A DYNAMIC MODEL FOR ADAPTIVE BUS SIGNAL PRIORITY

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ABSTRACT

The adaptive traffic signal control system, as well as the Transit Signal Priority (TSP) concept has both been viewed as important opportunities for reducing overall traffic congestions and improving bus transit services. However, few studies were conducted on combining them together. A dynamic signal timing optimization model was developed in this research, which aims at reallocating green times among the phases with considering the real-time traffic flow condition and the bus priority request. In the model, both arrival and departure flows are described by time-dependent functions, the arrival of a bus with priority request is represented by giving a weight factor to the traffic demand of the associated approach. The weight factor is also defined as a time-dependent function of three variables: present traffic demand and queuing conditions of the bus arriving approach vs. that of the intersection and the lateness of the target bus. As the bus is converted to a relevant number of arrivals of passenger vehicles by the weight factor, the objective of the dynamic model is to minimize the average delay at the intersection.

KEYWORDS

Adaptive traffic signal control, Adaptive Transit signal priority, Dynamic optimization model
INTRODUCTION

Control strategies for transit priority have long been recognized for having the potential to improve traffic performance for transit vehicles that could also result in improved schedule reliability, reduce operating costs and attract ridership. Several efforts are underway to develop transit signal priority strategies that take advantage of the recent developments in signal controller technology and communications and surveillance systems (1,2,3). However, there have been relatively few successful implementations of transit priority measures on urban networks with signalized intersections in coordinated signal systems.

In a recent research study, control strategies for transit priority in urban networks were developed and on a real-life arterial corridor (4). The strategies were developed for mostly fixed-time coordinated signal systems and placed major emphasis on minimizing the adverse impacts on the auto traffic. However, improved capabilities in traffic control and transit systems technology offer considerable potential in developing adaptive control strategies based on real-time traffic and transit data that outperform the existing signal priority techniques. There is a need to develop improved algorithms to take advantage of such technological advancements, comprehensive simulation tools for thorough laboratory evaluation of proposed strategies, and field demonstrations.

The objective of the research described in this paper is to develop adaptive signal priority control algorithms. It is an integral part of a comprehensive research effort at UC Berkeley’s PATH program to develop adaptive signal priority algorithms and modeling tools (5). The proposed algorithms and models will be field demonstrated and evaluated at a real-life corridor El Camino Real in San Francisco Bay Area in cooperation with San Mateo County Samtrans transit agency.

The following section describes existing and emerging control strategies for signal priority. Next, the proposed model is presented. A numerical example is presented next to illustrate the model application. The last section summarizes the major findings and outlines ongoing and future research.

BACKGROUND

Traffic signals along arterials and networks operate in coordination to provide for progression of the major through movements. Most of the systems operate with signal timing plans prepared off-line based on historical data. Transit priority is provided in off-line systems by determining the signal settings (cycle length, green times and offsets) to favor bus movements. Often, bus stop locations have to be alternated (if possible) between the nearside and farside at successive intersections, so the busses would not have to stop at both the stopline (when the signal is red) and the bus stop. Such passive priority strategies are effective on simple network configurations, high bus frequency and predictable dwell times.

Active priority strategies recognize the presence of the bus and alter the signal settings to provide priority. Options include holding the green until the bus clears the intersection (phase extension), or advance the start of the green for the phase serving the busses (phase advance). Other options may include bus activated exclusive signal phase, and skipping non-transit
serving phase(s). Bus detection is implemented by using strobe light emitters on the transit vehicles and special light detectors at the signal, radio control, or special loop detectors that recognize bus signatures. Recently, some transit priority systems use the information from automatic transit vehicle location/monitoring (AVI/AVL) systems to determine bus arrival times at the intersection.

Active priority strategies have been widely applied at isolated signals and for light rail, but several operating agencies have resisted implementing them in coordinated systems because of the potential adverse impacts to the rest of the traffic stream. Phase skipping or red truncation could cause confusion to the motorist, loss of coordination and high delays to the auto traffic. Several State and local agencies have developed guidelines for granting transit priority to minimize the potential adverse impacts to the rest of the traffic stream. For example, the interim Caltrans guidelines suggest that a) priority should only be given to busses behind schedule, b) at intersections with spare green time in the background cycle, c) no phase skipping, d) the signal settings are implemented subject to minimum times for vehicles and pedestrians with maximum allowable extension times of 10 to 20 percent of the background cycle length. Such guidelines may be restrictive and limit the effectiveness of transit priority strategies.

A number of “on-line” signal control systems exist, that update the timing plans in real-time based on data from detectors offer the potential of providing improved signal priority at the local or the systems level (6). There are no operational real-time control systems in the US with transit priority. Currently, improved algorithms for signal priority are being developed as part of a TCRP research project (7).

**PROPOSED MODEL FOR ADAPTIVE BUS SIGNAL PRIORITY**

We propose a method that dynamically optimizes the green time allocation under the real-time traffic flow conditions and with considering the bus priority requests. The inputs of the model include the arrival demand at each approach, the queuing status which is the dynamic variable known by time $t$, bus arrival time, and the existing signal timing parameters such as the minimum initial, permissive period point, maximum green point and the force-off point. The bus with priority request is converted to a relevant number of passenger vehicles by the weight factor, therefore, the objective is to minimize average delay of all vehicles during the certain period of time subject to prevailing capacity and operational constraints.

The traffic flows (arrival, departure flows at signalized intersections) are first described by smoothed time-dependent functions as if there were no interruptions at traffic signals. The optimized departure flow rates are then converted to signal parameters according to the predefined interrelations between the departure flow rates and signal parameters. The arrival of a bus with priority request is represented by giving the arrival demand of the associated approach a weight factor. Different with the traditional methods that take a constant factor, the weight factor in this model is defined based on a general consideration of present traffic demand and queuing conditions at every approach of the intersection and the information of the lateness of the bus running behind the schedule. The bus to the approach with higher demand and/or longer queue currently has higher weight over that to the approach with lower demand and/or shorter queue, the bus running 10 minutes late behind schedule has higher...
weight than that running 5 minutes late. The optimization model can be clearly decomposed with respect to current time \( t \), it calculates sequentially from the beginning of the study time period. During every specified time step, the model first searches the critical approaches of each phase, then it optimizes departure flow rates and converts it to signal parameters, finally, the optimized signal parameters are compared with ongoing signal timings to determine whether to replace them with the calculated parameters.

**Description of the model**

The departure flow at a signalized intersection approach can be represented by a stepwise function:

\[
\mu(t) = \begin{cases} 
    s(t) & \text{if } t \text{ in a green phase} \\
    0 & \text{if } t \text{ in a red phase}
\end{cases}
\]

where \( s(t) \) is the saturation flow and \( \lambda(t) \) is the arrival rate. However, as the signal states are unknown variables to be calculated in the model, departure flow rate \( \mu(t) \) can not be described by the above function. To deal with the problem, we smoothed out the departure flow at this stage as if there were no signal interruptions, thus both arrival and departure flows can be represented as smoothed time dependent functions. Because the direct traffic count information obtained from loop detectors or most of the traffic surveillance systems are directional flows, while the signal parameters are calculated based on stream and/or stream group volumes, we denote traffic flows both by directional flows and streams and the directional flows are combined as streams based on the given phase patterns. We use the following notation:

\[
\begin{align*}
\lambda_{ijk}(t) & = \text{arrival flow rate at link } (i,j) \text{ at time } t, \text{ which travels through node } i, j \text{ to } k, \\
\mu_{ijk}(t) & = \text{departure rate from link } (i,j) \text{ at time } t, \text{ which travels through node } i, j \text{ to } k, \\
A_{ijk}(t) & = \text{the cumulative arrivals at link } (i,j) \text{ which travels through node } i, j \text{ to } k \text{ by time } t, \\
D_{ijk}(t) & = \text{the cumulative departures from link } (i,j) \text{ which travels through node } i, j \text{ to } k \text{ by time } t.
\end{align*}
\]

\[
\begin{align*}
A_{ijk}(t) &= \int_{0}^{t} \lambda_{ijk}(t) dt \quad (1) \\
D_{ijk}(t) &= \int_{0}^{t} \mu_{ijk}(t) dt \quad (2)
\end{align*}
\]

\[
\begin{align*}
\lambda_{ij}^m(t) & = \text{arrival rate of stream group } m \text{ entering link } (i,j) \text{ at time } t, \\
\mu_{ij}^m(t) & = \text{departure rate of stream group } m \text{ departing from link } (i,j) \text{ at time } t, \\
S_{ij}^m & = \text{saturation flow rate of the lane group on which stream group } m \text{ is accommodated}, \\
A_{ij}^m(t) & = \text{the cumulative arrivals of stream group } m \text{ on link } (i,j) \text{ by time } t, \\
D_{ij}^m(t) & = \text{the cumulative departures of stream group } m \text{ on link } (i,j) \text{ by time } t, \\
X_{ij}^m(t) & = \text{the cumulative numbers left in stream group } m \text{ on link } (i,j) \text{ by time } t.
\end{align*}
\]
$d_{ij}^m(t) =$ average vehicle delay in stream group $m$ on link $(i,j)$ at time $t$,

\[ A_{ij}^m(t) = \int \lambda_{ij}^m(t) dt \]  
\[ D_{ij}^m(t) = \int \mu_{ij}^m(t) dt \]  
\[ X_{ij}^m(t) = A_{ij}^m(t) - D_{ij}^m(t) \]  

By defining an interrelated set $M$, the relationship between directional flows and streams can be denoted as:

\[ \sum_{m \in M} \lambda_{m}^p(t) = \sum_{(i,j,k) \in M} \lambda_{ijk}^p(t) = \sum_{(i,j,m) \in M} \lambda_{ij}^m(t) \]  
\[ \sum_{m \in M} \mu_{m}^p(t) = \sum_{(i,j,k) \in M} \mu_{ijk}^p(t) = \sum_{(i,j,m) \in M} \mu_{ij}^m(t) \]  

where,

\[ \lambda_m^p(t) =$ arrival flow rate of stream $m$ of phase $p$ at time $t$, \]
\[ \mu_m^p(t) =$ departure rate of stream $m$ of phase $p$ at time $t$, \]

the weight factor of the stream group $m$ of the phase $p$, $w_m^p(t)$ is denoted as,

\[ w_m^p(t) = \begin{cases} 
\frac{X_m^p(t)}{\sum_p X_m^p(t)} + \frac{\lambda_m^p(t)}{\sum_p \lambda_m^p(t)} + b & \text{if bus arrives at } t \\
0 & \text{if no bus} 
\end{cases} \]  

for $\sum_p X_m^p(t) \neq 0, \sum_p \lambda_m^p(t) \neq 0$

$b =$ late bus factor, a constant between [0,1], the percentage of the lateness of the current bus to the maximum lateness defined by the users.

When a bus is approaching the intersection and placing a priority call with an estimated arrival time $t$, the traffic demands at the associated approach is given a weight factor to represent the existence of the bus at time $t$. The weight factor is defined based on a comprehensive consideration of the queuing conditions, traffic demands and lateness of the bus at present time. The first two elements present the importance of the queuing condition and traffic demands, the approach with longer queue and/or higher demand at present time has higher weight. The third element is defined as the lateness factor of the bus, represented by the percentage of the lateness of the bus to the maximum lateness, e.g., if the maximum lateness is defined as 30 minutes, the $b$ factor of a bus running 10 minutes behind the schedule is 1/3.
To compare with the existing signal timing status, it is also denoted:

- $G_{p}^{\min}$ = minimum green time of phase $p$,
- $G_{p}^{\text{ff}}$ = force-off green time of phase $p$, $p$ is non-coordinated phase
- $G_{p}^{\max}$ = maximum green time of phase $p$, $p$ is non-coordinated phase
- $G_{yp}^{p}$ = green time of phase $p$ at the Yield Point, $p$ is the coordinated phase

$c = \text{cycle time}$
$L = \text{lost time}$
$\eta = 1 - L/C$

- $g_{p}^{\min}$ = minimum green split of phase $p$, $g_{p}^{\min} = G_{p}^{\min} / (C - L)$
- $g_{p}^{\text{ff}}$ = force-off green split of phase $p$, $g_{p}^{\text{ff}} = G_{p}^{\text{ff}} / (C - L)$, $p$ is non-coordinated phase
- $g_{p}^{\max}$ = maximum green split of phase $p$, $g_{p}^{\max} = G_{p}^{\max} / (C - L)$, $p$ is non-coordinated phase
- $g_{yp}^{p}$ = Yield Point green split of phase $p$, $g_{yp}^{p} = G_{yp}^{p} / (C - L)$, $p$ is the coordinated phase

As the bus is converted to a relevant number of passenger vehicles by the weight factor, the objective is to minimize average delay of all vehicles during the certain period of time. The objective function is defined as:

$$\text{Min. } F(t) = \sum_{ijk} d_{ijk}(t) = \sum_{ijk} \frac{1}{\int_{t} A_{ijk}(t)(1 + w_{ijk}(t)) dt} \int (A_{ijk}(t)(1 + w_{ijk}(t)) - D_{ijk}(t)) dt$$ (11)

It is equivalent to:

$$\text{Min. } F(t) = \sum_{ijk} \frac{1}{\int_{t} (1 + w_{ijk}(u)) \lambda_{ijk}(u) du} \int (\int_{u} (1 + w_{ijk}(u)) \lambda_{ijk}(u) du - \int_{u} \mu_{ijk}(u) du) dt$$ (12)

Combine directional flows to streams, it can be rewritten as:

$$\text{Min. } F(t) = \sum_{ijk} \frac{1}{\int_{t} (1 + w_{ijk}(u)) \lambda_{ijk}(u) du} \int (\int_{u} (1 + w_{ijk}(u)) \lambda_{ijk}(u) du - \int_{u} \mu_{ijk}(u) du) dt$$ (13)

The objective is subject to the queuing state. The $X_{ijk}(t)$ has been defined as the number of vehicles accumulated on the direction $(i,j,k)$ of link $(i,j)$, the state equation on $X_{ijk}(t)$ at present time $t$ can be denoted as:

$$X_{ijk}(t + dt) = X_{ijk}(t) + (1 + w_{ijk}(t)) \lambda_{ijk}(t) dt - \mu_{ijk}(t) dt \geq 0$$ (14)

where,
Therefore, the maximum departure rate of each directional flow is associated with present queuing condition and the arrival rate, it is defined as follows:

\[
\mu_{ijk}(t) \leq X_{ijk}(t)/dt + (1 + w_{ijk}(t))\lambda_{ijk}(t)
\]  

(15)

If we define:

\[X^p_m(t) = \text{the cumulative numbers accumulated in the stream } m \text{ which is accommodated in the phase } p.\]

The formula (15) can be rewritten in the term of stream as:

\[
\mu^p_m(t) \leq X^p_m / dt + (1 + w^p_m(t))\lambda^p_m(t)
\]  

(16)

Given background cycle and the phase pattern, the green time ratio of the cycle η is given as:

\[
\sum_p g_p = \eta
\]  

(17)

the stream departure rate \(\mu^p_m(t)\) is related to saturation flow rate \(s^p_m\) and green split \(g_p\):

\[
\mu^p_m(t) \leq s^p_m g_p \text{ for every } (p,m).
\]  

(18)

By accumulating the \(\mu/s\) through the critical streams of each phase, the constraint of maximum departure ratio of the intersection can be obtained by eliminating green split \(g_p\) as follows:

\[
\sum_p \max_m \left[ \frac{\sum_{m \in M} \mu^p_m(t)}{\sum_{m \in M} s^p_m} \right] = \sum_p \max_m \left[ \frac{\sum_{i,j,k \in M} \mu_{ijk}(t)}{\sum_{m \in M} s^p_m} \right] \leq \eta
\]  

(19)

for: \(\lambda^p_m(t), \lambda^p_m(t), \mu^p_m(t), \lambda_{ijk}(t), \mu_{ijk}(t) \in M\)

All the unknown variables in the formulation model should be non-negative:

\[
\mu_{ijk}(t) \geq 0, \mu^p_m(t) \geq 0
\]  

(20)
The solution algorithm

As depicted in Fig. 1, the model can be clearly decomposed with respect to current time \( t \) so that we can calculate sequentially from the beginning of the study time period. Since the cumulative arrival and departure curves have been obtained by time \( t \), the queue on lane group \( m \), i.e. \( X^m_{ij}(t) \) is a known variable by time \( t \), therefore, \( w^m_{ij}(t) \) as well as \( w^p_m(t) \) are also known by time \( t \). During every specified time step, the model first searches the critical approaches of each phase, then it optimizes departure flow rates and converts it to signal parameters. The optimized signal settings are compared with the current signal settings to determine whether to replace the existing plan with the optimized settings. The step is set to identical with the background cycle length, the complete solution algorithm is described below:

**Step 1:** initialize variables including present time, flow rates, queue, and cumulative arrival and departures

**Step 2:** combine stream groups by directional flows according to given phase sequence

**Step 3:** solve the linear program and obtain the \( \mu^m_{ij}(t) \)

**Step 4:** updating \( w^m_{ij}(t) \) and \( w^p_m(t) \) if there is bus calls

**Step 5:** convert the \( \mu^m_{ij}(t) \) of the critical approaches to \( g^p_p(t) \) according to

\[
g^p_p(t) = \frac{\text{Max}_{me,p} \mu^m_{ij}(t)}{s^m_{ij}}, \quad \text{if } g^p_p(t) < g^p_{\text{min}}, \quad \text{then } g^p_p(t) = g^p_{\text{min}}
\]

**Step 6:** check with the current signal settings:

- if there is no priority call, do nothing and perform current signal plan
- if there is a priority call on the phase \( i \), reallocate green time by \( g^i_i(t), i \in p \),
  - if \( i \) is the coordinated phase
    - if \( g^i_i(t) < g^i_{\text{min}}, \) then \( g^i_i(t) = g^i_{\text{min}}, \)
    - if \( g^i_{\text{min}} < g^i_i(t) < g^i_{\text{yp}}, \) then \( g^i_i(t) = g^i_{yp}, \)
  - if \( i \) is the non-coordinated phase
    - if \( g^i_i(t) < g^i_{\text{min}}, \) then \( g^i_i(t) = g^i_{\text{min}} \)

**Step 7:** if present time \( t \) is less than the modeling time period, go to step 1, otherwise exit from calculation.
NUMERICAL EXAMPLE

The proposed algorithm is illustrated through the following example. Figure 2 shows the layout of a real-life signalized intersection along the El Camino Real study arterial. Phase 1 serves the left-turns on the arterial, phase 2 serves the through and right turns (sync phase), and phase 3 serves the cross street traffic. Figure 3 shows the directional approach flows on two signal cycles (in veh-hr).

According to the given phase sequence, the relationship between directional flows and streams can be defined as follows:

\[
\lambda_1^1(t) = \lambda_{253}(t), \quad \mu_1^1(t) = \mu_{253}(t),
\]

\[
\lambda_2^1(t) = \lambda_{451}(t), \quad \mu_2^1(t) = \mu_{451}(t),
\]

\[
\lambda_1^2(t) = \lambda_{251}(t) + \lambda_{254}(t), \quad \mu_1^2(t) = \mu_{251}(t) + \mu_{254}(t),
\]

\[
\lambda_2^2(t) = \lambda_{452}(t) + \lambda_{453}(t), \quad \mu_2^2(t) = \mu_{452}(t) + \mu_{453}(t),
\]

\[
\lambda_1^3(t) = \lambda_{152}(t) + \lambda_{153}(t) + \lambda_{154}(t), \quad \mu_1^3(t) = \mu_{152}(t) + \mu_{153}(t) + \mu_{154}(t),
\]

\[
\lambda_2^3(t) = \lambda_{351}(t) + \lambda_{354}(t) + \lambda_{352}(t), \quad \mu_2^3(t) = \mu_{351}(t) + \mu_{354}(t) + \mu_{352}(t).
\]

according to the maximum departure ratio constraint:

\[
\text{Max} \left[ \frac{\mu_1^1(t)}{s_1^1}, \frac{\mu_2^1(t)}{s_2^1} \right] + \text{Max} \left[ \frac{\mu_1^2(t)}{s_1^2}, \frac{\mu_2^2(t)}{s_2^2} \right] + \text{Max} \left[ \frac{\mu_1^3(t)}{s_1^3}, \frac{\mu_2^3(t)}{s_2^3} \right] \leq \eta
\]

described by directional flows:

\[
\text{Max} \left[ \frac{\mu_{253}(t)}{s_1^1}, \frac{\mu_{451}(t)}{s_2^1} \right] + \text{Max} \left[ \frac{\mu_{251}(t) + \mu_{254}(t)}{s_1^2}, \frac{\mu_{452}(t) + \mu_{453}(t)}{s_2^2} \right] + \text{Max} \left[ \sum_{k} \frac{\mu_{15k}(t)}{s_1^3}, \sum_{k} \frac{\mu_{35k}(t)}{s_2^3} \right] \leq \eta
\]

The green times (splits) are calculated based on the critical traffic streams. Because in real-time every possible combination of streams at present time \( t \) might be “critical”, the formula can be expanded as:

\[
\left[ \frac{\mu_{253}(t)}{s_1^1} \right] + \left[ \frac{\mu_{251}(t) + \mu_{254}(t)}{s_1^2} \right] + \left[ \sum_{k} \frac{\mu_{15k}(t)}{s_1^3} \right] \leq \eta
\]

\[
\left[ \frac{\mu_{253}(t)}{s_1^1} \right] + \left[ \frac{\mu_{251}(t) + \mu_{254}(t)}{s_2^2} \right] + \left[ \sum_{k} \frac{\mu_{35k}(t)}{s_2^3} \right] \leq \eta
\]
\[
\begin{bmatrix}
\frac{\mu_{251}(t)}{s_1} \\
\frac{\mu_{251}(t)}{s_1} \\
\frac{\mu_{451}(t)}{s_2^1} \\
\frac{\mu_{451}(t)}{s_2^1} \\
\frac{\mu_{451}(t)}{s_2^1}
\end{bmatrix} + \begin{bmatrix}
\frac{\mu_{452}(t) + \mu_{453}(t)}{s_2^2} \\
\frac{\mu_{452}(t) + \mu_{453}(t)}{s_2^2} \\
\frac{\mu_{452}(t) + \mu_{453}(t)}{s_2^2} \\
\frac{\mu_{452}(t) + \mu_{453}(t)}{s_2^2} \\
\frac{\mu_{452}(t) + \mu_{453}(t)}{s_2^2}
\end{bmatrix} + \begin{bmatrix}
\sum_{m} \mu_{15m}(t) \\
\sum_{m} \mu_{15m}(t) \\
\sum_{m} \mu_{15m}(t) \\
\sum_{m} \mu_{15m}(t) \\
\sum_{m} \mu_{15m}(t)
\end{bmatrix} \leq \eta
\]

With given arrival demands, the program is a linear program that maximizes the departure flows, it can be described as the standard form of a LP program as follows (8):

\textbf{Maximize: } Z = CX

\textbf{subject to:}

\[AX \leq B,\]

\[X \geq 0.\]

By substituting the variables, the coefficients \(A\), \(B\), and \(C\) in the linear program is as follows:
Four cases of calculations were carried out to analyze four different scenarios:
moderate traffic without priority call, moderate traffic with priority call, congested traffic
without priority call and congested traffic with priority call. The results are presented in
Table 1 (the superscript \(c\) in \(X_{ijk}^c(t)\), \(\lambda_{ijk}^c(t)\), \(\mu_{ijk}^c(t)\) stands for “critical”).

In the first case, the intersection degree of the intersection during the calculation time period
is 0.67 and there are no overflowed approaches with each \(X_{ijk} = 0\). The spare time of each
phase was calculated by subtracting the needed green time from the designed values, as a
result, the signal will perform current signal plan. In the second case, a priority call was
placed on the coordinated phase under the same traffic flow conditions as in case one. A
weight factor was applied to the associated approach to represent the bus presence at the
present time. The arrival time of the bus is provided by an endogenous arrival time
estimation model; if the bus is predicted to be able to clear the intersection in the green time,
then no changes to the timings are required, otherwise, the model calculates the settings to
provide bus priority. The model calculates the time interval to extend the coordinated phase
for priority subject to no overflows on the other approaches. The maximum lateness of the
bus is defined as 30 minutes, the value of 0.3 of the \(b\) factor represents a bus running 9
minutes behind the schedule, and the weighting factor is 1.07. The calculation result shows
that 0.1 green time split (10 seconds) for the phase 1 and 0.13 (13 seconds) for the phase 2
must be protected so that all arrivals on the approaches accommodated within these two
phases can be discharged, on the other hand, the coordinated phase needs 0.66 green time split to service the weighted traffic flow.

In the third case, the saturation degree of the intersection was increased to 0.86. Without a without priority call, none of the approaches is oversaturated. In the fourth case, the priority call was also placed on the phase 2, due to the high demand on the critical approach of the coordinated phase, the weight factor also increased to 1.7. In this case, queues accumulated on several approaches during the phase 1 and the phase 3, which indicates that giving priority to the bus under current traffic conditions might cause overflows on the specific approaches.

**DISCUSSION**

Most of the active signal priority strategies in coordinated systems are based on predetermined changes to signal settings without taking into considerations of the real-life traffic conditions. We present a model that optimizes the signal settings in real-time taking into account of bus priority requests under the real-time traffic conditions.

The work reported in the paper presents work in progress of a comprehensive research program at the PATH program to develop adaptive signal priority algorithms and modeling tools. Ongoing and future research efforts include:

- Model refinement: test and refine the model based on extensive tests at intersections with different design and demand patterns and signal phasing. Test the sensitivity of the bus weighting factors to schedule lateness and queuing conditions at the intersection approach.

- Thorough laboratory testing of the proposed model through simulation. To this end, a hardware in the loop interface has been built between a 2070 signal controller and the PARAMICS microscopic simulation model. This modeling tool would permit detailed assessment of various real-time control algorithms developed by the research team and other researchers.

- Field demonstration and evaluation of the most promising algorithms along the el Camino Real study corridor.
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The contents of this paper reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views of or policy of the California Department of Transportation. This paper does not constitute a standard, specification or regulation.
REFERENCES

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FIGURE 2  The test intersection and the signal setting

FIGURE 3  The directional flows

TABLE 1   Summarized calculation results of the numerical example
FIGURE 1 Decomposition with discrete time

Cumulative vehicles

t

\[ A_{ijk}(t + \Delta t) \]

\[ A_{ijk}(t) \]

\[ X_{ijk}(t) \]

\[ D_{ijk}(t + \Delta t) \]

\[ D_{ijk}(t) \]

t_0

\( t \)

\( t + \Delta t \)
FIGURE 2  The test intersection and the signal setting
FIGURE 3  The directional flows
**TABLE 1** Summarized calculation results of the numerical example

<table>
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<tr>
<th>Time step</th>
<th>Cycle (sec)</th>
<th>Directional flow (i,j,k) veh/h</th>
<th>Flow (i,j,k) veh/h</th>
<th>Flow (i,j,k) veh/h</th>
<th>Saturation flow (veh/h)</th>
<th>Phases</th>
<th>Min. green (sec)</th>
<th>Split</th>
<th>Priority</th>
<th>Recalculated split</th>
<th>Spare time (split)</th>
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