Semi-Actuated Arterial Coordination for Traffic Control: A Practical Method

Yu-Liang Liu, Yanjie Duan, and Wenwen Kang

***Abstract*—Arterial coordination is a common method in urban traffic control. Traditional arterial coordination methods are usually off-line control methods based on mixed-integer linear program. These methods cannot adapt to changes of traffic flow, for instance, although there are very few cars in a branch road, timing plan will not adjust. Thus, we proposed a semi-actuated arterial coordination method which is a combination of practical actuated traffic control and traditional arterial coordination control. Five adjacent intersections of Huanghe Second Road in Binzhou City, Shandong Province, China are selected to test our method. We use microscopic traffic simulation software Q-PARAMICS to simulate and simulation results show that semi-actuated arterial coordination can effectively improve the performance index.**

I. Introduction

Arterials share the main traffic burden of a city. How to improve traffic capacity of arterials is a critical problem to improve the traffic efficiency of the whole road network. Currently, there are two types of arterial coordination methods which are methods of minimizing delays represented by TRANSYT and of maximizing bandwidth represented by MAXBAND. The methods of maximizing bandwidth are very popular in traffic engineers because their performance can be judged from the width of bandwidth.

Generally, methods of maximizing bandwidth are offline. Before calculate timing plans, all the parameters, such as locations of each intersection, band speed, queue clearance time, common cycle length, split, etc., should be obtained by investigation or calculation. However, when traffic flow varies apparently, these methods cannot adapt to the changes. In fact, green time will be wasted in this case.

Hence, a simple and practical arterial coordination method is needed to change timing plan with fluctuation of traffic flow. This paper proposed a semi-actuated arterial method which is a combination of practical actuated traffic control and traditional arterial coordination control. We use microscopic traffic simulation software Q-PARAMICS to simulate our method and the simulation results show that semi-actuated arterial coordination can effectively improve the performance index.

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II. The Basic Arterial Coordination Method

This section presents the formulation of the classical MAXBAND optimization model. This method is proposed by Little in 1981.In essence, MAXBAND is a mixed integer linear programming problem.

The geometric relations for the MAXBAND model are shown in Figure 1.The following variables are defined:

$b(\bar{b})$	outbound(or inbound) bandwidth;
S_i	intersection $i, i = 1, \Lambda\ , n$;
$r_i(\bar{r}_i)$	outbound(or inbound) red time at intersection S_i;
$w_i(\bar{w}_i)$	timefrom right side(or left side) of red at intersection S_i to left edge(or right edge) of outbound(or inbound) green band;
Δ_i	time from center of $\bar{r}_i$ to nearest center of r_i;
τ	time for queue clearance.

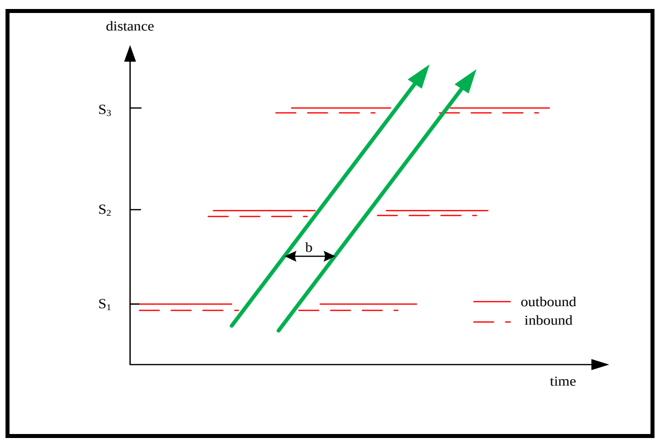

Figure 1. Geometric relations of MAXBAND.

All the variables related to time are the ratio to the cycle. According to Figure 1, we can obtain the basic mixed integer linear program (MILP1) for arterial coordination control for fixed phase sequence.

$$\text{MILP1: Find } b, \bar{b}, w_i, \bar{w}_i, m_i \quad to$$

$$\max \quad b$$

$$\text{Subject to} \quad \bar{b} = b$$

$$\left.\begin{array}{l} w_i + b \le 1 - r_i \\ \bar{w}_i + \bar{b} \le 1 - \bar{r}_i \end{array}\right\} \qquad i = 1, \Lambda \ , n$$

$$(w_i + \bar{w}_i) - (w_{i+1} + \bar{w}_{i+1}) + (t_i + \bar{t}_i) + \Delta_i - \Delta_{i+1}$$

$$= -(1/2)(r_i + \bar{r}_i) + (1/2)(r_{i+1} + \bar{r}_{i+1}) + (\bar{\tau}_i + \tau_{i+1}) + m_i \ , \quad i = 1, \Lambda \ , n-1$$

$$m_i = \text{integer}$$

$$b, \bar{b}, w_i, \bar{w}_i \ge 0 \ , \qquad i = 1, \Lambda \ , n$$

More generally, we take into account the optimization of phase sequence. Specifically, left turn time of the main phase can be picked to lead or lag in the hope of expanding bandwidth. Meanwhile, by operation the ratio of inbound to outbound bandwidth we can handle the asymmetric traffic flow. By adding a number of generalizations to MILP1, we derive a more versatile mixed integer linear program (MILP2) as follows.

$$\text{MILP2: Find } b, \bar{b}, z, w_i, \bar{w}_i, t_i, \bar{t}_i, \delta_i, \bar{\delta}_i, m_i \quad to$$

$$\text{Subject to} \qquad \max b + k\bar{b}$$

$$(1-k)\bar{b} \ge (1-k)kb$$

$$1/T_2 \le z \le 1/T_1$$

$$\left.\begin{array}{l} w_i + b \le 1 - r_i \\ \bar{w}_i + \bar{b} \le 1 - \bar{r}_i \end{array}\right\} \qquad i = 1, \Lambda \ , n$$

$$(w_i + \bar{w}_i) - (w_{i+1} + \bar{w}_{i+1}) + (t_i + \bar{t}_i) + \delta_i l_i - \bar{\delta}_i \bar{l}_i - \delta_{i+1} l_{i+1} + \bar{\delta}_{i+1} \bar{l}_{i+1} - m_i$$

$$= (r_{i+1} - r_i) + (\bar{\tau}_i + \tau_{i+1}) \ , \quad i = 1, \Lambda \ , n-1$$

$$\left.\begin{array}{l} (d_i / f_i) z \le t_i \le (d_i / e_i) z \\ (\bar{d}_i / \bar{f}_i) z \le \bar{t}_i \le (\bar{d}_i / \bar{e}_i) z \end{array}\right\} \quad i = 1, \Lambda \ , n-1$$

$$\left.\begin{array}{l} (d_i / h_i) z \le (d_i / d_{i+1}) t_{i+1} - t_i \le (d_i / g_i) z \\ (\bar{d}_i / \bar{h}_i) z \le (\bar{d}_i / \bar{d}_{i+1}) \bar{t}_{i+1} - \bar{t}_i \le (\bar{d}_i / \bar{g}_i) z \end{array}\right\} \quad i = 1, \Lambda \ , n-2$$

$$b, \bar{b}, z, w_i, \bar{w}_i, t_i, \bar{t}_i \ge 0 \ , \qquad i = 1, \Lambda \ , n$$

$$m_i = \text{integer}$$

$$\delta_i, \bar{\delta}_i = 0,1$$

Where k is the ratio of inbound to outbound bandwidth; T is cycle length(seconds); T_1 and T_2 represent the lower and upper limits on cycle length; $z = 1/T$ is signal frequency; d_i is the distance between intersection i to intersection $i+1$; e_i, f_i is lower and upper limits on outbound speed; $\bar{e}_i, \bar{f}_i$ is lower and upper limits on inbound speed; $1/h_i$ $1/g_i$ is lower and upper limits on change outbound reciprocal speed; $1/\bar{h}_i$ $1/\bar{g}_i$ is lower and upper limits on change outbound reciprocal speed.

MILP2 describes a modified arterial coordination approach to deal with asymmetric traffic flow, lead and lag left turn phase, etc. we call MILP1 and MILP2 MAXBAND methods. These kind of arterial methods have some basic limitation: they calculate the total bandwidth along each direction with the ratio of average volumes. When the platoons keep a constant size, these models can compute optimal progressions. However, traffic volumes often vary apparently because of turn-in and turn out traffic at each intersection. To overcome this defect, MULTI-BAND model was proposed (Gartner et al., 1991) as an extension of MAXBAND. This model is also a mixed-integer linear program problem. For details, please refer to Gartner's work.

III. SEMI-ACTUATED ARTERIAL COORDINATION METHOD

Essentially, both MAXBAN and MULTI-BAND methods are mixed-integer linear program problem. These methods do not change the *split* when the traffic volume of branch roads changes. Consequently, green time will be wasted. For instance, although there are very few cars in a branch road, a quite long time will be occupied. The semi-actuated arterial coordination method is designed to change the *split* in real time, but not change the *offset* and cycle *length*. The main procedure is shown in Figure 2, and details are described below:

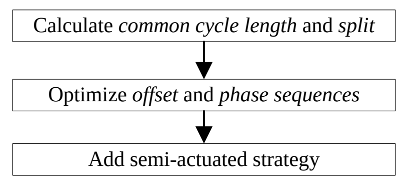

Figure 2. Main procedure of semi-actuated arterial coordination.

A. Calculate common cycle length and split

To achieve arterial coordination, all the signalized intersections must run with the same cycle length which is defined as common cycle length, although in few special case some signalized intersections within the arterial may run at double or one-half the common cycle length. A lot of single intersections timing optimization method have been proposed the second half of last century. One of the classical methods was presented by Webster, 1958. For the sake of simplicity we call it Webster Timing (WT) Method in this paper.

WT method aim at minimize average delay per vehicle of the intersection. We can calculate the cycle length for each intersection from equation (1):

$$c_0 = \frac{1.5L + 5}{1 - Y} \qquad (1)$$

Where c_0 is the optimal cycle length a, L is the total lost time each cycle, Y is the sum of y_i which is the highest ratio of flow to saturation flow for a given phase. In order to calculate the optimal cycle length for each intersection, we need to gather traffic flow data and estimate saturation flow. Generally, *common cycle length* is the maximum optimal cycle of all the related intersections.

We define that *split* is the ratio of *available green time* to *cycle length*. We can calculate *available green time* from equation (2):

$$g_i = \frac{y_i}{Y}(c_0 - L) \qquad i = 1, 2, \Lambda \qquad (2)$$

B. Optimize offset and phase sequences

Offset is the most important parameter in the arterial coordination. We can use MAXBAD or MULTI-BAND method which has been presented in section Ⅱ to obtain proper *offset* and *phase sequences*. We define the phase related to main road as *major phase* and the phase related to branch road as *minor phase* no matter it is a left-turn or straight phase. Traditional arterial coordination methods are only concerned about the *major phase*. Such as *offset* is often known as the beginning of the *major phase* and *phase sequences* is just a choice of lead or lag of the left-turn phase in the *major phase.*

C. Add semi-actuated strategy

As a matter of fact, *minor phase* is ignored by traditional arterial coordination methods. We Optimize *offset* and *phase sequences* based on historical traffic flow data. But traffic flow may oscillate between very low to fairly high. For example, although there are very few cars in a branch road, fixed *minor phase* time will be occupied still.

Therefore, we add a semi-actuated strategy to the *minor phase* in order to make full use of green time. Figure 3 shows the operation process of semi-actuated arterial coordination. *Major phase* contains the optimal parameters calculated by basic arterial coordination methods such as *offset* and related *phase sequence*. When entering *minor phase*, semi-actuated control is enabled. For the purpose of semi-actuated control, detectors need to be installed before stop line each lane to check if there is traffic demand in branch roads.

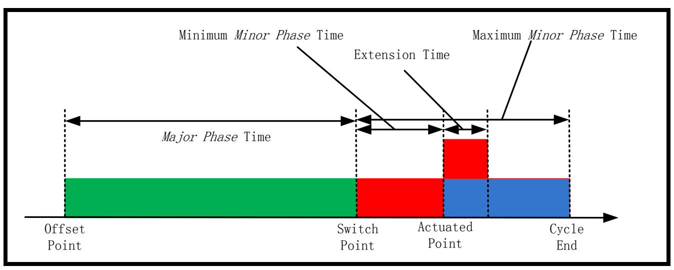

Figure 3 Operation process of semi-actuated arterial coordination.

*If there is only one ph*ase in *minor phase*, we can simply obtain a control strategy shown as figure 4. Firstly, initialize the semi-actuated arterial coordination system. All the initial parameters, including *cycle length*, *phase time*, *offset*, *phase sequences*, *maximum minor phase time*, *minimum minor phase time*, *extension time*, etc., will be set. *Major phase* is enabled after initialization. We check the parameters every time step.

- A *time counter* is created to observe whether major reach the end. If *time counter* is equal to major phase time, then *minor phase* will be enabled.
- When we get in the *minor phase*, we check whether the maximum green time is over. If maximum green time is over, *major phase* will be enabled again.
- If maximum green time is not over, then we check whether the minimum green time is over. If minimum green time is not over, *minor phase* will be hold on.
- If minimum green time is over, then we check whether there are any vehicles detected. If there is no vehicle detected, *major phase* will be enabled again.
- If there is minor phase traffic demand detected, *minor phase* will be for an extension time. When extension time is over, system will continue running as Figure 4.

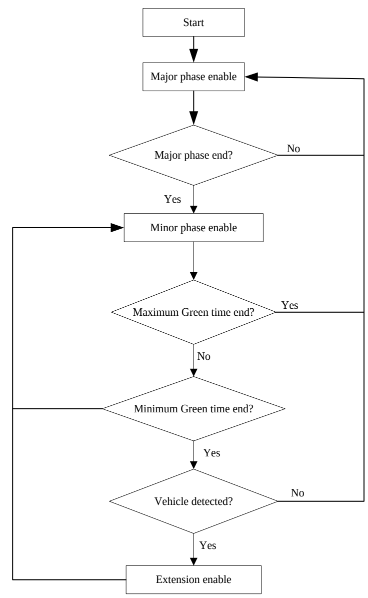

Figure 4. Control strategy procedure of minor phase.

When there are 2 or more phases within *minor phase*, we can still use the semi-actuated control method. Specifically, semi-actuated strategy can be utilized separately for each son phase.

IV. APPLICATION AND SIMULATION ANALYSIS

A. Simulation example

Five adjacent intersections of Huanghe Second Road in Binzhou City, Shandong Province, China are selected in our test. The Huanghe Second Road which joint east part and west part of Binzhou City and bear most of the traffic load o this district, is an apparently main road. Location and name of each intersection is shown in Figure 5.The speed limit here is 55 kilometers an hour.

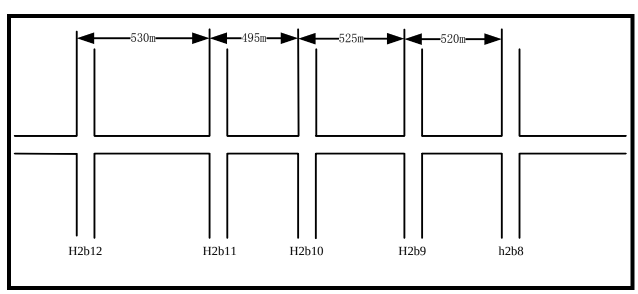

Figure 5. Five intersections of Huanghe Second Road in Binzhou City, Shandong Province, China.

Cooperated with the Traffic Police Department of Binzhou City, we have collected historical traffic flow data and timing plans in use. According to historical traffic flow data and pavement geometry, WT method is used to calculate the optimal cycle length. After comparison, H2b10 is the key intersection and the *common cycle length* is 120s. Because there is no lead or lag left-turn phase exist on this road, we use MILP1 model to optimize the *offset*. All of the parameters of basic arterial coordination have been obtained.

We test our semi-actuated arterial coordination method microscopic traffic simulation software Q-PARAMICS. PARAMICS consists of five parts: Modeller, Analyser, Processor, Monitor and Programmer. Modeller is the simulation engine that provides us with graphical interface to construct the road network, assign the OD demand and signal control, monitor and execute simulation. Analyser and monitor are used to analyze visually and measure the system performance during or after simulation. Programmer is the interface between core simulation process in the Modeller and users.

Modeller and Programmer are mainly utilized in our test. Firstly, as shown in Figure 6, road network of Huanghe Second Road is established by Modeller with the help of Bing Maps which can be embedded into PARAMICS. All the parameters of basic arterial coordination method are configured, including *common cycle length*, phase sequences, phase time, *offset*, etc.

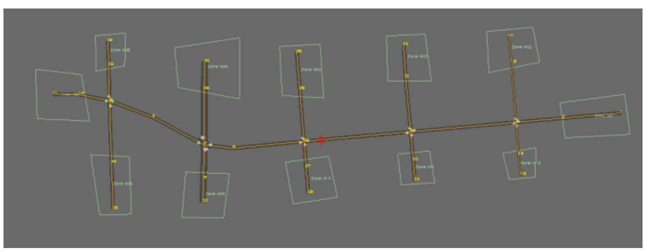

Figure 6. Road network created in PARAMICS.

Programmer provides API to customize applications as required. PRAMICS API is written in C language. We can use C language or C++ language to create a Dynamic Link Library file (in Windows operating system it is referred as “dll”) to utilize the API. When PRAMICS program is executed, the “dll” file is loaded into the simulation. Therefore, the file is often called “plug-in” for PARAMICS simulation.

We created a semi-actuated arterial coordination plug-in program to test our method. In our plug-in program, there are 3 key API functions.

- float qpg_DTL_occupancy(LOOP* loop, int type); This function returns the occupancy stored on the loop for the given query type.
- int qpg_DTL_count(LOOP* loop, int type); This function returns the count stored on the loop for the given query type. If the type argument passed to this function is zero the count value for all vehicle types will be returned.
- void qps_LNK_priority(LINK* link1, LINK* link2, int pri);This function is used to set the priority value for the specified turning movement(inbound link to outbound link).

We utilized the output file “general.csv” of PARAMICS to collect data every minute in simulation time. Three different control strategies are simulated in our test. They are fix time control (FTC) method, arterial coordination (AC) method and semi-actuated arterial coordination (SAAC) method. The FTC and AC using the same cycle length and phase time, the only difference is that the *offset* of FTC is zero but the *offset* of AC is calculated by basic MILP1.

B. Results Analysis

Two indexes are selected to evaluate the performance of our method. They are *average travel time* and *mean speed*. We set *queue clearance time* equals to 1second and 4secondrespectively and get results illustrated from Figure 7 to Figure 10.

Figure 7 and Figure 8 present a comparison of *average travel time* and *mean speed* with AC method, SAAC method and FTC method when *queue clearance time* is 1 second. As seen in these figures, the *average travel time* of SAAC method is much lower than AC method and FTC method and the *mean speed* of SAAC method is much higher than AC method and FTC method. AC method and FTC method have proximate *average travel time*. The possible reason is that *offsets* of different intersections are not changing intensely in this case.

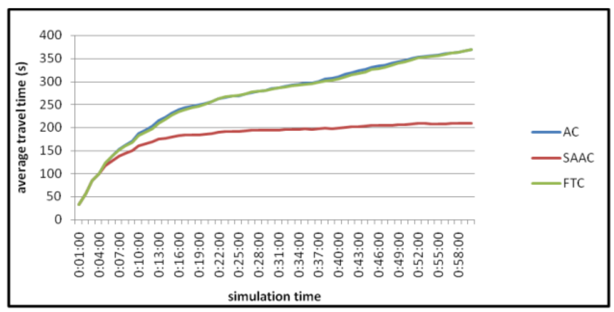

Figure 7. Average travel time when *queue clearance time*=1 second.

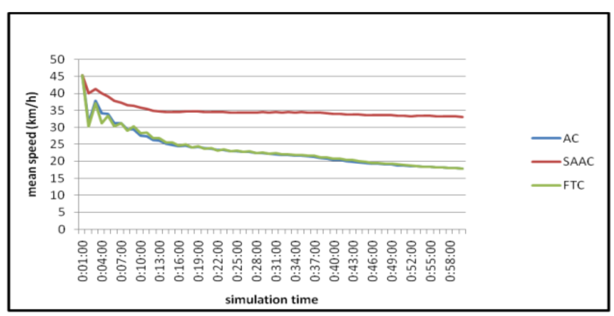

Figure 8. Mean speed when *queue clearance time*=1 second.

Figure 7 and Figure 8 present a comparison of *average travel time* and *mean speed* with AC method, SAAC method and FTC method when *queue clearance time* is 4 second. In this case, the performance index of AC method is a little better than FTC method. Our SAAC method is obviously much better than the other two methods.

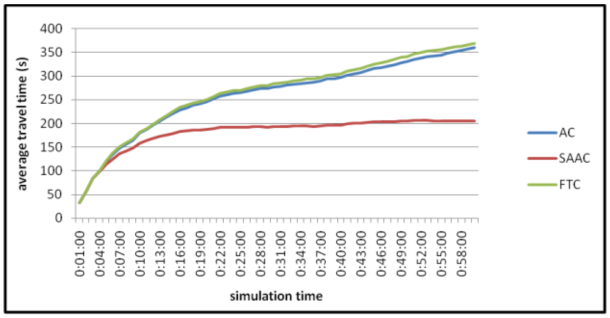

Figure 9. Average travel time when *queue clearance time*=4 second.

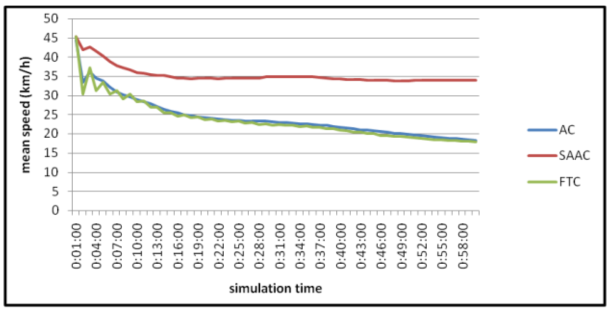

Figure 10. Mean speed when *queue clearance time*=4 second.

V. CONCLUSION

In this paper we proposed a semi-actuated arterial coordination method for urban traffic arterial coordination control. We test our method on microscopic traffic simulation software Q-PARAMICS.A five intersections road network is used to test our method. Simulation results show that the performance of traditional arterial coordination method has been improved when we add semi-actuated in. Future work will focus on improving grid road network by arterial optimization methods.

ACKNOWLEDGMENT

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