Queue Jump Lane, Transit Signal Priority, and Stop Location: Evaluation of Transit Preferential Treatments using Microsimulation

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Submitted to the Transportation Research Board for presentation and publication

July 14, 2014; revised November 14, 2014

Word Count: 4,741 words + 11*250 words (10 figures + 1 table) = 7,491 words
Abstract

Transit preferential treatments offer the potential to improve transit travel time and reliability. However, the benefits of these treatments vary greatly depending on the specific characteristics of the study area, including turning movement and pedestrian volumes, signal timing parameters, and transit stop location. To evaluate the performance of preferential treatments, practitioners typically rely on microscopic simulation models, which require a considerable amount of effort, or review previous studies, which may reflect a bias to the area characteristics. This paper develops a test-bed and a planning-level framework to help practitioners determine the benefits offered by various preferential treatments without developing a detailed simulation model. To evaluate preferential treatment benefits, the authors performed extensive simulation runs under various scenarios at an isolated intersection using VISSIM. The analyses show that the greatest benefit comes from relocating a near-side stop to a far-side stop, in which far-side stops can reduce delay up to 30 seconds per intersection. The highest savings that could be obtained with a queue jump lane is approximately 9 seconds per intersection. As the amount of right-turns increase along with the number of conflicting pedestrians, the benefit of queue jump lane disappears. Transit signal priority with 15 seconds of green extension and red truncation can offer up to 19 seconds of reduction in delay, where the benefits become more pronounced with high volume to capacity (v/c) ratio. With low v/c ratio, granting 10 seconds of green extension without red truncation provide very marginal benefits; only 2 seconds delay reduction per intersection.
**Introduction**

Transit preferential treatments such as queue jump lanes, bus-only lanes, and transit signal priority (TSP) have the potential to improve transit travel times and reliability in a mixed-traffic environment, which in turn reduce waiting time of passengers, unnecessary fleet size, and increase ridership [1] [2]. The benefits of these treatments, however, greatly depend on the area type characteristics as well as the physical configurations of the street network [1] [3] [4]. Transit stop location, signal timing parameters, turning movement and pedestrian volumes affect operations in an interdependent and non-linear manner. To evaluate the benefits, at the planning level, practitioners review previous studies and other resources to estimate the benefit that could be expected at their specific location. Yet, many of these previous studies analyze cases with unique configurations or systems of actual intersections, which, in turn, reflect a bias towards the specific parameters that were used. Microsimulation models, if calibrated properly, can reflect site-specific conditions and provide more reliable results. However, the development of simulation models can be cumbersome and may require many hours of modeling.

The objective of this study is to develop a test-bed and a planning-level framework for practitioners to determine the potential benefit offered by various preferential treatments without developing a detailed microsimulation model. To determine preferential treatment savings, the authors performed over 5,000 simulation runs at an isolated intersection using a microsimulation model, VISSIM, by changing one parameter at a time. These include the “input” parameters such as traffic volumes, green to cycle ratio (g/C), pedestrian volumes, and transit dwell times in combination with the “configurable” variables such as the location of a transit stop and the length of a queue jump lane. The results of this study will provide answers to the following questions:

- What is the expected delay reduction with queue jump lanes?
- What is the expected delay reduction with TSP?
• How do stop location (e.g., far-side vs. near-side) and dwell time affect bus delay?

Because our research included sensitivity runs with many factors that affect the operations in real life, it allows practitioners to obtain a close-to-reality measurement of benefits before weighing them off against the costs and the potential impacts of these treatments. The authors envision this research as a step towards developing transit preferential treatment warrants.

The remainder of this paper is organized as follows. The next section provides definition and literature review on preferential treatments as well as bus stop location. It is followed by the description of the applied methodology and simulation results for the preferential treatments. The last section of the paper presents the main conclusions.

**Queue Jump/Bypass Lanes**

Queue jump and bypass lanes allow the transit vehicle to skip the queue either all together or at least partially. Full skipping occurs when no other vehicles are allowed to enter the queue jump/bypass area. Partial skipping occurs when right-turning vehicles are allowed to use the queue jump/bypass lane.

**Figure 1** shows the difference between a queue jump lane and a bypass lane [5].
Even though queue jump and bypass lanes are the common terms used in the industry, the authors believe that the names are not self-explanatory and cause confusion among practitioners. Therefore, for the rest of this paper, “one-sided queue jump lane” and “two-sided queue jump lane” will be used for queue jump lane and queue bypass lane, respectively.

Transit Signal Priority

Transit signal priority (TSP) gives extra green time or less red time to transit phases at a signalized intersection to reduce transit delay associated with traffic signals [3]. It also reduces the variability in running times by reducing signal delays. Running time variability is a major challenge for transit agencies as it not only causes overcrowding on buses, but also increases the 90th percentile running time that is...
often used to determine scheduled running plus recovery time. This, in turn, determines fleet size and thereby operating cost [2].

**Bus Stop Location**

Transit stops in urban areas are either at mid-block locations or at near-side or far-side of intersections [6]. Intersections are generally preferred over mid-block locations as they typically come with pedestrian crossing accommodations and provide better access to side streets.

**Literature Review for Transit Preferential Treatments**

Transit Capacity and Quality of Service Manual (TCQSM) and Transit Cooperative Research Program (TCRP) Report 118 - Bus Rapid Transit Practitioner’s Guide - provide some guidance regarding the operations of one-sided and two-sided queue jump lanes [5] [7]. TCRP Report 118 estimates travel time savings in the range of 5 to 15 percent with one-sided queue jump lanes [7].

Zhou and Gan evaluated one-sided queue jump lanes under different TSP strategies, traffic volumes, dwell times, and bus stop locations [8]. Their results showed that special bus phase, which allows buses to merge back into the mainline easily, is necessary for one-sided queue jump lanes to be effective. Moreover, right-turn volumes were found to have an insignificant impact on bus delay.

Zlatkovic et al. [9] evaluated the individual and combined effects of one-sided queue jump lanes and TSP on performance of a Bus Rapid Transit (BRT) system in West Valley City, Utah. 13 signalized intersections were analyzed using VISSIM. Simulation results showed the combined queue jump lanes and TSP scenario yielded highest benefits: 13-22 percent reduction in BRT travel times and 22 percent increase in BRT speed.

Lahon [10] evaluated the benefits and impacts of TSP and one-sided queue jump lanes for the BRT system in the City of Pleasanton, California. Six signalized intersections were modeled in VISSIM. Results indicated that TSP and queue jump lanes reduced delay by 30 percent along the corridor. It was
also found that TSP and queue jump lanes are most beneficial when congestion levels are higher for the corresponding through movement.

Altun and Furth [2] developed a uniform delay model to predict transit delay reduction at a signalized intersection due to TSP. They demonstrated the relationship between benefits of green extension and red truncation strategies and their probability of occurrence during a signal cycle. Figure 2 shows this uniform delay model, where “r” is the red duration of mainline (bus movement), “C” is the cycle length, “x” is the green extension amount, “e” is the early green (red truncation) amount, “s” is the saturation flow rate, “v” is the volume, and “k” is a random variable between 0 and 1 that represents the random arrival of a bus at any point in the signal cycle.

\[
\text{Average Delay with Priority} = \frac{r - e - x}{2C} \left[ (r - e) \frac{s}{s - v} - x \right]
\]

\[
\text{Delay without priority} = r - \left( \frac{s - v}{s} \right) kC
\]

\[
\text{Delay with priority} = (r - e) - \left( \frac{s - v}{s} \right) kC
\]

**Figure 2 - Uniform Delay Model to Estimate Transit Signal Priority Benefits [2]**

Furth et al. [11] explored the marginal impact (i.e., change in bus delay, defined as “average net delay”) of bus stop location on bus delay. A deterministic model, accounting for deceleration,
acceleration, and queue interference, was developed at signalized intersections. The results showed that for far-side stops, average net delay is approximately -0.5 seconds, while for near-side stops, average net delay is about 10 seconds. Moreover, the results indicated that, with respect to setback for near-side stops, the average net delay is worst when the setback is small (25 to 100 feet) since queues block buses from reaching a stop line. Larger setbacks reduce delay by minimizing the chance that a queue will block the stop. Finally, with a bus-only lane, near-side stops yield negative net delay and are better than far-side stops. However, the study did not quantify the marginal impact of variable dwell times on bus delay.

TCRP Report 19 - Guidelines for the Location and Design of Bus Stops - developed guidelines for designing and locating bus stops [6]. The report performed a comparative analysis of bus stop locations and lists the advantages and disadvantages of far-side, near-side, and mid-block stops while considering the impacts on pedestrian safety, traffic safety, intersection capacity, and bus delay. However, the bus delay results were not quantified.

Finally, TCQSM [5] described bus preferential treatments at intersections including transit TSP, queue jump, curb extensions, and boarding islands. However, the discussion did not provide any quantifiable results on bus delay effects.

**Methodology**

To evaluate the potential benefits of transit preferential treatments and the impact of stop location on bus delay, a simulation test-bed was developed in VISSIM. The test intersection included the junction of a four-lane road with a two-lane road, with left turn bays on all approaches (Figure 3). A bus line operating in mixed traffic with 6-minute headway was introduced in the simulation model.
Figure 3 - Test Intersection Layout

The intersection operated by a fixed-time control with a 100-second cycle length. Keeping the volumes constant, green time for the “bus phase” was adjusted to test different volume to capacity ratio (v/c) for the corresponding through movement.

In VISSIM, transit vehicles enter the network based on the schedule provided by the user. Therefore, there exists no randomness in transit vehicle generation. To introduce a random arrival process for transit vehicles, a “dummy” bus stop was created at the beginning of the bus route. Because the intersection operated with a 100-second cycle length, a uniform distribution with minimum zero seconds and maximum 100 seconds was selected for the dwell time at the dummy stop so that buses arrive at the intersection at any time in a cycle.

Conventional TSP tactics (i.e., green extension and red truncation) were applied to evaluate the TSP benefits. 10 seconds and 15 seconds of green extension and red truncation were considered for the bus phase. The control logic for TSP was modeled using VISSIM’s vehicle actuated programming (VAP)
language, which enables simulating custom traffic signal control, including fully-actuated signal control and TSP [12].

For each transit preferential treatment, a “No Build” and a “Build” scenario (Build includes the preferential treatment) were modeled in VISSIM. 20 simulation runs with different random seeds were performed for each scenario. Each simulation run lasted 3,600 seconds following a 300-second warm-up period, thus providing 10 bus events per run. Therefore, each scenario includes 200 data points (20 runs x 10 buses/run). The benefits associated with each preferential treatment were calculated using Net Delay where the calculation of net delay is given by:

\[
Net\ Delay = Build\ Travel\ Time - No\ Build\ Travel\ Time
\]

Therefore, a positive net delay means an increase in bus delay while a negative net delay indicates bus delay reduction.

Results for Two-Sided Queue Jump Lane Scenario

Base Case: Varying Right-Turns without Conflicting Pedestrians

Two-sided queue jump lane was initially tested with no conflicting pedestrians and variable right turn volumes. Figure 4 shows intersection configuration under No Build and Build conditions and presents net delay as a function of bus phase v/c with the hourly right turn volume when conflicting pedestrian volume is zero. Note that for all the scenarios, the length of the queue jump lane was selected based on the 95th percentile queue length for the bus phase.
1. No Build – No Queue Jump Lane

2. Build – With Two-Sided Queue Jump Lane

Results indicate that net delay associated with queue jump lane approaches zero as v/c ratio for the bus phase decreases (Figure 4). In other words, the less congested the approach, the smaller the benefits. Also, the benefit decreases as the right turning volume increases, because right turning vehicles are allowed to use the queue jump lane, thereby interfering with the bus operations. With
moderate to high bus phase v/c ratio (v/c greater than 0.7), the benefits start to be more pronounced. Results show that approximately 10 second reduction in bus delay is possible when v/c is higher than 0.9 and right turn volume is lower than 100 vehicles per hour.

Sensitivity to the Length of Queue Jump Lane

Further experiments were conducted with variations in the length of queue jump lane. Variable lengths considered in the analysis included 95th, 85th, 50th, and 35th percentile bus approach queue length. No right turning vehicles and pedestrians were introduced in the model. Results are shown in Table 1.

Table 1 - Two-Sided Queue Jump Lane Net Delay (s) versus Bus Phase v/c Ratio under Different Queue Jump Lane Lengths

<table>
<thead>
<tr>
<th>Bus Phase v/c Ratio</th>
<th>95th Percentile</th>
<th>85th Percentile</th>
<th>50th Percentile</th>
<th>35th Percentile</th>
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<tr>
<td>0.90</td>
<td>-9.2</td>
<td>-8.9</td>
<td>-8.4</td>
<td>-7.9</td>
</tr>
<tr>
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<td>-6.7</td>
<td>-6.4</td>
<td>-6.1</td>
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<td>-4.3</td>
<td>-4.2</td>
<td>-3.9</td>
<td>-3.7</td>
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<td>0.41</td>
<td>-1.7</td>
<td>-1.6</td>
<td>-1.6</td>
<td>-1.5</td>
</tr>
</tbody>
</table>

Simulation results indicate that having a queue jump lane that corresponds to the 95th percentile queue instead of 35th percentile queue reduces bus delay by 1.3 seconds when bus phase v/c ratio is 0.90. The benefit of longer queue jump lanes is fairly small for all bus phase v/c ratios.

Effect of Pedestrians Conflicting with Right-Turns

Two-sided queue jump lane was also tested with variable right turning volume and pedestrians that are in conflict with the right turn movement. Two different No Build (base) scenarios were introduced to analyze the impact of pedestrians and right-turning vehicles on queue jump lane benefits. The first No Build scenario assumed operation with an exclusive right-turn lane (Figure 5) while the second No Build scenario assumed no exclusive right turn lane where right turning vehicles share the lane with the through vehicles (Figure 6).
Queue jump lane net delay results as a function of bus phase v/c ratio when No-Build includes an exclusive right-turn lane are presented in Figure 5.
1. No Build – No Queue Jump Lane

2. Build – With Two-Sided Queue Jump Lane

Note: The figure does not include results when the right-turn movement operates above capacity due to the influence of heavy pedestrian volumes.

Figure 5: Two-Sided Queue Jump Lane Net Delay (s) versus Bus Phase v/c Ratio under Different Pedestrian and Right Turn (RT) Volume, (a) RT=100, (b) RT=200, (c) RT=300
Results show that with the exclusive right-turn lane under the No Build, the benefit of queue jump lane disappears when hourly pedestrian volumes are greater than 150 under all right turn demand scenarios. Except for the low pedestrian interference and low right turn volume, the benefit is very small, less than 5 seconds. Another important finding is that when there is moderate to heavy pedestrian activity (e.g., more than 300 pedestrians), forcing buses to use the exclusive right-turn lane to bypass the through queue may cause substantial increase in bus delay, in particular when the right-turn movement is heavy.

Figure 6 provides queue jump lane net delay results when the No Build scenario does not include an exclusive right-turn lane. Note that given the same through and right-turn volumes, bus phase v/c ratios are different under the No Build and Build scenarios since Build scenario introduces a right-turn pocket, which in turn reduces through approach volume. For example, a bus phase v/c ratio of 0.9 in the Build scenario corresponds to a No Build v/c ratio of 1.0 when right turn volume is 100 vehicles, a v/c ratio of 1.09 when right turn volume is 200, and a v/c ratio of 1.18 when right turn volume is 300. The bus phase v/c ratios shown in Figure 6 are based on Build conditions. Results for v/c ratio of 0.9 are not included since it resulted in overcapacity under No Build.
1. No Build – No Queue Jump Lane

2. Build – With Two-Sided Queue Jump Lane

Note: The figure does not include results when the right-turn movement operates above capacity due to the influence of heavy pedestrian volumes.

Figure 6: Two-Sided Queue Jump Lane Net Delay (s) versus Bus Phase v/c Ratio under Different Pedestrian and Right Turn (RT) Volume, (a) RT=100, (b) RT=200, (c) RT=300
Results show that when the No Build scenario does not have an exclusive right-turn lane, introducing queue jump lane typically results in significant savings when bus phase v/c ratio is above 0.5, where some of this benefit can be attributed to an increase in approach capacity as a result of the added right-turn pocket. However, low bus phase v/c ratio and high pedestrian demand activity (e.g., more than 300 pedestrians per hour) could cause marginal increase in bus delay (less than 2 seconds).

**Results for Transit Signal Priority Scenario**

Net delay under different bus phase v/c ratio is shown in Figure 7. Not surprisingly, results show that TSP becomes more effective as the bus phase experiences more congestion. For example, with 10 seconds of green extension and red truncation, bus delay reduction per intersection is about four seconds when v/c ratio is 0.4, while the delay reduction becomes more than 12 seconds when v/c ratio is 0.9. With the maximum time span for TSP tactics of 15 seconds, the application of green extension and red truncation provide significant reductions in bus delay (ranging from 6 to 18 seconds, depending on the bus phase v/c ratio).

Similar to the results provided by Furth et al. [13], the findings suggest that TSP benefits would be higher for buses that use minor traffic streams (e.g., buses traveling on cross street or making a left-turn) than for those on the main street, because v/c ratios for minor streams are typically higher. Additionally, the TSP benefits would be less than what is reported in Figure 7 if buses are able to follow signal coordination between intersections. Our results reflect a case where a bus can arrive at an intersection any time in the cycle, either as a result of fully actuated operation where the cycle length is variable or due to variable dwell times at bus stops between intersections under coordinated operation. Further research is necessary to derive adjustment factors for TSP benefits when the bus operation is such that buses can take advantage of signal coordination (e.g., short segments without stops).
1. No Build – No TSP
2. Build – With TSP

Figure 7: Green Extension and Red Truncation Net Delay (s) versus Bus Phase v/c Ratio, (a) = 10 seconds of Green Extension and Red Truncation, (b) = 15 seconds of Green Extension and Red Truncation

To verify the uniform delay model developed by Altun et al. [2], which evaluates TSP savings at a signalized intersection, the savings (with different extension and red truncation parameters) obtained from the simulation model were compared to the uniform delay model results (Figure 8).
Figure 8: Expected Transit Signal Priority Saving (s) for the Delay Model versus Simulation Experiments

Results show the good agreement in expected savings when only green extension was granted.

The root-mean-square error (RMSE) when the maximum allowed green extension was 10 and 15 seconds was 0.43 seconds in both scenarios. When green extension was applied with red truncation, the model slightly overestimates the savings where the difference tends to increase with higher red truncation times and bus phase v/c ratio. When the maximum red truncation time was 10 seconds, RMSE was calculated as 0.68 seconds, and it increased to 0.75 seconds with 15 seconds of red truncation time. Moreover, uniform model delay results are within 7 percent of the simulation results in all TSP scenarios. Because these errors are relatively low, it can be concluded that the uniform delay model is a reliable indicator of TSP benefits.

Results for Near-Side versus Far-Side Stop Scenario

To evaluate the impacts of stop location on bus delay, stop setback distance (i.e., the distance between the stop bar and a near-side stop) was set as a variable. The net delay for near-side stops with different
setback distances was compared to far-side stop. **Figure 9** shows net delay relationship for various stop locations against the red to cycle length (r/C) ratio. Note that r/C ratio was used rather than bus phase v/c ratio since the authors believe that r/C ratio is a more relevant parameter that determines whether a bus can clear the intersection after serving a near-side stop. It was assumed that expected dwell time (t_{dwell}) at the bus stop is 20 seconds in all scenarios, corresponding to a t_{dwell}/C ratio of 0.2. The No Build scenario considered a midblock stop that does not interfere with the signal queues (i.e., not under the influence of signal delay, **Figure 9**).
1. No Build – Midblock Stop

2. Build – Near Side and Far Side Stops

Figure 9: Near-Side and Far-Side Stop Net Delay versus Red Ratio (r/C) for the Bus Phase

Results show that far-side stop net delay is just below zero and remains roughly constant for different red ratios. However, near-side stop with no setback distance (i.e., S=0) increases bus delay significantly, particularly for high red ratios. When red ratio is 0.66 (corresponding to a bus phase v/c...
ratio of 0.9), for example, a near-side stop increases bus delay by more than 30 seconds. This can be attributed to the fact that a bus may have to make “triple stops” when serving a near-side stop. The first stop occurs because queue in front of a bus blocks the stop. The second stop is to serve passengers, and finally a third stop may happen if a bus misses the green signal while serving the stop. With non-zero setback (e.g., S = 100 feet or 200 feet), increase in bus delay is much smaller, because larger setbacks reduce the probability that a queue will block the stop. Moreover, if the red ratio is high, certain portion of the dwell time may overlap with the red signal, further reducing delay for near-side stops with non-zero setback distances.

We also analyzed the impact of variable dwell times on bus delay. Figure 10 shows net delay for a variety of bus stop locations, bus stop setbacks, $t_{dwell}/C$ ratio, and red ratio. Results show that when $t_{dwell}/C$ is 0.60, increase in bus delay under near-side stop with zero setback is not as high as lower $t_{dwell}/C$ ratio, because a higher portion of the dwell time overlaps with the red signal. Moreover, near-side stops with non-zero setback provide comparable results with the far-side stop when $t_{dwell}/C$ is 0.60.

![Figure 10](image-url)

Figure 10: Near-Side and Far-Side Stop Net Delay versus Red Ratio ($r/C$) for the Bus Phase for (a) $t_{dwell}/C = 0.40$ and for (b) $t_{dwell}/C = 0.60$
Overall, far-side stop is superior to near-side stop with zero setback distance and yields consistent results under all scenarios. If setback distance is considerably large, then the signals have no effect on stop delay and near-side stop functions as would like a far-side stop.

**Conclusion**

The analyses show that the most significant benefit at an urban intersection could be obtained by relocating a near-side stop with zero setback to a far-side location. If the bus stop is on a congested approach with high r/C ratio, far-side stops may result in delay reductions of more than 30 seconds per bus per intersection. Moreover, on a congested approach, pulling the stop 100 feet or further back away from the intersection stop bar results in savings more than 20 seconds by preventing the traffic queue from blocking the stop (i.e., limited queue interference). Far-side relocation savings become smaller as dwell times increase since higher portion of the dwell time at a near-side stop overlaps with the red signal.

Another important finding is with respect to the upper limit of travel time savings that could be obtained via two-sided queue jump lanes. The results show that the highest savings with a queue jump lane is approximately 9 seconds per bus per intersection. This assumes the most favorable design and operating conditions (e.g., far-side stops, presence of a receiving lane and thus no required transit-only phase, no right-turning vehicles in the queue jump lane, queue jump lane corresponding to 95th percentile bus phase queue length, and high bus phase v/c ratio). As the amount of right-turns increase along with the number of pedestrians to whom the right-turners need to yield, the savings get smaller. For example, when the hourly pedestrian volume is more than 150 in conjunction with more than 100 right turning vehicles, the benefit of queue jump lane disappears. Similarly, the less congestion there is, the smaller the savings.
TSP with far-side stop and 15 seconds of green extension and red truncation can offer up to 19 seconds of reduction in delay, where the benefits become more pronounced with high v/c ratio. Results show that with low v/c ratio (e.g., 0.4), which may be the case for buses traveling on the main arterial at major-minor intersections, granting 10 seconds of green extension without red truncation provides only about 2 seconds delay reduction per intersection. Finally, the deterministic methods of estimating TSP benefits, which assume uniform traffic arrivals, closely match the simulation results (root mean square error is less than one second). Therefore, practitioners are also encouraged to use the deterministic model to obtain planning-level estimates of savings that could be obtained through TSP.

Acknowledgments

The authors would like to thank Prof. Peter Furth of Northeastern University for his valuable comments and suggestions to improve the quality of the paper.


