Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2023, 10(8):70-76**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Coordinated control of intelligent networked vehicles on narrow roads

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Abstract As an inevitable bottleneck section in the traffic scene, the cooperative passage of narrow roads is of great research significance. When the intelligent connected car passes through the narrow roads, it is easy to trigger the collision avoidance mechanism to form a dead knot, which seriously affects the traffic efficiency. The existing researches mainly focus on vehicle cooperative lane change, lane keeping and intersection cooperative control, there are few studies on the coordinated passage of narrow road sections. In this paper, the narrow roads is defined and a Cooperative Speed Harmonization (CSH) model is used. In this model, the two circular centers on the two sides of the narrow roads are drawn by two virtual waves: solid wave and dotted wave. At the same time, the vehicles on both sides of the narrow roads form a vehicle cluster in advance, and the virtual wave leads the vehicle cluster alternately through the narrow roads. In the experimental research, SUMO and MATLAB co-simulation are used, and three indicators are selected: The average waiting time, average journey time and average speed, compared with the passing efficiency under CSH model and free passage, the analysis shows that under the action of CSH model, vehicles pass alternately, there is no stopping and waiting phenomenon, the average waiting time is 0, the average journey time is reduced by 37.81%, and the average speed is increased by 90.86%. The traffic efficiency of narrow roads has been significantly improved.

Keywords Intelligent Connected Vehicle; narrow roads; CSH model; SUMO

1. Introduction

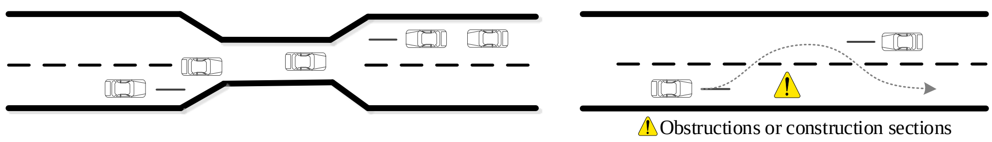
Research on vehicle cooperative control can be divided into longitudinal cooperative control and lateral cooperative control. The research focus of longitudinal cooperative control is ACC (Adaptive Cruise control), Ioannou and other scholars from the University of Southern California developed an autonomous intelligent cruise control system in 1993, which can automatically track vehicles, and studied the impact of this control system on traffic flow, and compared with other artificial driving models, the results show that, The performance of this control system is better than other driving models that consider people [1]. In 1995, scholars Yana Kiev and others from the University of California, Los Angeles proposed an adaptive nonlinear control scheme, which can be used for longitudinal control of automatic heavy vehicles, in which the headway changes linearly with the speed error [2]. Recently, Guo Lie and other scholars from Dalian University of Technology proposed a multi-objective adaptive cruise control strategy, which analyzed the mutual longitudinal kinematic characteristics between the front vehicle and the main vehicle from the perspective of vehicle spacing, relative speed, acceleration, and the changing law of acceleration of the front vehicle [3]. Xin Qi and other scholars from Chang 'an University studied the optimal speed function, introduced the constant headway and variable headway strategies, and proposed two new vehicle tracking models [4].

Lateral cooperative control mainly focuses on vehicle lane changing and lane keeping. Tzu-Chi et al. simulated various driving tasks by using vehicle and system dynamics of coordinated control architecture and proposed a control architecture that can realize improved vehicle lane changing and tracking [5]. Ding Wanting built a collaborative lane change model among multiple vehicles, which adopted the double matrix method and mainly considered how the main vehicle could quickly and efficiently make a collaborative lane change when it knew that surrounding vehicles needed to change lanes at the same time [6]. Yang Gang et al. focused on the complex scene with eight vehicles around the three lanes in the same direction, designed the track model of vehicle-vehicle collaborative lane change under the circumstance of vehicle-vehicle communication, and carried out simulation verification [7]. Xue Chunming designed a system based on neural network to recognize the driving characteristics of surrounding vehicles, which can predict the driving intention of surrounding vehicles with a high probability and improve the driving safety of intelligent networked vehicles in complex environments such as urban areas [8]. However, the above studies rarely focus on the collaborative passage of narrow road sections. This paper studies the collaborative passage of intelligent networked vehicles in narrow road sections.

2. Narrow roads scenario

Narrow roads is a common unavoidable bottleneck section, which is caused by road design, construction and maintenance, traffic incidents and lane narrowing. Lane narrowing under normal design can reduce land use to a certain extent, and is also one of the effective means to solve the current uneven speed and disorderly driving on urban roads. However, in practice, the problem of meeting congestion often occurs in these sections. Due to the narrow lane, the driver's operation behavior when following, overtaking or parallel is somewhat different from that of the wider lane. Generally, one side will stop or even reverse to make the other side pass first, so as to ensure the smooth road. Since the vehicle itself does not have any control strategy for meeting vehicles, the vehicle may trigger its own collision avoidance mechanism and stop in a narrow section, resulting in road congestion. Even if it can bypass the collision avoidance mechanism and pass smoothly, the traffic efficiency is still very low due to the lack of effective traffic strategy organization and guidance, and the road service level is seriously reduced.

According to the section where the meeting condition occurs, the meeting can be divided into narrow road meeting and narrow bridge meeting. According to the reasons for the formation of narrow sections, it can be divided into the meeting caused by obstructions and the meeting caused by the narrow road itself. The specific scenario is described in Figure 1.



(a)narrow bridge *(b)narrow roads*

Figure 1: Narrow roads meeting scene

3. Cooperative Speed Harmonization model

In order to make the vehicles on both sides of the narrow road alternately pass through the narrow road, avoid the occurrence of a dead knot in the narrow road, avoid traffic jams and unnecessary vehicle start and stop, and reduce the parking waiting time,The Cooperative Speed Harmonization model(CSH) model was used, which was used to solve an on-ramp junction on the E6 motorway in Gothenburg[9]. The two ends of the narrow road are taken as the two centers of the virtual wave, and the vehicles are grouped into clusters close to the nearest virtual wave by centralized control method. Virtual waves on both sides of the road guide vehicles on both sides to alternate through narrow sections at different times. The clustering process of vehicles on both sides of the narrow road is shown in Figure 2.

As can be seen from Figure 2, the left end point of the narrow road section is set as the center of the solid line wave, the right end point of the narrow road section is set as the center of the dotted line wave, the vehicles on the left side of the road are guided by the solid line wave, and the vehicles on the right side of the road are guided by the dotted line wave, and the vehicles adjust their own speed to get closer to the nearest virtual wave. Clusters 1 and 3 are formed on the right side of the road, and clusters 2 and 4 are formed on the left side of the road. Clusters one, two, three and four alternates through narrow sections in sequence.

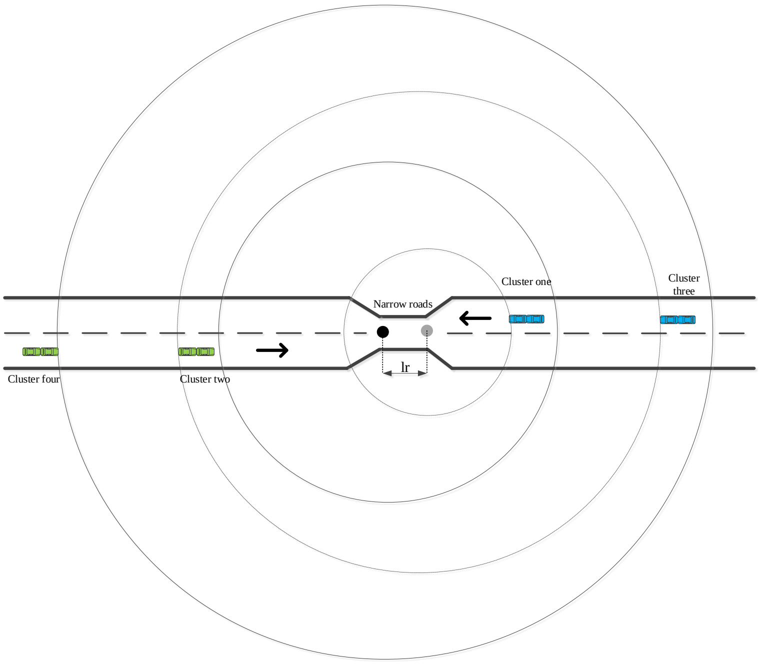


Figure 2: Diagram of vehicle clustering process

The method of obtaining the distance between the right side of the narrow road and the front wave of the vehicle is as follows:

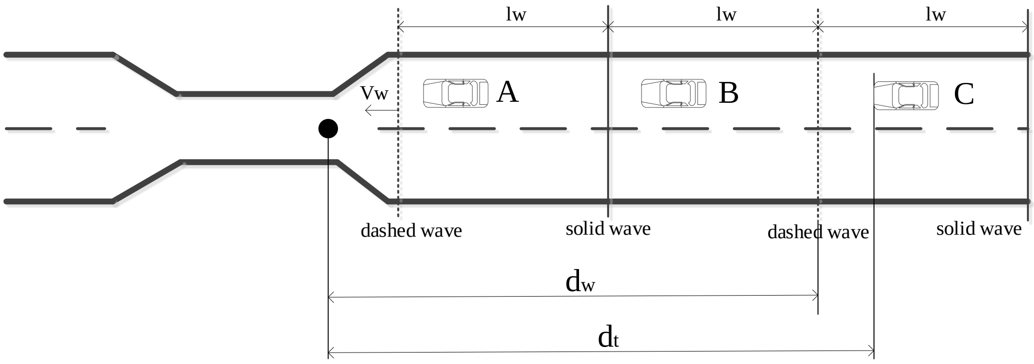


Figure 3: The distance diagram between the position on the right side of the narrow road and the front wave of the vehicle is obtained

First, the distance between the position on the right side of the narrow road and the front wave of the vehicle is obtained:

$$d_{wright} = l_w \times \lfloor d_{tright} / l_w \rfloor - v_w \times \mathrm{mod}(t, l_w / v_w) \qquad (1)$$

Where, l_w is wavelength, d_{tright} is the distance between the current vehicle and the center of the narrow road, v_w is the speed of the virtual wave traveling to the intersection, and t is the system time.

In order to make the arrival time of vehicles on both sides of the narrow road different, the virtual wave of vehicles on the left side of the narrow road is increased by 1/2 wavelength. The distance between the vehicle and its front wave is then calculated.

$$e_{tright} = \begin{cases} d_{tright} - d_{wright}, & d_{wright} < d_{tright} and n \le n_c \\ d_t - (d_w + l_w), & else \end{cases} \qquad (2)$$

Where, n is the number of vehicles in the current cluster, is the maximum number of vehicles in the cluster, n_c is a set constant.
Finally, the speed of the vehicle on the right side of the narrow road can be estimated as:

$$v_{vehicle} = \max\left\{ e_{tright} * P + \sum_{0}^{T} e_{tright} * I + \Delta e_{tright} * D, \ v_{\min} \right\} \tag{3}$$

Where P , I , D , T is the controller parameter, $v_{\min}$ is the minimum speed of the vehicle running, Δe_t is the difference between e_t , where the maximum operator can make the appropriate controller output speed when the difference is too low.
When vehicles on one side of the road are about to reach the narrow section, there may be a situation where there are no vehicles on the virtual wave on the other side. For example, when cluster 1 reaches the narrow section in Figure 5, cluster 4 is formed instead of cluster 2, which is related to the arrival time of vehicles in reality. In order to save the vehicle passing time and allow the vehicles of cluster 4 to break through the virtual wave speed, the vehicles of cluster 4 are made to reach the side of the narrow road approaching when the vehicles of cluster 1 pass through the narrow road.

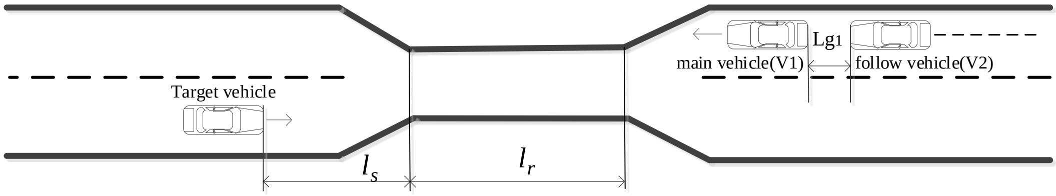


Figure 4: Schematic diagram of the narrow roads passage process

The length of the vehicle cluster is: L_c . If the vehicle cluster on the right side of the road has reached the narrow section, it can be obtained that the time required for the right side of the road cluster to pass the narrow section is:

$$t = \frac{L_c + l_r}{v} \tag{4}$$

Where, v is the speed of the cluster, $L_c + l_r$ is the total length of the cluster through the narrow roads. The recommended speed of the target vehicle can then be obtained:

$$v_s = \frac{l_s}{t} \tag{5}$$

When the cluster on the right is about to enter the narrow road section, the vehicles on both sides of the narrow road upload their positions to the road side unit through wireless communication. The road side unit calculates the distance between the target vehicle on the left side of the narrow road and the narrow road section at this moment, and feedbacks the suggested speed to the two target vehicles. When the target vehicle on the left side of the narrow road runs at the suggested speed, theoretically, after the main vehicle passes the narrow road, the road can be built up. Pass narrow roads without stopping.

4. Results & Discussion

SUMO and MATLAB co-simulation were used for experimental analysis, and a total of two sets of control simulation conditions were designed to make 50 vehicles pass through the narrow section. One of them passed through the narrow section under the CSH model, and the other vehicle passed through the narrow section freely according to its own driving model to simulate the free passage state under manual driving. The simulation scenario is shown in Figure 5.

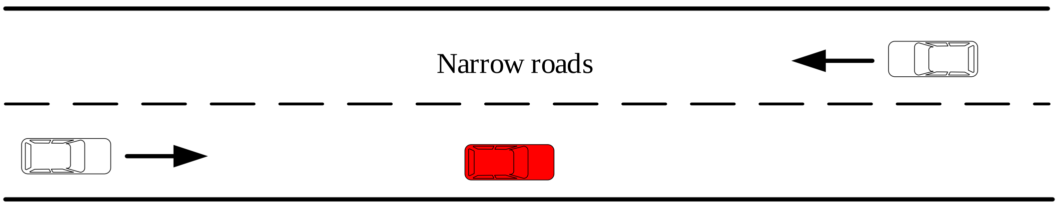


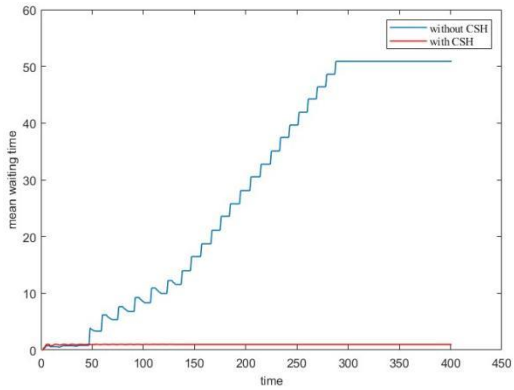
Figure 5: Simulation scene

In this simulation scenario, the vehicle cluster is set to 3 and the length of the narrow road section is 60m. The vehicle parameters generated at the starting and ending points are shown in Table 1.

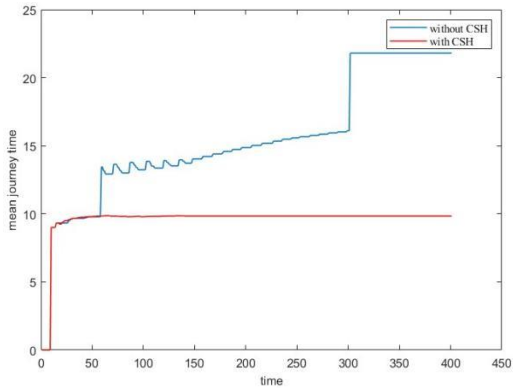
Table 1: Vehicle parameter list

Vehicle Parameters	Numerical Value
initial velocity/（m/s）	20
long/（m）	5
Minimum shop spacing/（m）	2.5
maximum acceleration/（m/s）	2.6
maximum deceleration/（m/s）	4.5

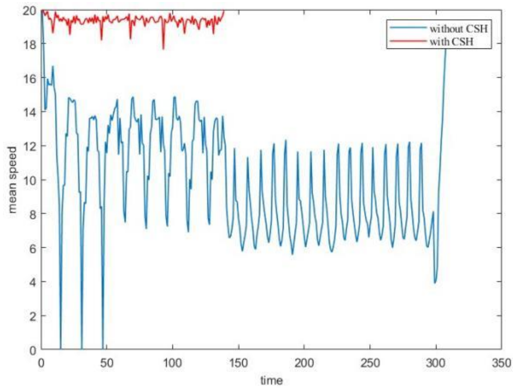
And set the obstacle vehicle on the road, its initial speed, maximum acceleration, and maximum deceleration are set to 0m/s, so that it is stationary on the road to form a narrow section of traffic. Considering comprehensively, this paper selects three evaluation indexes: average waiting time, average journey time and average speed. They can be obtained directly from SUMO simulation results, which is convenient and fast.After processing the obtained data, the comparison effect of narrow road passage and free passage based on CSH (cluster is 3, vehicle is 50), average waiting time, average journey time and average speed are obtained, respectively, as shown in Figure 6.



(a) mean waiting time



(b) mean journey time



(c) mean speed

Figure 6: Traffic effect comparison diagram

The average waiting time under free passage is much longer than the time required for CSH passage. At the same time, it can be seen that due to the reason that vehicles alternately pass through the CSH model, there is no parking waiting phenomenon, and the average waiting time is 0. The passing process of vehicles is more regular and the passing efficiency is higher. It can be seen from the average journey time that under the CSH model, the vehicles pass through the narrow road quickly, and the average journey time rises sharply at first, and then stays the same. The vehicles under free passage fluctuate slightly in the middle because there are many stops and waiting phenomena. In terms of average speed, the average speed under the CSH model is 20m/s on average, while under free passage, the average speed of the vehicle first rises and then falls, there are many ups and downs, after 150s, the vehicle does not stop, only decelerates through, and finally after 300s, there is no congestion, the average speed begins to rise. It can be seen from the figure that the vehicle has a more stable running speed and higher efficiency under the action of CSH model.

5. Conclusion

Overall, the average speed of vehicles under the CSH model is significantly increased, and the average journey time is significantly reduced. It is worth debating whether every car in the system benefits from this, and future transportation systems are identified by the vehicle's various sensors. For a long time, cars in the traditional sense had neither automation nor V2V capability. Most modern vehicles are equipped with automation equipment or V2V capabilities, and fully autonomous vehicles with both automation and V2V capabilities will soon become a reality. Due to the intelligence of the various players in the transportation system, adapting to the common interest will be a very big challenge. As the simulation shows, the overall operating efficiency of vehicles with and without the CSH crossing mechanism is significantly different, with vehicles using the mechanism running smoother on average, with shorter transit times and waiting times.

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