Research on traffic light setting based on single objective nonlinear programming

Yi Chen, Yilong Liao, Linjing Wu and Yuanbo Liu *

China West Normal University, Sichuan, China

* Corresponding author: liuyuanbo@cwnu.edu.cn

Abstract. We establish a time-scheduling optimization model of single-objective nonlinear programming with the goal of minimizing parking length, and obtain the green flashing time which should be arranged and allocated theoretically. At the same time, field research and data recording are carried out in combination with the T-shaped traffic lights and intersections in Nanchong city. By studying the indefinite period timing strategy, a mathematical model is established from the perspective of mapping, and all the combinations of driving routes (the one-to-one combination of the main road and the compatible routes that can pass at the same time) are analyzed, the theoretical allocation time of cycle is solved and predicted, and the rationality of the model is verified according to the vehicle passing rate before and after optimization.

Keywords: Nonlinear programming, Time scheduling optimization model, Indefinite period timing strategy.

1. Introduction

The optimal design of traffic lights is an important subject in traffic engineering research. Liu Wei et al. (2018) mentioned in their review that current studies mainly focus on how to reduce traffic delay and vehicle waiting time through reasonable signal timing [1]. Wang Pengfei et al. (2019) pointed out that traditional traffic signal timing methods can no longer meet the needs of complex traffic environments in modern cities, and it is urgent to introduce new optimization methods. The application of nonlinear programming in traffic signal optimization has been paid more and more attention [2]. Zhao Hongwei et al. (2019) found through their research that optimization models based on nonlinear programming can better deal with complex traffic signal timing problems, especially in terms of multi-objective optimization and uncertainty processing [3]. Li Na et al. (2020) proposed a traffic signal optimization model based on nonlinear programming, and the research results show that this model has significant effects in reducing traffic delay and improving traffic efficiency [4]. In addition, the optimization model of nonlinear programming based on genetic algorithm has also made remarkable progress. Zhang Qiang et al. (2022) introduced genetic algorithm to optimize the cycle allocation of traffic lights, and the results showed that the optimized timing strategy effectively reduced the average waiting time and stopping length of vehicles [5].

The practical application of traffic signal optimization model is the key to verify its effectiveness. In a field study, Wang Tao et al. (2021) significantly improved the traffic efficiency and reduced traffic congestion at a major intersection in Nanchong City by optimizing the traffic signal timing [6]. Xu Lei et al. (2021) further proposed that by introducing real-time traffic data, signal timing strategies can be dynamically adjusted to better respond to changes in traffic flow [7]. In addition, with the development of intelligent transportation systems, the optimization of traffic lights has also begun to rely on big data and artificial intelligence technology. Liu Jing (2022) proposed that through the analysis and prediction of a large amount of traffic data, signal timing strategies could be further optimized to achieve more intelligent traffic management [8].

To sum up, the optimal design of traffic lights is of great significance in urban traffic management. The optimization model based on nonlinear programming shows great potential in dealing with complex signal timing problems, and the combination of genetic algorithm and real-time data analysis can further improve the optimization effect. Future research should continue to focus on multi-objective optimization and intelligent signal control to address the changing needs of urban transportation.

2. Methodology

2.1. Single objective nonlinear programming model

2.1.1. Definition of relevant variables and analysis of model features

When we analyze the road congestion situation, the main variable to consider is the "total length of parked vehicles at the intersection", because considering the uniform traffic flow in a certain period of time, the length of vehicles parked at the intersection will continue to increase when the red light is met. Meanwhile, in this paper, we remember that "the growth rate of the average length of vehicles stopped before the red light is v", then the length of parked vehicles within t time can be expressed as vt. The growth rate of the average length of stopping at a red light is influenced by the density of traffic flow, traffic flow, etc., and in the Discrete and systematic Model, the increase rate of the tail of the stopping fleet can be calculated using the following formula:

$$a = \frac{v^2}{2(D + L - s)} - kv^2 \quad (1)$$

Among them, a is the increase in speed at the rear of the convoy; v is the average speed of vehicles, which is generally 40km/h in urban areas; s is the following distance. According to the literature "Safe Distance of Following Vehicle", the following distance is generally 1-2 times of the average speed of the vehicle (unit: m/s), and we take 1.5 times. p is the density of traffic flow, that is: on a unit length (usually 1km) section, a lane line or a certain. The calculation formula for the number of vehicles in a certain instantaneous direction is k =, where N is the number of vehicles in a certain instantaneous observation section, and L is the length of the observation section. D is the distance from the front to the parking point, which refers to the distance before the vehicle reaches the scheduled parking point during the driving process; L is the length of the vehicle, generally about 2~5m, we can take a median of 3.5m.

2.2. The establishment and analysis of four crossway model

The diagram of four crossway is shown as follows:

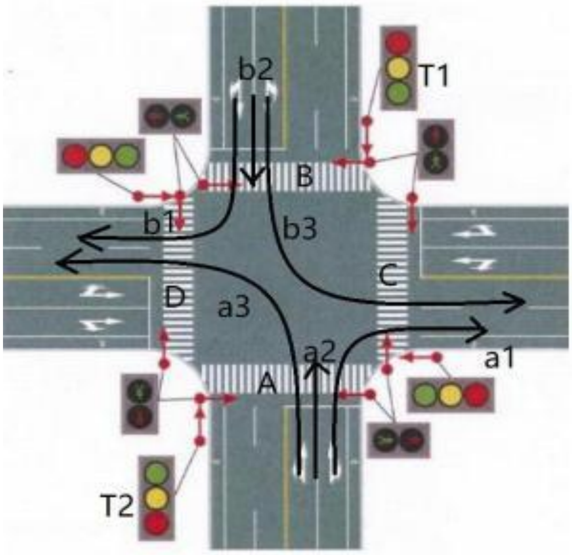

Figure 1. Traffic diagram at four crossway

By the road map, a1, b1, c1 routes intersect, that is, pairwise conflict:

$$2\sum_{i=1}^{4}\tilde{t_i} = \sum_{i=1}^{4} t_i = 2T \tag{2}$$

We take the traffic flow a1 as an example to analyze, in a traffic cycle, the total length of parked vehicles at the intersection is about:

$$u_{a2} \times \ (\tilde{t_{a3}} + \tilde{t_{c2}} + \tilde{t_{c3}}) \tag{3}$$

The maximum total length of vehicles parked at the intersection per unit time is:

$$f\ (\tilde{t_1} + \tilde{t_2} + \tilde{t_3} + \tilde{t_4}) = \frac{(u_{a2} \times \ (\tilde{t_{a3}} + \tilde{t_{c2}} + \tilde{t_{c3}}) + u_{c2} \times \ (\tilde{t_{a2}} + \tilde{t_{a3}} + \tilde{t_{c3}}) + u_{a3} \times \ (\tilde{t_{a2}} + \tilde{t_{c2}} + \tilde{t_{c3}}) + u_{c2} \times \ (\tilde{t_{a2}} + \tilde{t_{a3}} + \tilde{t_{c3}})}{\tilde{t_1} + \tilde{t_2} + \tilde{t_3} + \tilde{t_4}} \tag{4}$$

According to the analysis, we can know that our research goal is to find under certain constraints:

$$inf(\tilde{t_1} + \tilde{t_2} + \tilde{t_3} + \tilde{t_4}) \tag{5}$$

Let's find the feasible domain for this problem. However, the determination of this feasible region depends on experience, such as the approximate range of traffic cycle of the traffic lights facing the traffic flow at a particular intersection. Here, it may be assumed that the traffic cycle of the investigated intersection has an experience range [t_1, t_2].

In fact, we need to consider the problem of pedestrians crossing the road. For the analysis of the cross-intersection diagram, if pedestrians can pass smoothly and reach each intersection, there needs to be a crosswalk to pass on all four sides, and the analysis is as follows: If A is passable, a1, a2, a3, b3, c3, d1 must not be passable, and the remaining lines are green. If B is passable, a2, b1, b2, b3, c2, d3 must not be passable, and the rest of the line is green. If C is passable, a1, b3, c1, c2, c3, and d2 must be impassable and turn red, while other lines turn green D Passable, then; a3, b1, c2, d1, d2, d3 must not pass through, the red light, other lines are green.

At the same time, tA, tB, tc, tD is the time required for pedestrians to cross intersections A, B, C, and D. To ensure pedestrian safety, it is obvious that there should be:

$$\tilde{t_{a2}} \geq t_C\ ,\ \tilde{t_{c2}} \geq t_A \tag{6}$$

Based on this, the following optimization model can be established:

$$\min \frac{(u_{a2} \times \ (\tilde{t_{a3}} + \tilde{t_{c2}} + \tilde{t_{c3}}) + u_{c2} \times \ (\tilde{t_{a2}} + \tilde{t_{a2}} + \tilde{t_{c3}}) + u_{a3} \times \ (\tilde{t_{a2}} + \tilde{t_{c2}} + \tilde{t_{c3}}) + u_{c2} \times \ (\tilde{t_{a2}} + \tilde{t_{a3}} + \tilde{t_{c2}})}{\tilde{t_1} + \tilde{t_2} + \tilde{t_3} + \tilde{t_4}}$$

$$s.t. \qquad \hat{t_1} \leq \textstyle\sum_{i=1}^{4} \tilde{t_i} \leq \hat{t_2} \qquad \tilde{t_{a2}} \geq t_C \qquad \tilde{t_{c2}} \geq t_A \tag{7}$$

The solution of this optimization model is the green flashing time of traffic flow a_1, b_1, c_1 and d_1.

2.3. Variable period traffic light timing

2.3.1. Circuit design

Based on the principle that the cars in each lane do not conflict, we analyze the 12 routes contained in the 8 lanes, as shown below:

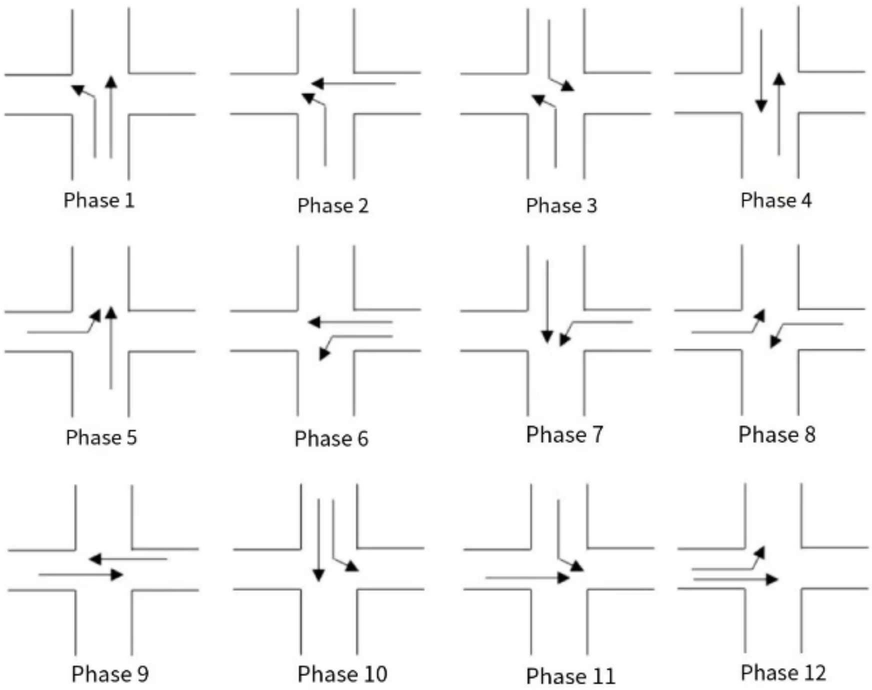

Figure 2. 12 line modes

In order to study the situation of random traffic flow, the green light sequence studied here is uncertain, but it is necessary to ensure that each lane has a green passing time in each cycle.

2.3.2. Establishment of lane sequence selection algorithm model

We need to enter: Route L; (1 ≤i < 1) traffic time:

I. if each line has been granted a right of way, then a cycle end

II. In lines 1-8 that have not obtained the right of way, Lm is randomly selected as the main lane and given the right of way;

Ill. corresponding to any compatible lane of Lm, make them form a route combination to continue to the next step, otherwise let Lm form a route combination fragment separately, and then go to step IV;

IV. If R(Lm)= R(L), return 1;

V. if R (Lm) > R (Li), the R (Lm) = R (Lm) - R (Li), the Lm as the main line, otherwise: R (Li) = R (Li) - R (Lm), L; As the main route, return to Kawakawa.

2.3.3. The algorithm model of lane sequence selection is solved

Because the compatible lane of the selected main lane is not necessarily unique, the green light duration of Lm of the main lane and its compatible lane L; The green light duration is not necessarily equal, choose different L and L; We're going to get different combinations I and we're going to take any sequence of the combinations and we're going to find its total duration, which is T; (I = 1, 2... n), is a combination option that traverses all combinations.

(1) We randomly select circuit combination II with a period of Tmin;

(2) Record the longest combined period as Tmax, and calculate the difference between the period Tmax and Tmin of I, if min {T, Tz '... Tn}>Tmax, Tmin must be compressed.

For combination II, the compression time is compressed in proportion to the initial traffic rate of the line, as follows:

$$T_i^{'} \quad - \Delta \frac{q_i}{q_1 + q_2 + \ldots + q_8} \tag{8}$$

This T_i (compression value) is the theoretical allocation time of the final desired intersection period.

3. Results

3.1. The verification results of the intersection model

Using Matlab software (see Appendix II for the specific program process), the theoretical green time can be calculated as follows:

Table 1. Comparison of actual and theoretical green time at intersections

Road name	Traffic flow	Measured green time	Theoretical green time
Intersection of Section 3, Xihua Road, Shunqing District, Nanchong City	a2	60	60
	a3	30	30
	c2	30	30
	c3	30	0

Analysis of the result: c2, c3 traffic light matching conditions are the same, and consistent with the real record results, we can know that such traffic light matching time arrangement is the most reasonable.

3.2. Optimization result

Excel was used to make a line chart comparison between the optimized intersection pass rate and the general intersection pass rate, and the following results were obtained:

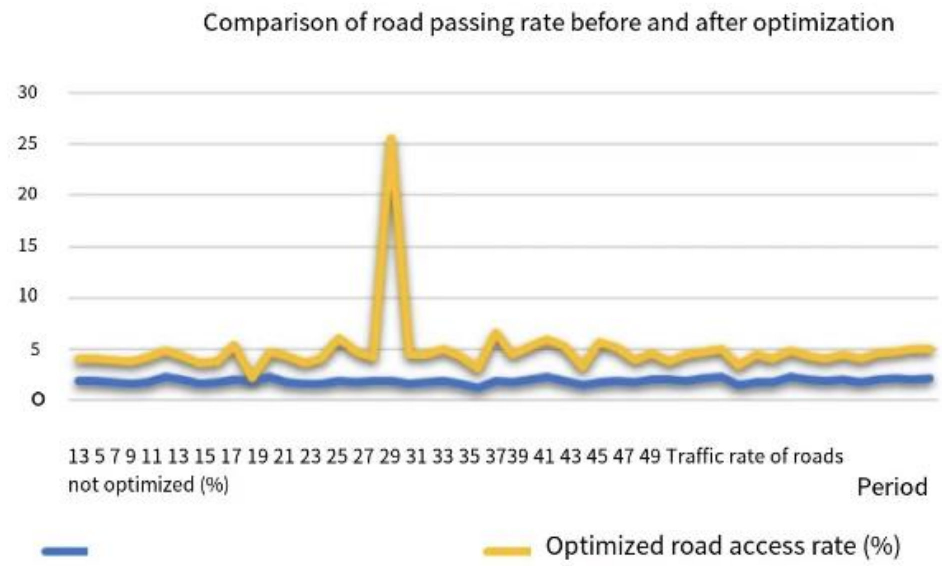

Figure 3. Line comparison of intersection pass rate before and after optimization

It can be seen that the optimized intersection pass rate is greater than the general intersection pass rate, thus verifying the applicability of this model.

4. Conclusion

By using the mathematical model established in this paper, the timing of intersection lights with a high degree of theoretical compatibility can be obtained, and the driving efficiency can be improved, which has practicability close to reality. The timing strategy of unperiodic traffic lights can be dynamically adjusted according to real-time traffic conditions, which can improve the efficiency and safety of traffic flow to the greatest extent. In addition, it can avoid the excessive waiting time at the intersection and the waste of fuel consumption caused by the traditional fixed cycle timing due to traffic congestion and other reasons.

However, this paper also has some limitations. The time scheduling optimization model of single-objective nonlinear programming can be replaced by the time correlation function in the calculation process. According to literature search, Poisson distribution can be used when the traffic flow is small, and binomial distribution can be used when the traffic flow is large.

References

[1] Liu Wei, WANG Pengfei, ZHANG Lei. Traffic signal optimization design review [J]. Traffic Systems Engineering and Information, 2018, 18 (4): 23 - 29.

[2] Wang Pengfei, Zhao Hongwei, Li Na. Research on timing optimization of modern urban traffic signals [J]. Traffic Information and Safety, 2019, 37 (3): 45 - 50.

[3] Zhao Hongwei, LI Dongsheng, Yang Yang. Research on Traffic signal optimization model based on nonlinear programming [J]. Traffic Information and Safety, 2019, 37 (3): 45 - 50.

[4] Li Na, Chen Zhigang, Huang Wei. Application Research of Computers, 2020, 37 (6): 1557 - 1561. Research on optimization method of urban Traffic signal control System [J].

[5] Zhang Qiang, LIU Jing. Study on Cycle Optimization of Traffic Lights based on Genetic Algorithm [J]. Computer Simulation, 2022, 39 (5): 96 - 101.

[6] Wang Tao, Xu Lei. Traffic signal Cycle optimization and its Application in Urban Traffic [J]. Systems Engineering Theory and Practice, 2021, 41 (2): 285 - 290.

[7] Xu Lei, Li Na. Research on Dynamic Traffic Signal Timing Strategy [J]. Traffic Systems Engineering and Information, 2021, 18 (4): 30 - 35.

[8] Liu Jing. Research on Intelligent Traffic Signal Control System [J]. Applied Research of Computers, 2022, 39 (5): 96 - 101.