Research on Intelligent Reasoning and Decision Algorithm for Autonomous Vehicle in Context of Narrow Road Intersections

Like Wang

North Automatic Control Technology Institute, Taiyuan, 030000, China

*Corresponding author.Email:tshwanglike@hotmail.com

Abstract. This article focuses on the precise decision-making problem of driving speed and safety of Autonomous Vehicle at narrow road intersections, and develops a collaborative decision-making platform for the safety of Autonomous Vehicle at narrow road intersections. The platform includes three parts: data collection, decision control, and intelligent collaboration. The design of an intelligent safety assistance system for Autonomous Vehicle at narrow road intersections mainly includes information collection, information extraction, decision control, and functional execution. Based on the position and speed of Autonomous Vehicle at narrow road intersections, the movement feature judgment mode of Autonomous Vehicle at narrow road intersections was analyzed. The intelligent signal lights at narrow road intersections can flexibly switch between three conditions, facilitating artificial intelligence information to prompt vehicles, increasing the speed of intersections, and providing reference for intelligent decision-making of Autonomous Vehicle at narrow road intersections.

Keywords: Narrow Roads; Cross Point; Autonomous Vehicle; Intelligent Reasoning

1 Introduction

The safe driving of vehicles at narrow road intersections has a significant impact on unmanned driving and underground structural stability. A narrow road intersection is an intersection of different narrow road routes. When the signal lights at the intersection of narrow road intersections change, the intelligent decision-making system for Autonomous Vehicle at narrow road intersections needs to quickly determine whether to stop or pass based on real-time traffic information [1,2]. Due to the need for accurate and fast judgment of the information of narrow road intersections by the intelligent decision-making system of Autonomous Vehicle at narrow road intersections, it is easy to make incorrect judgments, thereby delaying traffic and even causing safety accidents. The probability of accidents at intersections of narrow roads is relatively high, accounting for more than 70% of underground traffic accidents. The main reason is that the intelligent decision-making system of driverless vehicles at intersec-

A. Rauf et al. (eds.), *Proceedings of the 3rd International Conference on Management Science and Software Engineering (ICMSSE 2023)*, Atlantis Highlights in Engineering 20,
https://doi.org/10.2991/978-94-6463-262-0_76

tions of narrow roads makes mistakes in judging Braking distance, braking speed and road conditions at intersections.

Scholars at home and abroad have conducted extensive research on unmanned driving and intelligent decision-making systems. Li Zhipeng et al. [3] estimated the position and posture of robots based on maximum correlation entropy, improving the accuracy of robot positioning; Wang Zhifei [4] designed a dynamic feature visual odometer for road environments and achieved superior performance; Zhou Libing [5] systematically studied the unmanned driving system of vehicles and conducted in-depth discussions on a series of issues related to unmanned driving; Han Jianghong et al. [6] conducted research and development on unmanned driving systems, and predicted and predicted unmanned driving based on technologies such as network information; Liu Pengtao et al. [7] designed an autonomous driving system by studying autonomous driving algorithms and analyzed the key technologies of the designed system to ensure the safety of vehicle operations; Liu Xiaojie et al. [8] studied the Safety management system of driverless vehicles and successfully controlled driverless trucks through analysis; Kingdom Law et al. [9,10] conducted research and exploration on the latest issues and technological progress of unmanned driving intelligence, and analyzed the main problems and development directions faced by intelligence; Wang Zhongxin et al. [11] summarized intelligent transportation and analyzed the urgent problems that need to be solved in transportation systems. The above research mainly focuses on the research and analysis of autonomous driving, but there is relatively little research on intelligent decision-making at narrow road intersections.

This article analyzes the intelligent decision-making system for unmanned driving at narrow road intersections and proposes a collaborative safety decision-making system for unmanned driving at narrow road intersections. The driving characteristics of unmanned driving at narrow road intersections and the turning decision area model at narrow road intersections are analyzed. It has been well applied in virtual simulation and preliminary experiments, providing a reference for the on-site application of unmanned driving at narrow road intersections.

2 Model establishment

2.1 Intelligent Decision model for narrow road intersections

Safe driving of Autonomous Vehicle at narrow road intersections refers to the ability of Autonomous Vehicle to stop, avoid vehicles or pedestrians, and enter designated lanes smoothly through narrow road intersections before the change of the indicator light at narrow road intersections, to prevent situations where vehicles cannot continue to pass through narrow road intersections, slow down, and safely stop and wait. The main reason why Autonomous Vehicle cannot safely pass through narrow road intersections is due to factors such as the inability of vehicles to make self judgments and decision time constraints, which prevent them from turning or stopping at accurate positions, leading to accidents.

$$X_{\min} = v_0\delta_1 + \frac{v_0^2}{2a_1} \quad (1)$$

$$X_0 = v_0 t + 0.5a_2(t - \delta_2)^2 \quad (2)$$

In the formula (1) and formula (2), X_0 is the distance from the decision-making area, m; V_0 is the vehicle speed, m/s; δ_1 and δ_2 is the vehicle reaction time, s; A_1 and a_2 are the acceleration and deceleration of Autonomous Vehicle, m/s2; T is the decision-making time for autonomous vehicles, s; The decision-making of vehicles at narrow road intersections is shown in Figure 1. The minimum stopping distance for Autonomous Vehicle refers to the distance at which Autonomous Vehicle can safely stop at narrow road intersections.

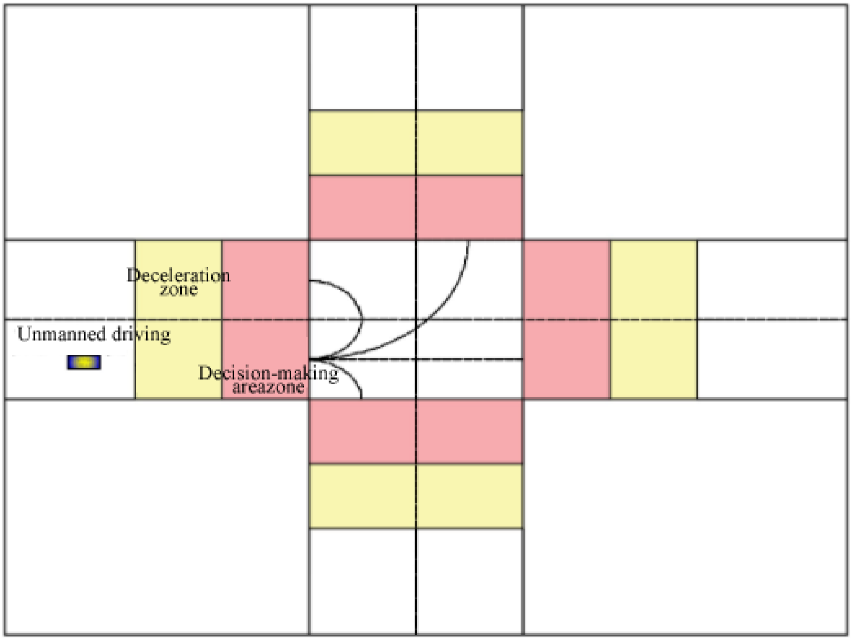

Fig. 1. Unmanned vehicle decision-making at narrow road intersections

If $X_{min}>X_0$, the zone between X_{min} and X_0 is the deceleration area. Autonomous Vehicle can slow down in the deceleration zone and pass smoothly at narrow road intersections; If a vehicle decelerates after entering the decision-making area, it cannot pass safely or stop at the parking line. The parameters of Autonomous Vehicle at narrow road intersections are set according to the safe distance. However, due to changes in road environment and other vehicle driving parameters, the relevant data of each node entering the narrow road intersection entrance should be collected and analyzed separately, in order to accurately determine the boundary of the narrow road intersection area. When an unmanned vehicle enters a narrow road intersection, it requires to determine whether to overtake or stop based on vehicle data, signal duration, distance between Autonomous Vehicle ahead, pedestrians and obstacles, and road conditions. If vehicles in the decision-making area cannot quickly and accurately grasp this data.

The decision-making errors of Autonomous Vehicle at narrow road intersections mainly include the following aspects:

1) Autonomous Vehicle cannot slow down in the deceleration zone, and vehicles pass through narrow road intersections at their current speed or danger of acceleration;

2) The decision-making area has a longer reaction time and a higher vehicle speed, which is not conducive to safe passage;

3) Vehicles can safely pass through the intersection, but the decision-making area makes deceleration and parking instructions, which reduces the passing rate of the intersection;

4) The vehicle slows down so slowly that make it to cross the parking zone and stop.

It is very important to reasonably and accurately grasp the boundaries of narrow road intersections and make correct decision instructions for vehicles. This can efficiently make vehicles to move non designated areas of narrow road intersections, shorten delays caused by decision time, improve road passing efficiency, and extend the safe use time of narrow roads.

2.2 Fixed point boundary model for narrow road intersections

Due to the fact that the boundary of the narrow road intersection area is determined by multiple factors and constantly changing, it is possible to determine whether Autonomous Vehicle are located in the narrow road intersection area by the speed, acceleration, and reaction time of vehicles at some parameters at the entry. Establish the Kinematics model of fixed points in the intersection area of narrow roads. When the speed and acceleration reach the distance of the stop line, if the vehicle can safely pass the stop line, the following equation will be met:

$$S_1 < v_L \times t + \frac{t^2 \cdot a_1}{2} = D_L \tag{3}$$

In the formula (3), S1 is the stopping distance, m; VL is the velocity, m/s; D_L is the distance from the vehicle to the turning position, in meters.

The principle of fixed points in the narrow road intersection area is shown in Figure 2. If $D_L > S_1$, the node can cross the parking line and pass smoothly. If $D_L < S_1$, the node cannot cross the parking line. At the same time, the speed and acceleration entering the vehicle will also have an impact on it.

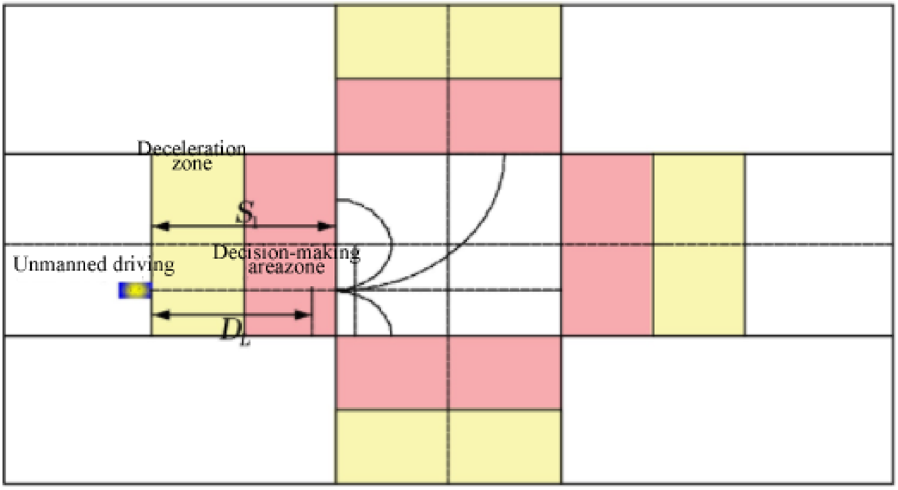

Fig. 2. Principle of Fixed Points in the Intersection Area of Narrow Roads

If the vehicle can slow down and stop in front of the parking area, the equation is satisfied:

$$S_2 \geq (\frac{v_0^2}{2a_1} + t \cdot v_0) \times \lambda_1 \times \lambda_2 = D_R \tag{4}$$

In the formula (4), S2 is the safe stopping factor of the vehicle m; λ1 is the correction coefficient for different vehicle models; λ2 is the friction correction coefficient for the unevenness of narrow roads.

The situation at the front of a narrow road intersection is used to determine whether the car can fully slow down or stop before the stop area in the current situation. In $D_R > S_2$, autonomous vehicles should slow down or come to a complete stop.

2.3 Auxiliary intelligent Decision model

The calculation formula (5) for the critical deceleration a2C is:

$$a_{2c} = \frac{v_0^2}{2(\frac{s_2}{\lambda_1 \times \lambda_2} - t \cdot v_0)} \tag{5}$$

When $a_{max} > a_{2C} > a_1$, all Autonomous Vehicle stop; When $a_{max} < a_{2C}$, if the critical deceleration of the car exceeds the maximum deceleration reference value, it is necessary to start and accelerate the car to pass the stop line. The calculation formula for vehicle acceleration time is as follows:

$$v_0(t+\Delta t)+\frac{a_0(t+\Delta t)^2}{2}\geq S_2 \tag{6}$$

In the formula(6), a0 is the initial acceleration of the unmanned vehicle, m/s2.

The auxiliary intelligent decision-making process is shown in Figure 3.

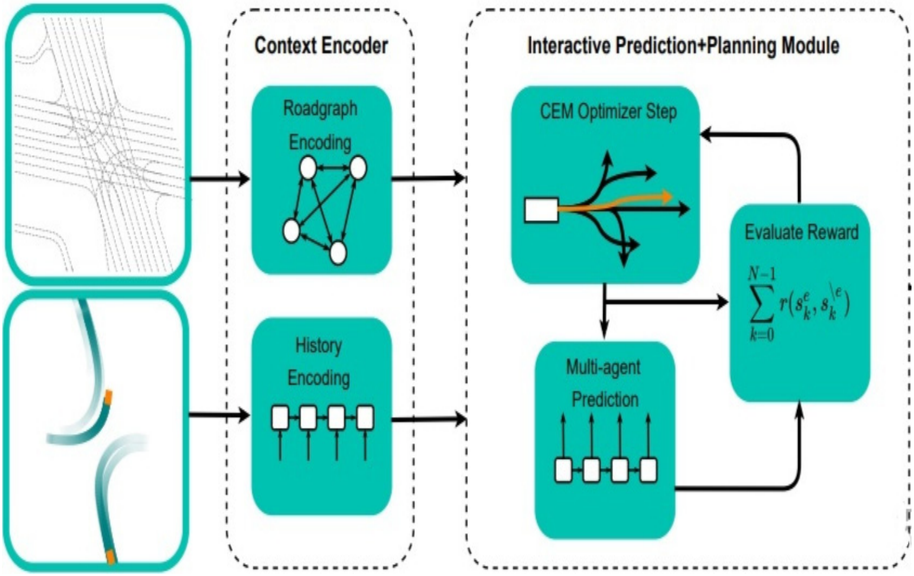

Fig. 3. Auxiliary Intelligent Decision Model

3 System Design

It is the system architecture of the intelligent safety assistance platform for autonomous vehicle at narrow road intersections as shown in Figure 4. The system mainly includes three functions: data collection, information extraction, decision control, and function execution. The data acquisition module collects information and acceleration/deceleration data closest to the vehicle through video speed measurement. The data extraction function reads the signal phase time information on the traffic signal sensor and the parameters data of the approaching target vehicle; The decision control function and intelligent control system use the fixed point boundary mode to evaluate the stability of the current driving behavior, and also control the intelligent underground lighting system and dynamic signal lights through the auxiliary control mode, providing decision-making technical support for driverless vehicles.

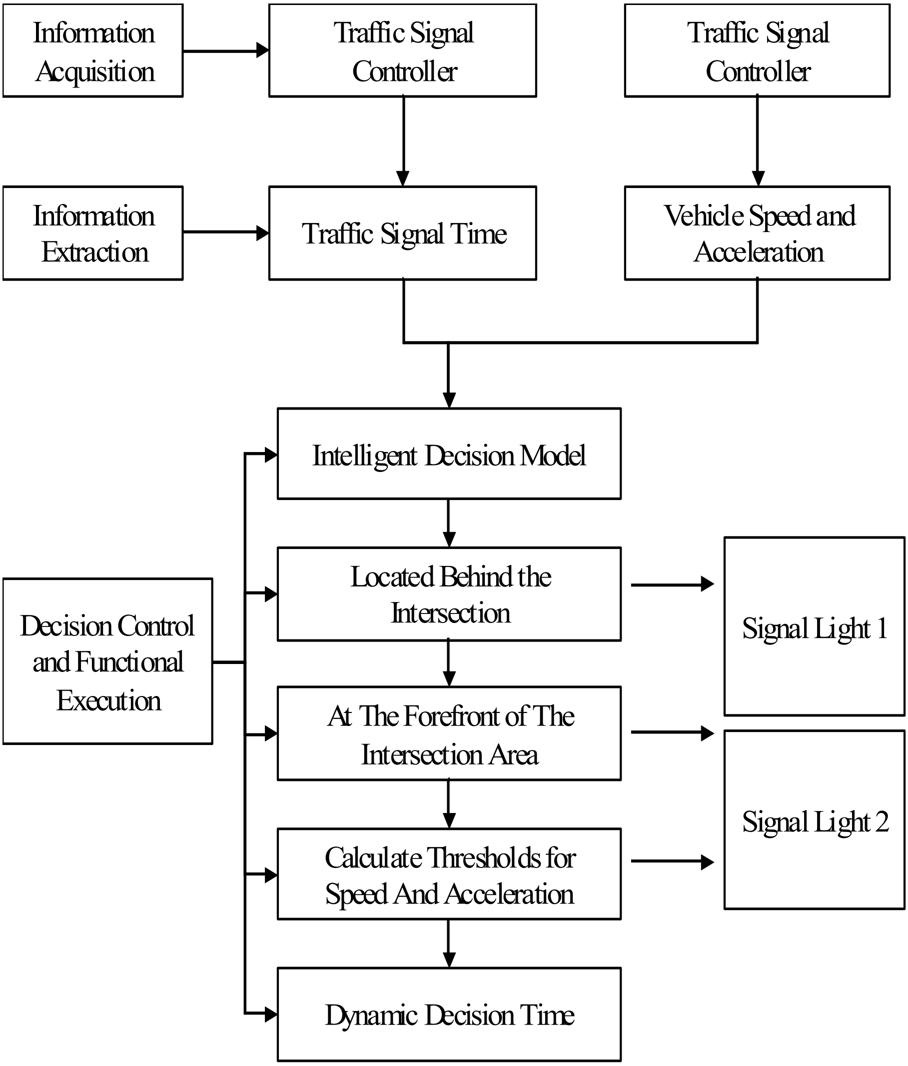

Fig. 4. Plafform Architecture

3.1 Control Unit

The decision control unit mainly includes four modules: signal phase processing module, video speed detection module, data processing module, and intelligent signal light control module. The signals collected by the central processing unit are evaluated for pedestrian safety status and willingness through the active safety decision-making module at narrow road intersections; The intelligent signal light control module monitors the switching status of underground lighting through the indication of the central processing unit, as shown in Figure 5.

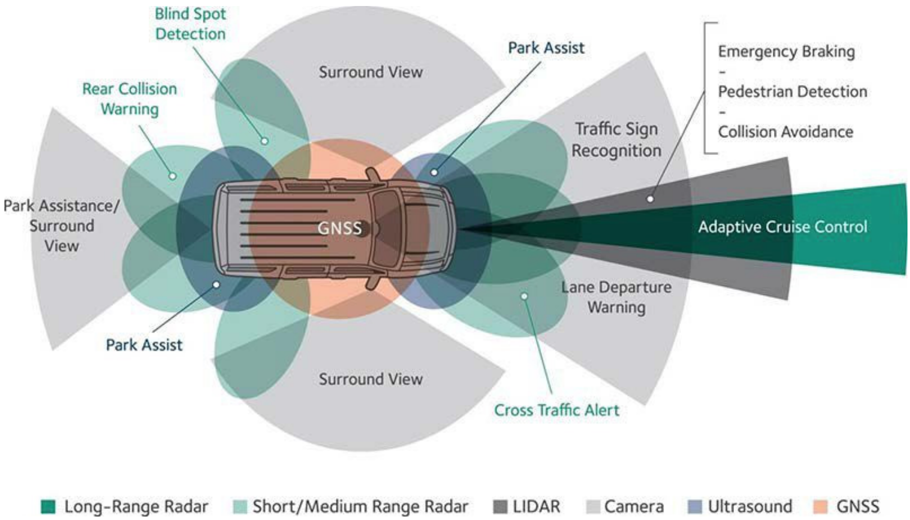

Fig. 5. Control Unit

3.2 Design of intelligent signal lights

The intelligent signal light system adopts a metal sleeve base installed on the edge of the road, and two intelligent indicator lights are installed in the direction of the intersection of narrow roads. The intelligent signal light is unidirectional, but it will not affect the driving of the car in any direction. The top of the intelligent signal light must be three centimeters above the ground, with a waterproof level of IP 67 or above. Outside the LED emitting area, a transparent tempered glass protective plate is embedded in the vertical grating, which can reduce the impact of intelligent signal lights on non motor vehicle lanes and pedestrians.

3.3 Location and Information of Underground Lights

Figure 6 shows the actual situation of road signal light setting and data collection. By stabilizing the brake position Sd indicator, it can be indicated that autonomous vehicle can stop at a narrow road intersection and slow down to a designated position at the safest and more suitable speed. When an unmanned vehicle move to this location, the control module can also determine whether the lights can light up through a preset decision assistance mode. The safe distance can make that the driverless vehicle can travel at the specified safe speed to effectively take braking measures for emergency braking. Se means that the driverless vehicle can decelerate and stop at a high deceleration before the stop line.

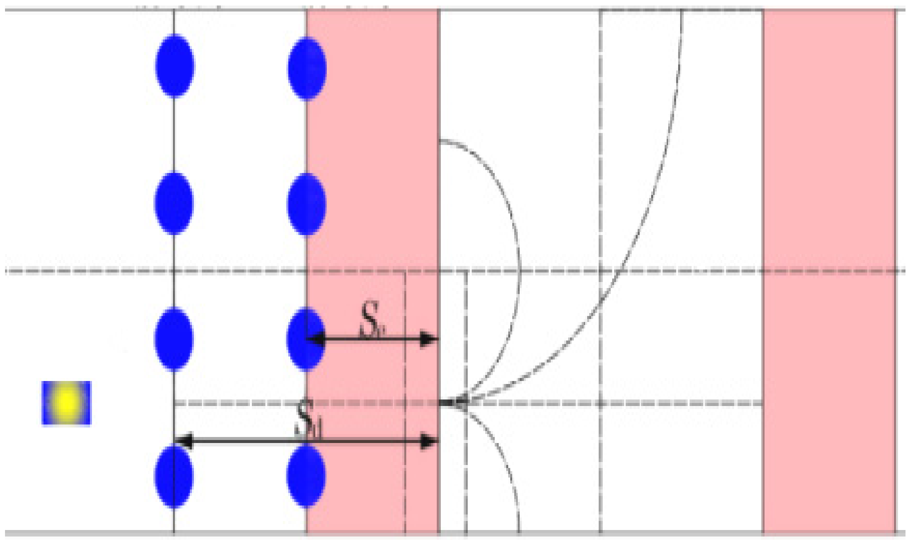

Fig. 6. Signal Lamp Position and Information Detection Position

3.4 Data Collection

The data collection unit collects and processes data on the acceleration signals of motor vehicles entering intersections through video image detection technology. Using the most common and advanced differential image process algorithm at present, and a function similar to the geomagnetic coil of the actual narrow road intersection is established to obtain the actual vehicle speed and acceleration values. Two point like monitoring loops are set up in front of the image detection zone of the narrow line intersection, and differential image analysis is used to approximate the vehicle speed v1 when passing through the midpoint of the narrow road intersection. After configuring loop 3 and loop 4 in the video detection area, the speed value v2 can be obtained. To avoid platform decision-making errors of vehicle lane, the widened length of narrow road intersections can be extended beyond the speed measurement area.

4 Unmanned driving test

Select a virtual road condition at a narrow road intersection as the experimental road and establish a simulated driving environment. In this experiment, 10 underground Autonomous Vehicle were used to pass through the intersection from different directions, and multiple unmanned driving simulations were conducted in the test environment with and without an auxiliary intelligent decision-making module, as shown in Figure 7.

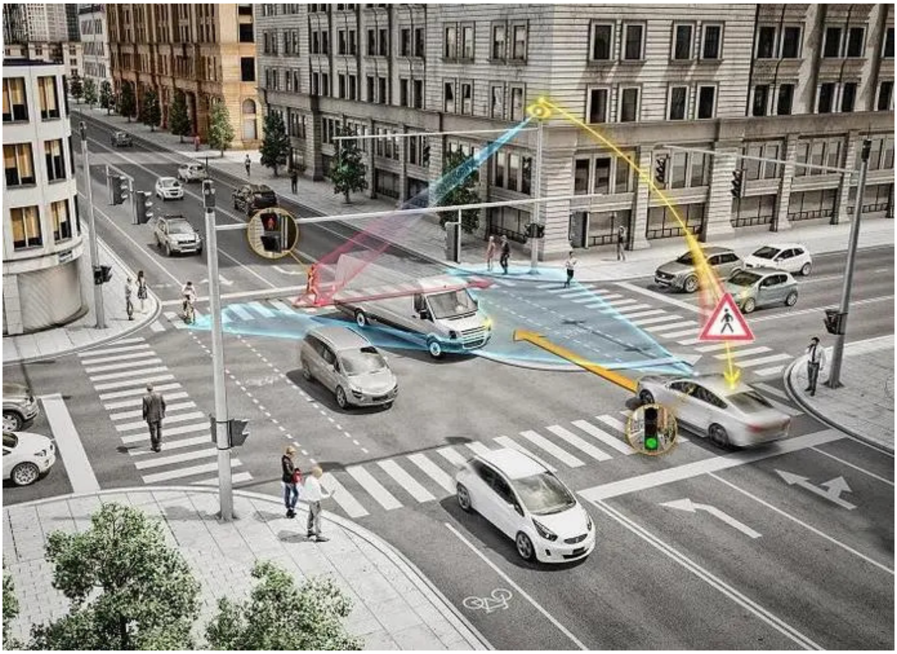

Fig. 7. Unmanned Virtual Test

Collect initial data of each autonomous vehicle driving 8 times and compare and analyze the results with or without an intelligent decision-making system. Among them, the effective driving times for installing an intelligent decision-making system are 78, and the effective driving times for vehicles without an intelligent decision-making system are 75. The safe and uniform passing, deceleration parking, acceleration driving, and frequency of vehicles are shown in Table 1.

Table 1. Test Comparison data

Mode	Safe and uniform passage	Slow down parking	Accelerate driving
With intelligent assistance	35	30	5
No intelligent assistance	30	23	10

As shown in Figure 8, in the simulated unmanned driving test, after being improved to slow down and stop, the proportion of vehicles equipped with auxiliary decision-making systems that slow down and stop increases, while the proportion of vehicles that accelerate and pass decreases.

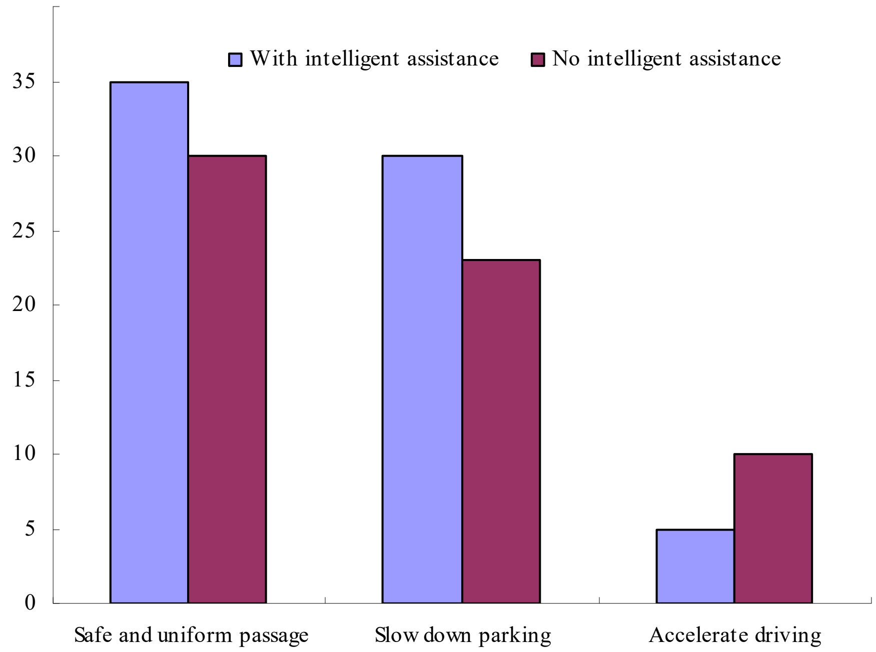

Fig. 8. Analysis of Test Results

5 SUMMARY AND OUTLOOK

According to the data of the dynamic factors of driverless vehicles at narrow road intersections, a fixed point boundary model at narrow road intersections is proposed, and an intelligent aided Decision model is established. By designing an active safety assisted intelligent decision-making system for narrow road intersections, accurate judgment of vehicle safety during signal transition can be achieved. Use signal lights to help the vehicle make visual decisions that reduce vehicle decision-making error behavior and reducing the risk of safety accidents at intersections. This platform promote the decision-making efficiency and safety of intelligent decision-making systems by reducing misjudgment of vehicles at narrow road intersections. The utilization of this platform is limited to specific complex narrow roads, and further optimization of the system is needed in future research. Experiments will be conducted on different narrow roads, underground structures, and intersections to obtain more data and provide more reliable references for optimizing the decision-making system of Autonomous Vehicle on narrow roads

References

1. Li Ping. Underground Space Utilization and Emergency Management Measures in Beijing [J] City and Disaster Reduction, 2020 (1): 39-41
2. Zhang Jing, et al. Implementation of Safety Monitoring and Maintenance System for Underground Structures in Rail Transit [J]. Journal of Civil Engineering and Management, 2018,35 (4): 152-157
3. Li Zhipeng, Cheng Lan, Wang Zhifei, et al. Mobile robot pose estimation based on maximum correlation entropy under the Kalman filter framework [J]. Journal of Taiyuan University of Technology, 2021,52 (6): 936-944
4. Zhao Jing Research on image feature extraction algorithm in visual SLAM [D]. Taiyuan: Taiyuan University of Technology, 2021
5. Zhou Ping. Research on the Unmanned Driving System of Trackless Rubber Wheeled Vehicles in Coal Mines [J]. Industrial and Mining Automation, 2022.48 (6): 36-48
6. Han Jing, et al. Key Technologies of Unmanned Driving System for Underground Locomotives in Coal Mines [J] Coal Journal, 2020, 45 (6) -2104 2115
7. Zhu Pingping, et al. Design and Application of Autonomous Driving Control Algorithm for Seismic Vehicle [J]. Journal of Mechanical Engineering, 2022, 58 (6) -211-220
8. Zhu Wu, et al. Research on Safety Control of Unmanned Trucks in Open Pit Mines [J] Chinese Journal of Safety Science, 2021-31 (S1): 43-48
9. Li Jing. Discussion on the latest technological progress and problems of coal mine intelligence [J] Coal Science and Technology, 2022,50 (1): 1-27
10. Zhao Guo, Research and Practice of Coal Mine Intelligence (Primary Stage) [J]. Coal Science and Technology, 2019,47 (8): 1-36
11. Li Jing. Current Situation and Development of Intelligent Transportation Technology in Open Pit Mines in China [J]. Industrial and Mining Automation, 2022, 48 (6): 15-26