Providing Bus Priority at Signalized Intersections with Single Lane Approaches

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Background

In urban areas, where road space is limited, it is important to utilize the existing space more efficiently. Reliable and efficient bus services can help serve more people using less space. Better bus services can be provided by implementing bus priority strategies on the roadways (e.g., to allow buses to jump car queues reducing bus travel times). Some of these strategies could also diminish the total people-hours traveled on a road network (for buses and cars), since buses typically have higher on-board occupancies. Also, with the use of bus priority strategies travel time variations of buses can be reduced, leading to more reliable service. Overall, the improvements in bus services can increase the attractiveness of the mode, leading to modal shifts from cars to buses. This shift can reduce roadway congestion, and also help urban traffic operations become more environmentally sustainable.

One of the major sources for bus delays in urban roadways is the interaction with car queues at signalized intersections. A typically used bus priority strategy to mitigate this effect is dedicating a lane for bus use only. This is usually done by the conversion of an existing car lane. However when only a single lane for each travel direction exists, it is physically impossible to do so. To this end, this research explores the use of additional signals (i.e, pre-signals) to give priority to buses near signalized intersections. This strategy seeks to eliminate (or nearly eliminate) bus delays while minimizing additional delays imparted to cars.

Pre-Signal Strategy

Pre-signals usually refer to a signal placed upstream of an intersection to stop cars when a bus approaches, in order to allow the bus to move to the front of the queue (Wu and Hounsell, 1998; Guler and Cassidy, 2012). They are used to intermittently change the allocation of a lane. Here, we will focus on a different type of pre-signal. We will look at signals used to intermittently change the direction rather than the allocation of a lane. The basic idea is illustrated in Figure 1. One additional signal is placed upstream of the main signal in the direction of bus travel (i.e., upstream pre-signal), and another additional signal is placed downstream of the main signal in the opposite direction (i.e., downstream pre-signal). Cars receive the green light at both pre-signals whenever buses are not present. When a bus approaches the upstream pre-signal location, cars in both directions are stopped at the upstream and downstream pre-signals in advance. This allows for the bus to jump the queue at the upstream pre-signal using the opposite direction's car lane and also, in certain cases, to travel through the main signal without encountering any car queues.

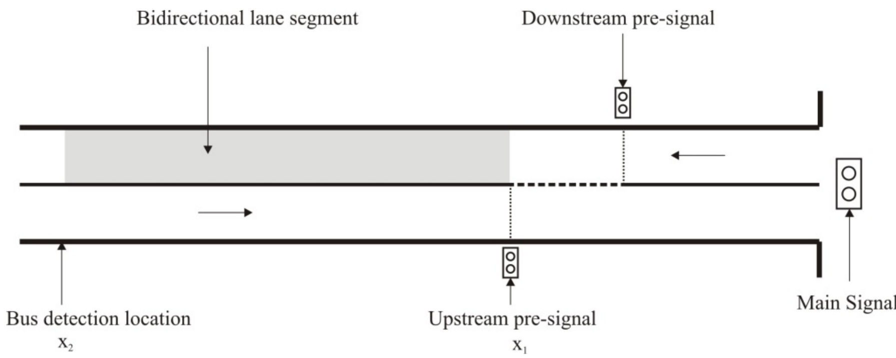

Figure 1 Typical layout for upstream and downstream pre-signals to change lane direction.

Project goals and methodology

The goal of this work is to quantify the length of the car queue and additional car delays that would be experienced when a pre-signal strategy of this kind is implemented. The queue lengths are of specific concern here since a queue spill-over to the intersection, generated by the downstream pre-signal in the opposite lane could lead to a significant loss of capacity at the main signal. The probability of a queue spill-over occurring can be reduced by placing both pre-signals further away from the intersection. However, in this case, the delays experienced by the bus will increase since now it is highly possible that an arriving bus will get stuck in the car queue formed at the main signal. Therefore, a trade-off between bus delays and car delays based on the location of the pre-signals exist.

To identify and evaluate the bus and car delays, as well as the car queue lengths we use traffic flow theory. Assuming a triangular fundamental diagram as shown in Figure 2, time-space diagrams depicting car and bus trajectories can be drawn. The traffic states that are important to the analysis which are shown in this figure are: *D*, arriving vehicles; *C*, vehicles discharging from a queue; *J*, vehicles in queue; and *O*, the empty arterial.

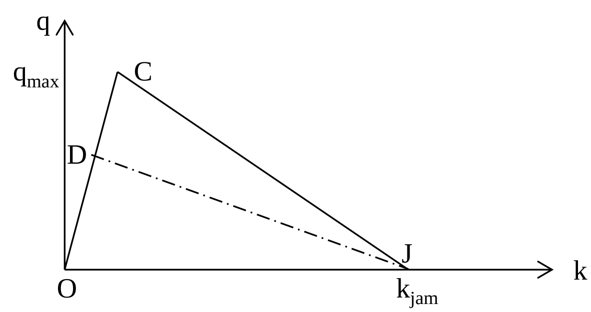

Figure 2 Fundamental diagram.

An example of a resulting time-space diagram for cars arriving to the intersection in the direction of bus travel, for one specific bus arrival time, is shown in Figure 3. Two different locations are identified with dashed lines: (*i*) x_1, the location of the upstream pre-signal; and (*ii*) x_2, the location where an arriving bus will trigger the red-signal for cars at both pre-signals. The trajectory of the bus is shown with the thick line. Note that the bus can pass through the queue of cars since it is travelling on the opposite direction's travel lane between x_2 and x_1; and, in this specific case, it travels the entire segment without encountering any delays. However, as discussed earlier, this may not always be the case, and the bus could sometimes be delayed due to the car queue at the main signal. The solid black lines represent the shock-waves between different traffic states when a bus is present. The solid gray line represents the shock-waves which would have occurred between different traffic states if the bus were not present. Hence, the shaded area represents the additional delay experienced by cars due to providing bus priority. The additional length of the queue is represented by Δx. The start and end of red times at the pre-signals are marked by t_1 and t_2, respectively. Using this duration a simple time-space diagram can be drawn to identify the delays and length of the car queue for the opposite travel direction as well.

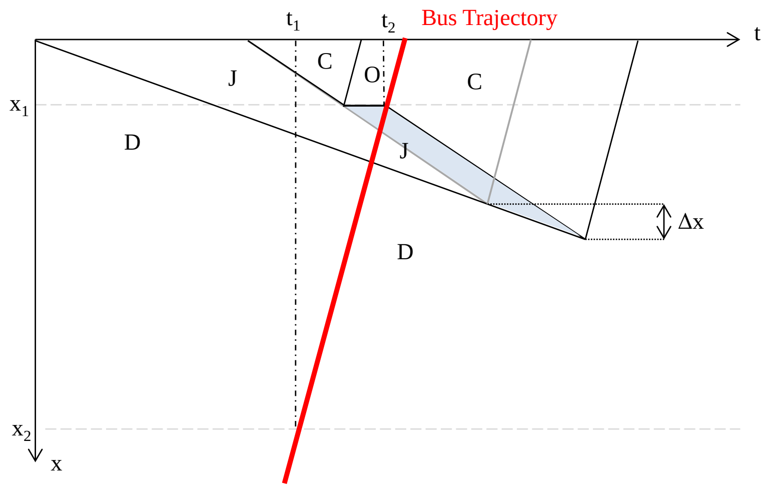

Figure 3 Illustrative time-space diagram of a bus arriving to an upstream pre-signal

Evidently, the characteristics of the time-space diagram will depend on the arrival time of the bus to x_2. Identifying these different cases, an expected value for the bus and car delays is calculated based on the demand of cars and the location of the pre-signals, and x_2. The optimum location for the two pre-signals and x_2 is determined by minimizing the system-wide delay (i.e., total person-hours of delay). Also completely mixed bus and car operations are compared to the use of additional signals to determine the domains of applications on bus occupancies when pre-signals provide smaller system-wide delays.

The full paper furnishes the formulations for the bus and car delays, additional queue lengths, and domains of application. In addition, the analytical work is verified with the use of empirical data collected in Rapperswil, Switzerland; where an implementation of such a bus priority strategy exists. The end product provides guidelines on when and where the use of pre-signals to change lane directions can benefit the traffic operations in an urban setting.

References

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