PROVIDING BUS PRIORITY USING ADAPTIVE PRE-SIGNALS

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ABSTRACT
Bus priority is important in cities to encourage people to use public transport. However, providing a dedicated bus lane is not always feasible. It might not be the most efficient solution either, especially if bottlenecks such as traffic signals exist. This paper examines an alternative strategy to use an additional signal upstream of the main signal (a pre-signal) to provide bus priority at signalized intersections. Its primary purpose is to allow buses to jump the car queues before the intersection while cars can still use all the lanes at the main signal to fully utilize the capacity of the intersection.

This paper formulates an online control algorithm to operate an intersection with such pre-signal infrastructure. The control algorithm is developed by determining the best operating strategy for the intersection at each demand level using a micro-simulation model in VISSIM. In a simulation case study, it is observed that compared to using a dedicated bus lane, the congestion upstream of the intersection during peak hours is mitigated. Meanwhile, compared to using mixed-use lanes, the average person delay during the off-peak hours is lower and bus priority is provided. Therefore, it is concluded that implementing a pre-signal with our proposed online control algorithm provides a good balance between providing bus priority and sustaining car throughput.
INTRODUCTION

Providing priority to public transportation (e.g., buses) in cities could reduce journey times of buses. Often, this kind of priority is provided with a dedicated bus lane. However, this might not always be feasible due to space restrictions or political issues. It might not be the most efficient solution either, especially if the bus flow is low, private vehicle (e.g., car) demand is high, or bottlenecks such as traffic signals exist. Under such situations, alternative strategies could be proposed to provide bus priority while minimizing negative impacts on cars.

One of these alternative strategies is to use an additional signal (hereafter referred to as a pre-signal) to provide bus priority at signalized intersections (1, 2, 3), see Figure 1. Its primary purpose is to allow buses to jump the car queues upstream of the intersection while cars can still use all the lanes at the main signal to fully utilize the capacity of the intersection. In this way, bus delays are reduced, while the capacity lost at the intersection is minimized.

A static operating strategy for pre-signals has previously been proposed (4). In this strategy, the pre-signal turns red in advance of a red main signal and also when a bus arrives to the pre-signal irrespective of the status of the main signal. The goal is to ensure that the space between the pre-signal and the main signal is kept free of cars for as long as possible, allowing any arriving bus to move in front of the car queue and discharge immediately when the main signal turns green. The pre-signal turns green in advance of the main signal when no buses are present such that cars do not experience additional delays, or after the bus has left the pre-signal when buses are present. This operating rule is adopted as the basis to develop the online control algorithm in this paper.

However, a static operation might not be the optimal strategy for traffic scenarios varying throughout the day. Different strategies have different effects on performance metrics of the road section. One possible strategy is to extend the dedicated bus lane up to the main signal with the pre-signal switched off (hereafter termed the bus lane strategy). This could further reduce the bus delay, and hence the average person delays if the bus occupancies or the bus frequencies are high. Another possible strategy is to use both lanes as mixed lanes (hereafter termed the mixed lane strategy). This could further increase the traffic throughput and reduce the upstream queue length when the traffic demand is high. As one would expect, different strategies may perform best with different car and bus demands. Therefore, there is a need to develop an online control algorithm to dynamically switch between different strategies to best achieve traffic management and control goals.

To develop an online control algorithm, this research builds, validates, and uses a micro-simulation model. This micro-simulation model is built in VISSIM and validated for a case study location in Zurich, Switzerland, using empirical data collected at this site. Next, the micro-simulation model is used to analyze delays and other performance metrics with different static operating strategies under different traffic demands. With a better understanding of the real-time effects of the static strategies, an online control algorithm is formulated and tested for an intersection with pre-signal infrastructure.

The remainder of the paper is organized as follows. In the next section, a review of existing literature on the operation of pre-signals is discussed. Then, the calibration and validation of a micro-simulation model for a case study site are discussed. Using this calibrated model, in the following section the performance metrics for the three different static operating strategies (i.e. the mixed lane strategy, the bus lane strategy, and the pre-signal

![FIGURE 1 Layout of a pre-signal (4).](image-url)
strategy) under different car demand values are investigated. Finally, an online control algorithm for an intersection with pre-signal infrastructure is developed and presented.

3 LITERATURE REVIEW

The idea of setting up a signal in front of the main signal (i.e. a pre-signal) is not new and has been analytically studied before. Pre-signals have been proposed for several purposes such as to recover the lost time at the intersection due to bounded acceleration (5) or to separate left-turning vehicles and through-moving vehicles to maximize the discharging capacity of the intersection for both directions (6). However, here the pre-signal is used to provide priority to buses.

The use of pre-signals to provide bus priority was first proposed in (1). That work provided guidelines to determine the pre-signal timing for minimizing the system vehicle delay. The operating strategy proposed was different from the one described in the introduction. Most notably, that strategy was proposed for intersections without bus detection infrastructure. To the best of the authors’ knowledge, implementations of pre-signals are rare; with only a few cases in U.K. cities, for example in London (7) with the operating strategy from (1). A similar idea for pre-signals is mentioned in the German Manual for Transit Priority (8), but no implementation of this strategy has been reported in Germany yet. In fact, to the authors’ best knowledge, the only pre-signal with this prescribed operating strategy is located in Langstrasse, Zurich, Switzerland.

The static operating strategy that we will use in this paper was studied analytically using queuing theory for isolated intersections assuming a fixed demand pattern (2, 3). For under-saturated intersections, the results show that implementing a pre-signal could lower the average person delay if bus occupancy is in the range of 10-70 passengers. For over-saturated intersections, the pre-signal strategy always resulted in lower average person delay compared to the bus lane strategy. Moreover, the pre-signal strategy resulted in lower average person delay compared to the mixed lane strategy if the peak demand was greater than 105% of the signal capacity.

There are numerous detailed studies of online control algorithms at signalized intersections, for example SCATS (9), and SCOOT (10). These online control algorithms apply to the main signal. However, the subject of this research is an online control algorithm for a new kind of infrastructure, namely the pre-signal. To the authors’ best knowledge, there is not yet research on this subject.

3 CASE STUDY LOCATION AND MICRO-SIMULATION MODEL

To develop and evaluate an online control algorithm for pre-signals, a micro-simulation model is used. However, to validate this approach, first the driver behavior near a pre-signal should be accurately modeled. To do so, the case study location and the corresponding empirical data, the micro-simulation model, and the calibration and validation results are presented below in three consecutive subsections, respectively.

3 DESCRIPTION OF THE SITE AND EMPRICAL DATA

The intersection on Langstrasse in Zurich has a pre-signal operation as described in the introduction and is used as a case study location. The layout of the streets is shown in Figure 2. On this section of the road, traffic comes from both upstream of the main signal and from the four side streets. The road upstream of the pre-signal consists of one bus lane and one car lane. Between the main signal and the pre-signal, these two lanes merge into a single shared lane.

Note that this is a special case because the road capacity before the main signal and the road capacity for cars before the pre-signal are the same, so the red signal length for the pre-signal and main signal are the same based on Guler and Menendez, 2013 (4).
Two data sets are used in this research. The traffic flow rates and traffic composition for both data sets are calculated and summarized in Table 1. Note that the category ‘trucks’ includes vans and lorries of various sizes. They are summarized in one category to simplify the calibration. Buses arrive with a uniformly scheduled frequency of 8 buses/hour based on data set 1.

The main signal timing is complicated since the signals are adaptive with an unknown algorithm, and also transit signal priority is implemented. Therefore, in reality each cycle might have a different cycle length, green-time and red-time. However, during each measurement period, these values remained nearly constant, and hence the signal is modeled as fixed-timed. Their average values are also summarized in Table 1. Note that as stated previously, the length of the red signal and green signal for both the main signal and the pre-signal are the same, with only a pre-signal offset. The ‘duration of the red signal with bus’ refers to the minimum duration of the red pre-signal before the bus passes the pre-signal when a bus is detected.

<table>
<thead>
<tr>
<th>TABLE 1 Summary of empirical data.</th>
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<tbody>
<tr>
<td><strong>Data set 1</strong></td>
</tr>
<tr>
<td>Date and time</td>
</tr>
<tr>
<td>Main road flow</td>
</tr>
<tr>
<td>Side street 1 flow</td>
</tr>
<tr>
<td>Side street 2 flow</td>
</tr>
<tr>
<td>Side street 3 flow</td>
</tr>
</tbody>
</table>
DESCRIPTION OF THE SIMULATION MODEL

The simulation model is built in VISSIM according to the exact geometry specifications of the site as in Figure 2, and the traffic flows and signal settings as in Table 1.

The desired speed in the simulation model (i.e. free-flow speed) is assumed to be the speed limit, which is 50 km/h in urban streets in Zurich. This is the same as in the calculation of the empirical data so the delay results are comparable. Travel times are measured for 6 sections: from the main road upstream to the pre-signal, from side streets 2-4 to the pre-signal, from side street 1 to the main signal, and from the pre-signal to the main signal. The average vehicle delay is calculated by taking the difference between the measured average travel time and the theoretical travel time at free flow speed assuming no signals.

MODEL CALIBRATION AND VALIDATION

This model is calibrated with data set 1 and validated with data set 2. The benchmark against which the model is calibrated and validated is the average car delay measured with the two data sets. The total delay is an output from VISSIM which measures the difference between the actual travel time and the free-flow travel time at the desired speed. The total delay is divided into two parts, one part due to the pre-signal (delay PS) and the other part due to the main signal (delay MS). The measured average car delays are summarized and compared to the calibration and validation results in Table 2.

Each simulation run is 3700 seconds long including a warm-up time of 100 seconds. A bus arrives every 450 seconds. The Wiedemann 74 car following model is used and all the three parameters (average standstill distance, additive part of safety distance, and multiplicative part of safety distance) are calibrated. For the lane changing behavior, only parameters for compulsory lane changes namely minimum headway and safety distance reduction factor, are calibrated. The average values over ten simulation runs, each with a different random seed, are used for calibration and validation. Table 2 summarizes the calibration and validation results.

From Table 2 we see that the measured values and the simulation results are close. We believe the micro-simulation correctly models the operation of a pre-signal and the driving behavior near the intersection. Therefore, it can be used as a basis to develop the online control algorithm.

TABLE 2 Summary of: a) calibration and validation results, and b) values for calibrated parameters.

<table>
<thead>
<tr>
<th></th>
<th>Average delay PS</th>
<th>Average delay MS</th>
<th>Total delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data set 1 measured</td>
<td>35.1s</td>
<td>6.3s</td>
<td>41.3s</td>
</tr>
<tr>
<td>Data set 1 simulation (calibration)</td>
<td>33.2s</td>
<td>6.5s</td>
<td>39.7s</td>
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<tr>
<td>Data set 2 measured</td>
<td>15.4s</td>
<td>6.0s</td>
<td>21.4s</td>
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<tr>
<td>Data set 2 simulation (validation)</td>
<td>17.3s</td>
<td>7.2s</td>
<td>24.5s</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Calibrated values for cars</th>
<th>Calibrated values for trucks</th>
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<tbody>
<tr>
<td>Average standstill distance</td>
<td>2.3m</td>
<td>2.5m</td>
</tr>
<tr>
<td>Additive part of safety distance</td>
<td>2.0m</td>
<td>2.0m</td>
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### TABLE

<table>
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<tr>
<th>Multiplicative part of safety distance</th>
<th>4.0m</th>
<th>4.5m</th>
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<tr>
<td>Minimum headway</td>
<td>0.7m</td>
<td>1.0m</td>
</tr>
<tr>
<td>Safety distance reduction factor</td>
<td>0.7</td>
<td>0.9</td>
</tr>
</tbody>
</table>

### SIMULATION OF DIFFERENT STRATEGIES AT A GENERAL INTERSECTION

To develop an online control algorithm, first the three possible strategies, namely, the pre-signal strategy, the mixed lane strategy and the bus lane strategy, are analyzed individually. By understanding the effects of the three strategies for different car demand levels, a general online control algorithm can be proposed. To do so, the general simulation model and the simulation results are described below in two consecutive subsections.

### DESCRIPTION OF THE GENERAL SIMULATION MODEL

In the general simulation model, four sections of two-lane roads upstream of the main signal are included to study the effects of a pre-signal as shown in Figure 3. In the first section, there are two lanes available to all vehicles between the pre-signal and the main signal. Upstream of the pre-signal, there is one dedicated bus lane on the left (marked with dashed lines in the figure) and one car lane on the right. Further upstream is a section of road for lane changes, with a normal road with mixed-use lanes upstream of it. The goal of the online algorithm is to minimize system average person delay without excessive negative impacts upstream. Therefore, it is important to include the sections of the road upstream of the main signal to fully capture the effects of each strategy for the following two reasons.

First, both the bus lane strategy and the pre-signal strategy involve introducing a section of road as a dedicated bus lane. Unless an extra lane becomes available to the buses, cars must make compulsory lane changes before the bus lane starts. This could lead to additional delays for cars due to the lane changing maneuvers and is an integral part of the effects of these two strategies. Note that mixed lane strategy does not involve this extra delay, so if the lane changing maneuvers upstream are ignored, there would be an unfair advantage for the pre-signal and the bus lane strategies. One could argue that an additional lane could be built for buses without taking away lanes from cars. However, if pre-signals are to be introduced to existing intersections in cities where currently no bus priority is provided, it would be much more costly to alter the configuration of the existing roads.

Second, when the demand is greater than the capacity, car queues could grow to be very long. This means the car drivers could experience delays far upstream of the intersection. Moreover, in cases where there is a dedicated bus lane, if the car queues become longer than the length of the bus lane, buses could also be stuck upstream in the congestion together with the cars. This effect is non-trivial because although buses enjoy priority on the bus lane, they could potentially get stuck longer before the bus lane becomes available to them due to the reduced capacity of the system. One could argue that the dedicated bus lane could be long enough to compensate the disadvantage for the buses upstream. However, note that if the pre-signal strategy is adopted on the arterial level, the buses and cars become mixed again after every intersection, and usually the distance between intersections in cities is not long enough for this effect to be negligible.

The distance between the pre-signal and main signal is calculated to be 95m according to (4) so that there is enough storage space for the main signal to potentially operate at capacity. The length for the other three sections of roads is arbitrarily chosen to be 1km as an example to investigate general effects and trends. Note that some of the conclusions of this paper depend on the choice of the lengths of these segments.

To compare the pre-signal strategy to the bus lane strategy and the mixed lane strategy, the latter two strategies were also simulated. When the bus lane strategy is adopted, the dedicated bus lane starts at the same location as in the pre-signal strategy but extends all the way up to the main signal. When the mixed lane strategy is adopted, all sections are the same with mixed-use lanes up to the main signal.
The parameters of the simulation are set as follows. Each lane has a capacity of 1900 veh/h. The main signal has a cycle length of 60 seconds with 35 seconds of red signal, so its capacity is about 1584veh/h if cars can discharge using both lanes. The pre-signal has an advance time of 7 seconds so that the last car passing the green pre-signal could just be discharged at the main signal (4). The length of the red pre-signal, however, will vary according to the car demand because the higher the demand, the more cars need to be stored in front of the main signal before it turns green. According to (12), the length of the red pre-signal with bus is set to be 10 seconds to provide enough priority to buses without penalizing cars too much. As an example, the buses are assumed to arrive with a frequency of 5 min/bus and a free flow speed of 30 km/h. The driving behavior parameters of the cars are as calibrated in the previous section.

The purpose of this simulation model is to study the effects of pre-signals under 10 levels of car demands so that an online control algorithm which switches between different strategies to best address each demand level can be formulated. The frequency of demand check and strategy update for the online algorithm is set to be every 15 minutes. If the update is too frequent, the road section could be confusing to the drivers; while if the update is too infrequent, the strategy does not respond to real time traffic demand. Therefore, the simulation model is run for 15 minutes (plus a 5-minute initial warm-up period) for each demand level.

Four performance metrics are chosen to examine the effects. The average delays for cars and the average delays for buses are measured for all vehicles that are discharged from the main signal during the 15 minutes period as the first two metrics. The average person delay is then calculated as the third metric. Lastly, when the demand is very high, the congestion often spills more than three kilometers upstream of the intersection, which means an accumulation of cars cannot enter into the simulation system. Under such scenarios, the upstream intersection and the performance of the network could be affected. Hence, this upstream accumulation (i.e. upstream queue length) is identified as an important performance metric and measured in the simulation as latent demand.

ANALYSIS AND COMPARISON OF EFFECTS OF THE THREE STRATEGIES

We define the traffic demand to main signal capacity ratio ($v/c$) as the traffic demand level. The simulations are run for 10 demand levels ranging from 0.2 to 2 for all three strategies. For each demand level, the results are averaged over 10 simulation runs with different random seeds. The effects of the three strategies on the four performance metrics, the upstream queue length, the average car delay, the average bus delay and the average person delay are summarized in Figure 4.
The first criterion for the control algorithm is that there must not be excessive delays and queues upstream of the intersection. For this purpose, the upstream queue length and the average car delays in Figure 4 are analyzed. An obvious change in the rate of increase in car delays is identified when the demand reaches capacity. This reflects a change in the nature of the car delay. When demand exceeds capacity, cars must wait for more than one cycle before discharging from the main signal. This overflow delay increases rapidly with increasing demand. Also, the delay due to lane changes becomes increasingly significant. Therefore the total delay increases at a higher rate and the queue quickly spills upstream. For a period of demand level higher than 1.5, both the bus lane and pre-signal strategies would cause more than 3 kilometers of upstream queue. This could affect the performance of the rest of the network. Therefore, for all over-saturated cases, the mixed lane strategy is adopted.

The second criterion for the control algorithm is to minimize the average person delay. For this purpose the average car delay and average bus delay are first analyzed separately in Figure 4, and the average person delay is analyzed subsequently.

It is observed that for low car demands, the cars suffer the most delay with the bus lane strategy and almost the same delay with the pre-signal and the mixed lane strategies. The buses suffer the most delay with the mixed lane strategy and almost the same delay with pre-signal and the bus lane strategies. This is expected because the bus lane strategy provides the most priority to the buses while the mixed lane strategy provides the least and is most beneficial to cars. The pre-signal strategy, however, offers a good balance between providing bus priority and sustaining car throughput.

For high car demand values which make the signal over-saturated, as expected the bus lane strategy results in the most delay for cars while the mixed lane strategy results in the most delay for buses. However, what is surprising is that, for v/c greater than 1.4, comparing the bus lane strategy to the pre-signal strategy, not only is the car delay higher, but also the bus delay. It seems that the implementation of a pre-signal at an intersection has a ‘discharging effect’ which improves the operation of a given bus lane for both cars and buses at over-saturated situations. This happens as there is only a limited section of dedicated bus lane (1km in this simulation) where the buses enjoy full priority, while there could be a much longer section of road upstream where the buses are in congestion. Therefore, when the implementation of a pre-signal improves the discharging rate of the intersection and still provides high priority for buses, it could be beneficial to both cars and buses, especially with short bus lanes. Note that the exact demand value for when this is observed depends on the length of the dedicated bus lane segment and could be quantified analytically. However, this is not a part of this paper because for over-
saturated cases, the mixed lane strategy is always adopted due to the first criterion and delay is not the main concern here.

For under-saturated cases, the pre-signal strategy provides the lowest average person delay for the range of bus occupancy to car occupancy ratios (20-60) considered (namely, occupancy ratios in Figure 4). Note that although bus frequency could potentially affect the interaction between buses and cars in extreme cases, it was shown in previous work (2) that this holds true for bus frequencies as high as one bus per cycle. Also note that the bus lane strategy is always the worst for all bus occupancies and car demands, although it performs increasingly better with increasing bus occupancies. For car demands near capacity, the mixed lane strategy provides the lowest system average person delay for the range of bus occupancies considered. Although a pre-signal strategy performs increasingly better with increasing bus occupancy, it could only potentially outperform the mixed lane strategy if the occupancy were extremely high (over 100), which is unrealistic. Therefore, for under-saturated cases, the mixed lane strategy is chosen for demand levels greater than 0.8 and the pre-signal strategy is chosen for demand levels less than 0.8.

Summarizing the analysis based on the two criteria, the mixed lane strategy is chosen for demand levels greater than 0.8 while the pre-signal strategy is chosen for demand levels smaller than 0.8. Note in particular that this is not a contradiction to previous results (2, 3) where it was concluded that the pre-signal strategy minimizes average person delay not only for under-saturated cases but also for over-saturated cases. Firstly, that analysis is based on a static and fixed demand where a peak over-saturated period is followed by an off-peak under-saturated period. The average delay is calculated based on the entire duration. In contrast, this analysis is based on a dynamic demand and the best strategy for the next 15 minutes is chosen. Secondly, average person delay is the only criterion in that work while upstream queue length is also a determining criterion in our analysis. Although the pre-signal strategy could potentially result in the minimum average person delay for over-saturated cases, it causes an upstream queue that can potentially reduce the performance of the network.

**THE ONLINE CONTROL ALGORITHM: GUIDELINE AND CASE STUDY**

Based on the analysis in section 5, we propose the following guidelines for the implementation of a pre-signal with an online control algorithm to improve traffic operation at an intersection. The goal of the online algorithm is to minimize system average person delay without excessive negative impacts upstream. The relevant parameters and the necessary infrastructure are listed below.

Real time inputs:

- Traffic volume (\(v\)): Predicted traffic volume from the traffic flow detector.
- Main signal capacity (\(c\)): Effective discharge capacity of the main signal.
- Traffic demand level (\(D\)): Nearest 0.05 of the \(v/c\) ratio.

Calculated parameters:

- \(R_{pd}(i)\): List of calculated length of the red pre-signal during a normal cycle for all demand levels based on (4).
- \(R_{bus}\): Length of the red pre-signal before the bus arrives at the pre-signal. Maximum recommended length is 10 seconds based on (12).

Required infrastructure:

- Main signal: The main signal at the intersection operates as normal.
- Clear marking between the main signal and the pre-signal: Note that irrespective of the demand level, all lanes in this space are shared by cars and buses and should be marked clearly.
- Pre-signal: The pre-signal is to be built according to the guidelines in (4).
- Bus lane: The bus lane in front of the pre-signal should be clearly marked.
- Bus detector: A vehicle detector should be set up upstream of the pre-signal on the bus lane. The detector should be far enough upstream to be triggered at least \(R_{bus}\) seconds before the bus arrives at the pre-signal.
- Bus lane message board: A traffic information board should be put up before the bus lane to indicate in real time whether the bus lane is open to cars or not.
• Traffic flow detectors: Traffic flow detectors (loop detectors, cameras, radars, etc.) should be set up upstream to measure real time traffic volume. The detector should be far enough upstream so as not to be affected by the upstream queue under usual conditions.

The online algorithm is as follows.

Every 15 minutes, the traffic volume (v) is calculated based on real time detection and historical data (notice that the exact algorithm for traffic demand prediction is not the focus of this paper). The traffic demand level (D) is calculated and compared to a threshold value 0.8. This determines how the traffic operates for the next 15 minutes.

• If D is greater than 0.8, the bus lane message board indicates that the bus lane is now open to cars. The pre-signal operation is switched off.

• If D is less than 0.8, the bus lane message board indicates that the bus lane is closed to cars. The pre-signal operation is switched on with Rp calculated from the list of Rps(i) based on the demand level D.

Note that in none of the two cases, the operation of the main signal is affected. Also, the trigger input from the bus detector will only have an effect on the pre-signal if the pre-signal operation is on.

The above online algorithm is implemented in a case study. The case study examines the traffic performance of the intersection with the online control algorithm for a pre-signal with a hypothetical demand between 06:00 and 19:00. This time period includes the morning peak, evening peak and off-peak hours in between. The traffic demand level is as shown in Figure 7.

The pre-signal operates with the above online control algorithm where the strategy is updated every 15 minutes. In particular, note that between 06:15-09:30 and 15:15-18:30 the mixed lane strategy is used in the control algorithm.

Two traffic performance metrics are included in this simulation. First, a 2-meter loop detector is placed 500 meters before the bus lane starts to detect car occupancy, i.e., density. The average car occupancy is calculated for every time period. Second, the average person delay is calculated for all vehicles that are discharged from the main signal during every time period. The occupancy ratio of cars to buses is assumed to be 40. The two traffic performance metrics are compared across three strategies.

During the peak hours, the pre-signal is switched off with our proposed online control algorithm. Hence the pre-signal strategy is the same as the mixed lane strategy. It is obvious from Figure 5 that they perform much better than the bus lane strategy. If a dedicated bus lane is implemented, a queue grows quickly from the intersection and congestion appears even 2500 meters upstream of the intersection. This results in the most average person delay.

During the off-peak hours, the pre-signal is switched on with our proposed online control algorithm. It is observed that the pre-signal strategy provides the lowest average person delay. Note that the bus enjoys a section of bus lane before the pre-signal, so bus priority is still provided and public transport is promoted.
CONCLUSIONS

This paper developed an online control algorithm to dynamically switch between different traffic control strategies at an intersection with pre-signal infrastructure. The goal of the online algorithm is to minimize system average person delay without excessive negative impacts upstream. This online control algorithm was analyzed with a micro-simulation model in VISSIM and is expected to function well in a wide range of scenarios. In a case study, compared to the bus lane strategy, the congestion upstream of the intersection during peak hours is mitigated. Compared to the mixed lane strategy, the average person delay during the off-peak hours is lower and bus priority is provided. All in all, implementing a pre-signal with our proposed online control algorithm provides a good balance between providing bus priority and sustaining car throughput.

Methodologically, this paper validates the micro-simulation in VISSIM to study pre-signal operation. This builds the foundation to use micro-simulation models to study the effects of pre-signals on the arterial and network level in future research, which is difficult to fully examine analytically. The ultimate goal is to identify the optimal operating strategy for pre-signals at the network level so that bus priority is provided without penalizing the cars too severely and the right balance is achieved at the network level.
REFERENCE


