Evaluating Arterial Street Transit Preferential Treatments

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Authors

Jim Dale, P.E.
Vice President
Innovative Transportation Concepts, LLC
811 1st Ave., Ste., 212
Seattle, WA 98104
jdale@itc-world.com.

Thomas Bauer, P.E.
President
Innovative Transportation Concepts, LLC
1128 NE Second St., Ste. 204
Corvallis, OR 97330
tbauer@itc-world.com.

Tim Bevan, P.E.
Transportation Project Manager
CH2M Hill
777 108th Avenue, N.E.
Bellevue, WA 98009-2050
tbevan@ch2m.com

Kirk McKinley
Planning Manager
City of Shoreline
1110 N. 175th St., Ste. 108
Shoreline, WA 98133-4912
kmckinle@ci.shoreline.wa.us

Todd Slind
Transportation Planner
CH2M Hill
777 108th Avenue, N.E.
Bellevue, WA 98009-2050
tslind@ch2m.com.

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ABSTRACT

Aurora Avenue is a major arterial street passing through Shoreline, Washington. In anticipation of substantial traffic growth over the next 20 years, the City of Shoreline initiated a project, Aurora Avenue North Multimodal Corridor Study, to identify a preferred design alternative for this critical roadway. Four alternatives consisting of various transit and roadway improvements were evaluated using the simulation model, VISSIM. The existing study area contained six signalized intersections, several driveways, on-street parking, and bus routes with in-lane stops and bus pullouts. The study area is shown in Figure 1.

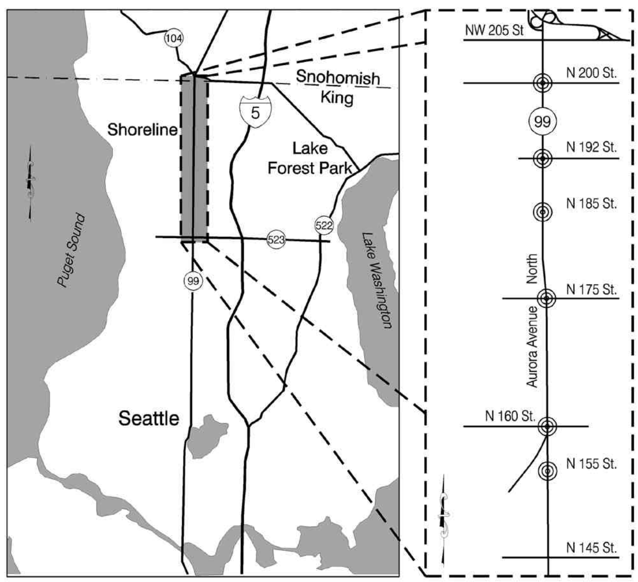


Figure 1. Study Area

While traditional improvements (e.g., adding turn bays) aimed at increasing capacity for general-purpose traffic were evaluated, another focus was on moving more people through transit preferential treatments. These treatments included:

- transit signal priority
- queue by-pass lanes
- exclusive transit lanes

This paper documents the evaluation of the transit preferential treatments applied in each of the four design alternatives. Measures of effectiveness (MOEs) used to compare alternatives were:

- travel speed
- schedule reliability
- transit capacity

In addition to the quantitative analysis, qualitative results are presented. The qualitative results discuss the success of using simulation in Shoreline to communicate design alternatives to decision makers and public audiences and thus to support the decision making process.

The simulation analysis lead to the following conclusions:

1. Transit only lanes provided the greatest transit benefit by removing buses from congestion in the general purpose travel lanes.

2. Transit queue by-pass lanes also produced substantial transit benefits. The length of the through queue at a signalized intersection influenced the effectiveness of these lanes.

3. Using far side stops with queue by-pass lanes appeared to reduce delay associated with buses being "trapped" in the near side bus bay when queues form at a downstream signal.

4. The VISSIM simulation model was an effective tool for (a) illustrating the benefits and impacts of various transit and roadway design alternatives with the Shoreline City Council and during Open House events with the community and (b) supporting the decision making process.

The primary recommendations to emerge from the application of simulation to the Aurora Avenue North Multimodal Corridor Study address when to use simulation:

- when traditional isolated intersection analysis tools do not adequately capture the system/multimodal impacts of the proposed alternatives and

- when transit and traffic operations resulting from complex or new designs need to be clearly conveyed to the public and decision makers.

Whereas the experiences gained through this project were in some ways unique to Shoreline, Washington, these experiences can provide insight to other transportation professionals considering similar corridor studies.

PROJECT BACKGROUND

In 1998, the City of Shoreline began the Aurora Avenue North Multimodal Corridor Study. This study is the first phase in the redevelopment of Aurora Avenue North along the segment within the City of Shoreline. The City of Shoreline Planning and Development Services Department was the lead agency for the pre-design study phase. The Public Works Department will lead the project through environmental documentation, design engineering, and construction. The product of the Multimodal corridor study was a Study Report that will serve as a master plan for proposed improvements to Aurora Avenue North, which the City hopes to accomplish within the next 10 years.

The City of Shoreline is a city of 52,000 located in suburban Seattle. Recently incorporated in 1995, the City has an activist community with strong civic ideals. Improving Aurora Avenue North is one of the community's top priorities.

Aurora Avenue North is a part of signed State Route 99 (SR 99). Shoreline's three-mile portion of the route extends from the Seattle city limits, north to the King County/Snohomish County border. SR 99 once served as the West Coast's primary north-south route connecting Mexico with Canada. This route now serves local and regional trips within and through Shoreline.

Study Area

Aurora Avenue North is a major arterial carrying approximately 39,000 (1998) vehicles per day as it passes through downtown Shoreline. The study area extended from 200th Street at the north end to 152nd Street at the south end. The P.M.-peak hour with 2020 traffic volumes was the study period. Since northbound is the peak direction during the P.M.-peak hour, the analysis results focused on the northbound transit movements.

Transit Alternatives

Four transit alternatives were analyzed. The primary characteristics of these alternatives are presented in Table 1.

No Build

The No Build alternative primarily consisted of a 5-lane section with a center two-way left turn lane. Transit signal priority was the sole transit preferential treatment for the No Build alternative.

Transit Queue By-pass Lanes

Queue by-pass lanes were added at each signalized intersection. These lanes allowed buses to by-pass a queue of through vehicles. These lanes developed approximately 150 feet upstream of the intersection and continued approximately 200 feet downstream. Far-side stops were used with this treatment. As the bus departs the stop, it must begin to merge back into the through lanes.

Table 1. Alternative Summary

Features	Alternatives			
	No Build	Queue By-pass Lane	Transit Lane	Transit Lane-Modified
Transit				
Headways	6 minutes	6 minutes	6 minutes	6 minutes
Preferential Treatment	• TSP	• TSP • queue by-pass lanes	• TSP • transit lane	• TSP • transit lane
Geometry Modeled				
	• 5-lane section, 2-way left turn lane was not modeled	• right turn bays added to Aurora • turn bays added to all cross-streets	• turn lanes added to Aurora • through/ auxiliary lane added at signalized intersections	• transit lanes serves as right turn bay at signals along Aurora • turn bays added to selected cross-streets
Signals Modeled				
Intersections	6	6	6	10
Peds Only	--	--	--	4

At three of the six signalized intersections, the queue by-pass lanes also served as exclusive right turn lanes for general purpose traffic. Exclusive right turn bays were added to Aurora at the remaining signalized intersections. The primary cross-street improvement was the addition of turn bays at all signalized intersections except 192nd Street.

Exclusive Transit Lanes

A business access and transit (BAT) lane adjacent to the curb was added to Aurora that provided a continuous transit lane in both directions throughout the study area. General purpose traffic also used this lane to access driveways and turn bays at signalized intersections.

A third through lane ("auxiliary" lane) on Aurora was added to all signalized intersections with the exception of 192nd Street and in the southbound direction at 175th and 155th Streets. This lane was fully developed approximately 200 feet upstream and continued approximately 200 feet downstream of the selected signalized intersections. Traffic using this lane was required to merge back into the two through lanes on the far side of the intersection. Although lane utilization will likely be an issue if this lane is implemented, lane utilization was not considered in the analysis. The lane was available to all traffic. A median with mid-block access points was also added that required modeling U-turns at signalized intersections and at the mid-block access points. Turn bays were also added to Aurora at key signals. Fewer turn bays were added to the cross street than in the Transit Queue By-pass alternative.

Exclusive Transit Lanes-Modified

This alternative was the preferred alternative to emerge during the project. The primary differences between it and the Exclusive Transit Lanes alternative included: (1) eliminating the auxiliary lane and (2) adding four signalized intersections and four signalized pedestrian crossings. The reason for adding the signals was to avoid any issues that could be raised about the model not accurately depicting the preferred alternative. This alternative is considered here since it captured the impact of adding signals on transit performance.

Traffic Volumes

Traffic volumes were forecasted for the year 2020 using the travel demand model EMME/2. After capacities were adjusted for each alternative, a separate EMME/2 run was performed to arrive at a unique volume set for each alternative. The same volumes were used for Alternative 2 and the Preferred alternative. The final study area volumes varied as follows:

- 4 percent increase from No Build to Alternative 1,
- 7 percent increase from No Build to Alternative 2/Preferred, and
- 3 percent increase from Alternative 1 to Alternative 2/Preferred.

These volumes were expected to increase since each subsequent alternative added more capacity, which resulted in attracting more traffic to the study area.

Transit Operating Characteristics

Sixty-foot articulated buses were assumed to operate on 6-minute headways during 2020. The bus stop types included both in-lane stops and bus bays. The number of stops and types also varied by alternative as shown in Table 2.

Table 2. Bus Stop Types—Northbound

Bus Stop Type	Alternative			
	No Build	1	2[1]	Preferred
In-Lane	1	--	13	16
Bus Bay	11	11	--	--
Total	12	11	13	16

1. Buses stopped in the business access and transit (BAT) lane for Alternative 2 and the Preferred alternative.

Washington State Law requires motorists to yield to buses exiting a bus bay. Field observations and discussions with bus operators, however, revealed that motorists rarely abide by this law. Therefore, priority rules were coded in VISSIM that required the bus to wait for a gap in curb lane traffic before exiting the bus bay.

Signal Timing

Optimization Process

Traffic volumes and geometry corresponding to each alternative were entered into the signal optimization program, PASSER II, and then optimized. The resulting signal timings were then entered in VISSIM.

Signal Controller Type

For this study, the PEEK LMD9200 firmware running on a NEMA signal controller was emulated in VISSIM at each signalized intersection. Emulating the firmware provided a more accurate assessment of transit and traffic operations since it captured how the controller actually responds to traffic without making assumptions that could dramatically skew the analysis results. This feature is especially important when transit signal priority (TSP) is involved. How TSP is implemented is dependent on the logic coded in the firmware. Therefore, for an accurate assessment of TSP, it is important to emulate the firmware in the simulation model. TSP was provided at each signalized intersection along Aurora in each alternative.

At the time of this study, it is important to note that the Econolite firmware was operating the signals within the study area. Funding to incorporate this firmware into VISSIM is provided through an entirely separate project. Since funding was not released at the time of this study, it was decided to use the PEEK LMD9200 controller since it was readily available. Although some differences exist between the controllers in regard to TSP, it was not viewed as a critical issue since comparisons were made based on the differences between the alternatives which all had TSP.

Transit Signal Priority Logic

TSP is provided to both northbound and southbound Aurora. The TSP logic emulated in VISSIM for the PEEK LMD9200 firmware used a green extension/red truncation strategy. Green extension provides added green time if a TSP service call is requested from an approach currently being serviced. Red truncation, sometimes called early return to green, applies when a TSP service call is requested during that approach's red phase. Once requested, the other approaches receive reduced green splits to accelerate the return to the approach where the requested TSP service call is active. The TSP strategy maintains pedestrian and vehicle clearances and does not permit skipping signal phases.

After a TSP event, it is important to know how the signal controller begins to transition back to its normal timings. Short Way Offset Seeking is one of the common and more efficient methods that several signal controller software packages, including PEEK, use to transition between timing plans whether for TSP events, preemption, or time-of-day plan changes. As the timing plan changes, the controller software recognizes that the local timings are not in sync with the system master clock. Using the offset, the software determines how far local zero is out of sync with the master zero. Knowing this time, the software determines whether it is quicker to add or remove time from the local cycle (i.e., splits) to get back in sync. If adding time is necessary, one second is added for every five seconds of cycle time until synchronization is achieved. If subtracting time is necessary, every 5^{th} second is removed until synchronization is achieved. Through a regional TSP demonstration project, the City of Shoreline and King County, who maintains the signal timings along Aurora, agreed that TSP cannot reduce green time for all other movements by more than 20 percent of the cycle length. Therefore, with Short Way Offset Seeking, the maximum time that the local controller could be out of sync is 20 percent of the cycle length. Since recovery occurs at a rate of 20 percent per cycle (1 second/5 seconds), the longest it would take to recover is one cycle.

STUDY APPROACH

Analysis Methodology

Simulating traffic and transit operations was performed with VISSIM, a microscopic simulation model developed to simulate urban traffic and public transit operations. The program can analyze transit signal priority strategies, transit schedules and stops, various traffic compositions, and unlimited roadway and intersection geometries. VISSIM's analytical capabilities make it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness.

Ten model runs were performed for each alternative with different random seeds to capture randomness in traffic volumes, transit dwell times, and transit schedule adherence. MOEs resulting from these 10 runs were averaged to derive mean operating characteristics.

Although several transit, traffic, and system MOEs were reported for this study, the focus of this paper is evaluating transit preferential treatments. Therefore, the following transit MOEs are presented for the peak (northbound) direction:

- average travel speed
- schedule reliability
- transit capacity

Average transit travel speed (miles/hour) was determined by averaging the travel times for each bus that traversed the entire study area and then dividing by the distance over which travel times were measured.

Transit schedule reliability was indirectly measured by computing the standard deviation in bus travel times. Every bus' travel time was recorded during each simulation run. These travel times were combined for the 10 simulation runs and then the standard deviation was computed. The standard deviation was described as a measure of schedule reliability to the Shoreline City Council. Schedule reliability is expected to improve if the variation in travel times, as measured by the standard deviation, decreases.

Completed bus trips was an indirect indicator of transit capacity provided by each alternative. Since the bus headway did not change, the greater the number of buses completing their trip represented greater capacity.

The VISSIM Model

VISSIM is a microscopic, time step and behavior based simulation model developed to analyze the full range of functionally classified roadways and public transportation systems. VISSIM can model integrated roadway networks found in a typical corridor as well as various modes consisting of general purpose traffic, buses, HOV, light rail, heavy rail, trucks, pedestrians, and bicyclists. The model was developed at the University of Karlsruhe, Germany during the early 1970s. Commercial distribution of VISSIM began in 1993 by PTV Transworld AG, who continues to distribute and maintain VISSIM today. VISSIM version 2.91 was used in this study.

The model consists of two primary components: (1) simulator and (2) signal state generator (SSG). The simulator generates traffic and is where the user graphically builds the network. The user begins by importing an aerial photo or schematic drawing of the study area into the simulator. Next, the user begins "drawing" the network and applying attributes (e.g., lane widths, speed zones, priority rules, etc.). Although links are used in the simulator, VISSIM does not have a traditional node structure. The lack of nodes provides the user with the flexibility to control traffic operations (e.g., yield conditions) and vehicle paths within an intersection or interchange.

The SSG is separate from the simulator. It is where the signal control logic resides. Here, the user has the ability to define the signal control logic and thus emulate any type of control logic found in a signal controller manufacturer's firmware. The SSG permits the user to analyze the impacts of signal operations including, but not limited to: fixed time, actuated, adaptive, transit signal priority, and ramp metering. It is important to note that fixed time control can be implemented in the simulator. The SSG reads detector information from the simulator every time step. Based on the detector information, the SSG decides the status of the signal display during the subsequent time step.

VISSIM provides a variety of user definable MOEs. These MOEs include: system, intersection, and person delay, travel times, stops, queue lengths, and emissions.

RESULTS

Quantitative analysis results are first presented followed by more qualitative results. The quantitative results focus on analyzing transit operations based on: (1) travel speed, (2) schedule reliability, and (3) transit capacity. Again, the results are presented for the peak (northbound) direction. The qualitative results discuss the success of using simulation in Shoreline (1) to communicate design alternatives to decision makers and public audiences and (2) to support the decision making process.

Transit Operations

Travel Speed

Average transit travel speeds increased with the degree of transit preferential treatment offered by each alternative (refer to Figure 2). When compared to the No Build alternative, transit queue by-pass lanes increased transit speeds by 4.3 mph (55 percent). As expected, a substantially greater benefit was observed with the transit only lanes where the speed more than doubled with an increase of 9.0 mph (115 percent). This 9.0 mph increase was even more significant after realizing this alternative added two additional bus stops.

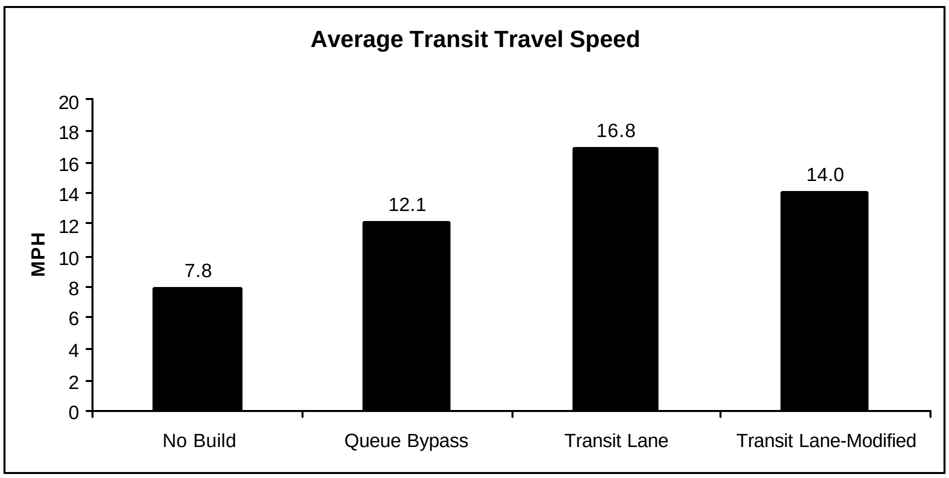
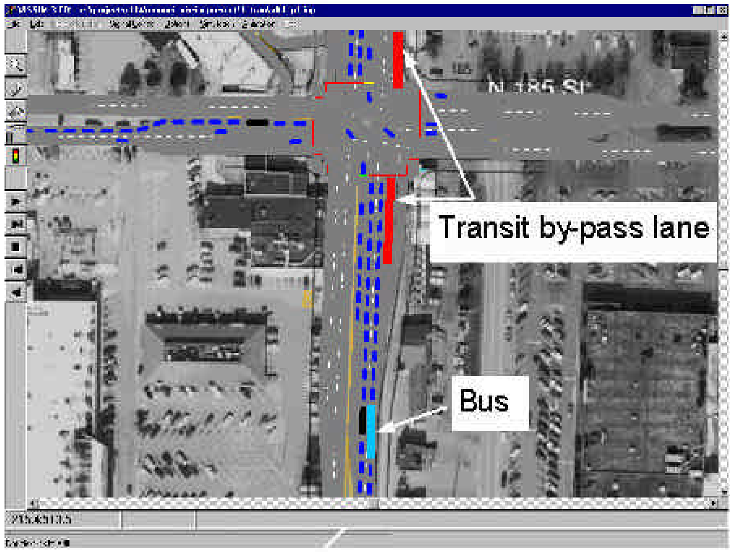


Figure 2. Average Transit Travel Speed

The Transit Lane-Modified demonstrated a speed reduction, 2.8 mph (17 percent), when compared to the Transit Lane. The reason for the speed reduction is due to the eight signals added to the Transit Lane-Modified alternative. These signals resulted in additional delay to the buses, thus reducing their average travel speed.

A side-by-side, full motion comparison of the simulations was performed during a Shoreline City Council meeting to illustrate the benefits of the transit only lane compared to the transit queue by-pass lanes. The simulations demonstrated how critical the length of the queue by-pass lanes was. If they were too short, a through queue, as shown in Figure 3 (top), could block a bus from accessing the by-pass lane. Here, the bus unfortunately did not receive any benefit from the lane. On the other hand, the transit only lane illustrated the benefit to transit as the bus passed the through queue unimpeded (Figure 3, bottom).



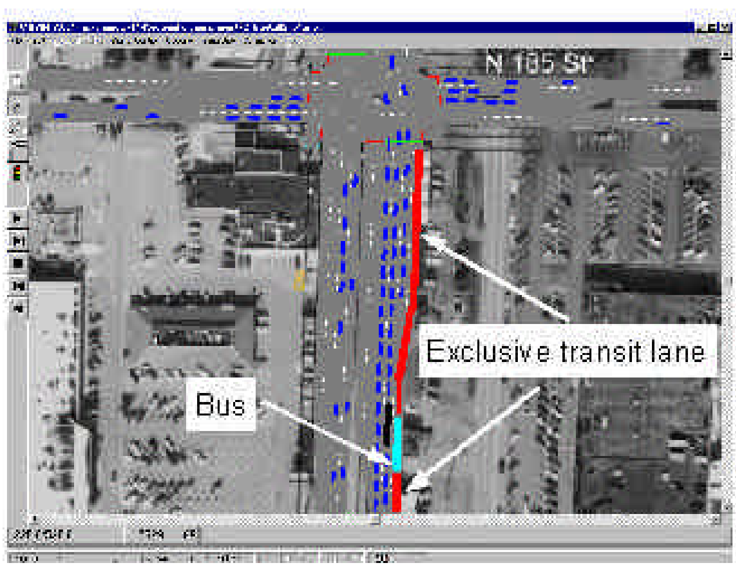


Figure 3. Transit Queue By-Pass Lane vs. Exclusive Transit Lane

Schedule Reliability

Schedule reliability (i.e., on-time performance) is a key measure that transit agencies use to assess route performance. Based on passenger feedback, several transit agencies have found that improving schedule reliability is viewed as a greater benefit than reducing travel times.

The schedule reliability results (Figure 4) were similar to the travel speed results; the greater the degree of transit preferential treatment, the greater the improvement in schedule reliability. Schedule reliability improved nearly 75 percent when comparing the queue by-pass lanes to the No Build alternative. This improvement was due to: (1) less congestion on Aurora due to the capacity improvements and (2) relocating two (175th and 185th) bus stops to the far side of the intersection. The far side stops provided more gaps for the buses to merge back into the through lane than the near side stops did. Exiting the near side stops was hindered by the queues building at downstream signals. The transit lane improved schedule reliability by almost 90 percent when compared to the No Build. The transit lane eliminates delays due to (1) buses "trapped" in bus bays and (2) general purpose traffic congestion. Again, the slight increase in schedule reliability shown by the Transit Lane-Modified alternative is likely due to the increased number of signals. The additional signals were added at intersections with relatively low cross-street volume; none totaling more than 200 vehicles/hour. Therefore, the chance of being stopped at one of these signals was low. It was the rare occasions when a bus had to stop, that was believed to result in the slight degradation in schedule reliability.

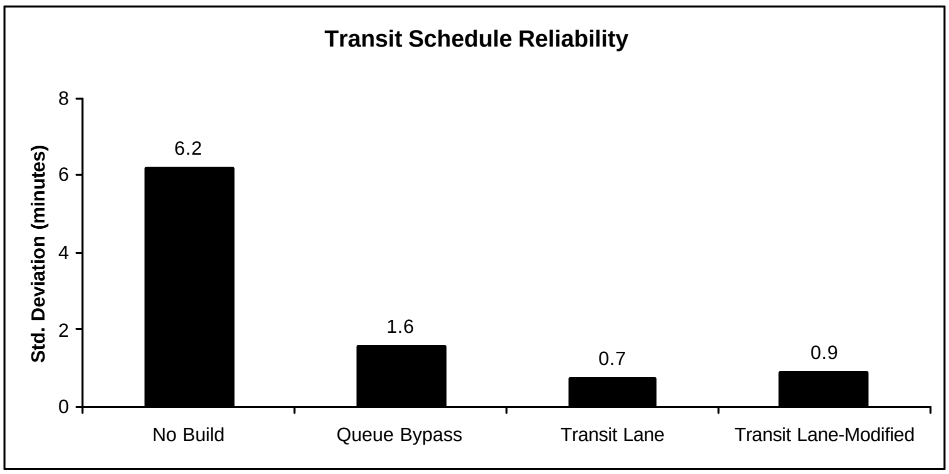


Figure 4. Transit Schedule Reliability

Transit Capacity

The number of buses making a complete trip through the study area was averaged over the 10 simulation runs. Completed bus trips were used as an indirect measure of transit capacity provided by each alternative. The results are illustrated in Figure 5. As seen previously, the Transit Lane alternative produced the best performance. The congestion observed in the No Build had a dramatic impact on transit capacity. The queue by-pass lanes increased transit capacity by more than 250 percent when compared to the No Build. Again, the capacity improvements along Aurora and the queue by-pass lane configurations were responsible for this improvement. The transit only lane increased transit capacity by more than 370 percent when compared to the No Build. The slight reduction (three buses over 10 hours) in capacity for the Transit Lane-Modified alternative was expected to be attributed to the increased number of signals. The location of these three buses when the simulation ended was not investigated. It is possible that they could have almost completed their trip when the simulation ended.

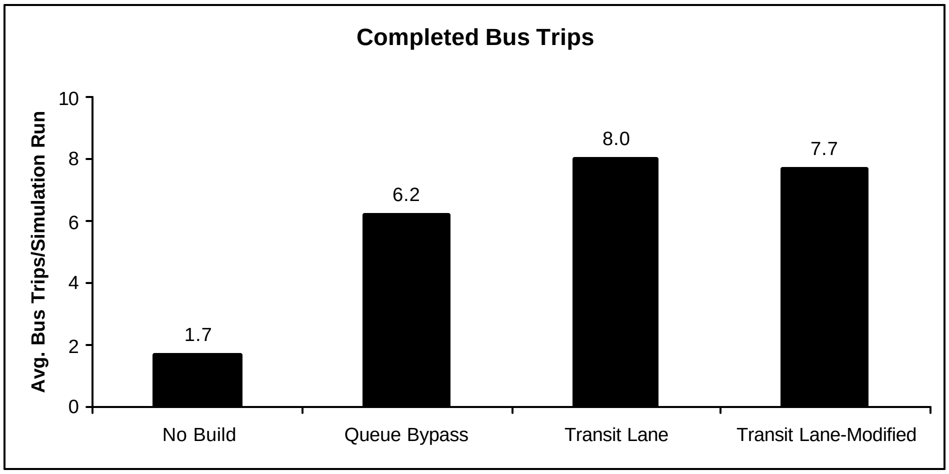


Figure 5. Transit Capacity

Simulation and the Decision Making Process

The controversial nature of this project created a need to provide information to the public and decision-makers that would enable them to reach a consensus recommendation on a preferred alternative. Evaluation of relative performance of transit options is particularly challenging because of the diverse opinions regarding the value and benefits of transit investments. Also, when the decisions are being made with extensive public participation, the technical information should to be presented in simple terms that can be understood by non-technical people.

Therefore, the VISSIM simulation software was chosen as the most appropriate tool for traffic and transit operations comparisons. This software provided several advantages for this project. It enabled the project team to include an aerial base map along the corridor which provided study participants with many reference points to landmarks in their community. The various design alternatives could be "painted" into the operations demonstrations in an efficient way, giving the participants an easier understanding of the designs during demonstrations. Dynamic demonstrations of the simulations allowed the project team to illustrate the logic of the data results by showing examples of why they performed as they did. An example is showing why a near-side bus pullout causes transit schedule reliability problems. Just listing corridor wide data that includes a higher travel time or higher travel time standard deviation would not by itself be sufficient to make a decision regarding in-lane stops versus pullouts. However, that data along with example clips of simulations that illustrate where and how the delays occur, provided the information that was desired for decision making.

The visual demonstrations were used several times during the study process. First during early project open houses, VISSIM demonstrations were used to show future No build conditions versus Existing Conditions to give the public and decision makers a perspective on the extent of the future problem. Then when results of traffic operations and transit operations comparisons were presented, a combination of data results and demonstration clips were used. At final City Council hearings on the comparisons between alternatives, several brief comparisons were made. For each case, the project team first described the measure being compared (e.g. transit schedule reliability), the importance of the measure and how it was measured. Then a simple data comparison summary was presented and an explanation of the significance of the findings was provided. Last, one or two short VISSIM demonstration clips were presented live on screen using a projector. These were shown with alternatives projected side-by-side, so that viewers could see the contrast. Each clip was prepared so that the example could be shown in less than one minute each. As the clips were shown, the computer cursor pointer was used to point out aspects of the simulation that were relevant to the discussion.

CONCLUSIONS

The primary findings that emerged from evaluating transit preferential treatments as part of the Aurora Avenue North Multimodal Corridor Study included:

1. Transit only lanes provided the greatest transit benefit by removing buses from the congestion in the general purpose travel lanes.
   - transit travel speeds (115 percent improvement compared to No Build)
   - transit schedule reliability (90 percent improvement compared to No Build)
   - transit capacity (370 percent improvement compared to No Build)
2. Transit queue by-pass lanes also produced substantial transit benefits. The length of the through queue at a signalized intersection influenced the effectiveness of these lanes. Traffic volumes and signal timing need to be considered when designing the length of these lanes.
   - transit travel speeds (55 percent improvement compared to No Build)
   - transit schedule reliability (75 percent improvement compared to No Build)
   - transit capacity (250 percent improvement compared to No Build)
3. Using far side stops in conjunction with queue by-pass lanes appeared to reduce the delay associated with buses being "trapped" in the near side bus bay due to a queue at a downstream signal.
4. The VISSIM simulation model was an effective tool for illustrating the benefits and impacts of the various transit and roadway design alternatives to the Shoreline City Council and during Open House events with the community. It supported the decision making process and ultimately lead to the approval of the preferred alternative.

RECOMMENDATIONS

Simulation proved to be a valuable tool not only for its ability to analyze complex multimodal alternatives, but also for communicating the benefits and impacts of these alternatives to the public and decision makers. Therefore, based on the experience gained from the Aurora Avenue North Multimodal Corridor Study, the following recommendations/suggestions address when to use simulation:

- when traditional isolated intersection analysis tools do not adequately capture the system/multimodal impacts of the proposed alternatives and
- when the transit and traffic operations resulting from complex or new designs need to be clearly conveyed to the public and decision makers.