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# Research on Traffic Signal Timing Method Based on Ant Colony Algorithm and Fuzzy Control Theory

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## Abstract

The number of private cars has a blowout growth with the development of economics, which leads to the existing limited traffic resources cannot meet the normal traffic demand. The emergence of intelligent traffic has improved this phenomenon. Using intelligent traffic technology to conduct intersection vehicles can alleviate the congestion effectively. Traffic signal timing method plays an important role in intelligent traffic research. An independent intersection dynamic timing method combined with fuzzy control theory and improved ant colony algorithm is proposed in this paper. According to the characteristics of traffic flow distribution, the timing period is obtained with the improved webster algorithm. Through the optimal solution obtained by ant colony algorithm and the added delay of traffic signal calculated by fuzzy control method, the dynamic timing period of the traffic signal is obtained. The validity of the proposed method is proved by comparing with the original time period and the traditional algorithm.

**Keywords:** intelligent traffic, dynamic timing, fuzzy control, ant colony

## 1. Introduction

In recent years, road congestion results in an increasing number of traffic accidents and serious traffic problems. Many metropolises, at the beginning of the design, did not take the rapid growth of vehicles into account, so the urban road design could only cope with the number of vehicles at that time. However, the process of urbanization is swift and the number of vehicles is growing at a geometric level, the scale of roads has not kept pace with the growth in the number of vehicles. Traffic congestion will lead to chaos in the traffic order, which wastes energy and causes economic losses. Urban emerging vehicles such as metro can shorten the time of travel, but fail to solve the traffic congestion fundamentally.

Mitigation of urban road congestion can be considered from three aspects: widening the road, reducing the intersection and optimizing the traffic signal control system at the intersection. The investment in road broaden is huge and the effect is not obvious in a short time. The establishment of the viaduct can reduce road intersection to achieve effective shunt, but the cost is high. Therefore, optimizing the traffic signal control system is the most effective approach. Real-time traffic flow can be obtained through monitoring facilities. Adjusting the traffic signal period, according to the traffic flow to reduce the stopping time of road intersection and alleviate the traffic congestion effectively. At present, more and more attention has been received to the traffic signal timing method.

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Optimizing the traffic signal control system is an efficient way to relieve traffic congestion. However, how to optimize efficiently is the key issue we need to study. The past crossroads are exactly the same for the opposite red and green time. The current traffic structure has changed a lot, the viaduct, fork road, and traffic flow is gradually increasing. The time of the traffic signal on opposite direction is different now, even the traffic signal period of two adjacent intersections is different, which stems from the measures taken to alleviate the traffic congestion by analyzing the traffic flow and calculating the traffic signal period. At present, numerous cities optimize the traffic signal timing method in various degrees. Through the acquisition of mass data and optimization algorithm to enhance the coordination ability of traffic lights on the arterial road. The application of the intelligent signal timing system is mainly considered the fixed length of traffic signal, and it is still not good enough to match the space-time resources with the traffic demand. The purpose of this paper is to use automatic control technology, information technology and computer technology to dynamically adjust the traffic signals at intersections and efficiently alleviate traffic congestion, which has a wide range of practical and broad prospects for development.

## 2. Signal Control Principles

### *2.1. Plane intersection*

This paper studies the plane intersection, which means all roads intersect in the same plane, but do not involve multiple paths intersecting in different planes. Common plane intersection, including crossroads, T-junctions, Y-junctions and roundabout. The different directions pointed in the intersection lead to the intersection as a traffic accident prone point, which is called the conflict point. In order to reduce the conflict points, the intersection of multiple junctions is often set up as a roundabout. With fewer vehicles, there are no conflict points at the earliest roundabout. Generally, the roundabout is suitable for the junction with smaller traffic flow; however, as the number of vehicles increased, the roundabout is exposed to the disadvantages of large area but low traffic capacity. This paper studies the crossroad and the conflict point are aimed at motor vehicles. There are usually 16 conflict points at a crossroads.

### *2.2. Basic parameters*

(1) Phase: At the signal control intersection, each control state, which is the combination of different light colors shown in different directions of each inlet, is called a signal phase.

(2) Timing period: The combined time of red lights, green lights and yellow lights in one intersection.

(3) Effective green time: The total period minus the red light time and the time lost when the vehicle starts.

(4) Green ratio: Green ratio refers to the proportion of vehicle passing time and period in the traffic signal period.

(5) Traffic flow: The sum of all vehicles passed by a certain section of a unit time.

(6) Queue length: Queue length refers to the total length of vehicles parked within the actual line of a certain phase intersection.

(7) Delay time: Delay time is the time difference between the actual taken time to cross the intersection, and the time should be taken when crossing the intersection.

(8) Parking rate: Parking rate is the number of times a car has been parked from one intersection to another.

(9) Traffic capacity: Traffic capacity refers to the maximum number of vehicles that passed at one intersection within a unit of time.

(10) Green wave belt: According to the time that the vehicle needs to pass a certain section and coordinates the traffic signals at each intersection, then the vehicle can continuously obtain the green light when passing.

*2.3. Signal timing method*

*2.3.1. Webster algorithm*

Webster algorithm is the most classic single-intersection traffic signal timing algorithm. This algorithm takes the minimum traffic flow delay as the standard and reasonably sets the green time [1]. Webster algorithm has the advantage that: when arterial road is in a heavy traffic flow situation and secondary road is in a less traffic flow situation, this algorithm can guarantee the arterial road traffic and avoids wasting the green time of the secondary road. The disadvantage is that the algorithm's timing effect is almost indistinguishable from the timing control when the road is oversaturated. Since webster algorithm only considers the delay time, more optimization algorithms are proposed to add more indicators to the model. Such as adding coefficient of parking compensation [2] or traffic capacity [3] into webster algorithm and combined delay time with parking rate to evaluate the signal timing. Or combined these two indicators into a nonlinear function model and introduced genetic algorithm and simulated annealing algorithm [4].

*2.3.2. Ant colony algorithm*

An ant colony algorithm is a probabilistic algorithm based on the evolution of bionics. Its main purpose is to solve optimization problems. In this paper, the optimization model of ant colony algorithm is proposed to optimize the signal timing of intersection. The main idea of ant colony algorithm is to treat the path of each ant from the origin to the destination as a solution. The set of these solutions constitutes the solution space for the problem we want to optimize. According to the characteristics searching for ant colony, more ants will choose the better path [6], which can be the optimal solution of the problem.

*2.3.3. Fuzzy control method*

With the advent of big data technologies, intelligent traffic equipment such as speed measuring equipment and traffic flow measuring equipment are now installed in many urban intersections, which brought great convenience to traffic signal timing research. Fuzzy controller is not an accurate calculator, it relies on the expert experience to fuzzy theory. So it is difficult to adjust the membership function and the fuzzy rule in the absence of experience and knowledge. Based on the detected real-time traffic flow data of intersections, the fuzzy control theory can be used to optimize the traffic signal timing method dynamically, which is better than webster algorithm [5]. Although ignoring important indicators such as queue length, it is a novel idea to apply fuzzy control theory to the dynamic timing of signal lights.

## 3. Traffic Signal Timing Method

Comprehensive consideration of above algorithms, this paper presents a signal dynamic timing method for intersection with fuzzy control system and improve the ant colony algorithm. In the optimization model of ant colony algorithm, the average delay, the parking rate and the traffic capacity are used as the evaluation criteria to obtain the improved traffic signal period. In the fuzzy control system, a fuzzy controller with double input and single output is adopted to calculate the traffic signal delay, which use the queue length as the evaluation criterion. The experimental results confirm that this approach has superior regulation performance on the intersection vehicles.

*3.1. An improved model of ant colony algorithm*

*3.1.1. Basic principle of ant colony algorithm*

An ant colony algorithm is a heuristic algorithm based on the development of bionics [7]. All paths from the initial point to the terminal point represent all solutions of the problem. According to the process of searching optimal solution by the information exchange of pheromones can be seen that the pheromone concentration is maximum on the optimal path, which causes more ants to choose this path. The positive feedback mechanism applied to the computer is a continuous iteration process from disorder to order [8].

For a given directed graph G(V, E), V represents the set of nodes and E represents the set of edges among nodes. The state transfer probability of ant k from the initial point i to the terminal point j at t time is $p_{ij}^{k}(t)$, as shown in Eq. (1). $\alpha$ and $\beta$ are heuristic factors. $\tau_{ij}(t)$ represents the pheromone concentration of the path from node i to node j at t time. The heuristic function represented by $\mu_{ij}(t)$ is shown in Eq. (2), where $d_{ij}$ represents the distance between node i and node j. $allowed_k$ represents the next optional target node set, as shown in Eq. (3), where $tabu_k$ represents the tabu list of paths.

$$p_{ij}^{k}(t)=\begin{cases}\tau_{ij}^{\alpha}(t)\mu_{ij}^{\beta}(t)\Big/\sum_{s\in allowed_k}\tau_{is}^{\alpha}(t)\mu_{is}^{\beta}(t) & , j\in allowed_k\\ 0, & else\end{cases} \tag{1}$$

$$\mu_{ij}(t)=1\Big/d_{ij} \tag{2}$$

$$allowed_k=V-tabu_k \tag{3}$$

The pheromone formula needs to be updated as Eq. (4) when all ants pass through n paths. $\rho$ represents the residual coefficient of pheromone. $\tau_{ij}^{k}(t)$ represents the pheromone left by the k ant [9]. $Q$ is the mass coefficient and $Q>0$. $L_k$ indicates the path length of k ant.

$$\tau_{ij}(t+n)=\rho\cdot\tau_{ij}(t)+\sum_{k=1}^{m}\tau_{ij}^{k}(t) \tag{4}$$

$$\tau_{ij}^{k}(t)=\begin{cases}\dfrac{Q}{L_k}, & if\ the\ ant\ passes\ by\ (i,j)\\ 0, & else\end{cases} \tag{5}$$

### 3.1.2. Improved ant colony algorithm

The total number of experimental ants is m and each ant correspond to a path in the algorithm, which is a solution to the problem. The updated state transfer probability is defined as Eq. (6). $\tau_{ij}(t)$ indicates the amount of residual information on edge (i, j) at t time.

$$p_{ij}^{k}(t)=\tau_{ij}(t)\Big/\sum_{r=1}^{m}\tau_{ir}(t) \tag{6}$$

At $t+n$ time, the pheromone concentration of edge (i, j) is updated as Eqs. (7) and (8). f is the objective function value at t time, $f_{max}$ and $f_{min}$ are the maximum and minimum values of the current objective function.

$$\tau_{ij}(t+n)=\rho\cdot\tau_{ij}(t)+Q\cdot\triangle\tau_{ij}(t) \tag{7}$$

$$\triangle\tau_{ij}(t)=(f_{\max}-f)\Big/(f_{\max}-f_{\min}) \tag{8}$$

The algorithm steps are as follows:

(1) Initialize the number of iterations $N=0$ and set up $N_{max}$. Randomly release ants and set the quantity to m. Assign initial values to $\tau_{ij}(t)$ and $\Delta\tau_{ij}(t)$.

(2) $N \leftarrow N + 1$

(3) $k \leftarrow k + 1$

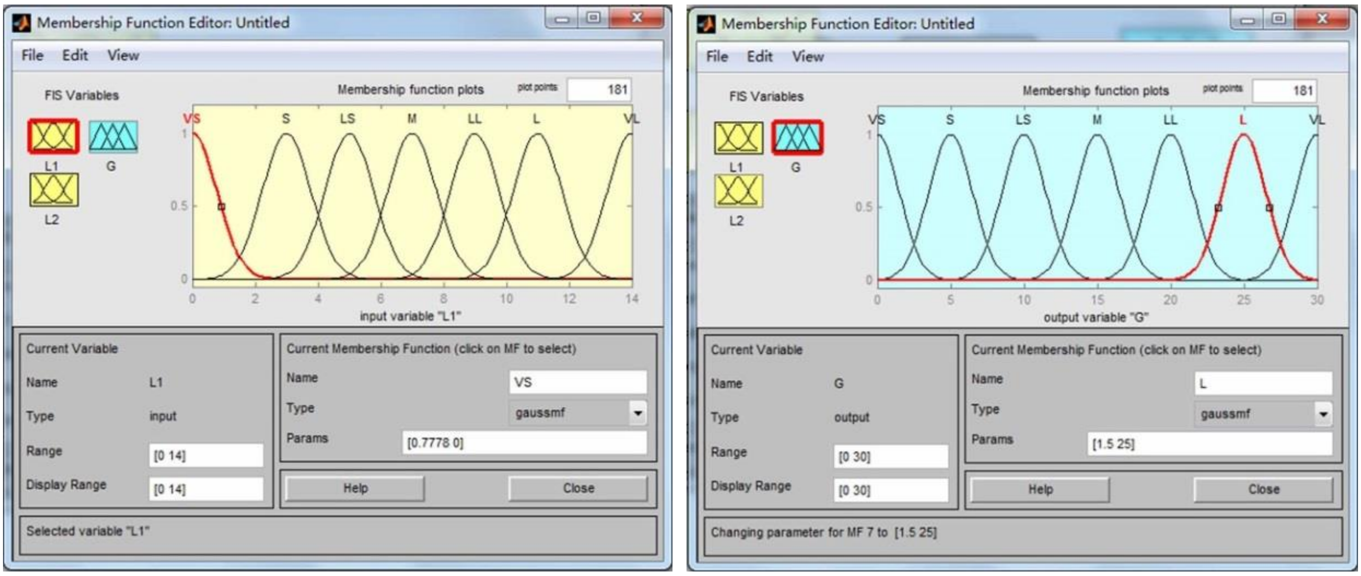
(4) All initial nodes are stored in tabu list and local search is conducted according to the state transfer probability. When the target node is determined, it will be stored in the tabu list until the tabu list is full [10].

(5) Update the pheromone of the path and calculate the pheromone increment of the path in the tabu list.

(6) Update all path pheromones according to Eq. (7). Find the shortest length of the path and empty the tabu list, then loop through the step (4).

(7) To iterate continuously and calculate the optimal solution that satisfies the condition.

### *3.2. An additional delay method based on fuzzy control system*




(a) Input data (b) Output data

Fig.1 Membership Function

Considering the influence of the vehicle queue length of traffic signal timing, this section uses fuzzy control method to calculate the additional delay of traffic signals through the vehicle queue length. The “double input-single output” fuzzy controller is adopted to calculate the additional green light time, according to the queue length of the current phase and the next phase. Seven fuzzy have been divided from very short to very long and have been set up for two sets of input data and one been set of output data respectively. And the Gauss function is selected as the membership function as shown in Figs. 1(a) and (b).

The purpose of fuzzy control is to reduce the average delay time. The flow diagram of the simulated intersection is shown in Fig. 2.

Based on the above data, 49 input-output fuzzy rules are established as Table 1.

Table 1 Fuzzy rules

| | VS | S | LS | M | LL | L | VL |
|---|---|---|---|---|---|---|---|
| VS | VS | VS | VS | VS | S | S | S |
| S | VS | VS | VS | S | S | S | S |
| LS | S | S | S | LS | LS | LS | LS |
| M | LS | LS | LS | M | M | M | M |
| LL | M | M | M | M | LL | LL | LL |
| L | LL | LL | LL | L | L | L | L |
| VL | L | L | VL | VL | VL | VL | VL |

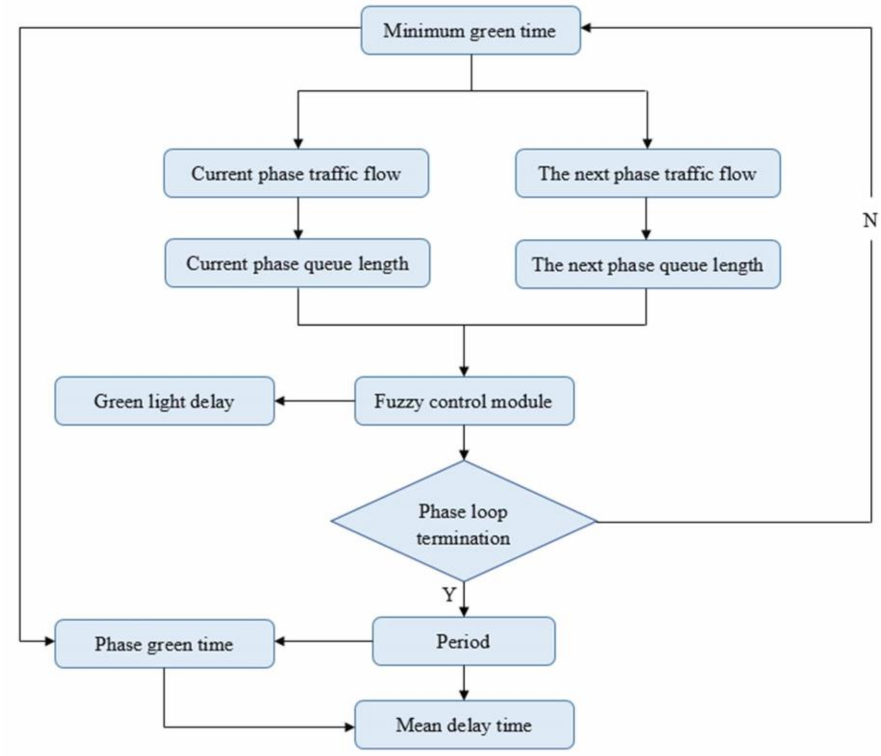



Fig. 2 Simulated intersection flow diagram

The implication relationship of the system is as follows:

$$R = R_1 \cup R_2 \cup \cdots R_{48} \cup R_{49} = \bigcup_{i=1}^{49} R_i \tag{9}$$

Finally, the output of additional delay is as Table 2.

Table 2 Additional delay

| Delay | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 4 | 5 | 5 | 5 | 5 | 5 | 5 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 4 | 5 | 5 | 5 | 5 | 5 | 5 |
| 2 | 1 | 1 | 1 | 1 | 1 | 2 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 3 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| 4 | 4 | 4 | 4 | 4 | 4 | 4 | 6 | 7 | 8 | 8 | 8 | 8 | 8 | 8 | 8 |
| 5 | 5 | 5 | 5 | 5 | 5 | 5 | 8 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| 6 | 8 | 8 | 8 | 8 | 8 | 8 | 10 | 12 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| 7 | 10 | 10 | 10 | 10 | 10 | 10 | 12 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| 8 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 15 | 17 | 18 | 18 | 18 | 18 | 18 | 18 |
| 9 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 16 | 18 | 20 | 20 | 20 | 20 | 20 | 20 |
| 10 | 18 | 18 | 18 | 18 | 18 | 18 | 20 | 20 | 20 | 22 | 23 | 23 | 23 | 23 | 23 |
| 11 | 20 | 20 | 20 | 20 | 20 | 20 | 22 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 12 | 20 | 20 | 20 | 20 | 21 | 21 | 23 | 25 | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| 13 | 25 | 25 | 25 | 25 | 26 | 27 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 |
| 14 | 25 | 25 | 25 | 25 | 26 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 | 29 |

### *3.3. Experiments*

#### *3.3.1. Evaluation metrics*

The delay time, parking rate and traffic capacity are selected as the evaluation metrics criteria for multi-objective optimization [11].

(1) Delay time

Reducing vehicle delay time is conducive to the release of road resources and is an important indicator of road service level. Eqs. (10) and (11) is used to calculate the delay time. $d_i$ represents the average delay time of vehicle in phase i. $q_i$

represents the actual traffic flow of i phase. C denotes the signal period and $\lambda_i$ represents the green ratio of i phase. $x_i$ and $y_i$ represent the road saturation and traffic intensity of the i phase respectively. Y is the sum of the maximum flow ratio of each phase; L stands for the lost time.

$$D = \frac{\sum_i^n d_i q_i}{\sum_i^n q_i} = \frac{\sum_i^n \frac{C(1-\lambda_i)^2}{2(1-\lambda_i x_i)} q_i}{\sum_i^n q_i} \tag{10}$$

$$\lambda_i = \frac{y_i (C-L)}{YC} \tag{11}$$

(2) Parking rate

Parking rate is also an index to be optimized in this paper. $h_i$ is the average parking number of the i phase and H indicates the average parking number of intersections.

$$H = \frac{\sum_i^n h_i q_i}{\sum_i^n q_i} = \frac{\sum_i^n \frac{0.9 \times C(1-\lambda_i)}{1-y_i} q_i}{\sum_i^n q_i} \tag{12}$$

(3) Parking rate

The multi-objective optimization algorithm mainly optimizes the traffic capacity of intersection. The total capacity of the intersection is as Eq. (13), in which $S_i$ represents the saturation volume of phase i.

$$Q = \sum_i^n Q_i = \sum_i^n S_i \lambda_i \tag{13}$$

### 3.3.2. *Model selection*

Choose the intersection of an arterial road in D city. The three phases are selected as follows: the straight line and the right turn line in the direction of East and West are the first phase; the left turn line in the direction of East and West is the second phase; the straight line and the right line in the direction of North and South are the third phase. According to the delay time and the parking rate is the decreasing function and the traffic capacity is the increasing function, the combination objective function can be established. $D_0$, $H_0$, $Q_0$ represent the initial values. $\alpha$, $\beta$ and $\gamma$ respectively represent the weight of delay time, parking rate and traffic capacity. The specific formula is as follows.

$$\min f = \alpha \frac{D}{D_0} + \beta \frac{H}{H_0} - \gamma \frac{Q}{Q_0} \tag{14}$$

$$\alpha = C \frac{1-Y}{1800} \tag{15}$$

$$\beta = y_i (1-Y) \tag{16}$$

$$\gamma = CY \tag{17}$$

Table 3 Arterial road intersection data

| Entrance / Traffic flow | East | | | | West | | South | | North |
|---|---|---|---|---|---|---|---|---|---|
| | left | straight 1 | straight 2 | right | straight left | straight right | straight left | straight right | total |
| Lane flow | 198 | 497 | 457 | 440 | 6 | 580 | 304 | 186 | 111 |
| Phase flow | 198 | 1394 | | | 6 | 580 | 490 | | 111 |

The experimental data selection is shown in Table 3. Based on the data can calculate the initial average delay is 29s, the initial parking time is 85 and the initial traffic capacity is 4901 $pcu/h$. Set the number of ants to 30 and the iterations number to 100. $\beta$ is 0.9 and $Q$ is 0.8. The optimal solution that obtained by the ant colony optimization algorithm will be combined with the additional delay time that calculated by the fuzzy control method. And the final solution C=149 seconds are obtained. Compared with the original period and the traditional algorithm as follows.

Table 4 Comparison of experimental results

| Timing Method | Period | Green time / Green ratio | | | Delay Time | Parking Rate | Traffic Capacity |
|---|---|---|---|---|---|---|---|
| | | Phase 1 | Phase 2 | Phase 3 | | | |
| Original | 114 | 57/0.5 | 23/0.2 | 25/0.22 | 29 | 85 | 4901 |
| Webster Algorithm | 72 | 34/0.47 | 14/0.19 | 15/0.21 | 20 | 57 | 4448 |
| Improved Algorithm | 149 | 79/0.53 | 29/0.19 | 32/0.22 | 25 | 109 | 5259 |

As can be seen from the Table 4, compared with the current traffic timing scheme of D city, the webster algorithm decreases the average delay time at the expense of reducing traffic capacity. Although the method proposed in this paper has increased the parking rate, the traffic capacity has been greatly improved while the average delay time decreases. When the traffic flow is heavy, this improved algorithm will have a significant effect on the traffic diversion at the intersection.

## 4. Conclusions

This research puts forward an optimization method of traffic signal timing, which combined the improved ant colony algorithm with fuzzy control method for single intersection signal timing. Through experimental verification, the proposed method is confirmed to improve the traffic capacity of intersection vehicles and reduce the delay time of vehicles. Traffic signal control system is not only a way to improve the efficiency of the vehicle in a certain intersection, it can also control the traffic flow of the whole traffic network after the gradual optimization of the system, by this way can the urban road capacity achieve to the best.

The traffic signal timing system needs to be continued optimize with the increasing number of vehicles. Although this research made improvements on the traffic signal timing method, there are still many problems have not been ponderer. To sum up, firstly, this research considered only a case of cross intersection. In actual traffic, there are a lot of traffic nodes in various forms. How to control traffic reasonably according to the different intersections is the main subject of current research. Secondly, this paper considered only the traffic condition of motor vehicles when simulating the traffic signal system, and does not take pedestrians and non-motor vehicles into account, since the large number of pedestrians and non-motor vehicles are considered, the difficulty of control will be greatly increased. How to improve the traffic efficiency of vehicles while ensuring the safety of pedestrians and non-motor vehicles through intersections will be the key issue of future research. In addition, the priority of buses is not considered in this paper; signal priority to give the bus green light permissions also increased the difficulty of crossroads control.

## Conflicts of Interest

The authors declare no conflict of interest.

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