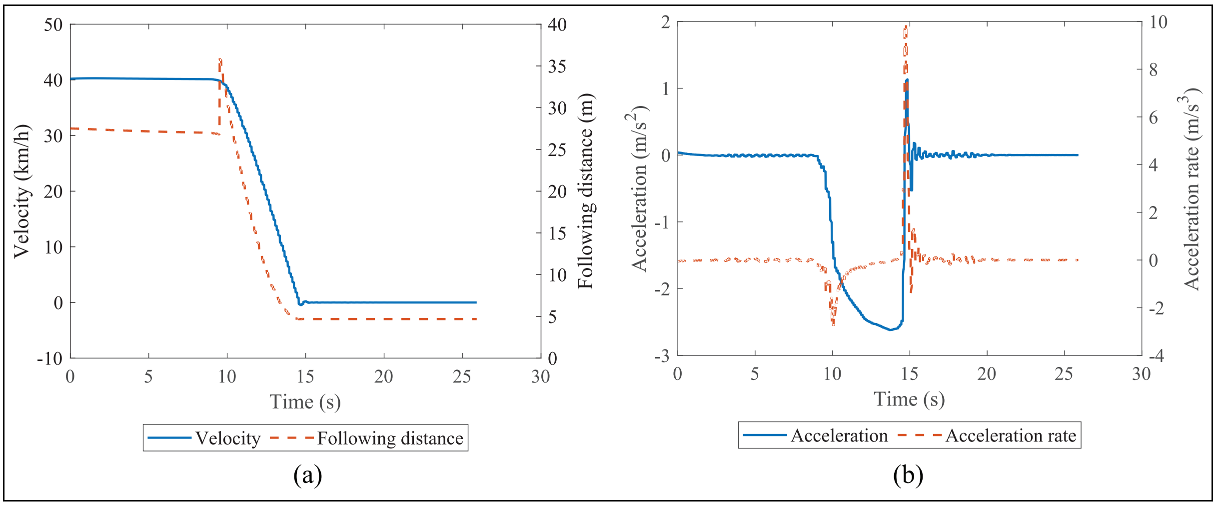

Figure 15. Simulation results of lead vehicle cut-out: (a) velocity and distance and (b) acceleration and acceleration rate.

When there is no evaluation phenomenon, it means that the comfort is very good.

Then the psychological load item is evaluated. When evaluation phenomenon 1 and 2 both appear, it's indicated that the drivers need to pay extreme attention. When one of the evaluation phenomena appears, it means that the drivers have paid much attention. When there is no evaluation phenomenon, the drivers choose the attention level according to the time when the drivers observe the distance from the vehicle ahead and whether the ego vehicle is in the middle of the lane.

Results and discussion

Tested TJA algorithm

To verify the subjective and objective evaluation method, the TJA algorithm provided by the Automated Driving Toolbox in Matlab2019a[36] is selected as the tested object.

Evaluation results and discussion

Objective evaluation results and discussion. The given TJA algorithm is tested in all proposed cases. This paper only gives the test results of several test cases that challenge TJA algorithm when the test speed is 40 km/h, such as lead vehicle cut-out, lead vehicle cut-in with braking, lane ahead merging, lane ahead diversion, and lane ahead narrowing.

Lead vehicle cut-out. It can be seen from Figure 15 that when the lead vehicle cuts out, the TJA algorithm recognizes the vehicle in front of the lead vehicle as a new lead vehicle, and the following distance changes suddenly. Because the new lead vehicle stops, the TJA algorithm controls the ego vehicle to brake. The final following distance is 4.68 m, which is safe enough. The maximum acceleration of ego vehicle is 2.62 m/s^2 during the test, which is less than 0.35 g. It's within the acceptable range of the human body. The maximum acceleration rate is 9.96 m/s^3, which is less than 15 m/s^3.

Lead vehicle cut-in with braking. It can be seen from Figure 16 that when the lead vehicle cuts in and has a braking deceleration of 0.3 g, the final following distance is 8.78 m. The distance is enough for ego vehicle. The maximum acceleration is 2.62 m/s^2 during the test, and the maximum acceleration rate is 5.20 m/s^3, which is comfortable for drivers and passengers. When the braking deceleration of the lead vehicle is 0.6 g, the ego vehicle will collide with the lead vehicle. It's because the TJA algorithm limits the maximum deceleration to meet the requirement of comfort. The results also show that the corner cases are necessary for evaluations of TJA.

Lane ahead merging. As shown in Figure 17, although the number of the lane changes, the maximum offset distance of the vehicle controlled by TJA is 0.012 m, and the maximum lateral acceleration is 0.02 m/s^2. The simulation results show that the offset distance is relatively small, and the vehicle successfully entered the merged lane.

Lane ahead diversion. It can be seen from Figure 18 that when the number of lanes increases, the maximum offset distance is 0.008 m, and the maximum lateral acceleration is 0.0082 m/s^2. It's indicated that the vehicle successfully entered the diversion lane.

Lane ahead narrowing. It can be seen from Figure 19 that when the ego vehicle goes into the narrow lane, the maximum offset distance is 0.35 m, and the maximum lateral acceleration is 2.99 m/s^2. The TJA controls the vehicle to quickly adapt. The vehicle finally successfully entered the narrow lane.

Subjective evaluation results and discussion. Referring to the research of Kobayashi,[37] this experiment selects ten

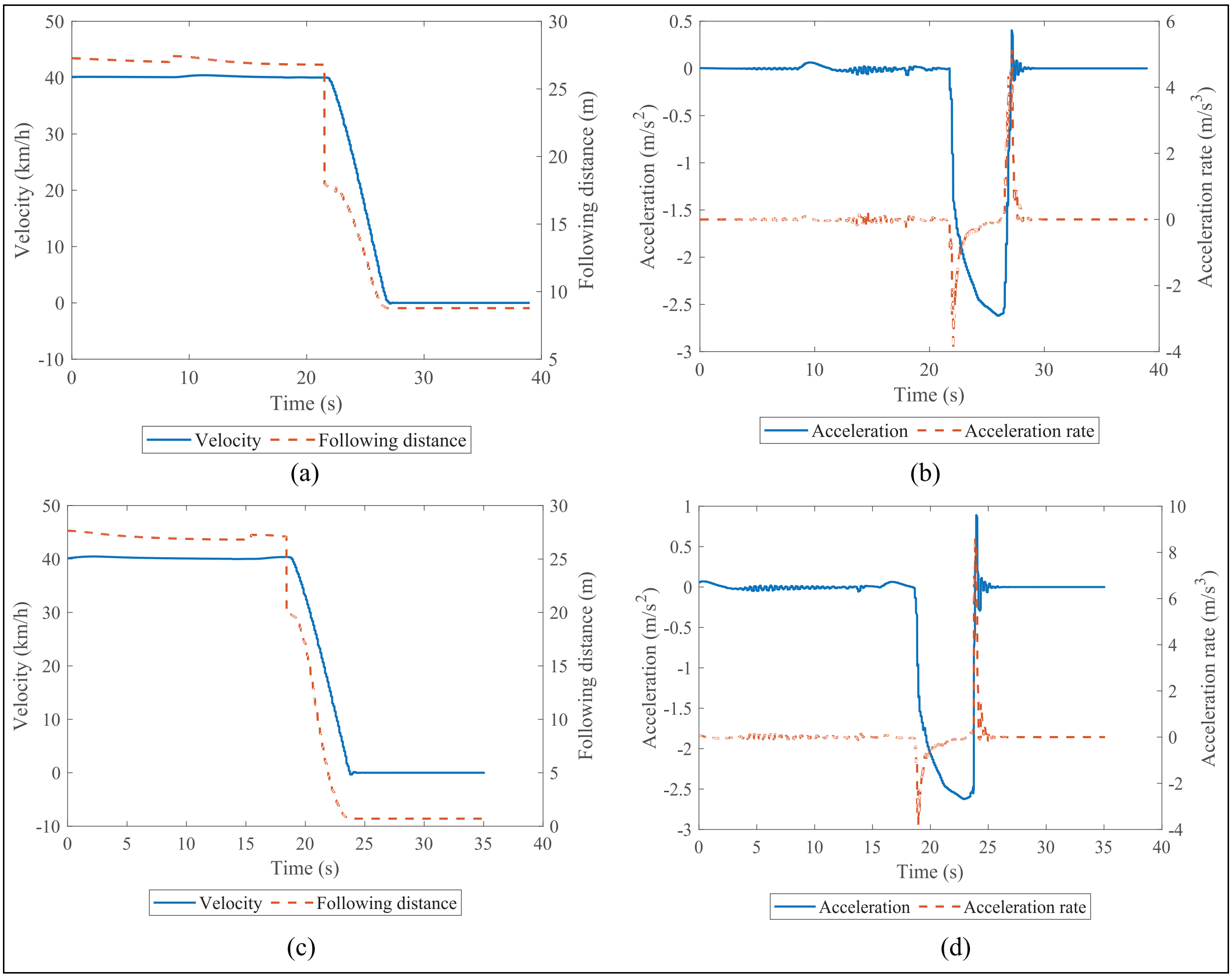

Figure 16. Simulation results of lead vehicle cut-in with braking: (a) velocity and distance when braking deceleration is 0.3 g, (b) acceleration and acceleration rate when braking deceleration is 0.3 g, (c) velocity and distance when braking deceleration is 0.6 g, and (d) acceleration and acceleration rate when braking deceleration is 0.6 g.

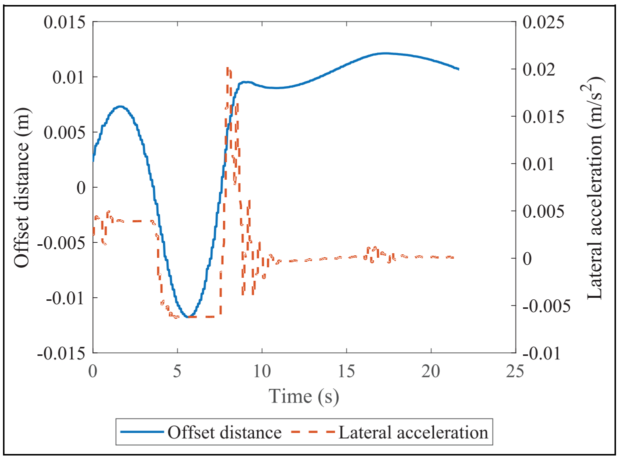

Figure 17. Simulation results of lane ahead merging.

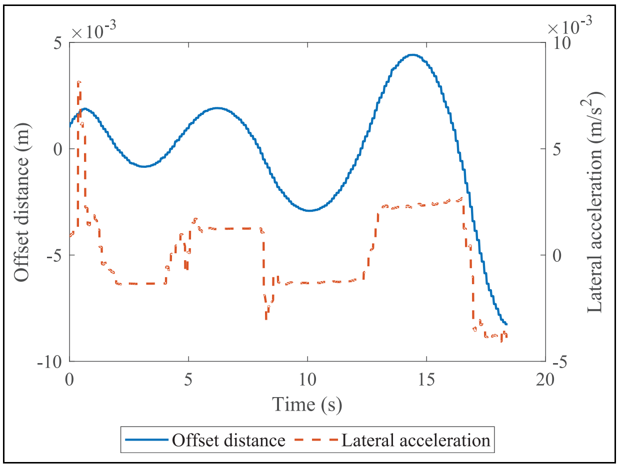

Figure 18. Simulation results of lane ahead diversion.

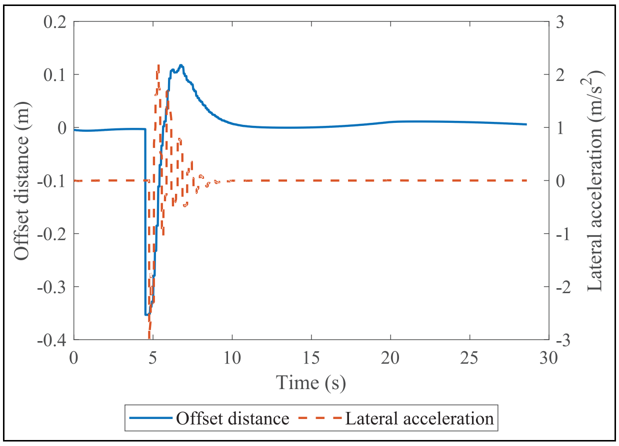

Figure 19. Simulation results of lane ahead narrowing.

volunteers as the testers. The average age of the testers is 25.1 years, and the average driving experience is 4.1 years. The test scenarios of subjective evaluation are the same as the objective tests. The steps of subjective evaluation are:

(1) Before the start of the test, explain the purpose of the test to each tester and issue a subjective score table.
(2) Introduce the working principle of TJA, the meaning of the test scenario, the scoring rules, the evaluation content, and the evaluation phenomena of the subjective evaluation index.
(3) The tester conducts a test drive on the driving simulator. The tester is familiar with the operation of the driving simulator and the effects provided by the test platform.
(4) The tester fully experiences the control effects of TJA in the cockpit of the driving simulator and then completes the subjective scoring as required.
(5) Collect the subjective scoring table, and the next tester will continue the test. When analyzing the scores, this paper does not conduct a thorough study of the weights of various test scenarios and the evaluation indices on the overall score.

There are six indices in subjective evaluation. Finally, the average scoring results of 10 testers about six indices are shown in Figure 20. The ease of use score in the acceptance is relatively low. It means when the testers use the TJA system, they agree that TJA can perform the longitudinal following and lateral lane keeping functions, but the following distance and the lane keeping effect can't meet their ideal expectations. The overall score of comfort is higher, which is indicated that the control effect of TJA is relatively good. The psychological load score is 2.19 points, and the tester believes that the use of TJA will cause a certain degree of psychological load.

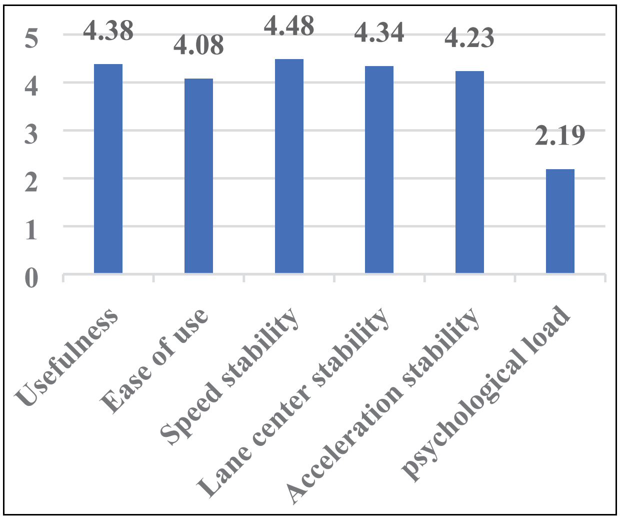

Figure 20. Results of subjective evaluation index.

Conclusion

In this paper, a virtual test and evaluation platform for intelligent vehicles was built. It was based on a high-fidelity driving simulator and VTD traffic simulation software. And a virtual subjective and objective evaluation method of TJA was proposed.

(1) The platform consisted of a high-fidelity driving simulator and VTD was suitable for objective and subjective evaluation of intelligent vehicle algorithms.
(2) The paper proposed a comprehensive and systematic objective evaluation method of TJA, and the method can test the longitudinal and lateral performance of TJA comprehensively and systematically. The objective evaluation system was composed of 11 test scenarios and 49 detailed test cases. Test scenarios included five longitudinal scenarios and six lateral scenarios. Longitudinal scenarios included lead vehicle accelerating then decelerating, lead vehicle emergency braking, lead vehicle cut-out, lead vehicle cut-in with braking and free braking. Lateral scenarios included lane ahead merging, lane ahead diversion, lane ahead narrowing, lane ahead widening, partial missing of the lane line ahead, and straight road to the curve.
(3) The paper proposed a subjective evaluation system for TJA, which was composed of acceptance, comfort, and psychological load. And the detailed evaluation indices and scoring method were given.
(4) The proposed objective and subjective evaluation method was applied to the TJA algorithm in Matlab as an example. The typical objective test results and analysis were presented, and the subjective scores of 10 volunteers were given.

In the future, it's necessary to investigate new methods to generate test scenarios and cases corresponding to other ADAS functions. Another important topic is to consider more factors affecting the subjective evaluation of automated driving.

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