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Review of Coordinated Control Strategies for Urban Arterial Road

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Abstract

Urban arterial coordinated control strategy is an effective way to alleviate urban traffic congestion. The current urban coordinated control methods can be divided into maximum green wave band method and minimum performance index method. This paper, two different coordinated control methods are reviewed, and the advantages and disadvantages of urban road arterial coordinated control methods are analyzed, and the future research direction in this field is prospected.

Keywords

Arterial Road Signal Coordination Control Strategies; Green Wave Band; Performance Indexes.

1. Introduction

With the rapid development of urbanization and modernization in China, the number of motor vehicles is increasing, the traffic flow is growing rapidly, and the contradiction between supply and demand in urban traffic is increasing day by day, showing the phenomenon of traffic congestion and low utilization rate of road resources. Improving road traffic efficiency and reducing vehicle delay is an important part of current urban traffic construction. The most direct and effective way to solve such traffic problems is to develop infrastructure such as roads and Bridges. However, this method is often limited by urban space. Scientific channelization design and reasonable signal timing of urban roads become the key to avoid the waste of time and space resources of urban roads.

As a key node of urban traffic network, road intersections carry important functions such as convergence and turning of traffic flow. By adjusting parameters such as signal period and green signal ratio of a single intersection, the traffic efficiency of the intersection can be improved. However, the correlation between adjacent intersections in the road network is often large. It is difficult to achieve the desired effect only by optimizing and adjusting the signal timing of a single intersection, and even lead to more congestion at other intersections of the whole trunk road. Therefore, a reasonable control strategy is adopted to coordinate the timing of each adjacent intersection signal of the urban trunk line and reduce the number of running vehicles encountering red lights, which can effectively alleviate the problem of urban traffic congestion. At present, there are mainly two common arterial coordinated control strategies, the maximum green wave band method and the minimum performance index (average queue length, delay time, stop times, etc.) method. This paper reviews the domestic and foreign research results of the above-mentioned arterial coordinated control methods.

2. Maximum Green Band

The basic principle of the maximum green wave belt method is to adjust the period and signal difference of each intersection, so that the vehicle can pass through multiple intersections in a

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certain speed range, forming a green wave belt, the maximum green wave belt mainly has three methods: graphic method, numerical method and model method.

2.1. Graphic Method

The graphic method is to achieve the maximum green wave bandwidth by drawing the time interval diagram and adjusting the signal period, speed and other control parameters constantly. Wu Bing introduced the basic idea of graphic method and the steps of use in detail[1].

Lin Xiaohui proposed a bidirectional green wave design method applicable to the conditions of separate release of imports with asymmetric geometric conditions and unbalanced direction flow, and verified the effectiveness of the method [2]. In the traditional graphical method, the signal timing of a single intersection is often ignored. Zhou Jun first applied Webster method to reconfigure the timing of each intersection inlet road, and then used the graphical method to solve the signal phase difference at each intersection[3]. Chang Yulin proposed an improved graphic method to realize bidirectional green wave signal control. Compared with the traditional graphic method, the improved graphic method can realize bidirectional green wave coordinated control with different bandwidth requirements according to actual traffic needs, and is suitable for symmetrical import release and independent import release. At the same time, it also applies to situations such as unbalanced two-way flow, queued vehicles at intersections, and changes in speed[4]. In order to solve the problems of narrow band width and large phase difference error in bidirectional green wave control design caused by traditional graphic methods, Chen Xin proposed a bidirectional green wave control graphic method based on the intersection point of the center line of the green wave band[5].

The graphic method is easy to understand and analyze because of its intuitive expression, but it also has some limitations. First, the graphic method is suitable for the situation where the traffic flow is relatively stable and the road conditions are relatively simple, and its effect will be greatly affected for the traffic flow and complex traffic network; Secondly, graphic method is a design method based on static traffic data, which is difficult to adjust according to real-time traffic conditions. In actual traffic conditions, changes in traffic flow, vehicle speed and other factors will also reduce the implementation effect of green wave band.

2.2. Numerical Method

The numerical method obtains the optimal phase difference control scheme by finding the minimum of the maximum shift of the actual signal from the ideal signal in the system. The numerical method is easy to calculate, easy to operate and easy to implement, and is suitable for bidirectional symmetrical trunk roads. It has a good control effect under unsaturated traffic conditions. However, the scientific nature and rationality of the algorithm are ignored in the application of the traditional numerical method. Therefore, many scholars have improved the logarithmic solution, broadened the scope of application and made up for the shortcomings of the method itself. Wang Dianhai analyzed and improved the traditional numerical solution, and proposed a modified calculation method of green wave band width and phase difference, as well as a matching method between actual and ideal intersections[6]. Cao Jianfeng segmented the complex road, carried out bidirectional coordinated green wave belt control on the segmented road in a simplified way, and then connected and coordinated multiple objects with certain methods to achieve bidirectional green wave band coordinated control of the whole lane[7]. Jing Binbin proposed a numerical solution algorithm based on bidirectional maximum green wave bandwidth, which broke through the limitation of fixed value of green wave upstream and downstream design speed[8].

Compared with the graphical method, the numerical method is also susceptible to traffic flow and cannot be optimized in real time. At the same time, the calculation amount of the numerical method is increased and it is easy to fall into the local optimal solution. Its application effect is

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also greatly affected by the difference between the ideal intersection distance and the actual intersection distance.

2.3. Model Method

The model method is a method to obtain the maximum green wave bandwidth by solving the mathematical model between green wave bandwidth and phase difference, signal period, vehicle speed and other related parameters. In 1966, Little proposed a mixed integer linear programming model that could simultaneously optimize common period, phase difference and vehicle travel speed[9]. Subsequently, Little proposed a coordinated control model - MAXBAND MODEL[10] on the basis of previous studies. Based on the research results of Little, Chang proposed the MAXBAND-86 model, which solved the coordination control problem of the closed road network surrounded by multiple arterial roads[11]. Based on the control idea of MAXBAND, Gartner proposed a variable bandwidth trunk green wave model - MULTIBAND MODEL for different road conditions[12]. Similar to the MAXBAND model, Stamatiadis proposed the online MULTIBAND-96 model to overcome the complexity of large-scale road network solution optimization[13]. Domestic scholars Tang Keshuang removed the restriction of symmetry along the center line of the green wave band and added the position constraint of the green wave band. Based on the MULTIBAND model, they improved the applicability of the model and the stability of the green wave band operation[14]. Chang Yulin artificially reduced the impact of intersecting road left-turn saturation flow on trunk lines, improved the efficiency of trunk coordination control, considered the inclusion of partial green time at intersections into the coordination phase, and improved the MULTIBAND model[15]. Zhang Yiyuan proposed a route green wave coordinated control method based on superimposed phase design to solve the problem of mismatch between the green light turning on time at the intersection of trunk lines and the arrival time of traffic flow in the corresponding direction in the existing graphic and numerical filtering coordinated control methods[16].

In practical applications, the implementation effect of green wave has a great relationship with the running state of the road. The coordination effect of the maximum green wave bandwidth solved by the model needs to consider the changes of various factors such as weather and traffic flow. Generally, the effect of the maximum green wave bandwidth model is significant in the medium and low saturated traffic state.

3. Minimum Performance Index

At present, a large number of scholars have done research in the field of the green wave coordinated control method of the main line using the optimal minimum performance index, and most of them choose parameters such as delay time, stopping times, and energy consumption as optimization indicators. Hillier, a foreign scholar, analyzed the dissipation process of queuing vehicles at the entrance of adjacent intersections, established the functional relationship between vehicle delay time and phase difference, and obtained the green wave coordinated control model of trunk line based on the minimum delay time[17]. Liu proposed a coordinated control model of the trunk road that can select different optimization indexes according to different states of the trunk road, and optimized the solution through genetic algorithm[18]. In China, Wan Xujun used the classical triangle delay theory to add the variable phase difference to the model and put forward the phase difference optimization model of the linear control system[19]. On this basis, Pei Yulong analyzed the shortcomings of the classic triangle delay model and established a parallelogram model with the arrival of vehicles at the intersection as the physical pulse mode, which makes all signals more coordinated and easier to solve mathematically[20]. By analyzing the traffic flow characteristics of two intersecting trunk lines, Yuan Zhan proposed the linkage coordination control method of intersecting trunk lines based on minimum delay[21]. Aiming at minimizing vehicle delay and stopping times, Jiang

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Xiancai established a bidirectional optimization model of speed guidance signal control scheme with the help of the information interaction function between vehicles and infrastructure, which proved that the utilization efficiency of green light was improved[22].

The difficulty of the minimum performance index method lies in the selection of the index and the solving process of the nonlinear model is usually complicated, so selecting the appropriate performance index and solving algorithm is particularly important for this kind of method.

4. Conclusion and Prospect

By optimizing the parameters of common cycle, green signal ratio, phase difference and so on, the traffic signal linkage control of trunk line is realized, so as to improve traffic efficiency and alleviate traffic congestion. The research on trunk coordination control abroad started early, the theory is solid, and the practical application effect is good. China has introduced foreign advanced design concepts and mature signal control systems, but due to the complexity of China's traffic system and different traffic rules, the practical application effect is not good. In order to adapt to China's traffic system, domestic scholars have made many improvements and achieved good results, but there are still shortcomings. The multi-objective optimization model can be considered to establish the optimal model of comprehensive performance. In terms of solving algorithm, more advanced artificial intelligence algorithm is considered to solve the problem, and the effectiveness of the green wave coordinated control scheme of the trunk is increased by more accurate models and solving methods.

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