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Study on Traffic Flow Control Based on Matlab Data Analysis

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Abstract: *This study addresses the traffic signal optimization problem at a median-west median intersection. Based on 36 days of time-segmented traffic volume data, it combines the NS traffic flow model, Webster signal timing model, and genetic algorithm to propose a dynamic phase control scheme. By analyzing the traffic characteristics during morning rush hour, evening rush hour, off-peak hours, and nighttime, differentiated signal phases are designed: high-flow turning maneuvers (such as U-turns and left turns) are prioritized during peak hours, combined phases are added during off-peak hours, and induction control is used at night. After optimization, the average speed on the main road during morning rush hour increases from 28 km/h to 42 km/h, with delays reduced by 35%, and off-peak traffic capacity improves by 25%. The scheme achieves maximum traffic flow speed on the main road through phase conflict avoidance, green wave coordination, and dynamic parameter adjustments, providing a data-driven and model-coordinated solution for optimizing complex urban intersections.*

Keywords: *NS Traffic Flow Model, Webster Signal Timing Model, Dynamic Phase Control Scheme*

1. Introduction

With the rapid increase of urbanization and vehicle ownership, traffic congestion has become a key problem restricting the sustainable development of cities. According to the Global Traffic Congestion Report, residents of major cities around the world lose an average of more than 150 hours a year due to congestion, and direct economic losses amount to hundreds of billions of dollars. The traditional fixed timing signal light is difficult to adapt to the dynamic traffic flow, which leads to the overflow of the peak queue and the empty green light at the peak, which reduces the traffic efficiency of the road network. Therefore, the intelligent transportation system (ITS) with data-driven dynamic signal optimization has become the key to alleviate congestion, in which the time-segment signal timing model can improve the traffic capacity and user experience of the main road. In this study, a dynamic optimization method combining NS traffic flow simulation and Webster signal matching and genetic algorithm is proposed to solve the problems of delayed response of traditional model and insufficient coordination of multiple intersections, and to provide theoretical and practical solutions for urban traffic management.

Traffic signal timing is the key of intelligent transportation system and has always been the focus of research. Reasonable timing is of great significance for improving traffic efficiency and alleviating congestion. As technology and transportation needs evolve, the field moves from theory to application, from traditional methods to the integration of new technologies. In 1958, Webster proposed the signal period formula, which laid the theoretical basis of static timing, but it was difficult to adapt to real-time fluctuations because it was based on the fixed flow assumption [1]. 1982 UK SCOOT system can dynamically adjust the timing, but rely on high-density sensors, high cost, complex calculation. In 1975, Gartner proposed a green wave coordination model to reduce stops and delays, but it did not incorporate time-sharing traffic characteristics and was not effective. There are also various problems in the follow-up research, such as the inability to adjust the burst traffic change in time, poor interpretability, and the lack of deep coupling with the signal optimization algorithm [1].

In view of the pain points such as insufficient consideration of real-time traffic fluctuations and poor model interpretability in previous studies, this paper constructs a solution of "dynamic simulation-theoretical timing - global optimization". The NS traffic flow model is applied to simulate the vehicle movement according to the microscopic following rules, capture the flow characteristics at different periods, and provide accurate data for signal optimization. The fusion framework of Webster

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and Genetic algorithm is constructed, the initial timing parameters are calculated using Webster model, and then the key parameters are globally searched and optimized by genetic algorithm, so that the timing can be dynamically adjusted. At the same time, combined with the periodic fluctuation of traffic flow, the time-sharing green wave coordination strategy is implemented, and the green wave bandwidth is designed according to the traffic difference in different periods, so as to achieve efficient collaborative control of multiple intersections and improve the operation efficiency of the traffic network.

2. Algorithmic principles

2.1 NS traffic flow model

The motion of the vehicle is simulated by following the micro-following rule, quicken:

$$\mathrm{v_n}(t+1)=\min(v_n(t)+1,v_{\max}) \tag{1}$$

The motion of the vehicle is simulated by following the micro-following rule, Reducing:

$$v_n(t+1)=\min(v_n(t),d_n) \tag{2}$$

Randomization: random P deceleration by probability.

2.2 Webster signal timing model

Minimize vehicle delays:

$$C_{\mathrm{opt}}=\frac{1.5L+5}{1-Y} \tag{3}$$

$$Y=\sum\frac{q_i}{s_i} \tag{4}$$

Among them q_i, the lane flow s_i is the saturation flow rate.

2.3 Modeling of flow-velocity relationship

Based on the simulation data of NS model, the internal relationship between the traffic q_t and the average speed $\overline{v_t}$ in the period t is deeply analyzed, and the following mapping relationship is established:

$$\overline{\mathrm{v}_t}=v_{free}(1-\frac{q_t}{n_{lane}q_{jam}}) \tag{5}$$

Where, v_{free} represents the free flow speed, set to 60 km/h; q_{jam} indicates the congestion density, which is 150 vehicles per kilometer lane, n_{lane} Number of lanes on the main road. In this study, the main road is a two-way 4-lane road. The model can accurately reflect the change of average speed of the main traffic flow under different flow conditions, and provides an important basis for the subsequent optimization of signal parameters.

2.4 Period weight coefficient

In order to more accurately reflect the importance of traffic flow in different periods, the weight is dynamically adjusted according to the proportion of peak traffic:

$$\mathrm{w_t}=\frac{q_t}{\sum_{t=1}^{T}q_t} \tag{6}$$

ISSN 2616-5767 Vol.8, Issue 4: 102-109, DOI: 10.25236/AJETS.2025.080414

This dynamic adjustment method makes the objective function more flexible to adapt to the traffic conditions of different periods, and ensures that the optimal timing of traffic signals can be achieved when the traffic flow changes greatly.

2.5 Genetic algorithm optimization process

Coding: Delay rate DR, Signal period C, green λ_i signal ratio Δt and phase difference coding are chromosomes.

Adaptation function:

$$f = \bar{v} - 0.1 \times DR \tag{7}$$

Operation: selection, crossover (single point), mutation (gauss)

3. Mathematical model

3.1 Objective function

$$\max \bar{v} = \frac{1}{N} \sum_{i=1}^{N} v_i \tag{8}$$

3.2 Constraint condition

Signal cycle: 40s≤C≤120s

Minimum green light, $t_{green} \geq 10s$, time: (pedestrian safety)

3.3 Solve the algorithm

The genetic algorithm (population size 50, iteration 100) was used to verify the fitness through NS model simulation.

4. Algorithm analysis

4.1 Data source and preprocessing

If missing values are found, process them using cubic spline interpolation. This method approximates the interpolation of given data points through a series of piece wise cubic polynomial functions. It effectively maintains the smoothness and continuity of the data, reducing the loss of information.

Traffic flow calculation:

$$T = \frac{N}{Q} \tag{9}$$

Among them N, is the number T of vehicles, Q is the length of time period, and is the traffic flow per hour. The number of vehicles can be converted into traffic flow by this formula.

After visual analysis, most of the traffic flow data are concentrated in a certain interval, so the average of weekdays (23 days) is considered to estimate the traffic flow at different times and directions as shown in the following table, as shown in Table.1.

According to Table 1, in terms of different time periods, the traffic flow in off-peak hours is far higher than that in peak hours, which is different from traditional cognition. This special flow distribution requires the traffic signal control system to have a stronger dynamic adaptability, and it is necessary to dynamically adjust the signal period and phase according to real-time traffic changes, so as to avoid the waste of green time or the situation of vehicles waiting for a long time, and realize the efficient use of road resources.

ISSN 2616-5767 Vol.8, Issue 4: 102-109, DOI: 10.25236/AJETS.2025.080414

Table 1 Traffic flow in different directions at different times

Traffic value	morning peak	evenign peak	Peak times	night
Direction 1	255	468	1204	555
Direction 2	114	312	899	384
Direction 3	138	166	506	359
Direction 4	110	199	564	387

4.2 Detailed explanation of the model system

4.2.1 Traffic flow model

The NS (Nagel-Schreckenberg) traffic flow model is used to simulate the operation of vehicles on roads and the dynamic changes in traffic flow. It simulates vehicle movement and congestion generation through simple rules and algorithms: when two vehicles are too far apart, they start to slow down; when they are too close, they begin to accelerate; when the distance is appropriate, they proceed normally.

The simulation results through the traffic flow model are shown in the figure 1.

Figure 1 Simulation results

4.2.2 Signal timing model

Core parameters[2]:

Cycle duration C the time for a complete cycle of a signal light.

Green light r ratio:the proportion of green light time in each phase to the total cycle.

Phase design: traffic rights are divided according to the direction of traffic flow (such as straight and left turn phase).

4.2.3 Model selection

Webster Model: classical signal timing model to minimize vehicle delay.

$$C = 1.5L + \frac{5}{1-Y} \tag{10}$$

$$Y = \sum \frac{q_i}{s_i} \tag{11}$$

Among them L, is the total Y loss time, intersection q_i saturation, s_i is lane flow, is saturated flow rate.

Adaptive timing model: dynamically adjust the cycle and green signal ratio according to real-time traffic.

4.2.4 Application method

Differentiated design by time period: Based on the time period division of problem r C, and are calculated for peak, off-peak and low-peak periods respectively.

Peak hours: extend the green light time of the main road straight ahead and shorten the secondary phase time.

Off-peak period: balance the time of each phase to avoid empty release.

ISSN 2616-5767 Vol.8, Issue 4: 102-109, DOI: 10.25236/AJETS.2025.080414

4.2.5 Optimization algorithm

The fitness function takes into account the average speed and delay penalty terms[3]:

$$f = \sum_{t=1}^{T} w_t \overline{v_t} - \alpha \sum_{t=1}^{T} Delay_t \tag{12}$$

Where, α is delay penalty coefficient, the value is 0.1; $Delay_t$ Indicates the total delay (seconds) of time period t, which is obtained through NS model simulation. The fitness function not only seeks to maximize the average speed of the main road traffic flow, but also punishes the possible delay, so as to guide the genetic algorithm to search for a better signal timing scheme.

4.2.6 Objective function

$$\max imizex = \frac{1}{N}\sum_{i=1}^{N} v_i \tag{13}$$

Constraints include signal period range C(usually within this [40s,120s]), minimum green light time (pedestrian safety time), etc.

4.3 Algorithm selection

Genetic algorithm (GA): suitable for high-dimensional and nonlinear optimization problems.

Coding: The signal period, green signal ratio, phase difference and other parameters are coded into chromosomes.

Fitness function: the average velocity v is used as the evaluation index.

Cross and variation: generate new solutions through random operation to gradually approach the optimal solution.

Dynamic programming (DP): phase difference optimization for multi-intersection green wave coordination.

4.4 Detailed explanation of the green wave coordination control model

The core of coordinated green wave control[4] is to precisely control the phase difference of traffic lights at adjacent intersections, allowing vehicles to pass through multiple intersections continuously without encountering red lights while traveling at a specific speed (i.e., "target speed"). This design forms continuous "green wave zones," significantly reducing stop-and-go traffic and enhancing the efficiency of main road traffic[5].

According to the 36 days of traffic flow data provided, the turning traffic from each direction at the intersection of Zhong lu and Wei zhong Road was screened out, and it can be obtained based on the data analysis in Table 2

Early morning rush hour (7:00~9:00): the flow of U-turn (1-1) and left turn (4-1) is prominent, followed by right turn (4-2).

Late evening rush hour (17:00~20:00): The flow of U-turn (1-1) and left turn (4-1) further increases, and the flow of right turn (4-2) reaches the peak.

Ping feng (9:00~17:00): The flow of U-turn (1-1) surged to 1581, and the flow of right turn (4-4) surged to 1129. It needs key coordination.

Night (19:00~7:00): the overall flow decreased, but the turn (4-4) was still high.

The vehicle motion is simulated by Nagel-Schreckenberg model. The key parameters are set as follows:

Maximum speed: 60 km/h (main road limit)

Random deceleration probability: 0.3 (simulate driving behavior uncertainty)

Initial density: allocated according to time period flow data

ISSN 2616-5767 Vol.8, Issue 4: 102-109, DOI: 10.25236/AJETS.2025.080414

Table 2 Number of times in different directions at different times

	U-turn	Straight	Right turn	Left turn
Morning rush hour (7:00~9:00)	394	0	38	182
Late evening rush hour (17:00~20:00)	589	0	49	271
Peak times	1581	0	167	686
night	730	0	51	261
	Straight (1-2)	U-turn (2-2)	Left turn (3-2)	Right turn (4-2)
Morninghour (7:00~9:00)	7	0	9	76
Late evening rush hour(17:00~20:00)	5	0	25	98
Peak times	33	0	75	388
night	7	0	27	107
	Left turn (1-3)	Right turn(2-3)	U-turn (3-3)	Straight (4-3)
Morningrush hour (7:00~9:00)	22	0	46	4
Late evening rush hour(17:00~20:00)	31	0	55	0
Peak times	87	0	190	9
night	39	0	80	12
	Right turn(1-4)	Left turn (2-4)	Straight (3-4)	U-turn (4-4)
Morningrush hour (7:00~9:00)	22	0	10	233
Late evening rush hour(17:00~20:00)	80	0	14	387
Peak times	185	0	52	1129
night	105	0	24	585

Optimization algorithm parameter setting (genetic algorithm) Population size: 50 candidate solutions Encoding method: [period C, phase 1 green light, phase 2 green light, phase 3 green light] Fitness function: Iteration termination condition: continuous 10 generations of fitness improvement <1%

5. Interpretation of result

In the key field of time-segmented traffic signal optimization, evaluation indicators serve as a critical quantitative tool for measuring the effectiveness of optimization, whose importance goes without saying. With the help of the provided data tables, this study mainly uses the following two core evaluation indicators, which accurately reflect the actual effects of traffic signal optimization from different dimensions.

5.1 Average speed

Definition: Average speed specifically refers to the average driving speed of a vehicle over a specific period, as it passes through a target section (for example, the intersection of Zhonglu and Wuzhonglu), measured in km/h. This metric acts like a mirror, reflecting the traffic efficiency of a road in a direct and clear manner. In practical terms, higher speeds indicate smoother traffic flow, allowing vehicles to travel more efficiently on the road, reducing time wasted due to congestion and other factors[6].Alculation method:

$$\overline{\mathrm{v}} = \frac{\sum_{\mathrm{i}=1}^{N} v_i}{N} \tag{14}$$

Calculation is performed $\overline{\mathrm{v}}$ average velocity v_i using the formula. Here, $\overline{\mathrm{v}}$ represents the speed of a single vehicle, recording the N instantaneous speed of each vehicle during its journey; N is the total number of vehicles counted, covering all vehicles passing through the target section during that specific time period. This method of calculation takes into account the speed of all vehicles, resulting in an average value that represents the overall traffic flow rate.

Ptimization Significance: During the morning peak hours, vehicle speeds increased significantly from an initial 28 km/h to 42 km/h, with a growth rate of +50%. This notable improvement clearly demonstrates that the optimized traffic signal timing strategy played a crucial role in successfully alleviating traffic congestion during peak hours, allowing vehicles to travel at faster speeds. During off-peak hours, vehicle speeds rose to 52 km/h, with a growth rate of +30%, further indicating that the optimization strategy can effectively tap into the potential of road capacity even when traffic volume is relatively low, thereby increasing vehicle speeds and enhancing the efficiency of road resource utilization.

ISSN 2616-5767 Vol.8, Issue 4: 102-109, DOI: 10.25236/AJETS.2025.080414

5.2 Delay reduction rate (Delay Reduction Rate)

Definition: The delay reduction rate[7] refers to the proportion of waiting time at intersections that has been reduced after optimization, expressed as a percentage (%). It is a key indicator for accurately quantifying the effectiveness of traffic light optimization in reducing traffic delays. Traffic delays have long been a major pain point in urban transportation, and this metric clearly demonstrates the success of optimization measures in reducing vehicle waiting times, alculation method:

$$DDR = (1 - \frac{D_{\text{post}}}{D_{\text{pre}}}) \times 100\% \tag{15}$$

DDR Delay reduction rate D_{pre} Average delay before optimization D_{post} Average delay after optimization. Here, the average delay usually refers to the average parking waiting time per vehicle at the intersection, measured in seconds per vehicle. By comparing the average delay before and after optimization and calculating, according to the DDR, one can determine the specific percentage reduction in delays, thereby intuitively demonstrating the extent to which the optimization measures have improved traffic congestion.

Ptimization Significance: During peak morning hours, delays were reduced by 35%. This figure is the result of a series of effective optimization measures, such as extending the green light duration on main roads, allowing more time for vehicles on the arterial roads to pass through intersections and reducing stop-and-go times; adding dedicated phases to control traffic flows in specific directions, further optimizing the flow of vehicles and effectively reducing queue lengths, thus significantly decreasing overall delay time. During off-peak hours, delays were reduced by 18%, primarily due to the application of phase balancing and green wave coordination strategies. Phase balancing ensures more reasonable distribution of traffic signals across all directions, avoiding situations where one direction has excessively long or short green light durations; green wave coordination achieves signal synchronization between multiple intersections, enabling vehicles to encounter more green lights during travel, reducing unnecessary stops, and consequently lowering delay times.

The optimization results are verified by NS model simulation, as shown in Table.3.

Table 3 Comparison of results before and after optimization

Interval	Optimize the even speed	Optimized even speed	Delays reduced
Morningpeak	28km/h	42km/h	35%
evenignpeak	25km/h	38km/h	28%
Peak times	40km/h	52km/h	18%
night	50km/h	55km/h	8%

Phase sequence:

Phase 1 (west import left turn (4-1) + North import U-turn (1-1)) (25s) → Phase 2 (South import right turn (3-1) + East import right turn (4-2)) (15s) → Phase 3 (North import straight (1-2) + East import straight (3-4)) (10s)

Green Wave Coordination:

The phase difference between Zhonglu and Weizhonglu is 10s, forming a two-way green wave belt (target speed 45km/h).

Dynamic adjustment rules:

If the turn around (1-1) queue exceeds 100m, the phase 1 green light is extended for 5s. If the right turn (4-2) flow is>100 vehicles/hour, a dedicated phase is enabled.

Through the above rich and comprehensive evaluation index system, the scientificity and practicability of the time-segmented traffic signal optimization scheme can be fully quantified and verified, which provides solid data support for the urban traffic management department, helps to formulate more scientific, reasonable and efficient traffic management strategies, and improves the overall operation level of urban traffic.

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6. Conclusions

In order to comprehensively improve the operation efficiency and safety of the urban traffic system, this scheme focuses on time-segmented traffic signal control and uses a series of refined strategies to alleviate traffic congestion and meet diversified travel needs.

Dynamic Real-time Monitoring and Intelligent Timing: High-precision flow detectors are installed at key intersections to collect and analyze real-time traffic data every 15 minutes. Leveraging intelligent algorithms, the timing parameters are dynamically updated based on the latest traffic flow. When there is a sudden surge in traffic in a particular direction, the system automatically extends the green light duration for that direction to ensure rapid vehicle passage, ensuring that traffic signals always align with real-time conditions.

This solution enhances the efficiency of traffic flow on main roads by optimizing the NS traffic flow model, Webster model, and genetic algorithm in tandem. Under strict traffic safety guarantees, it focuses on improving the operational efficiency of vehicle flows on main roads. Practical tests have shown that during peak hours, the speed of vehicles on main roads can increase by up to 50%, effectively alleviating traffic congestion and enhancing the overall performance of urban transportation.

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