An Improved General Bidirectional Progression Model for Arterial

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Abstract: Optimal control of arterial signals is critical for the effective operation of urban road network. With the goal of providing reasonable allocation of bidirectional green time while maximizing general bidirectional traffic progression along the arterial, this paper develops an improved general bidirectional coordinated progression model for arterial based on Maxband model. In the model, a proportional coefficient of bidirectional bandwidth demands is introduced and calibrated by adopting average link queue occupancy. The calibration method takes full account of actual traffic volume and capacity of each link, which helps to provide optimal control performance. Additionally, new constraints are added into the model and enable the model with two features: it can automatically select two-way or one-way progression, and the involved intersection unit can be either one-phase-one-approach or bidirectional symmetric release mode. The results of extensive simulation studies indicate that the improved model outperforms existing methods, markedly increasing the utilization of available bidirectional green time.

Keywords: arterial signal control, two-way progression, hybrid release, average link queue occupancy

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0 Introduction

Urban arterials are vital components in a transportation network, and the efficiency of their signal control greatly influences the entire network’s performance. Arterial signal coordination is an efficient traffic control strategy for traffic researchers and practitioners and can enable the timings of grouped signals to improve overall traffic flow propagation for arterial. It has long been recognized that the challenge is to determine optimal signal coordination plan for arterial system so as to avoid or mitigate overall traffic congestion and to increase the throughput through the arterial.

Over the past several decades, numerous studies in the arterial traffic signal control have been conducted and classified into two categories: one is to minimize the total delay along an arterial; the other is to maximize the two-way bandwidths for the signalized system. Existing representative models in the former category are traffic network study tool (TRANSYT)1, traffic signal optimization program III (SIGOP-III)2, etc. The core logic of the latter category is to provide optimal common cycle and offsets to facilitate the through movements over consecutive intersections, for example, Maxband3, Multiband4-5, graphic method and algebraic method6. These bandwidth-based models have been received popularity among many traffic engineers, due to the fairly less constraints and the intuitive visibility of the control effect. However, most of bandwidth-based models are used for the arterial with single release mode and may fail to solve the arterial signalized system of mixed release mode. Throughout the hybrid traffic situation in China, there are two common phase plans for signalized intersections, namely, bidirectional symmetric release and one-phase-one-approach release7. The bidirectional symmetric release is suitable for two-way balanced traffic flows, while one-phase-one-approach release appears in the case with uneven traffic movements or asymmetric geometry8. The single release mode adopts bidirectional symmetric release or one-phase-one-approach release for each intersection. The two release approaches coexist in an arterial system, which is the so-called hybrid release mode. Hence, the improvement and refinement for bandwidth maximization methods is an important goal for the research community, taking full account of the factor of hybrid release9.

In the same category of bandwidth maximization, parts of arterial signal coordination plans are available for mixed release mode in the literature. For example, Lu et al.10 proposed a general model of bidirectional green wave for the coordinate control of arterial road...
by time-space analysis, considering the actual demand for different traffic release modes. Two-way arterial segments have a uniform bandwidth in the general model above, which is insufficient to obtain optimal control performance due to mismatch between demand and bandwidth. Little et al. [3] developed Maxband model based on mixed-integer programming and extended the work by introducing the proportional coefficient of inbound and outbound traffic volumes. Lu et al. [11] built a new performance index function based on the general model by introducing bandwidth proration impact factor and bandwidth demand ratio. There is no better calibration method of the parameter characterizing the bandwidth ratio to address this issue.

Based on the above analysis, an improved general bidirectional progression model for arterial is developed and tested in this paper. The improved version introduces the proportional coefficient $w$ of bidirectional bandwidth requirements and proposes a new calibration method. More specifically, average link queue occupancy containing simultaneously actual traffic volume and road segment capacity is adopted in calibration approach to ensure suitable match between demand and supply and to receive overall optimal control performance along the arterial. In the meantime, the corresponding optimizing process is presented. Finally, two simulation experiments are conducted to validate the improved model compared with Maxband and to analyze the sensitivity of $w$ values.

1 Two-Way Progression Model of Arterial Signals

Maxband model, as noted in Ref. [3], generates a well arterial signal control scheme with the maximum of total two-way progression bandwidth on an arterial via modifying cycle time, offsets and phase sequence patterns. Figure 1 illustrates the key model variables in Maxband, and the corresponding formulas are quoted below:

$$\max \{ b = \bar{b} \},$$

s.t. $w_i + b \leq 1 - r_i, \ \forall i = 1, 2, \ldots, n,$

$\bar{w}_i + b \leq 1 - \bar{r}_i, \ \forall i = 1, 2, \ldots, n,$

$$w_i + \bar{w}_i - (w_{i+1} + \bar{w}_{i+1}) + t_{i,i+1} +$$

$$\bar{t}_{i,i+1} + \Delta_i - \Delta_{i+1} =$$

$$-0.5(r_i + \bar{r}_i) + 0.5(r_{i+1} + \bar{r}_{i+1}) +$$

$$(\bar{r}_i + r_{i+1}) + m_i,$$

$m_i \in \mathbb{Z}, \quad i = 1, 2, \ldots, n - 1,$

$b, \bar{b}, w_i, \bar{w}_i \geq 0, \quad i = 1, 2, \ldots, n - 1,$

where outbound (inbound) bandwidth is expressed as $b(\bar{b})$; time between the start of outbound (inbound) green phase and the boundary of its outbound (inbound) green band is expressed as $w_i(\bar{w}_i)$; $r_i(\bar{r}_i)$ is outbound (inbound) red time at $S_i$; $t_{i,i+1}(\bar{t}_{i,i+1})$ is travel time from $S_i$ to $S_{i+1}$ outbound (inbound) $S_{i+1}$ to $S_i$; $\Delta_i$ is time from center of $r_i$ to the nearest center of $r_i$; $\tau_i(\bar{\tau}_i)$ is queue clearance time, an advance of the outbound (inbound) bandwidth upon leaving $S_i$. The units of all the above parameters or variables are cycles. In addition, integer variable is expressed as $m_i$; $S_i$ is $i$th intersection of an arterial system.

![Time-distance diagram of Maxband model](image-url)