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Providing bus priority at signalized intersections with single-lane approaches

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Abstract

Signalized intersections often represent a major source of bus delays. One typical strategy to mitigate this problem is to dedicate an existing car lane for bus-use only to minimize the interactions between cars and buses. However, this is physically impossible at approaches where only a single travel lane is available for each direction. To this end, this research explores a novel method to provide priority to buses at signalized intersections with single-lane approaches through the use of additional signals in a way that (nearly) eliminates bus delays while minimizing the negative impacts imparted to cars. Using these signals, the bus can jump a portion of the car queue using the travel lane in the opposite direction.

This paper theoretically quantifies the delay savings buses can achieve, and the negative impacts imparted onto cars when this pre-signal strategy is applied. The negative impacts are measured as the additional car delays experienced when the intersection signal is under-saturated, and the reduction in car-discharge capacity when the intersection signal is over-saturated. In the under-saturated case, the results show that moderate average bus delay savings (~5-7 seconds per vehicle) are achieved if the pre-signal is always in operation; and these results decrease the total system-wide delay (measured in person-hours) only if bus occupancies are very high. However, if the pre-signal operation is targeted to only provide priority to the buses that would benefit the most, significant bus delay savings can be achieved (delay benefits to buses which receive priority are about doubled) while also reducing the system-wide delay, even if the ratio of bus to car occupancy is relatively modest (greater than about 20). In the over-saturated case, bus delay savings can be much more significant than under-saturated cases (greater than 30 seconds per bus), and this delay saving can increase further for longer block lengths (greater than 100 m). However, the capacity of the intersection decreases by up to 25% during each cycle in which a bus arrives to the intersection. Simulation tests confirmed that the general trends and magnitudes of bus delay savings and negative impacts to cars hold for more realistic behaviors. The overall benefits are slightly smaller in the simulations, but nevertheless the strategy seems promising as a bus priority strategy at intersections with single-lane approaches in the field.

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1. Introduction

Public transportation is a viable way to combat urban traffic congestion as public transport vehicles (e.g., buses) are able to use urban roadspace more efficiently compared to private vehicles (e.g, cars). However, when buses and cars interact, the operation of both modes could be impaired. This is very evident at signalized intersections, which constitute one of the major sources of vehicular delays in urban environments. For example, buses dwelling at stops near a signalized intersection could significantly reduce discharge capacity and this could lead to increased car queues and delays (Gu et al., 2013, 2014). More worrying to public transportation operations is that buses can also get delayed by car queues, leading to more unreliable transit service. Mitigating the impacts of these harmful interactions on transit vehicles is essential to promote public transportation as a solution to urban traffic congestion.

One strategy typically used to minimize negative bus-car interactions is to dedicate an existing car lane for bus-use only. When these bus lanes are implemented throughout an entire public transit line or network, bus delays can be significantly reduced and transit service can be made more reliable. However, it is not always possible to provide a dedicated bus lane in urban environments. Urban roads are generally narrow, often with only one travel lane in each direction. There is no physical space available to provide a bus lane at intersections with single-lane approaches, even if building a new dedicated bus lane were feasible. The only current option available to provide priority for transit vehicles at these locations is to implement Transit Signal Priority (TSP) at the main intersection signal (Rakha and Zhang, 2004; Christofa and Skabardonis, 2011). While useful, TSP still forces buses to mix with cars, which can result in significant delays at the intersection.

To this end, this research explores a novel method to provide priority to buses at signalized intersections with single-lane approaches through the use of additional signals in a way that (nearly) eliminates bus delays while minimizing the negative impacts imparted to cars. Previous work has examined placing an additional signal upstream of a signalized intersection (called a pre-signal, or a bus gate with signals) to stop cars on mixed-used lanes, allowing a bus approaching on a dedicated lane to bypass any car queues it might otherwise encounter (Wu and Hounsell, 1998; Guler and Cassidy, 2012; Guler and Menendez, 2014a,b; He et al., 2015). These types of pre-signals intermittently change the *allocation* of the lane downstream of the pre-signal from mixed-use to bus-use only. This allows the bus to travel unencumbered by car traffic, and only impacts vehicles traveling in the same direction as the bus.

Here, we focus on a pre-signal that operates differently: it intermittently changes both the *direction* and *allocation* of travel allowed on a lane, and negatively impacts vehicles traveling in both directions. The idea is to clear cars out of the opposite direction travel lane ahead of an arriving bus, such that the bus can use this lane to jump a portion of the car queue. To do this, pre-signals are required on travel lanes in both directions. The pre-signal on the opposite direction travel lane allows that lane to clear of cars so that a bus can safely use it as an intermittent bus lane. The pre-signal on the lane in the same direction stops cars and allows the bus to merge back onto its original lane without conflict. The details of this dual pre-signal operation are explained in the following section.

The goals of this paper are two-fold: 1) to define this new pre-signal operating strategy, and 2) to theoretically evaluate both the benefits to buses and the corresponding negative impacts to cars. Only through an exhaustive analysis can a complete understanding of the operation and the bounds of application of this strategy be determined. The benefits to buses are quantified by the delay savings when compared to a no priority strategy. The negative impacts to cars due to the pre-signals are measured differently based on the operating conditions expected at the main signal. If the intersection signal is expected to be under-saturated, the negative impacts are quantified by the additional delays imparted onto cars. In this case, there exists a clear metric that can be used to assess the overall impact of this strategy – change in overall delay to all users of the system. On the other hand, when the intersection signal is expected to be over-saturated, the negative impacts are quantified as the reduction in total throughput (i.e., capacity) at the main signal. Here, the overall impacts are harder to quantify due to the trade-offs between reductions in bus delays vs. reduction in throughput. They can be better determined by how an agency values car-moving capacity and transit delay. The theoretical results are then confirmed with tests performed through a micro-simulation.

The remainder of the paper is organized as follows. The details of the pre-signal operation are described in Section 2. Next, theoretical models to analyze the delays and the capacity changes associated with the pre-signals for under-saturated and over-saturated intersections are developed in Sections 3 and 4, respectively. The results of simulation tests and comparisons with theory are presented in Section 5. Finally, some concluding remarks and discussion are presented in Section 6.

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