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Research Article

Single-Point Adaptive Control Method for Urban Mixed Traffic Flow

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In urban traffic, motor vehicles, nonmotor vehicles, pedestrians, and other traffic are mixed, which seriously affects the urban traffic efficiency. At the intersections of urban roads especially, the priority setting of various travel modes is crucial to improve the urban traffic efficiency. In the urban hybrid traffic system, the architecture and algorithm flowchart of the single-point adaptive control system for urban hybrid traffic flow are presented. The control effect of this method is verified by VISSIM software. The simulation results show that the traffic efficiency of the priority objects at the intersection is increased by 6.03%, and the overall traffic efficiency is also significantly improved. This method has a certain practical value.

1. Introduction

With the acceleration of China's urbanization process, increasingly people are living in big cities, and the amount of urban traffic is greatly improved, and the urban traffic problem is becoming increasingly serious. Serious urban traffic problems affect the daily travel of residents and the healthy and rapid development of the city. Urban traffic has become a bottleneck that restricts sustainable development. The main body of travel behavior in urban traffic mainly includes motor vehicle, nonmotor vehicle, and pedestrian. Their travel rules and traffic characteristics are quite different, but their travel behaviors can bring urban traffic pressure. In the complex traffic problems of the city, the traffic behavior at the intersection is one of the breakthrough points to solve the traffic problems. Therefore, how to improve the efficiency of mixed traffic at urban road intersections in China will become a difficult problem to solve in urban traffic management and control [1–3]. The proportion of nonmotor vehicles in China is as high as 40–65%, and this mode of travel has the characteristics of high time share and high accident rate. At present, some scholars have studied the traffic conflicts of motor vehicles, nonmotor vehicles, and pedestrians at intersections, analyzed the causes of the conflicts, and put forward corresponding solutions [2]. Among the existing research results, some scholars put forward reasonable control strategies for the travel behaviors of nonmotor vehicles and pedestrians [4–8]. However, no one has studied how to automatically assign priority to urban road intersections according to the dynamic demand of mixed traffic flows. At present, with the development of urban traffic information technology, urban traffic management and control system is gradually improved, and urban mixed traffic management and control ability is also improved.

Based on the above situation, the cellular automaton model is used to analyze the characteristics and requirements of the mixed traffic in the intersection. At the same time, combining the traffic functions and characteristics of urban road intersections, the decision-making logic of traffic priority of mixed intersections is formulated, the mixed traffic flow table of urban road intersections is proposed, and the adaptive control method is adopted to effectively improve the traffic efficiency of mixed traffic at urban road intersections.

2. Traffic Demand Analysis of Mixed Traffic Flow at Intersection

For mixed traffic intersections, the premise of traffic management and control is to obtain more accurate traffic demand of mixed traffic flow. Because there are differences in occupied area and speed between motor vehicles, nonmotor vehicles, and pedestrians, the flow of the three is converted into standard vehicles equivalent (passenger car unit, PCU), which can reflect the real traffic demand [9].

Standard vehicle equivalent conversion to mixed traffic flow refers to the process of converting the detected vehicle flow q_a , nonmotor vehicle flow q_b, and pedestrian flow q_c into standard vehicles conversion equivalent vehicle equivalent, and according to different conversion coefficients [10]. The traffic characteristics of motor vehicles, nonmotor vehicles, and pedestrians are analyzed using cellular automaton model [11, 12], as shown in Figure 1.

In Figure 1, A is a motor vehicle model, B is a nonmotor vehicle model, and C is a pedestrian model. In the spatial dimension, due to the difference of vehicle spacing, body width, and lane width, the three traffic objects can establish the conversion relationship shown in the figure. In terms of time dimension, there are differences in the speed of different objects in the actual traffic process. These differences also affect the conversion coefficient. Therefore, it is necessary to synthesize the space and time dimensions to get the standard equivalent conversion coefficient of motor vehicles, nonmotor vehicles, and pedestrians [13].

Because the behavior of traffic objects is random, a large number of data surveys are usually needed to calibrate a reasonable conversion coefficient K. For example, in the calibration of the conversion coefficient of nonmotor vehicles, the area occupied by nonmotor vehicles is about 1/5, so the conversion coefficient is about 0.2. However, the speed of nonmotor vehicles is lower than that of motor vehicles when passing through intersections, so the conversion coefficient should be greater than 0.2. According to the data and the research of some scholars, the empirical value of the best conversion coefficient of nonmotor vehicles is basic in the range of 0.25–0.3 and that of pedestrians is about 0.5. The practical application is based on the actual calibration results.

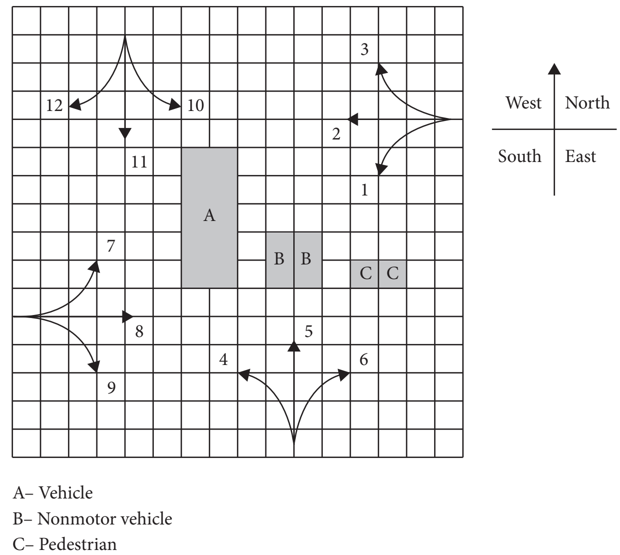


Figure 1: Schematic diagram of mixed traffic flow at intersection.

3. Priority Decision of Intersection Release

Because of the difference of mixed traffic flow and the different function orientation of intersections, urban road intersections often present different mixed traffic states and traffic characteristics. This difference in mixed traffic status and traffic characteristics reflects the actual demand for priority clearance at intersections and is the main factor affecting the decision-making of priority allocation of road rights. However, there are some dynamic changes in these factors. In this section, priority comprehensive evaluation rules are formulated to make priority allocation decisions. The decision process is shown in Figure 2. Firstly, dynamic priority assessment is carried out based on mixed traffic flow demand, and static priority assessment is carried out based on intersection function positioning. Finally, dynamic and static evaluation results are integrated for decision-making to obtain intersections. The results of priority assignment of comprehensive are road rights. For intersections with special needs, the final priority can be directly determined by manual intervention.

3.1. Dynamic Priority Assessment Based on Mixed Traffic Flow Demand. Section 1 converts motor vehicles, nonmotor vehicles, and pedestrians at intersections into standard vehicles equivalent q'_a, q'_b, q'_c. When η is defined as the weight value of mixed traffic flow, the weight value of each traffic object can be expressed as

$$\eta = \frac{q'}{q'_{\text{total}}}. \quad (1)$$

In the formula, q' is the standard vehicle equivalent of an object in mixed traffic flow, PCU; q'_{total} is the sum of the standard vehicle equivalent of all kinds of traffic flow at the intersection, PCU, i.e., $q'_{\text{total}} = q'_a + q'_b + q'_c$.

η_a, η_b, and η_c represent the weights of motor vehicles, nonmotor vehicles, and pedestrians in the whole mixed traffic flow, respectively. The size of the weights reflects the dynamic demand for the release of such objects in the mixed traffic flow at the whole intersection. Obviously, the range of η is $[0, 100\%]$. The traffic object corresponding to $\eta_{\max} = \max(\eta_a, \eta_b, \eta_c)$ and $\eta_{\max}$ is defined as the object requiring priority release. The magnitude of $\eta_{\max}$ value reflects the strength of priority release demand, which determines the strength of specific priority release strategy. Seven priority states and strengths are obtained by numerical segmentation of $\eta_{\max}$, as shown in Table 1. In Table 1, letters are used to denote priority release categories: A denotes priority release for motor vehicles, B denotes priority release for nonmotor vehicles, C denotes priority for pedestrians, and O denotes freedom release; numbers are used to denote priority release intensity: 1 denotes general priority intensity, and 2 denotes

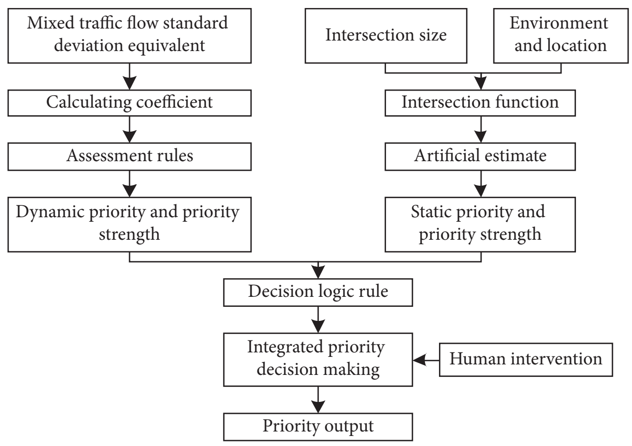


Figure 2: Decision-making process of intersection releasing priority.

Table 1: Category and degree of intersection releasing priority.

η_{max}	Value priority	Category	Priority intensity
η_a	(33.3%, 40%]	Free release	O
	(40%, 55%]	Vehicle	A1
	(55%, 100%]	Vehicle	A2
η_b	(33.3%, 40%]	Free release	O
	(40%, 55%]	Nonmotor vehicle	B1
	(55%, 100%]	Nonmotor vehicle	B2
η_c	(33.3%, 40%]	Free release	O
	(40%, 55%]	Pedestrian	C1
	(55%, 100%]	Pedestrian	C2

strong priority intensity, of which 40% and 55% are artificially set critical values, which can be fine-tuned according to o an actual situation.

3.2. Static Priority Assessment Based on Intersection Functional Location. Due to the difference between the road scale and the location environment, urban road intersections often have different functional orientations, which affect the objectives and focus of traffic control, and are one of the influencing factors of the decision of the intersection release priority. The dynamic and randomness of the mixed traffic flow, the function of the intersection is relatively stable, and the travel of the residents near the intersection is subject to the regularity of the building function around the intersection. This regularity reflects the priority of the intersection. Release static requirements.

According to the different road grades formed by intersections, urban intersections can be generally divided into six categories as shown in Table 2.

The six different types of intersections have unique functional positioning. For example, Class 1 intersections are the intersections of urban main roads. They bear the main motor vehicle flow and often need to give priority to the right of motor vehicles; for roads 4, 5, and 6, at the intersection, motor vehicles may be relatively low, and it is often necessary to give priority to the right of nonmotor vehicles and pedestrians.

Table 2: Intersections sorted by scale.

Road classification	Intersection classification		
	Main road	Secondary road	Branch road
Main road	1	2	3
Secondary road	2	4	5
Branch road	3	5	6

The environment in which the intersection is located also affects the mixed traffic flow at the intersection, such as intersections between hospitals, schools, shopping malls, and pedestrian streets, and the density of people; the factories near the suburbs and the intersections near the business districts are often dense during commuting hours. In terms of nonmotorized traffic, intersections in urban commercial centers, government, and stations are often densely trafficked. This is also a relatively regular factor in the process of prioritizing decisions at intersections.

The difference in the functional location of the intersection caused by the size of the intersection and the environment in which it is located reflects the static demand of the priority of the intersection. This kind of demand tends to be stable in a certain period of time, and it is difficult to quantify. Therefore, it is generally evaluated by expert experience, and the different intersections are manually divided into (A) motor vehicle priority, (B) nonmotor vehicle priority, (C) pedestrian priority, and (O) freedom to pass four categories of priority. The priority strength defaults to level 1, which can be adjusted according to the actual situation.

Table 3 shows the general logical rules for the decision of right priority allocation at urban road intersections. In practical application, the static priority of manual decision can be divided into finer boundaries and different priority intensity can be set to meet different control requirements. The dynamic priority decision boundary based on the flow can also be adjusted according to the actual control effect. After the comprehensive right-of-way priority allocation decision is formed, human intervention enjoys the highest priority and can finally adjust the priority object and intensity output to the signal control algorithm.

4. Single-Point Adaptive Control Algorithms for Mixed Traffic Flow

Urban road intersections have different isolation status for mixed traffic flow. The algorithm does not consider the influence of pedestrian crossing bridges and other factors on the mixed traffic flow at the intersection. The standard motor vehicle, nonmotor vehicle, and hybrid pedestrian control intersections are selected (Figure 3). For the example of the algorithm, the standard four-phase control strategy [14] is adopted by default, and the phase sequence is shown in Table 4.

4.1. Algorithmic Flow. The single-point adaptive control algorithm for mixed traffic flow is based on the characteristics of the mixed traffic flow state at the intersection and the

Table 3: Logic rules of integrated release priority decision.

Priority type	A1	B1	C1	0
A2	A2	A1	A1	A2
A1	A1	0	0	A1
B2	B1	B2	B1	B2
B1	0	B1	0	B1
C2	C1	C1	C2	C2
C1	0	0	C1	C1
0	A1	B1	C1	0

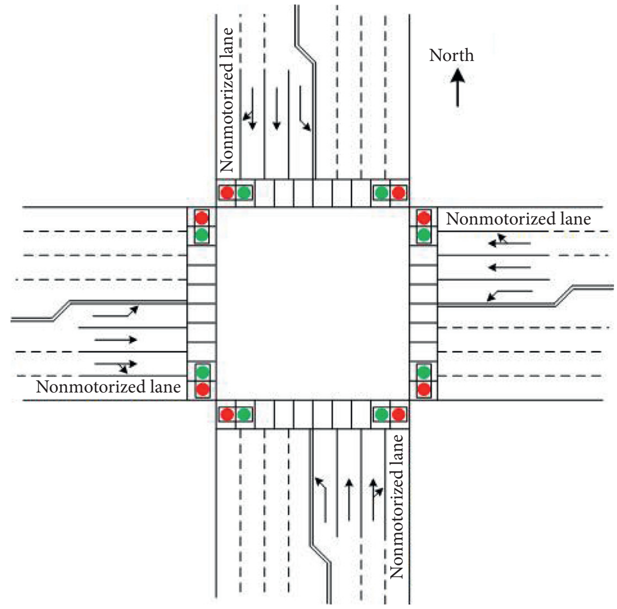


Figure 3: Mixed control intersection.

function of location of the intersection. The assignment of the right priority is made, and the phase, green time, and period of the intersection control are automatically adjusted. Regarding the algorithm of automatic control, the algorithm flow is shown in Figure 4. The priority allocation decision has been introduced in detail in Section 2. The three core processes of priority control strategy selection, green time calculation, and cycle calculation are highlighted here.

4.2. Scheme Computation

4.2.1. Priority Control Strategy. The maximum capacity of urban road intersections is fixed. For mixed traffic flow, the preferential traffic of one object means the loss of the right of other objects. According to the priority, the priority control strategy of mixed traffic flow is divided into free strategy. For passage, motor vehicles, nonmotorized vehicles, and pedestrians should have the priority access.

Free passage means that motor vehicles, nonmotor vehicles, and pedestrians have equal rights of passage and are released according to the conventional phase. Motor vehicles have priority access, generally through the late and early break of nonmotor vehicles and pedestrian phases. The traffic jam mainly comes from the preferential traffic of motor vehicles, nonmotor vehicles, and pedestrians, all of which are realized by the late and early break of the phase of the motor vehicle. When the east-west flow direction and the north-south flow preferentially have greater priority, the pedestrian phase can be increased at the end of the phase. The phase release diagram is shown in Figure 5. The other phases are not released for pedestrians, reducing mutual interference.

Taking the motor vehicle east-west direction and turning right to the priority behavior example, according to the corresponding priority control strategy, the release phase is adjusted as shown in Table 5. The adjusted phase is prematurely broken by the late passage of nonmotor vehicles and pedestrians, realizing the priority of motor vehicles. In practical applications, it is also possible to use only one of the late or early break strategies for priority release.

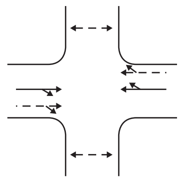
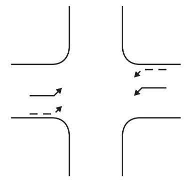
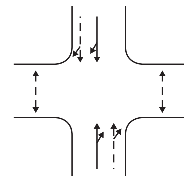
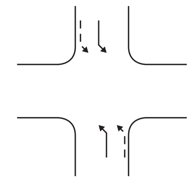
4.2.2. Phase Green Light Time. Taking the motor vehicle east-west right-turning priority behavior example in Table 4, the green time of the motor vehicles, nonmotor vehicles, and pedestrians in the flow direction is calculated. According to the road right priority allocation strategy in Section 3, it can be known that when the motor vehicle is preferentially trafficked, $q_a' = \max(q_a', q_b', q_c')$, and at this time, the nonmotor vehicle and pedestrian are late and early, and the green light time calculation process of the phase pass is

$$\begin{aligned} t_{g\_s}^{a} &= \min\left(q_a' \cdot h_{0\_s}, t_a^{\max\_g}\right), \\ t_{g\_s}^{bc} &= \max\left(\max\left(q_b' \cdot q_c'\right) \cdot h_{0\_s}, t_b^{\min\_g}, t_a^{\min\_g}\right), \\ \Delta t &= t_g^a - t_{g\_s}^{bc}, \\ t_{g\_s}^{bc\,\prime} &= t_{g\_s}^{a} - \beta \cdot \Delta t, \end{aligned} \tag{2}$$

where $t_{g\_s}^{a}$ is the green time required for the passage of the motor vehicle, s; h_{0_s} is the standard vehicle straight-line saturated headway time, (s/veh); $t_a^{\max\_g}$ is the maximum green time of the motor vehicle, s; $t_{g\_s}^{bc}$ is the green time required for the passage of a relatively large vehicle equivalent of a motor vehicle or a pedestrian standard vehicle, s; $t_b^{\min\_g}$ is the minimum green time of the nonmotor vehicle, s; $t_c^{\min\_g}$ is the minimum green time of the pedestrian, s; Δt is the reference time that can be delayed and prematurely broken, s; $t_{g\_s}^{bc}$ is the passing green time of the final nonmotor vehicle and pedestrian, s; β is the phase delay and early break time correction coefficient. The value of β is affected by the priority strength and is a configurable parameter. When the priority strength is 1, β takes 30%–60%; when the priority strength is 2 or higher, β takes 60%–100%. The principle of determining the late-onset and early-break time is to ensure the theoretical release time of all traffic objects without manual intervention. The calculation of the remaining phase green time is similar to this method and will not be described.

4.2.3. Cycle. By definition, the signal period of the intersection is the sum of the green, yellow, and red light times of each phase. For the single-point adaptive control algorithm of mixed traffic flow, the green time of each phase contains the transit time of different objects, and the maximum value is taken as the green time of the phase. The formulas are, respectively,

TABLE 4: Standard four-phase control strategy.

Phase sequence	Phase 1	Phase 2	Phase 3	Phase 4
Phase map				

The solid line represents the phase of the motor vehicle; the dotted line represents the phase of the nonmotor vehicle; the dashed line represents the phase of the pedestrian.

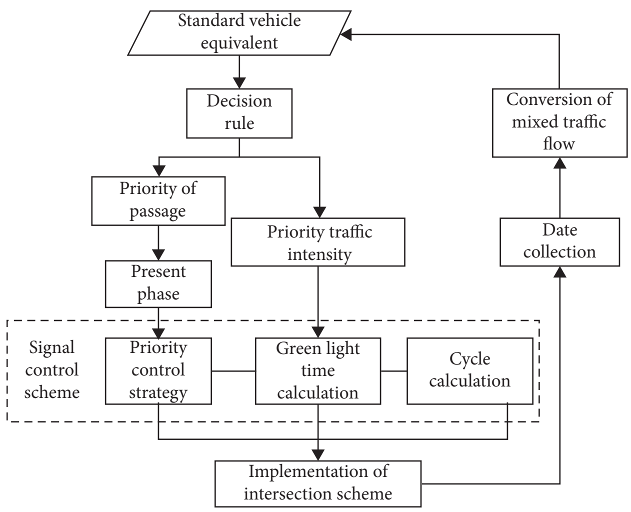


FIGURE 4: An adaptive signal control algorithm process of mixed traffic flow.

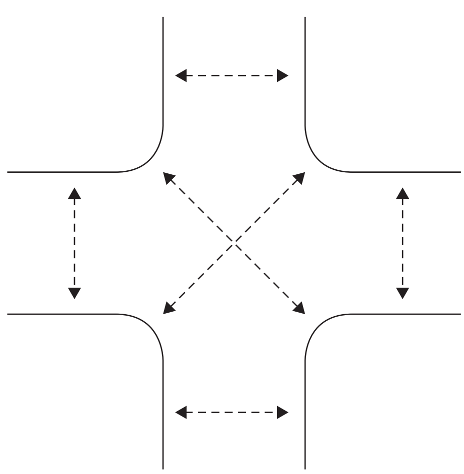


FIGURE 5: Separate releasing phase for pedestrians.

$$T = \sum_{i=1}^{n}\left(t_{g,i} + t_{y,i} + t_{r,i}\right),$$
$$t_{g,i} = \max\left(t_{g,i}^{a} + t_{g,i}^{b} + t_{g,i}^{c}\right), \quad (3)$$

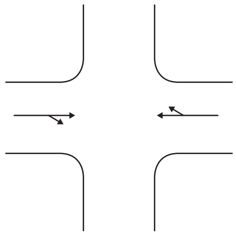
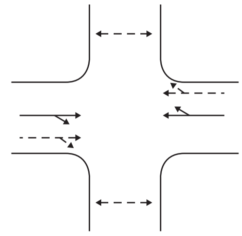
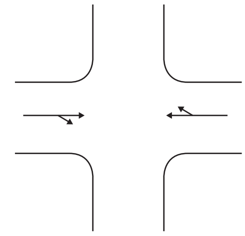
where T is the signal cycle time performed by the intersection; $t_{g,i}$, $t_{y,i}$, and $t_{r,i}$ are the phase green time, yellow time, and full red time of phase i; $n$is the number of phases; $t_{g,i}^{a}$,$t_{g,i}^{b}$, and $t_{g,i}^{c}$ are phase i of motor vehicles, nonmotor vehicles, and pedestrians travel time, respectively.

5. Simulation Verification

The intersection of the actual mixed traffic flow in a certain city is selected. The northwest corner of the intersection is a commercial complex of large supermarkets. Therefore, pedestrians in the north and south have strong demand for traffic, and motor vehicles and pedestrians are likely to interfere with each other during the passage. The VISSIM software is used to simulate the traffic flow state, as shown in Figure 6 [11]. In the case of equal free release of motor vehicles, nonmotor vehicles, and pedestrians, the priority release strategy is not considered, and the signal control scheme of the intersection is as shown in Table 6.

Comparing Tables 6 and 7, it can be seen that the new scheme takes a late-breaking and early-breaking control strategy for the motor vehicle phase because it takes into account the priority of pedestrians. The purpose is to extend the pedestrian transit time so that pedestrians can smoothly pass through the intersection and reduce interference with the motor vehicle. Analyzing Table 8 data, after selecting the pedestrian priority release strategy, the pedestrian's total delay was reduced by 6.03%, the traffic capacity was significantly improved, the total delay of the motor vehicle was also reduced by 3.02%, and the traffic capacity was not significantly weakened. This is because the pedestrian priority release strategy takes into account the strong demand for pedestrians at the intersection, which improves the pedestrian transit time and reduces the conflict between pedestrians and motor vehicles, so that the overall traffic capacity of the intersection is significantly improves. The simulation results show that the single-point adaptive control method of urban mixed traffic flow can improve the traffic capacity of mixed traffic intersections and has important significance for relieving local congestion.

Table 5: Nonmotorized pedestrian phase.

Phase type	Nonmotorized pedestrians are late	Mixed square	Nonmotorized pedestrians prematurely
Phase map			

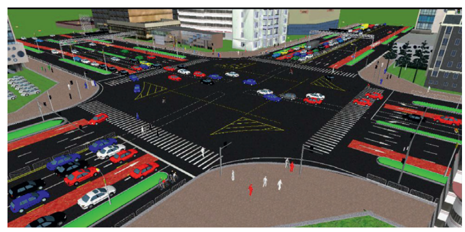


Figure 6: A simulation of mixed traffic flow in a real city intersection.

Table 6: Timing scheme of nonfavoured traffic signal control.

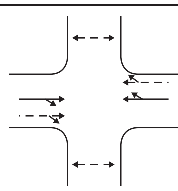
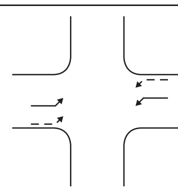
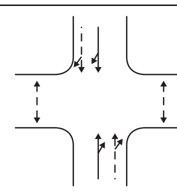
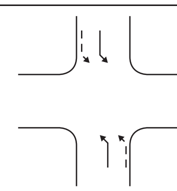
Phase sequence	Phase 1	Phase 2	Phase 3	Phase 4
Phase map				
Phase time	G27Y2R1	G22Y2R1	G27Y2R1	G22Y2R1

Table 7: Timing scheme of pedestrian-priority signal control.

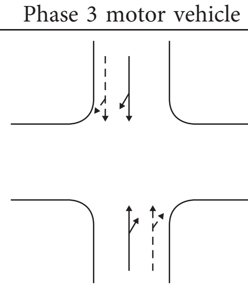
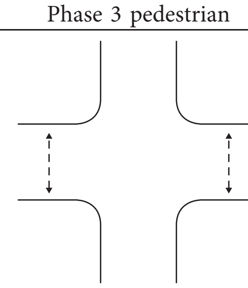
Phase type	Phase 3 motor vehicle	Phase 3 pedestrian
Phase map		
Phase time	G27Y2R5	G30Y2R2

Table 8: Simulation results under two circumstances.

Traffic object	Delay	Time/s Free passage	Time/s Pedestrian priority	Range of change/%
Vehicle	Total delay	82162	79397	−3.02
	Average delay	26.47	25.67	
Pedestrian	Total delay	20250	18831	−6.03
	Average delay	34.38	32.30	

6. Conclusion

Urban traffic problem is a common problem in cities all over the world. The capacity of urban road intersection affects the operation efficiency of the whole city traffic. Improving the comprehensive capacity of urban road intersections is of great significance for easing urban traffic congestion. This paper has studied single-point adaptive control method for urban mixed traffic flow, and the following conclusions were obtained:

(1) In this paper, a single-point adaptive control algorithm for hybrid traffic flow is proposed, which is helpful to solve the problem of low hybrid traffic efficiency at urban road intersections.

(2) The single-point adaptive control algorithm of mixed traffic flow can be used to analyze the traffic characteristics of different traffic objects in mixed traffic flow. The algorithm considers the dynamic and static factors that affect the allocation of road weight priority, and it clarifies the decision logic rules of the allocation of road weight priority.

(3) To select ordinary urban road intersections, for example analysis, the simulation results show that the traffic efficiency of the priority objects at the intersection is increased by 6.03%, and the overall traffic efficiency is also significantly improved. This method has a certain practical value.

Data Availability

The data used in this study are available upon reasonable request from the corresponding author at 7340606@qq.com.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

References

[1] S. Calvert, H. Mahmassani, J. N. Meier et al., "Traffic flow of connected and automated vehicles: challenges and opportunities," 2018.

[2] N. G. Polson and V. O. Sokolov, "Deep learning for short-term traffic flow prediction," *Transportation Research Part C: Emerging Technologies*, vol. 79, pp. 1–17, 2017.

[3] H. Demirel and W. Shoman, "Spatio-temporal analyses for dynamic urban road network management," *Transportation Research Procedia*, vol. 22, pp. 519–528, 2017.

[4] E. Cristiani and S. Sahu, "On the micro-to-macro limit for first-order traffic flow models on networks," *Networks and Heterogeneous Media*, vol. 11, no. 3, pp. 395–413, 2016.

[5] M.-X. Zhu, J.-N. Zhang, Y. Li et al., "Partial discharge signals separation using cumulative energy function and mathematical morphology gradient," *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 23, no. 1, pp. 482–493, 2016.

[6] Li Tang, Fengce Gao, R. Krishnan et al., "Right-of-way reallocation for mixed flow of autonomous vehicles and human driven vehicles," *Transportation Research Part C-Emerging Techonlogies*, vol. 115, pp. 168–188, 2020.

[7] M. Amirgholy, M. Shahabi, and H. Oliver Gao, "Traffic automation and lane management for communicant, autonomous, and human-driven vehicles," *Transportation Research Part C: Emerging Technologies*, vol. 111, pp. 477–495, 2020.

[8] L. V. Scott, Y. Kong, X. Liu, and J. Polak, "Vehicle automation and freeway "pipeline" capacity in the context of legal standards of care," *Transportation*, vol. 46, no. 4, pp. 1215–1244, 2019.

[9] G. Shen, W. Chen, "Scheme selective regional coordination control method and application," *Journal of Zhejiang University of Technology*, vol. 44, no. 3, pp. 237–241, 2016.

[10] A. Talebpour and H. S. Mahmassani, "Influence of connected and autonomous vehicles on traffic flow stability and throughput," *Transportation Research Part C: Emerging Technologies*, vol. 71, pp. 143–163, 2016.

[11] C. Roncoli, M. Papageorgiou, and I. Papamichail, "Traffic flow optimisation in presence of vehicle automation and communication systems-Part II: optimal control for multi-lane motorways," *Transportation Research Part C: Emerging Technologies*, vol. 57, pp. 260–275, 2015.

[12] A. V. Kuznetsov, "A simplified combat model based on a cellular automaton," *Journal of Computer and Systems Sciences International*, vol. 56, no. 3, pp. 397–409, 2017.

[13] S. V. Kumar and L. Vanajakshi, "Short-term traffic flow prediction using seasonal ARIMA model with limited input data," *European Transport Research Review*, vol. 7, no. 3, p. 21, 2015.

[14] Y. Luo, B. Xie, and W. Peng, "Virtual reality vehicle intelligent motion simulation based on Vega Prime," *Journal of Zhejiang University of Technology*, vol. 41, no. 4, pp. 458–463, 2013.