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Title	Effects of a simplified operating strategy of pre-signals at a single intersection
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Abstract	**Haitao He, S. Ilgin Guler, Monica Menendez** **ETH Zurich** A pre-signal is an additional signal upstream of the main signal at a road intersection. There is at least one dedicated bus-lane upstream of the pre-signal and the pre-signal controls only the operation of private vehicles on the car-lanes. Its primary purpose is to reduce the bus delay at the intersection without increasing the system-wide person hours of delays. By providing bus priority at the intersection, the public is encouraged to use the more sustainable bus mode for transport, without causing extra congestion to the overall traffic. To this end, Guler and Menendez (2014) have proposed a specific operating strategy for a pre-signal at a single intersection. 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. In this way, the lane allocation of the section between the pre-signal and the main signal changes intermittently. The goal is to ensure that any arriving bus can move in front of the car queue, and discharge at the earliest possible time from the main signal. The pre-signal turns green in advance of the main signal such that cars do not experience additional delays in cycles when buses are not present. According to Guler and Menendez (2014), this operating strategy minimizes system-wide person hours of delay. This was examined by building an analytical model to study the effects of this strategy on the average car delay, the average bus delay and the average system delay. The analytical model was validated with empirical data collected at an intersection in the city of Zurich. To recreate this scenario, He, Guler and Menendez are also working to build and validate a micro-simulation model of this pre-signal operation with VISSIM. Although the proposed operating strategy minimizes system-wide person hours of delay, it is not the easiest strategy to implement in real life. Firstly, this operating strategy requires the use of selective-vehicle-detection technology to detect an incoming bus. This requires additional equipment installation on the buses, the road, and the signal controller. Secondly, in the proposed operating strategy, when an incoming bus arrives during a green pre-signal, the pre-signal turns red for cars immediately even if the green phase has only just started. Additional complications will arise during implementation because a minimum amount of green time is normally required for signal operations due to safety and operational reasons. Lastly, if the car demand is high, or the frequency of buses is high, or the bus occupancy is low, the original operation strategy may cause too much extra delay to cars. These cases will be out of the boundary within which the original operation strategy would minimize the system-wide person hours of delay. The goal of this work is to examine the effects of a pre-signal at a single intersection with a simplified operating strategy. In this operating strategy, the pre-signal turns red only in advance of a red main signal and turns green only in advance of a green main signal. The offset between the two signals follows the prescription in the original operating strategy devised by Guler and Menendez(2014). However, notice that with this simplified operating strategy, bus actuated devices are not necessary. Therefore, it is easier and cheaper to

implement. There is also no complication arising from a bus arriving when the pre-signal has just turned green, and therefore less on-site calibration is needed.

We expect this simplified operating strategy to provide a level of bus priority at the intersection in between the original pre-signal operating strategy and the scenario without pre-signal. It provides bus priority when the main signal is red, so arriving buses can move in front of the car queue and discharge immediately when the main signal turns green. However, it does not provide bus priority when the main signal is green. Therefore, in cases when the car demand is high, the simplified strategy will cause less additional car delays than the original strategy. Also, when the incoming buses are frequent or the bus occupancy is low, the simplified strategy may result in the minimum system-wide person hours of delay.

To examine the effects of the pre-signal with this simplified operating strategy at a single intersection, an analytical model using queuing theory is built in this research. The formulation of the analytical model follows that developed by Guler and Menendez (2014). Depending on the arrival time of the bus, there are three cases for the time-space diagram of the incoming bus, namely, the bus arrives at a red pre-signal and is queued in front of the red main-signal; the bus arrives at a green pre-signal and is queued at a red main signal; the bus arrives at a green pre-signal and is discharged at a green main-signal. Note that the bus gets no priority in the last two cases, hence essentially the intersection operates as the scenario without a pre-signal. This differs from the original operating strategy where the bus always gets priority.

Based on the analytical model, the two operating strategies are compared in terms of the average car delay, the average bus delay, and the average system delay. Two main questions are analyzed and answered. The first question is within which boundary conditions the simplified operating strategy results in fewer system-wide person hours of delay than the original operating strategy. The second question is, when the original operating strategy is better, how many more system-wide person hours of delay the simplified operating strategy causes. There are clear pros and cons between the two strategies and the simplified strategy may be acceptable and justifiable when the cost to implement the original operation strategy is significantly higher.

We also develop a micro-simulation model of the single intersection case with VISSIM to simulate and compare both operating strategies. We assume a layout that includes one bus lane and one car lane to simulate the simplest model of a pre-signal. In this set-up, bus and car demands could be adjusted and the two operating strategies are compared under different conditions.

Ultimately, we aim to understand the operation of pre-signals at the network level and identify the overall optimal operating strategy. The insights on the effects of a pre-signal at single intersections can provide us with a systematic methodology to examine the effects on the arterial and network level. A more effective and less costly implementation strategy of pre-signals on the network level could provide bus priority network-wide without causing extra congestion to the overall traffic. In the long term, the public will be encouraged to use the more sustainable bus mode for transport.

1. Guler, I. and M. Menendez (2014) Analytical formulation and empirical evaluation of pre-signals for bus priority, *Transportation Research Part B* (accepted).