Research on induction signal control method of queuing length

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Abstract— This paper aims at the problems of traditional induction signal control. By comparing the advantages and disadvantages of other timing signal control methods and induction signal control methods, an induction signal control method based on queuing length is proposed. The signal setting method of induction signal control method based on queuing length is analyzed in combination with the characteristics of queue length change and traffic flow. The method presented in this paper is introduced to optimize the length of the green light in the various phases of the previous period, the number of vehicles and the length of the queue, to predict the average head time distance and the queue length of the next cycle, so as to calculate the green light time and the period length of the next cycle of the intersection. At last, VISSIM simulation software is used to compare and analyze the traffic efficiency of induction signal control and traditional induction signal control based on queuing length, and verify the adaptability, feasibility and effectiveness of the scheme.

1. Introduction
Since the 21st century, people's living standards have been increasing day by day, and new challenges have been raised for transportation needs. The number of motor vehicles has grown rapidly. At the same time, there are generally lags in the technology and level of traffic management and control, low public awareness of traffic, unreasonable road layout and channelization[1]. These problems directly or indirectly lead to an imbalance between traffic demand and traffic supply, which leads to a series of traffic problems such as traffic congestion, environmental pollution, increased vehicle delays, and decreased travel satisfaction of residents. The increasing traffic problems have seriously hindered the development of cities[2]. The acceleration of the urbanization process has made congestion more common in cities. In order to remedy this problem, governments around the world have actively taken countermeasures, such as adding or expanding transportation infrastructure or optimizing traffic lights through canalization.

Research and practice at home and abroad have shown that urban traffic problems cannot be solved simply by widening newly-built roads. A more scientific and reasonable management and control is an effective means to solve urban traffic congestion problems[3]. In recent years, there has been more and more traffic on the road, and the problems with the inductive signal control are becoming more and
more obvious. The shortest green light time is mostly set based on the time distance of the front of the vehicle, which cannot meet the traffic demand of the intersection. Therefore, improving and optimizing the induction control model, reducing vehicle queuing and delay time at intersections is still the key to improving road capacity[4].

Inductive signal control is a signal timing feedback control method that adapts to traffic changes[5]. It can better adapt to the randomness of arriving traffic, reduce the number of vehicle stops, and guide traffic. It has profound significance for the study of inductive signal control at urban intersections.

Studies have not considered the dissipation characteristics of vehicles queued at the beginning of the green light signal. The given green light time is usually less than the actual value. This will cause vehicles queued in the previous cycle may not pass through the intersection in the next cycle, resulting in a second queue of vehicles phenomenon. The existing inductive signal control strategy will inevitably cause the running phase to pass by fewer vehicles, while the other phases are lined up for a long time, causing secondary parking and affecting the efficiency of intersection traffic[6].

Most of the existing studies assume that the vehicle's arrival follows a certain distribution, but in reality the vehicle's operation will deviate from the assumption, resulting in inadequate control of the induction signal. Under the premise of fully considering the randomness of vehicle arrival, how to improve the efficiency of induction control is an urgent problem to be solved in the future.

2. Induction signal control basic parameters

2.1. Minimum green time
The minimum green light time is a period of time that must be run regardless of whether or not a car arrives at each induction phase to ensure pedestrian crossing and vehicle driving safety[7]. The detector generally starts working after the shortest green light time is over and sends vehicle-related information to the signal. At least to ensure that the vehicle stopped between the detector and the parking line during a certain phase of the red light enters the intersection through the parking line.

2.2. Unit green light extension time
The length of the green light extension time depends largely on the unit's green light extension time[8]. Before the end of the minimum green light time, if the vehicle is detected within the unit green light time, the green light time will be extended; if the vehicle is detected by the detector, then the green light of this phase is ended and the phase is switched. When the unit's green light changes for an extended period of time, the effect of inductive signal control will be greatly affected. If the time is too long, it will cause a waste of green light time. If the unit's green light extension time is too short, it is not a problem of the unit's vehicle. It is difficult for the vehicle to safely leave the intersection, resulting in the early end of the green light extension. The extension time of the green light of the traditional unit is generally obtained by dividing the distance between the detector and the parking line by the average speed of the entrance.

2.3. Maximum green time
The maximum value of the green light extension time in induction control is called the maximum green light time. The maximum green light time can control the problem of unbalanced green light time in induction control[9]. If the green light extension time of a certain phase reaches the maximum green light time, the phase is forcibly ended and the next phase is switched to. The operating efficiency of an intersection depends to a large extent on the maximum green light time of the intersection, so optimization and quantitative calculation of the maximum green light time are very important[10]. Under normal circumstances, the maximum green light time should not appear frequently in each phase. If the maximum green light time is too short, this phenomenon will often occur. In this case, induction control is equivalent to timing control. In order to avoid the unreasonable value of the maximum green light time, we should analyze the previous statistical data on the basis of studying the traffic
characteristics, and study the reasonable and effective method for determining the maximum green light time of the induction intersection, instead of simply using empirical values.

3. Research on induction signal control method based on queue length

3.1. Queue length prediction

In order to calculate the green light display time $G_k$ of the i-th phase in the k-th cycle, we first need to predict the number $q_k$ of vehicles in the k-th cycle based on the number of vehicles in this phase in the previous cycles. In this paper, we take the number of vehicles $q_{k-1}$, $q_{k-2}$, $q_{k-3}$, $q_{k-4}$, and $q_{k-5}$ in the first 5 cycles measured by the detector for the i-th phase, and then use an exponential smoothing method to calculate $q_k (k \geq 6)$. In this paper, an exponential smoothing method is used to smooth the queue length of the first 5 cycles. The smoothing coefficient is used to eliminate the influence of accidental factors, and the total queue length of the kth cycle is more accurately predicted. This method is flexible and easy to operate.

The predicted value $q_k$ of the total queue length of the i-th phase in the k-th cycle can be calculated by the following formula:

$$q_k = \alpha y_{k-1} + \alpha(1-\alpha) y_{k-2} + \alpha(1-\alpha)^2 y_{k-3} + \alpha(1-\alpha)^3 y_{k-4} + \alpha(1-\alpha)^4 y_{k-5}$$ (1)

In the formula, $y_{k-n}$ is the actual value of the k-nth cycle; $\alpha$ is the smoothing coefficient, and $0 < \alpha < 1$.

In the prediction process, several $\alpha$ can be taken for trial calculation, and the smoothing coefficient value with the smallest prediction error is used. The specific value of $\alpha$ can be based on the actual intersection running process, counting the total queueing length of a certain phase in different periods of the day for several consecutive cycles, and performing multi-day data statistics to calculate the different periods. The $\alpha$ value is used as the weighting factor for this phase.

In the same way, the average headway $h_k$ of a certain phase of the k-th cycle is predicted by the exponential smoothing method.

3.2. Green light time calculation

The headway time has a proportional relationship with the vehicle type and phase complexity, and the headway time of the turning traffic at the intersection is greater than that of the straight-way traffic. Therefore, using a determined average headway time value cannot meet the changing vehicle queuing situation. However, the average head distance of vehicles in the same phase of adjacent cycles passing through the parking line is not much different, so the average head distance of the i-th phase in the k-th cycle is used for the calculation of the green light time of this phase in the kth cycle.

The number $Q_{k-1}$ of vehicles passing by the i-th phase in the green light time of the k-1th cycle can be measured by the detector. Considering the start delay time $t$ of the first car, the average headway of the k-1th cycle can be calculated:

$$h_{k-1} = \frac{n(G_{k-1}-t)}{Q_{k-1}}$$ (2)

The formula for calculating the average headway $h_k$ is as follows:

$$h_k = \alpha h_{k-1} + \alpha(1-\alpha) h_{k-2} + \alpha(1-\alpha)^2 h_{k-3} + \alpha(1-\alpha)^3 h_{k-4} + \alpha(1-\alpha)^4 h_{k-5}$$ (3)

Considering the above constraints, the shortest green light time model of the current phase of the kth cycle can be obtained:

$$G_k = \begin{cases} \frac{h_k \times q_k}{n} + t, & 0 \leq h_k \times q_k + t \leq G_{\text{max}} \\ G_{\text{max}}, & h_k \times q_k + t > G_{\text{max}} \end{cases}$$ (4)
Where \( n \) is the number of lanes in the current phase; \( t \) is the start delay; \( G_{\text{max}} \) is the maximum green light time; \( q_k \) and \( h_k \) are the predicted values based on the first five cycles, and the start delay time \( t \) is taken according to the actual situation of the different phases of the intersection. Value, the maximum green light time is determined in the same way as the traditional induction signal control.

3.3. Optimization of cycle time
Using the above method can calculate the green light display time of each phase, and then need to optimize the cycle time. In the \( k \)th cycle, the difference between the green light time \( G_1^k \) of the first phase and the green light time \( G_{1-1}^k \) of the phase in the \( k \)-th cycle is the adjustment of the green light time of the first phase to adapt to the change in the length of the vehicle queue, and then consider the \( k-1 \) cycle duration \( C_{k-1}^1 \), which can be adapted to the dynamic changes of traffic flow, and the adjusted cycle duration \( C_k^1 \):

\[
C_k^1 = G_k^1 - G_{k-1}^1 + C_{k-1}^1 \quad (5)
\]

After the first phase ends, run the next phase, you can get the readjusted cycle time \( C_k^2 \), and so on. When each phase of the \( k \)th cycle ends, you get the cycle time \( C_k \) that matches the real-time change of traffic flow. The calculation formula is as follows, where \( m \) is the number of phases at the intersection.

\[
C_k = G_1^k - G_k^1 + G^2_k - G_{k-1}^2 + ... + G^m_k - G_{k-1}^m + C_{k-1} \quad (6)
\]

The intersection of traffic flow arriving at random, the traffic situation is more complicated, it is difficult to use a series of changing data to describe in real time, and the induction control method in this paper can overcome these difficulties to a certain extent, optimize the signal timing with a more accurate control model, reduce vehicle queue length and delay time.

4. Case Study

4.1. Simulation example
Taking an intersection in Beijing as an example, the east-west, north-south directions are two-way four-lane, and each entrance lane is provided with a left-turn dedicated lane, a right-turn dedicated lane and two straight lanes. The intersection is controlled by two phases, the first phase is the key phase, and the phase sequence is that the north and south vehicles are released first (second phase), then the east and west are released (first phase), and the right turn is not restricted by the signal lights.

Assuming that the traffic capacity of the straight lane at the intersection is 1200pcu/h, according to the traffic survey results, the ratio of left-turning and right-turning vehicles at the intersection can be found. The road capacity is 3582pcu/h. Simulate and verify the induction signal control optimization model based on queuing length proposed in this paper, and compare and analyze with the traditional induction control control scheme to verify the feasibility, practicability and effectiveness of the induction control optimization model based on queuing length.

4.2. Simulation operation
In order to evaluate the feasibility of the optimization model, simulation experiments were conducted on the optimization model and the intersection under the control of traditional induction signals, and the evaluation data were compared and analyzed. The evaluation indicators selected in this study are average travel time, average delay and average queue length. Use the VISSIM software to set the control mode of the signal light group to VAP, write and import the program file (VAP file) and configuration file (PUA file) for simulation.
4.3. Evaluation of simulation results
Use VISSIM software to simulate and evaluate the traditional induction signal control and the optimized induction signal control based on queuing length respectively, and obtain the average travel time, average delay and average queuing length of each entrance, and optimize the east, west, south and north imports. The comparison of the evaluation indicators before and after is shown in Table 1.

| Intersection | Flow direction | Average travel time/s | Average delay/s | Average queue length/m |
|--------------|----------------|-----------------------|-----------------|------------------------|
|              |                | Before optimization   | After optimization | Before optimization | After optimization |
| East         | Straight travel| 19.36                 | 15.50           | 18.45                  | 10.97               | 39.38 | 19.00 |
|              | Left turn      | 35.51                 | 15.73           | 21.48                  | 15.73               |
| West         | Straight travel| 17.95                 | 13.00           | 10.12                  | 5.47                | 43.75 | 30.50 |
|              | Left turn      | 34.56                 | 22.92           | 25.24                  | 14.86               |
| South        | Straight travel| 45.16                 | 34.56           | 34.24                  | 26.15               | 42.00 | 28.20 |
|              | Left turn      | 51.97                 | 22.92           | 40.00                  | 15.48               |
| North        | Straight travel| 14.59                 | 12.71           | 4.84                   | 4.87                | 35.00 | 22.50 |
|              | Left turn      | 21.45                 | 23.43           | 12.33                  | 15.20               |

It can be seen from the experimental results that the average travel time, average delay and average queue length of the optimized induction signal control are reduced to a certain extent compared with the traditional induction signal control, except for the average travel time of the southbound straight train. Compared with traditional induction control, the control effect of the proposed induction control parameter optimization model based on queuing length has been significantly improved. It can be seen that the induction control parameter optimization model based on queuing length is feasible.

5. Conclusions
The main research results of this article are as follows:
• Introduce the queuing length-based induction signal control method. Combine the queuing length variation characteristics and traffic flow operation conditions, analyze the signal setting method based on the queuing length induction signal control method.
• Compare the advantages and disadvantages and adaptability of other timing signal control methods and inductive signal control methods, and analyze the adaptability, setting principles and basic steps of the inductive signal control method based on queue length.
• Using VISSIM simulation software, comparative analysis of the passage efficiency of the induction signal control based on the queue length and the traditional induction signal control has verified the adaptability, feasibility and effectiveness of the scheme.

Induction signal control was introduced in my country late, so it is not widely used in China, but induction signal control can overcome many shortcomings of timing control, and its development prospect is very impressive. This thesis focuses on the determination of control parameters of inductive signals to improve the operational efficiency of inductive signal control. This study has the following shortcomings:
• Although the queuing length and the average headway time are predicted in the paper, the prediction results obtained by the prediction model are different from the actual situation and need to be further improved.
• This paper only considers the situation of single-point signal induction control, and should continue to further study the establishment and simulation of green wave control and regional trunk coordination signal control model.
• This article does not consider the impact of mixed traffic on intersections. In the next step of the research work, it is necessary to establish non-motorized pedestrians. The inductive signal control model of the intersection of influencing factors, thus forming a perfect signal control scheme suitable for China's national conditions.

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