International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 08 Aug. 2024, pp: 434-440 www.ijaem.net ISSN: 2395-5252

Research on the Optimization of Urban Intersections Based on the Priority of Pedestrian and Non-Motorized Traffic

Lei Wang[1]
(1. College of Traffic and Transportaion, Chongqing JiaotongUniversity,Chongqing, China)

Date of Submission: 15-08-2024 Date of Acceptance: 25-08-2024

ABSTRACT
Urban intersections are critical nodes in the urban transportation system. Traditional intersection design and signal control methods often emphasize vehicle flow and speed, while neglecting the needs of pedestrians and cyclists, as well as other non-motorized traffic. This paper proposes an optimization method for urban intersections based on priortizing pedestrian and non-motorized traffic, aiming to enhance their passage efficiency and safety. By establishing traffic simulation models and conducting field surveys, this study employs a non-motorized traffic priority strategy to optimize intersection design and signal control. The effectiveness and feasibility of this approach are evaluated through experiments and analysis. The results demonstrate that the optimization method based on prioritizing non-motorized traffic significantly improves the traffic conditions for non-motorized users, thereby enhancing the overall efficiency and sustainability of the urban transportation system.
Keywords: Pedestrian and Non-Motorized Traffic Priority; Urban Intersection; Non-Motorized Vehicles; Signal Control; Traffic Simulation

I. INTRODUCTION

With the development of China's economy and the increasing demands for better transportation conditions, the highway transportation industry in China has seen rapid growth. The number of vehicles, drivers, and driving mileage in China has been continuously increasing. According to the latest data, by 2022, the total number of motor vehicles in China reached an impressive 417 million, a remarkable achievement with an increase of 22 million vehicles compared to the previous year, representing a 5.28% growth. While cars have brought convenience to residents' lives, they have also introduced some challenges. The large number of motor vehicles has led to traffic congestion, frequent traffic accidents, and traffic pollution. These issues in urban road transportation have become bottlenecks, seriously hindering the development of urban transportation systems[1].

As the key nodes connecting different roads within the urban road network, intersections play a crucial role in managing urban traffic. Scholars in China have conducted extensive research on optimizing the traffic organization at urban intersections. In the field of signal timing, Wu Renlianget al.[2]proposed a method for improving the effectiveness of intersection signal control by selecting key indicators and calculating the benefit index according to the control needs at different times of the day. Regarding channelized intersection design, Song Cancan et al.[3]focused on optimizing the effectiveness of traffic at highway curves with changing environments by using driving trajectories, steering angles, and driving speeds as evaluation indicators, thereby improving the rationality of current road signs and markings. In terms of non-motorized traffic, Shao Haipeng and Yang Xiaoguang[4]proposed the separation of motor vehicles and non-motorized vehicles, effectively solving the problem of mixed traffic between pedestrians and vehicles.

Traffic mixing at intersections can disrupt traffic flow and lead to accidents. In recent years, the lack of design optimization for non-motorized traffic at grade intersections has led to frequent traffic accidents and insufficient space for non-motorized traffic. The status and travel environment of non-motorized traffic in the road network have been restricted, which is closely related to urban planning, design, and management. Therefore, optimizing the traffic organization at grade intersections with a focus on non-motorized traffic has become an urgent priority.

II. ANALYSIS OF SLOW TRAFFIC AND MOTOR VEHICLE TRAFFIC CHARACTERISTICS

2.1 Definition of Slow Traffic

Slow traffic refers to transportation modes characterized by low travel speeds. Typically, slow traffic encompasses modes with speeds not exceeding 15 km/h and includes both pedestrian and non-motorized vehicle transportation[5].

2.2 Analysis of Traffic Characteristics of Slow Traffic Users

Compared to motor vehicles, slow vehicles have distinct characteristics in terms of travel speed, space occupancy, lane width, and travel distance, which significantly impact traffic flow at intersections. Slow traffic moves at relatively low speeds, with walking speeds typically ranging between 3.5 km/h and 5 km/h, and cycling speeds generally between 10 and 15 km/h. The dynamic space occupancy of slow traffic is relatively small, with an average dynamic space occupancy of 0.8 to 1.2 square meters per pedestrian and 0.6 square meters per bicycle. Additionally, slow traffic features smaller average passenger capacity and quicker starts, which increases the likelihood of conflicts with motor vehicles at intersections, such as instances of lane encroachment.

2.3 Analysis of the Demand Characteristics of Slow Traffic Users

In the daily operation of transportation systems, the demands of pedestrians in traffic spaces differ from those of other traffic participants. Therefore, it is essential to thoroughly understand pedestrian travel patterns and incorporate them into transportation planning and design.

This paper categorizes the demands for optimizing intersection traffic organization for slow traffic into the following levels:

(1) Safety Needs

Safety needs refer to ensuring pedestrian safety while crossing intersections, which includes both crossing the intersection and walking along it. Intersection design must account for pedestrian behavior patterns and needs, such as the size of pedestrian waiting areas, crossing time, and safety line placement.

(2) Convenience Needs

Convenience needs refer to providing pedestrians with efficient and straightforward ways to cross intersections. This can be achieved by reducing pedestrian waiting times, providing pedestrian overpasses or underpasses, and implementing measures such as signage, road markings, and lighting. The convenience of transportation is a key factor influencing people's choice of transport modes. Intersections are critical points for delays involving both motor vehicles and slow traffic; therefore, coordinating the travel efficiency of both is an important goal in traffic organization.

(3) Travel Space Needs

When designing and planning intersections, it is crucial to consider the travel needs of slow traffic users to optimize intersection organization and traffic flow management, thereby enhancing safety and travel experience. Additionally, incorporating green belts and landscaping can improve the travel environment for slow traffic, making the journey more pleasant and comfortable for pedestrians and cyclists.

2.4 Analysis of Conflicts Between Slow Traffic and Motor Vehicle Traffic at Intersections

In China, conflicts between slow traffic and motor vehicle traffic at intersections arise due to various factors such as traffic characteristics at intersections, signal timing, and road user violations. The specific issues are as follows:

(1) Motor Vehicle Volume

In urban areas, high traffic volumes and road congestion lead to increased friction between pedestrians, non-motorized vehicles, and motor vehicles, making traffic accidents more likely. An increase in the number of motor vehicles passing through pedestrian and non-motorized vehicle crossings over a period can lead to a higher potential for conflicts, which translates into a greater number of actual conflicts. Therefore, an increase in motor vehicle numbers raises the likelihood of traffic accidents involving pedestrians.

(2) Duration of Pedestrian Signal Red Lights

In some countries and regions, such as Japan, the fast pace of life and lower safety awareness can lead to impatience if pedestrian waiting times are too long, making extended waiting times undesirable. Various control indicators have been proposed by scholars in different countries to ensure pedestrian safety and maintain good traffic order.

(3) Right Turns Allowed During Red Lights

In traffic management, ensuring the safety of both pedestrians and vehicles is crucial. Allowing right turns during red lights, if not properly controlled, can pose significant safety risks to crossing pedestrians and cyclists. Therefore, when designing right turns during red lights, it is essential to consider the presence of pedestrians and cyclists and implement measures to protect their safety.

(4) Encroachment or Misuse of Pedestrian and Non-Motorized Vehicle Spaces

Uneven distribution of road space puts considerable pressure on slow traffic, which is one reason for the reduction or elimination of slow traffic lanes in some areas. If not properly addressed, this can force slow traffic users onto motor vehicle lanes, leading to significant safety hazards and traffic disorder.

(5) Lack of Traffic Signage

The absence of necessary traffic guidance facilities can lead to accidents, congestion, and even reduce the overall efficiency of the city's traffic system. The lack of signage at intersections and bus stops can cause significant inconvenience for travelers. Additionally, insufficient traffic warning signs and pedestrian crossings near congested areas like schools pose safety risks for students.

(6) Lack of Comfort in the Travel Environment

Poor road conditions severely impact the safety and efficiency of slow traffic, increasing the risk of accidents. For example, water accumulation on roads during rainy weather, poor skid resistance, and inadequate nighttime lighting on some slow traffic routes can lead to slips and accidents. Furthermore, insufficient illumination at night can increase safety hazards for both pedestrians and drivers.

(7) Excessive Intersection Size and Inefficient Traffic Channelization Design

Excessively large intersection areas occupy more construction land, violating the principle of land use efficiency. Such designs can hinder the safety, convenience, and comfort of pedestrian and bicycle traffic. An intersection designed with a focus on motor vehicles, while neglecting the needs of pedestrians and cyclists, can create an unsafe and inconvenient environment for them, benefiting only motor vehicles.

(8) Improper Bus Stop Design

Improperly designed bus stops, lacking proper bays or reasonable platform designs, can cause numerous inconveniences and hazards to road traffic.

(9) Lack of Scientific and Effective Traffic Management Measures

Many cities lack scientific and systematic approaches in traffic planning, leading to imbalanced traffic facility planning, travel bottlenecks, and congestion issues. Outdated traffic management techniques and a lack of modern digital and intelligent technologies result in inefficient management.

III. INTERSECTION CHANNELIZATION AND PHASE DESIGN PRIORITIZING SLOW TRAFFIC

Intersections, as crucial components of urban road networks, play a vital role in the efficiency and safety of urban traffic operations. Proper planning and design of intersection traffic channelization can effectively guide and divert vehicles and pedestrians by setting up lanes, directional markings, traffic signs, and other traffic management facilities. This helps to reduce the occurrence of traffic accidents, improve the road environment, and enhance traffic flow and operational efficiency.

3.1Motor Vehicle Channelization Design

Motor vehicles are the primary traffic flow at intersections, and their traffic efficiency impacts the overall operation of the intersection. Effective green light duration and the number of traffic conflict points are two important factors affecting intersection efficiency.

(1) Design of Dedicated Left-Turn Lanes and Left-Turn Waiting Areas

A dedicated left-turn waiting area is a designated space at an intersection for vehicles waiting to make a left turn. This area should be designed based on road conditions and traffic volume. The main purposes of setting up a left-turn waiting area are: to reduce the waiting time for left-turning vehicles; to separate left-turning vehicles from through traffic; and to enhance the safety of intersection traffic

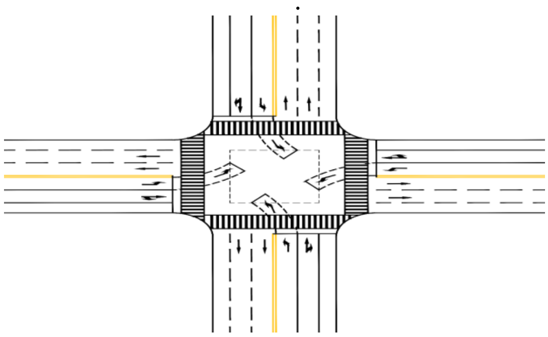


Fig.1 Schematic diagram of the channelization of the left turn waiting area at the intersection of two phase signals

(2) Design of Dedicated Right-Turn Lanes for Motor Vehicles

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 08 Aug. 2024, pp: 434-440 www.ijaem.net ISSN: 2395-5252

With the increase in the number of non-motorized and motor vehicles, setting up dedicated right-turn lanes for motor vehicles can effectively resolve conflicts between motor vehicles and non-motorized vehicles. Additionally, this design helps to shorten the waiting time for right-turning vehicles, ensure their safe passage, and improve the overall traffic capacity of the road.

3.2 Optimization of Slow Traffic Channelization

Common channelization methods for non-motorized vehicles at intersections include: dedicated right-turn lanes for non-motorized vehicles, secondary crossings for left-turning non-motorized vehicles, advancing the stop lines for non-motorized vehicles, and establishing non-motorized vehicle lanes.

(1) Dedicated Right-Turn Lanes for Non-Motorized Vehicles

When the volume of right-turning non-motorized traffic is high and land conditions at the intersection permit, a dedicated right-turn lane should be established for non-motorized vehicles. Measures such as green belts, safety islands, separators, and pavement markings can be used to separate the travel space of motor vehicles from non-motorized vehicles. This helps to reduce conflicts and collisions between motor vehicles and non-motorized vehicles at the intersection, thereby enhancing traffic safety, as illustrated below.

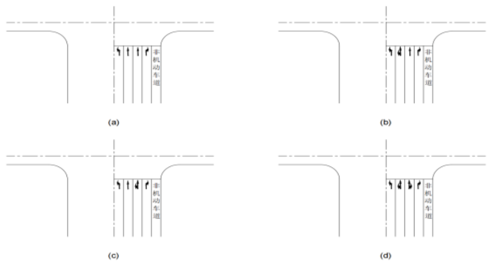


Fig.2 It can be divided into four motorized lanes and different combinations of non-motorized lanes

(2) Secondary Crossing for Left-Turning Non-Motorized Vehicles

The secondary crossing for left-turning non-motorized vehicles, also known as the "two-stage straight-through" method, is a traffic channelization measure designed to reduce conflicts between motor vehicles and non-motorized vehicles.

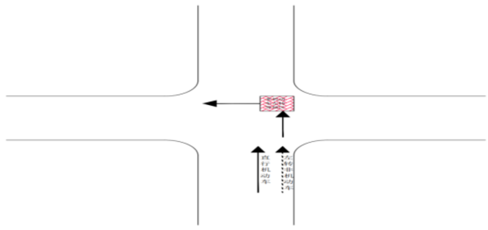


Fig.3 Schematic diagram of the second crossing of the street for non-motor vehicles turning left

(3) Advancing the Stop Line for Non-Motorized Vehicles

This design scheme involves positioning the stop line for non-motorized vehicles ahead of the stop line for motor vehicles. This approach takes into account the quick start and urgency of cyclists to cross the street. By placing the stop line for non-motorized vehicles ahead, it allows non-motorized vehicles to enter the intersection more quickly, thereby minimizing potential interference and conflicts with motor vehicles that may occur when both types of traffic pass the stop line simultaneously.

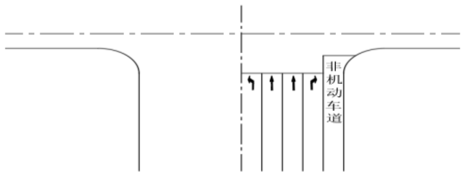


Fig.4 Schematic diagram of the forward movement of the non-motor vehicle parking line

(4) Setting Up Safety Islands

A safety island is a traffic facility designed to provide a temporary stopping place for pedestrians, typically set up at intersections or streets with high traffic volumes and wide roadways. The safety island should be large enough to accommodate pedestrians and provide them with sufficient standing space. It is generally designed with convex or circular geometric shapes and may be equipped with traffic signals to indicate when pedestrians can safely continue crossing the street.

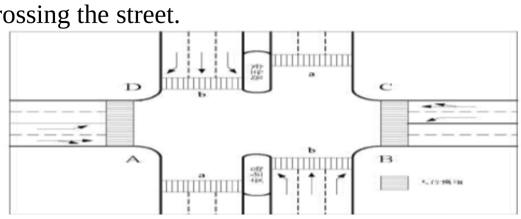


Fig.5Schematic diagram of intersection safety island setup

(5) Setting Up Bidirectional Pedestrian Crossings

Implementing bidirectional pedestrian crossings can effectively reduce traffic conflicts

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 08 Aug. 2024, pp: 434-440 www.ijaem.net ISSN: 2395-5252

between vehicles and pedestrians, improving pedestrian crossing efficiency and safety. When setting up these crossings, it is important to choose sections with relatively low traffic volumes to minimize the impact on vehicle flow. Additionally, it is essential to enhance pedestrian guidance and management to prevent pedestrians from violating crossing rules and causing traffic accidents. Specific channelization measures are illustrated in the figure below.

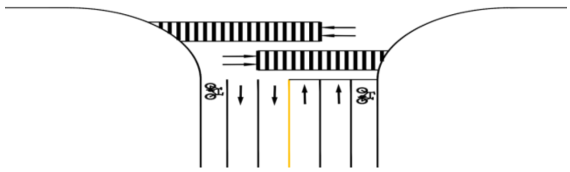


Fig.6Two-way pedestrian crossing channelization design drawing

IV. OPTIMIZATION OF SIGNAL CONTROL AT INTERSECTIONS UNDER THE INFLUENCE OF SLOW TRAFFIC

4.1 Optimization Model for Intersection Signal Timing

Based on actual traffic conditions, with the objectives of minimizing delay, reducing the number of stops, and maximizing traffic capacity, a weighted coefficient that can adjust to changes in traffic demand is used to combine these three objectives into a single objective function. The optimization model is as follows[6]:

$$min_x\, f(x) = \sum_{i=1}^{n} K_i^1 D_i + K_i^2 H_i - K_i^3 Q_i \quad (1)$$

$$\begin{cases} x_i - a_i \geq 0, 1 \leq i \leq n; \\ \sum_{i=1}^{n} (x_i + l_i) \leq b\,; \\ 0.75 \leq \dfrac{y_i C}{x_i} \leq 0.95, 1 \leq i \leq n; \end{cases}$$

In the formula: a_i is the minimum effective green time for phase i (in seconds); l_i is the lost time for phase i; b is the maximum cycle time (in seconds); x_i is the effective green time for phase i; y_i is the traffic intensity for phase i, defined as the ratio of traffic flow to saturation flow.; C is the signal cycle.

K_i^1, K_i^2 and K_i^3[7] represent the weight coefficients for delay time, number of stops, and traffic capacity, respectively. These coefficients are functions of traffic flow. Since the objective function uses the negative value of traffic capacity, minimizing $f(x)$ will result in the smallest weighted delay time and number of stops while maximizing the weighted traffic capacity. Specifically, the coefficients are[8]: $K_i^1 = 2(1.0 - Y)\sqrt[7]{s_i}$, $K_i^2 = \sqrt[7]{s_i}(1.0 - Y)/0.9$, $K_i^3 = 2YC/3600$。

4.2 Case Study

4.2.1Current Status of the Intersection

The selected signalized intersection for this study is located in the Huaiyin District of Jinan City, where Liu Changshan Road intersects with Kelangshan Road. This intersection is a typical example of a mixed traffic flow intersection with various types of traffic. To the north of the intersection are primarily residential areas and various street-level commercial shops, including an elementary school. The southeast side is mainly commercial and market areas. The details are shown in the figure below.

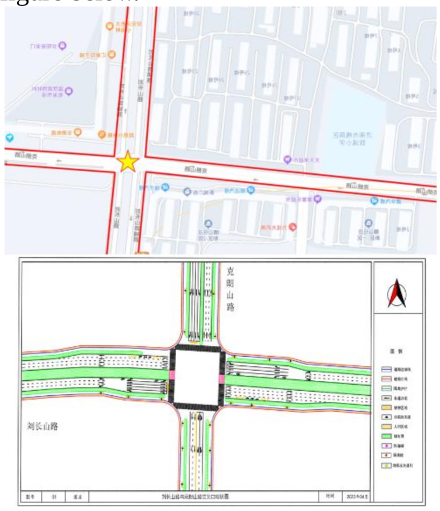
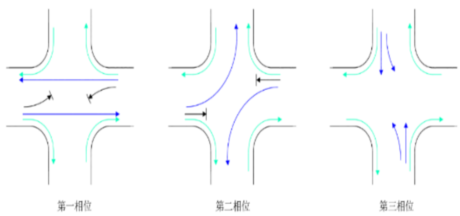


Fig.7. Current situation of the intersection

Liu Changshan Road and Kelangshan Road form a cruciform signalized intersection with three signal phases. The signal timing cycle is 180 seconds. The current signal timing diagram for the intersection is shown in the figure below.



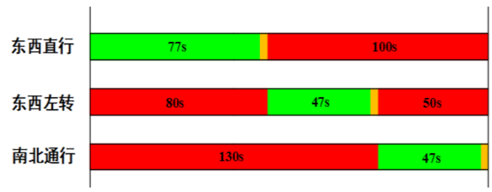


Fig.8 Intersection status map Fig.9 Intersection signal timing diagram

4.2.2 Intersection Channelization Design

International Journal of Advances in Engineering and Management (IJAEM)
Volume 6, Issue 08 Aug. 2024, pp: 434-440 www.ijaem.net ISSN: 2395-5252

Based on the channelization design methods mentioned above, the channelization design for this intersection has been optimized. The optimized intersection is shown in Figure 10.

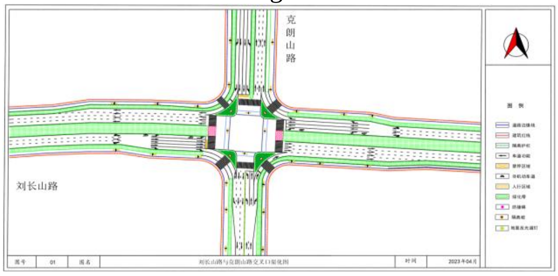


Fig.10. Canalization diagram of the intersection

4.2.3 Signal Timing Optimization Design

By substituting the relevant data, the objective function expression can be obtained as follows:

$$min_x\, f(x) = \frac{1.4(x_2+x_3+15)^2}{x_1+x_2+x_3+15} + \frac{1.4(x_2+x_3+15)}{x_1+x_2+x_3+15} - 3.6x_1 + \frac{0.74(x_1+x_3+15)^2}{x_1+x_2+x_3+15} + \frac{0.74(x_1+x_3+15)}{x_1+x_2+x_3+15} - 1.3x_2 + \frac{0.85(x_2+x_1+15)^2}{x_1+x_2+x_3+15} + \frac{0.85(x_2+x_1+15)}{x_1+x_2+x_3+15} - 3.28x_3。$$

$$\begin{cases} 0.75x_1 \le 0.38(x_1+x_2+x_3+15) \le 0.95x_1 \\ 0.75x_2 \le 0.2(x_1+x_2+x_3+15) \le 0.95x_2 \\ 0.75x_3 \le 0.23(x_1+x_2+x_3+15) \le 0.95x_3 \end{cases}$$

By calculation, the optimal values of the objective function are obtained when $x_1 = 65$, $x_2 = 34$, $x_3 = 40$. This results in the following signal timings for the Liu Changshan Road and Kelangshan Road intersection:

(1) First phase (east-west through movement): Effective green time of 63 seconds.

(2) Second phase (east-west left turn): Effective green time of 26 seconds.

(3) Third phase (north-south movement): Effective green time of 39 seconds.

The total cycle time is 148 seconds.

4.2.4 Comparative Analysis of Results Before and After Optimization

A segment model with and without channelization was constructed using VISSIM simulation software. By setting the corresponding traffic flow and signal timing parameters, the traffic conditions before and after channelization can be simulated. This allows for the assessment of changes in indicators such as traffic capacity, congestion levels, and travel time before and after channelization.

Tab.1 Comparison of each traffic flow parameter before and after optimization

Method	Cycle Duration	Effective Green Time			Traffic Capacity			Average Delay			Average Number of Stops		
		Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3	Phase 1	Phase 2	Phase 3
Survey Results	180	77	47	47	3444	757	1911	47.48	61	64.14	0.83	0.825	0.87
Objective function method	143	63	26	39	3547	527	1996	36.05	59.32	49.4	0.81	1.1	0.85

(1) After channelization, the length of vehicle queues at the intersection significantly decreased compared to before channelization. The south entrance improved the operational efficiency of the intersection.

(2) Following channelization, the number of stops made by vehicles entering the intersection also decreased notably. The average number of stops for vehicles at the intersection is less than one, meaning vehicles no longer need to stop again when passing through the intersection, which substantially reduced delays. After channelization, the number of stops for southbound motor vehicles decreased significantly, wait times shortened, and traffic capacity improved.

(3) After optimization through channelization, the average vehicle delay rate at the intersection significantly decreased. The time vehicles spend at the intersection during the evening peak period was notably reduced, leading to a significant improvement in the intersection's traffic capacity.

V. CONCLUSION

Given the characteristics of mixed traffic involving motor vehicles, non-motorized vehicles, and pedestrians in urban traffic in China, phase design for intersections affected by slow traffic has been discussed, outlining the principles and methods of intersection channelization.

By studying and analyzing a real intersection, problems such as excessive traffic flow, inadequate width of non-motorized vehicle lanes, and pedestrian traffic safety hazards were identified. Corresponding optimization measures were proposed, including increasing the number of motor vehicle lanes, widening non-motorized vehicle lanes, setting up pedestrian crosswalks, and adding traffic signs. An optimization model with the objectives of minimizing delay, reducing stops, and maximizing traffic capacity was used to optimize the signal timing of the intersection. Finally, based on simulation results, the optimization led to reduced vehicle delays and significantly improved traffic capacity at the intersection.

REFERENCES

[1]. Liu Dewu. Highway and Automobile Transport,2002(06):60-62.
[2]. Wu Renliang,YangHao,LiuTong.Evaluation index and method of road intersection signal control benefit[J].Journal of Nanjing Normal University(Natural Science Edition),2019,42(02):37-43.)
[3]. Song Cancan,GuoZhongyin,QIAOYadan.Evaluation index of highway flat curve sign marking combination design[J].Journal of Tongji University(Natural Science Edition),2018,46(07):913-919+981.)
[4]. Shao Haipeng,Yang Xiaoguang,Dong Haiqian. Research on road traffic improvement method for machine-non-mixed traffic [J]. Urban Transport,2007,vo1.5(l):83-88.
[5]. Wang Jianxin,QianYongsheng,ZengJunwei,et al. Optimization design of traffic microcirculation road network considering the influence of slow traffic[J].Science Technology and Engineering,2023,23(17):7566-7572.)
[6]. Xu Zhi. Research on timing optimization method of signalized intersection under mixed traffic conditions[D]. Beijing Jiaotong University, 2008.
[7]. Yan Yanxia,LIWenquan. Real-time timing model and ant algorithm of single-point intersection signal[J] .Journal of Highway and Transportation Research and Development,2006,11
[8]. Li Ruimin, Lu Huapu. Multi-objective Optimization of Traffic Signal Control Based on Genetic Algorithm[J]. Journal of Chang' an University Natural Science Edition,2009,29(3):85-88.