

Light Rail Transit Signal Priority in a Downtown Environment

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1. SUMMARY

The Westside Light Rail Transit (LRT) extension is an important link in the future transportation network for the Portland metropolitan area. The extension runs from downtown Portland west to downtown Hillsboro where it terminates. The LRT alignment through downtown Hillsboro is located in the center of Washington Street and passes through 10 closely spaced signalized intersections and two gate crossings. The study area is shown in Figure 1 (all figures are at the back of the paper). Developing a LRT operational strategy within a downtown environment presented a number of issues that were addressed through simulation.

This paper documents the application of VISSIM, a microscopic simulation model, to analyze the impacts of full LRT signal priority in downtown Hillsboro, Oregon. Emphasis is placed on the issues raised by the road and transit agencies regarding LRT operation and how these issues were addressed through simulation. The referenced work was performed prior to the opening of the LRT extension during the Fall of 1998.

The simulation analysis lead to the following conclusions: (1) full LRT signal priority is possible under current LRT headways and traffic volumes; (2) back-to-back train arrivals compounded queue spillbacks at downstream signalized intersections which actually lead to increased LRT delay; (3) LRT typically produced a slight increase in average intersection delay; and (4) the low volume of mid-block left turns and opposing throughs did not affect LRT operations.

The primary recommendation to emerge from the simulation analysis was to implement full LRT signal priority on opening day realizing that future traffic growth will likely require modifications to the priority strategy. The development of Intergovernmental Agreements among road and transit agencies was also recommended to establish a collaborative process to resolve issues that arise in the future regarding the operation of LRT in Hillsboro.

Whereas the experiences gained through this analysis are in some ways unique to Hillsboro, Oregon, these experiences can provide insight to other transportation professionals developing LRT signal priority strategies within a downtown environment.

2. PROJECT BACKGROUND

The City of Hillsboro, Oregon and Washington County, Oregon have expressed concern about the impact that a previously defined LRT preemption strategy will have on both traffic and transit. In addition, concern has been expressed about the operational impact of mid-block left turns across the LRT tracks.

This study evaluates the opening day LRT schedule under year 2000 traffic volumes through downtown Hillsboro. The study specifically addresses the following questions:

1. How does LRT affect delays and queue lengths along 1st, 6th, and 10th Avenues?
2. Is it feasible to implement LRT preemption across (a) 1st Avenue and (b) 10th Avenue?
3. Do mid-block left turns across the LRT tracks on Washington Street affect LRT operations?
4. How often and for what duration do queues originating on 10th Avenue at Washington Street back into adjacent intersections with LRT implementation?

3. STUDY APPROACH

The approach to conducting this study involves two primary phases. Developing the simulation models occurs in the first phase. Analyzing the LRT and traffic operations occurs in the second Phase.

Simulation Model Development

Simulating traffic and LRT operations is 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.

VISSIM simulation models were developed using year 2000 traffic and opening day train schedules. Washington Street driveway counts were collected by Traffic Smithy and were included in the model. Tri-Met provided a half- and full-train schedule. A half-train schedule was supplied as an alternative to mitigate potentially unacceptable delays that may occur with the full-train schedule. Preliminary results revealed that the full- and half-train schedules produced no noticeable change in intersection delay. Therefore, only the full-train schedule was considered in the final analysis. Final model runs were completed for the following scenarios:

- A.M.-peak hour, no trains
- A.M.-peak hour, full-train schedule
- P.M.-peak period, no trains
- P.M.-peak period, full-train schedule

Ten model runs were performed with different random seeds to capture randomness in traffic volumes, transit dwell times, and transit schedule adherence from the east. Measures of effectiveness (MOEs) resulting from these 10 runs were averaged to derive mean operating characteristics.

Traffic volumes are used to identify peak hours. The A.M.-peak hour occurs from 7:30 a.m. to 8:30 a.m. and P.M.-peak hour from 4:25 P.M. to 5:25 p.m. Since the P.M.-peak hour for train operations does not coincide with the highest traffic volume hour, the P.M. simulation model is expanded to two hours (4:25 p.m. to 6:25 p.m.) to capture the period with higher train frequencies that begins near 5:45 p.m.

LRT and Traffic Operations Analysis

Both LRT and traffic operations are analyzed. The reasons for analyzing the following LRT and traffic operation characteristics are explained in more detail in Section 5, Results.

LRT

- Frequency of back-to-back train events (opposing trains approaching 10th Avenue within 18 to 240 seconds of one another) at 10th Avenue
- Frequency of static calls at 10th Avenue
- Frequency of LRT stops due to mid-block left turn vehicles stopped on tracks

Surface Street Traffic

- Average intersection stopped delay
- Queue lengths
- Duration of queue spillbacks on 10th Avenue at Washington Street

4. NETWORK CHARACTERISTICS AND MODEL ASSUMPTIONS

Study Area

The study area contains the 22 intersections listed below. The LRT tracks are located in the median of Washington Street. Driveways along Washington Street are also included in the models.

Four LRT stations exist within the study area. Two additional dummy stations are modeled in the westbound direction east of the 12th Avenue Station. The dummy stations were added to more accurately simulate the randomness (Note: Combined effect of dummy station dwell times/randomness: 46 percent dwell for less than 5 minutes and 40 seconds, 90 percent for less than 9 minutes and 50 seconds, and 99 percent less than 14 minutes) of trains approaching from the east, i.e., downtown Portland.

Washington St.	1 st Ave.	10 th Ave.	Main St.
Gate Crossing*	Main St.	Main St.	12 th Ave.
1 st	Parking Garage*	Baseline St.	6 th Ave.
2 nd	Baseline St.	Oak St.	
3 rd	Oak St.	Walnut St.	
4 th		Maple St.	
5 th			
6 th			
7 th			
8 th			
9 th			
10 th			
12 th * (w/gate)			

Note: All unsignalized intersections are denoted by an “*”.

Surface street traffic is assigned speeds distributed about the following average speeds: Washington Street—25 mph, 1st Avenue—25 mph, and 10th Avenue—30 mph. LRVs are also assigned speeds that are distributed around a 25 mph average speed except in the crossover section east of the Government Center Station where average speeds are eight miles per hour. The deviation in LRT speed distributions is coded to be much smaller than traffic.

Traffic Volumes, LRT Schedule, and Traffic Signal Control

The study analyzes traffic operations for the forecast year 2000. Traffic peaking characteristics on 1st Avenue are critical. Therefore, traffic volumes entering the study area at intersections along 1st Avenue are entered in 15-minute intervals to more accurately capture peaking conditions. Driveway counts were conducted during the spring of 1998. Driveway volumes are assumed constant for the two years from 1998 to 2000.

The projected LRT schedules are supplied by Tri-Met for “day-of-opening”. Schedules reflect 6 to 12 minute headways during the A.M.-peak hour and 6 to 10 minute headways during the P.M.-peak period.

All signals within the study area are Type 170. Signals along Washington Street operate with either two, three, or four signal phases. Signal timing plans were developed in TRANSYT-7F. All intersections operate in coordinated, actuated mode, except for 1st and Main and 6th and Main which operate fully actuated.

LRT Signal Control

The LRT preemption strategy proposed for Hillsboro, and modeled in VISSIM, provides full LRT preemption with additional features to more efficiently accommodate surface street traffic. Basically, the LRT preemption strategy permits eastbound and westbound LRT phases to occur concurrently with eastbound and westbound

pedestrian phases. All other signal phases are prohibited during the LRT phase except at 10th Street, where eastbound throughs are serviced concurrently.

Wapiti W4IKS-LRT ver. 41 is the signal control software running the controllers along Washington Street. The proposed LRT preemption logic, as described below, is incorporated into this software.

In order to more thoroughly explain the LRT preemption strategy, the following discussion is separated into the three primary preemption stages: (1) LRV (light rail vehicle) Approach, (2) LRV Entry, and (3) LRV Departure.

LRV Approach

A number of events occur prior to a LRV entering a signalized intersection. First, the LRV must be detected (i.e., check-in). LRV detection occurs through VETAG loops located at fixed points along the tracks. Due to close intersection spacing through downtown, one check-in loop serves to place a call to multiple downstream controllers (i.e., call cascading). For example, as a westbound LRV departs the 12th Avenue Station, calls are cascaded to controllers at 10th, 9th, and 8th Avenues (refer to Figure 2). The call is what informs the controller to interrupt normal signal operations and begin clearing the intersection for LRV entry. As implemented in the field, the VISSIM model cascades calls to all downstream, signalized intersections between two stations.

Once a LRV is detected and prior to actually sending a call to the controller, a delay timer starts. The delay timer causes the call to be “delayed” before the controller receives it. In some cases the delay timer may be set to zero meaning the controller receives the call immediately after the train is detected. The delay timer allows the signal to continue operating normally until it must begin clearing the intersection to allow the LRV to enter. Delay timers are shown in Figure 2.

After a controller receives a call, a time-to-green (TTG) timer starts (refer to Figure 2). The TTG timer ensures that any active pedestrian and vehicle phase is serviced without violating minimum times (e.g., pedestrian clearance interval and minimum vehicular green) and FLASHING DON'T WALK starts immediately. When the TTG timer times out, the LRT signal must exhibit a vertical white bar indicating the LRV can enter the intersection. The TTG time is equal to the sum of two components: (1) the longest pedestrian clearance time or minimum vehicular green whichever is longer and (2) the subsequent vehicle change interval (i.e., amber and red clearance time). Cross streets along Washington Street exhibit the longest pedestrian clearance times and are therefore used to compute the TTG times.

A few other actions occur after a controller receives a call. These actions include: (1) inhibiting pedestrian calls, (2) truncating all “WALK” times, and (3) starting the FLASHING DON'T WALK signal.

In summary, the following process occurs prior to a LRV entering a signalized intersection: (1) detect LRV, (2) start delay timer, (3) send call to controller (after delay timer times out), (4) start TTG timer, (5) truncate “WALK” signal, (6) inhibit pedestrian

calls, and (7) display “GO” signal for LRV to enter intersection. Current vehicle phases rest in green until the end of TTG ignoring any force-offs or the yield point.

LRV Entry

At this point in the preemption process, the LRV can now enter the intersection. Eastbound and westbound LRT phases occur concurrently with eastbound and westbound pedestrians. All other signal phases are prohibited during the LRT phase except at 10th Street, where eastbound throughs are serviced concurrently.

Related to LRV entry is the prohibition of right turns on red onto Washington Street at all times. This restriction is invoked to improve safety. One scenario that creates a safety concern occurs when a vehicle makes a right turn onto Washington Street as a LRV approaches from the driver’s left side. If the driver of the vehicle then wants to make a mid-block left turn across the tracks and starts this maneuver without looking over his shoulder, the driver may not see the LRV and turn into its path thus causing a collision. Another concern arises when drivers making a right turn have their view of an approaching LRV obstructed by a truck or other large vehicle on the conflicting approach to their left. The driver, not seeing the LRV, may make the right turn wide and possibly collide with the LRV.

LRV Departure

The next step in the LRT preemption strategy is to return the signal to coordination. This process starts with a checkout loop. When the rear of the LRV passes over the checkout loop, a call is sent to the controller indicating that the LRV has exited the intersection and can begin the process to return to coordination. Checkout loops, for the most part, are located immediately upstream of the intersection.

Once checkout or “max out” occurs, recovery begins with the controller servicing a specified return phase. The return phase is always the coordinated phase. Along Washington Street, however, the coordinated phase varies from intersection to intersection. In this study, the return phase is eastbound and westbound Washington Street at the following intersections: 2nd, 3rd, 4th, 5th, 7th, 8th, and 9th. The return phase at the remaining intersections, 1st, 6th, and 10th, services northbound and southbound movements.

A dwell timer is used to hold the controller in the return phase for a minimum amount of time. After the dwell timer times out, the controller remains in the return phase until it reaches either (1) the yield point or (2) dwell point. If the controller reaches the yield point first, recovery is completed and the controller is back in coordination. On the other hand, if the dwell point is reached first, the controller then serves all non-coordinated phases (if calls exist) to their forceoff (as long as the phase does not gap out) and the coordinated movement minimum green time. After serving the coordinated phase for the minimum green time, the controller rests in the coordinated phase until it reaches the yield point. The location of the dwell point in the

cycle is strategically placed so the maximum time to return to coordination does not exceed the cycle length plus the dwell timer time.

At this point, it seems prudent to briefly discuss the logic behind the placement of the dwell point within the cycle. To illustrate this logic, the intersection of 7th Avenue and Washington Street during the P.M.-peak hour is used as an example. Normal signal operation is depicted in Figure 3. Basic signal operation involves two phases with the northbound (phase 8) and southbound (phase 4) phases occurring concurrently. Phase 2 is the eastbound phase. Westbound vehicular movements are not permitted. Figure 3 illustrates points within the cycle where if checkout occurs either the yield point or dwell point will be reached first. If LRV checkout occurs in the shaded area, the signal reaches the yield point first. If LRV checkout occurs at any other point in the cycle, the dwell point is reached first. The controller then services the non-coordinated movements and the coordinated movement's minimum green time. The dwell point location allows enough time to service the non-coordinated movements to their forceoff (if needed) and the coordinated minimum green before reaching the yield point. The key is to allow enough time to service these movements before reaching the yield point. Therefore, the controller always reaches the yield point after reaching the dwell point once.

Static Calls

On occasion, a LRV may be delayed in reaching a signalized intersection due to a mid-block left turn vehicle stopped on the tracks or it may be blocked from entering the intersection due to queue spillback from an adjacent intersection across the LRT tracks (e.g., northbound queue spillback at 10th Avenue from Main Street). If the LRV is sufficiently delayed, it will miss its signal phase because it reaches its maximum time. (LRT maximum phase times are set to 30 seconds at all intersections except 1st Avenue. At 1st Avenue, the maximum time is 35 seconds in the westbound direction to accommodate the slower approach speeds required through the crossover section.) In order to recall the LRT phase, the LRV has to pull over the near side VETAG loop at the intersection to place a static call. Static calls ignore delay timers and immediately start the TTG timer. Because of call cascading, the LRV has to place static calls at every intersection between the first static call and the next downstream station.

Mid-Block Left Turns

Priority rules are coded in VISSIM to accurately model mid-block left turn movements across the LRT tracks. The general approach is to give the right-of-way to the first arriving vehicle thus causing the second vehicle to yield. To model this approach, priority rules are coded in VISSIM for vehicles entering and exiting driveways and for LRVs. Priority rules provide flexibility in assigning minimum gap acceptance times. A typical application of driveway priority rules is shown in Figure 8.

Description of Simulation Tool—VISSIM

VISSIM is a microscopic simulation model developed to model urban traffic and public transit operations. The program can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stops, etc., thus making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness.

VISSIM's traffic flow model is a discrete, stochastic, time step based microscopic model, with driver-vehicle-units (DVU) as single entities. The model contains a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements (lane changing). The model is based on the on-going work of Wiedemann (1974, 1991) at the University of Karlsruhe, Germany.

Vehicles follow each other in an oscillating process. A faster vehicle approaching a slower moving vehicle on a single lane has to decelerate. The action point of conscious reaction depends on the speed differential, distance and driver dependent behavior. On multi-lane links, vehicles check whether they can improve their operation by changing lanes. If so, they check the possibility of finding acceptable gaps on neighboring lanes. Car following and lane changing together form the traffic flow model, being the kernel of VISSIM.

The simulation system itself includes first the traffic flow model and secondly the signal control model. The traffic flow model is the master program which sends second-by-second detector values to the signal control program (slave). The signal control uses the detector values to decide on the current signal state. Signal control itself can be performed by actual controller software, an external controller (e.g. interface to NEMA or Type 170 controller) or the programmable signal control software VAP (Vehicle Actuated Phasing). VAP is used to model the signal control logic in this study.

The basic elements of a modeled network are single or multilane links and connectors. A connector primarily serves to "connect" links and can be placed at any position on a link. Connectors are also used to model lane utilization by placing connectors on a specific link lane and then routing a predetermined portion of the approach traffic over that connector. Routing decision points are placed throughout the model to route traffic through single or multiple intersections.

Signal control is modeled by placing the signal heads at the stop lines. Detectors collect traffic flow data for the signal control (i.e. presence, gap, occupancy, etc.) and for microscopic and macroscopic measurements (i.e. speeds, volumes, travel times, etc.). The desired speed in urban areas is not derived directly from the technical data of a car but rather from the geometrical layout of the street and its intersections.

A transit route is defined in VISSIM as a sequence of stops along routes using specific transit lanes (i.e. tracks) if existing. Transit stops are either on the link or adjacent to it in case of a bus pullout. Transit vehicles enter the network according to their scheduled arrival time. Modeling of random "lateness" is accomplished by placing

transit stops (dummy stations) at the entrance to the network. Train schedules used reflect Tri-Met's planned "day-of-opening" schedule.

Traffic volumes are entered in VISSIM for 1-hour intervals for the A.M.-peak hour and 2-hour intervals in the P.M.-peak hour. Entering traffic along 1st Avenue, however, is entered in 15-minute intervals to more accurately capture the peaking characteristics of this roadway. For each time interval, whether it be 15 minutes or one hour, VISSIM assumes a POISSON arrival distribution.

5. RESULTS

A general overview of transit and traffic operations results is first presented followed by a more detailed analysis that addresses the specific questions presented in the Introduction. The general overview addresses average intersection delay and queue lengths at critical intersections identified by the City of Hillsboro, Tri-Met, Washington County, and ODOT and the associated impact on LRT operations. For the most part, these intersections exhibit higher traffic volume relative to the other study area intersections and either intersect or are within one block of the LRT line. The evaluation results are presented in the following order:

- Average intersection delay
- Queue lengths
- Ability to implement LRT preemption at 1st and 10th Avenues
- Operational impacts of mid-block left turns
- Queue spillback on Washington Street at 10th Avenue

Average Intersection Delay

Table 1 presents the average intersection stopped delay results at the critical intersections for the "with LRT" and "without LRT" scenarios during both peak hours. In general, LRT operations cause a slight increase in average intersection delay that ranges from 0.0 seconds to 5.0 seconds per vehicle. All intersections continue to operate at an acceptable LOS (LOS B to LOS C) with LRT operational during both peak hours, except the intersection of 10th Avenue and Main Street. This intersection operates at LOS E during both peak hours with and without LRT (note: A.M.-peak hour conditions without LRT were borderline LOS D/E with a delay equal to 40.0 seconds/vehicle). Due to the intersection's proximity to the LRT line, LOS E could result in northbound queues forming across the LRT tracks. Queue lengths are discussed in the next section.

Table 1. Average Intersection Stopped Delay¹

Intersection	A.M.-Peak Period				P.M.-Peak Period			
	Delay			w/LRT LOS	Delay			w/LRT LOS
	w/o LRT	w/LRT	Δ^2		w/o LRT	w/LRT	Δ^2	
First								
Main	10.4	11.2	0.8	B	18.3	20.8	2.5	C
Washington	8.6	8.6	0.0	B	13.4	18.4	5.0	C
Baseline	8.8	9.1	0.3	B	10.8	10.8	0.0	B
Oak	7.8	7.8	0.0	B	8.3	8.8	0.5	B
Total	8.8	9.7	0.9	B	12.2	13.7	1.5	B
Tenth								
Main	40.0	43.9	3.9	E	53.2	46.2	-7.0	E
Washington	12.6	16.8	4.2	C	22.9	22.0	-0.9	C
Baseline	12.5	12.6	0.1	B	16.6	17.7	1.1	C
Oak	5.8	5.8	0.0	B	9.4	9.9	0.5	B
Total	17.8	19.4	1.6	C	25.0	23.5	-1.5	C

1. Delay reported in seconds/vehicle.

2. Delta represents the delay change relative to the without LRT scenario.

Before leaving the delay discussion, it is important to explain the delay reduction during the P.M.-peak period at the intersection of 10th Avenue and Main Street that results from implementing LRT. This reduction is explained by observations of LRT and traffic operations in VISSIM. As a LRV passes through the 10th Avenue and Washington Street intersection, the northbound platoon is frequently truncated. Truncating the platoon typically results in the downstream left turn phase at Main Street not being actuated since left turn vehicles do not arrive until the next phase. Since the low volume (four vehicles/cycle on average), non-critical northbound left turn phase is not serviced, additional green time (approximately 11 seconds) is available for the more critical southbound through movement. The southbound through delay savings (approximately seven seconds/vehicle) results in the intersection delay reduction.

Queue Lengths

Table 2 reports queue lengths for 11 key locations. These locations are the most likely locations where either the formation of traffic queues could hinder LRT operations or where LRT operations could cause queue spillbacks into upstream intersections.

Maximum queue lengths are chosen to evaluate queue lengths since they represent the worst case scenario. It is important to note that maximum queue length is an average of the maximum queue lengths recorded over all 10 simulation runs.

Queue lengths increase at all study locations after LRT is operational. While the average maximum queues on 1st and 6th Avenues do not exceed storage capacity, a few individual runs reported maximum queues that do exceed the available storage after LRT implementation. This finding indicates that queues will periodically exceed available storage on opening day. Average maximum queues do exceed storage capacity along 10th Avenue.

LRT operations result in average maximum queue lengths that exceed storage capacity in only one location that did not experience this condition prior to LRT implementation: southbound 10th Avenue at Washington Street during the P.M.-peak period. Although this condition is undesirable, the maximum queue length exceeds storage capacity by slightly less than four car lengths (assuming 25 foot car lengths).

In regard to queues forming across the tracks, the results indicate that 10th Avenue traffic backs across the tracks in the northbound direction during both peak periods and in the southbound direction during the P.M.-peak period. Depending on the timing of the queues, LRVs may incur additional delay as they wait for traffic to clear the intersection. As observed in VISSIM, if the end of the queue blocks the tracks for only a short duration and the LRV "GO" signal is still displayed, the LRV reduces speed, waits for traffic to clear the tracks, and then proceeds through the intersection. If the queue duration is longer, the LRT "GO" signal reaches its maximum time and the LRV has to stop and place a static call. This condition substantially increases delay for westbound LRVs since they must now place a static call at each intersection (10th, 9th, and 8th Avenue) until reaching the Tuality Station.

Table 2. Maximum Queue Lengths¹

Intersection	Direction of Travel	A.M.-Peak Period			P.M.-Peak Period		
		w/o LRT	w/LRT	Capacity ²	w/o LRT	w/LRT	Capacity ²
First							
Main	NB	195	225	400	220	238	400
Washington	NB	109	185	385	107	184	385
Washington	SB	214	298	400	237	400	400
Baseline	SB	232	258	385	227	275	385
Sixth							
Main	NB	173	194	400	231	307	400
Washington	NB	112	113	400	193	265	400
Washington	SB	169	219	400	314	376	400
Tenth							
Main	NB	317	365	270	282	422	270
Washington	NB	144	329	400	178	363	400
Washington	SB	236	262	270	211	357	270
Baseline	SB	252	304	400	573	632	400

1. Queue lengths reported in feet.

2. Capacity measured from downstream stop line to upstream intersecting curb line.

Note: Outlined data indicates locations where the average maximum queue spillback exceeds storage capacity. Shaded data identifies locations where (1) at least one individual run produced a queue length that exceeds storage capacity and (2) the average maximum queue over all 10 runs was equal to or less than the storage length.

In summary, LRT implementation does not produce a substantial change in either delay or queue lengths when compared to the without LRT condition. The results, however, indicate that queue spillback from Main Street and Baseline Street on 10th Avenue can impact LRT operations during the peak periods.

Ability to Implement LRT Preemption at 1st and 10th Avenues

As stated in the Introduction, one of the primary questions to answer in this study is the following:

Is it feasible to implement LRT preemption across (a) 1st Avenue and (b) 10th Avenue?

All 1st Avenue intersections operate at an acceptable LOS during the A.M.-peak period (LOS B) and P.M.-peak period (LOS B to LOS C) after LRT implementation. Similarly, queue lengths do not exceed storage capacity at the locations studied along 1st Avenue. Therefore, based on these findings, it appears feasible to implement LRT preemption across 1st Avenue on opening day. The ability to maintain preemption in the future may be limited by traffic growth that will cause queues to back into adjacent intersections more frequently.

Tenth Avenue queues at Main Street and Baseline Street that back across the LRT tracks raise some concern about whether LRT preemption is feasible at 10th Avenue. Although the queue spillbacks occur across the tracks during normal signal operation, the magnitude of these queues, as observed in VISSIM, increases when back-to-back trains arrive at 10th Avenue. This observation was most evident in the northbound direction. As the first train arrives, the signal truncates the northbound progressed platoon. After the train passes, the truncated platoon now departs for Main Street with another platoon immediately behind it. The signal at Main Street, however, is red. At this point, another train approaches from the opposing direction and is blocked by the two northbound platoons departing Washington Street. The LRV then places a static call and has to wait for the next "GO" signal before passing through the intersection. One conclusion to be drawn from this observation is that the impact of the signal priority strategy has more of an impact on traffic operations during recovery (after the LRV departs the intersection) than it does when the strategy is first initiated (when the LRV approaches the intersection).

The scenario described above generates longer queues than those occurring during normal signal operation. The next step is to quantify the impact of the queues on LRT operations. The basic approach is to identify the frequency of back-to-back train arrivals, determine whether the back-to-back train arrival results in a static call, and finally, compare the back-to-back train static calls to the total number of static calls.

Back-to-back train arrivals are defined when the following three steps occur: (1) a train arrives at the intersection, (2) the signal returns to servicing surface street traffic, and (3) another train arrives in the opposing or same direction between 18 and 240 seconds after Step 2 began. Back-to-back train events occur in the same direction due to the time range (240 seconds) used to define a back-to-back train event and station

dwelling time randomness. Through operator control, Tri-Met can manually maintain the headways between trains thereby avoiding back-to-back trains in the same direction. The arrival of the second train in relation to the first train correlates to the length of queue. If the arrival of the second train coincides closely with the arrival of the first train, surface street traffic is not serviced (i.e., both trains use the same phase) and the two platoons have time to dissipate prior to the next (third) train arrival. This scenario established the lower limit, 18 seconds, of the range used to define a back-to-back train event. Similarly, if enough time exists between train arrivals, the queues formed by the first train also have time to dissipate prior to the second train arriving. Furthermore, longer times between trains allow the signal to recover and return to coordination, thus minimizing queue buildup. The upper limit, 240 seconds, is a conservative estimate of the time needed to dissipate a queue created by the first train and therefore not contribute to the queue created by the arrival of the second train. Therefore, any trains placing a call between 18 and 240 seconds of each other were considered to create a back-to-back train condition. The frequency of back-to-back train arrivals is summarized in Table 3.

Table 3. Back-to-Back Train Data at 10th Avenue

Run	A.M.-Peak Period					P.M.-Peak Period				
	Total Trains		Back-to-Back Trains	Back-to-Back Trains Resulting in a Static Call	Total Static Calls	Total Trains		Back-to-Back Trains	Back-to-Back Trains Resulting in a Static Call	Total Static Calls
	WB	EB				WB	EB			
Total ¹	54	51	45	2	2	120	137	132	2	2
Avg. ²	5.4	5.1	4.5	0.2	0.2	12.0	13.7	13.2	0.2	0.2

1. Total is the sum over 10 simulation runs.

2. Average refers to average occurrences per run.

Note: More back-to-back train arrivals occur in the P.M.-peak period than the A.M.-peak period since train headways are shorter and the simulation period is two hours compared to one hour for the A.M.-peak period.

The single most important finding presented in Table 3 is all static calls occur during back-to-back train arrivals. Increasing the time between back-to-back trains could reduce the frequency of static calls. Consequently, LRT delay could be reduced along with the frustration LRT passengers may experience having to stop at a signal.

Therefore, based on the findings presented above, it appears feasible to implement LRT preemption across 10th Avenue on opening day 1998. With the future increase of traffic volumes as well as LRT train frequency, negative impacts on traffic and LRT operations may make LRT preemption unfeasible.

Operational Impacts of Mid-Block Left Turns

Mid-block left turn traffic entering and exiting driveways along Washington Street is insignificant. The highest hourly mid-block left turn volume from a single driveway was 11 with the next highest being five. To capture the impact of mid-block left turns on

LRT operations, the average number of times an LRV stops for mid-block left turns blocking the tracks was recorded. Results are shown in Table 4.

The above results indicate that mid-block left turns have little to no impact on LRT operations. It is important to note that driveway volumes were collected during 1998. Driveway volumes were held constant from 1998 to 2000. Future development may increase mid-block left turn volumes on Washington Street although the City of Hillsboro will typically require new developments to only have access (via driveways) to north/south streets when feasible. If this scenario were to occur, the impacts of mid-block left turns on LRT may be quite different from those impacts reported here.

Table 4. LRT Stops Due to Mid-Block Left Turn Traffic¹

Location ²	Direction	A.M.-Peak	P.M.-Peak
Adams – 1 st	EB	0.0	0.0
	WB	0.2	0.0
2 nd – 3 rd	EB	0.0	0.1
	WB	0.0	0.0
4 th – 5 th	EB	0.0	0.1
	WB	0.0	0.0
5 th – 6 th	EB	0.0	0.0
	WB	0.0	0.0
6 th – 7 th	EB	0.0	0.0
	WB	0.0	0.0
9 th – 10 th	EB	0.0	0.0
	WB	0.0	0.0

1. LRT stop data is averaged over 10 simulation runs (average stops/LRV).
2. These locations are the only locations with driveway traffic that crosses the tracks.

Queue Spillbacks on 10th Avenue from Washington Street

Concern about queue spillbacks on 10th Avenue at Washington Street into adjacent intersections resulted in the question:

How often and for what duration do queues originating on 10th Avenue at Washington Street back into adjacent intersections?

Queues could extend into the intersections at Main Street and Baseline Street thereby leading to increased delays and potential gridlock. The effect LRT has on 10th Avenue queues, beyond that already discussed, is analyzed in VISSIM. Loops are placed on the departures from Main Street (southbound) and Baseline Street (northbound) heading toward Washington Street. Frequency and duration of loop occupancy are measured at these locations for the before and after LRT conditions. Results are shown in Table 6.

In all cases, queue spillbacks are more frequent after LRT is implemented. The greatest change is seen on the southbound approach to Washington Street where the frequency of spillbacks into Main increases from 1.5 to 7.2 during the P.M.-peak period.

Only a slight change in queue spillback duration is seen after LRT begins operation. The queues last between 0.5 and 2.6 seconds longer after LRT is implemented. On the southbound approach to Washington Street, however, the queue duration actually decreases by 2.8 seconds. The relatively small change in spillback duration is explained by the randomness of traffic arrivals. Therefore, concluding that any change in spillback duration is attributable to LRT is not possible.

Table 5. Queue Spillbacks on 10th Avenue from the LRT Tracks to Main Street and Baseline Street

Run	Main ¹				Baseline ²			
	Avg. Frequency During Peak		Avg. Duration During Peak (seconds)		Avg. Frequency During Peak		Avg. Duration During Peak (seconds)	
	w/o LRT	w/LRT	w/o LRT	w/LRT	W/o LRT	w/LRT	w/o LRT	w/LRT
A.M.	0.5	1.1	7.2	9.8	0.0	0.3	0.0	0.5
P.M.	1.5	7.2	12.5	9.7	0.0	1.6	0.0	1.8

1. Main is the closest signalized intersection north of LRT tracks.
 2. Baseline is the closest signalized intersection south of the tracks.
- Note: The results are based on averages over 10 simulation runs.

6. FINDINGS

The primary findings that emerged from analyzing the traffic impacts of LRT in downtown Hillsboro include:

1. Full LRT signal priority (i.e., preemption) is possible under current LRT headways and traffic volumes.
2. With the future increase of traffic volumes as well as LRT train frequency, negative impacts on traffic at 1st, 6th, and 10th Avenues and LRT operations may make LRT preemption unfeasible.
3. Implementing LRT typically produced a slight increase in average intersection delay (not greater than 5.0 seconds/vehicle).
4. Back-to-back train arrivals compounded queue spillbacks at downstream signalized intersections which actually lead to increased LRT delay.
5. LRT causes maximum queues to exceed storage capacity on 1st, 6th, and 10th Avenues. A few locations along 10th Avenue, however, experience queues exceeding the available storage prior to LRT implementation.
6. Queues on 10th Avenue at Main Street and Baseline Street back across the LRT tracks

7. RECOMMENDATIONS

Based on the LRT simulation results, it is recommended to implement LRT preemption at all intersections on Washington Street on opening day 1998. With the future increase of traffic volumes as well as LRT train frequency, negative impacts on traffic and LRT operations may make LRT preemption unfeasible. It is therefore recommended to develop appropriate mitigation measures that can be applied in the future when traffic and LRT impacts reach unacceptable levels. Potential mitigation measures could include:

- Inhibiting consecutive preemption calls in the signal controller (via a user-definable time period) to prevent back-to-back train scenarios.
- Inhibiting preemption calls in the signal controller during certain portions of the signal cycle (user-definable) to prevent 10th Avenue northbound and southbound platoons from being cut off at Washington Street.
- Granting full preemption only to eastbound trains to prevent back-to-back train scenarios.
- Continue the process started by City of Hillsboro and Tri-Met at Washington Street to widen southbound 10th Avenue to three lanes.

In order to implement the first three potential mitigation measures, a signal for the LRT operator could be installed at the respective upstream stations. Through hardware and software, the station signal display would be interconnected with the intersection signal controller thus informing the operator when to depart.

Additional recommendations include:

- Investigate the use of 2070 controllers and software to more efficiently accommodate LRT and traffic.
- Develop solutions to address the capacity deficiencies observed at 10th Avenue and Main Street.
- Restripe southbound 10th Avenue at Baseline Street to provide an exclusive right turn lane.

Develop Intergovernmental Agreements (IGAs) among the City of Hillsboro, ODOT, Tri-Met, and Washington County that establishes a collaborative process to identify transportation problems regarding LRT and to select mitigation measures. Partners in the IGAs would vary according to the roadway experiencing a problem.

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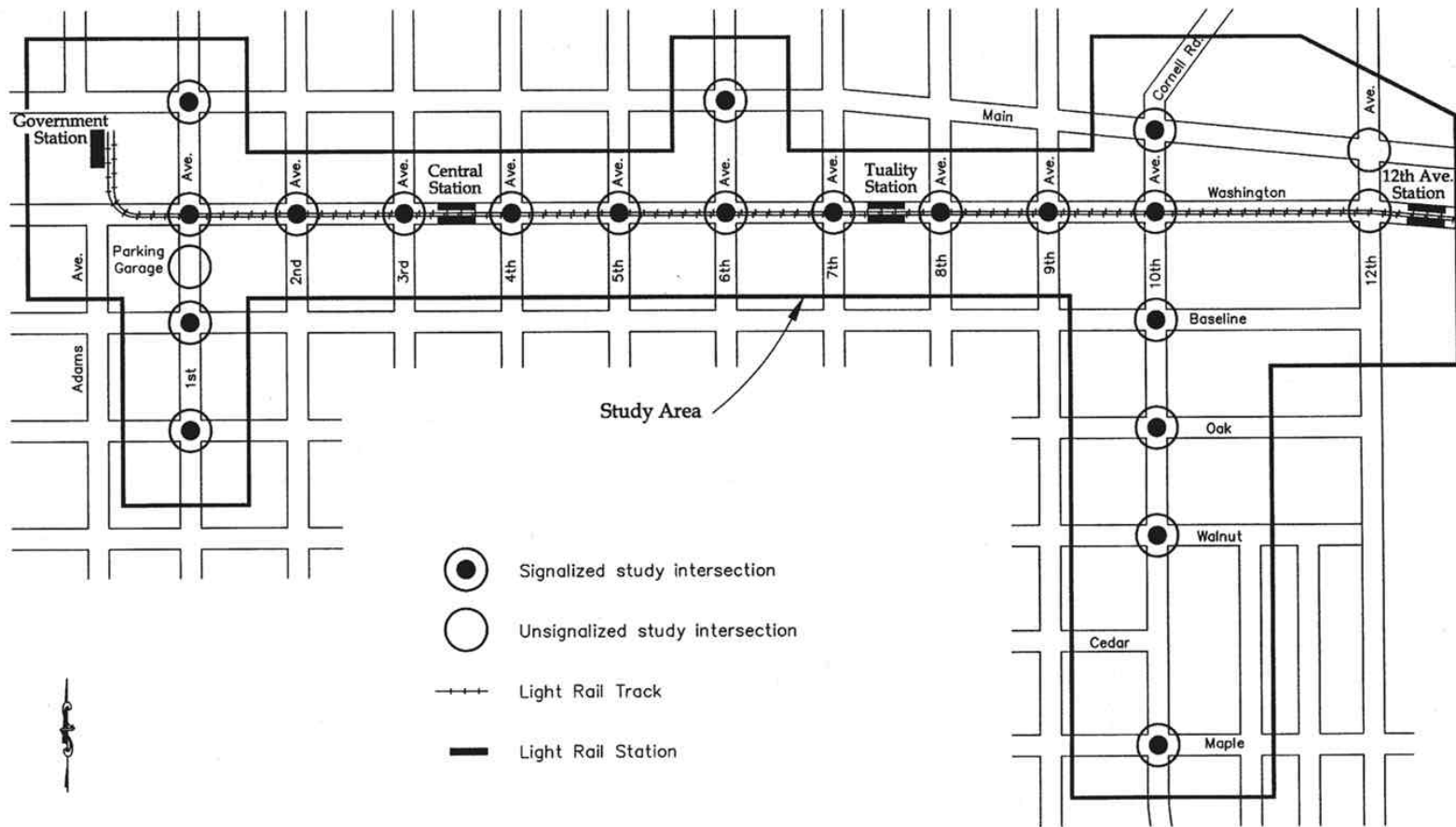


Figure 1. Hillsboro, Oregon Study Area

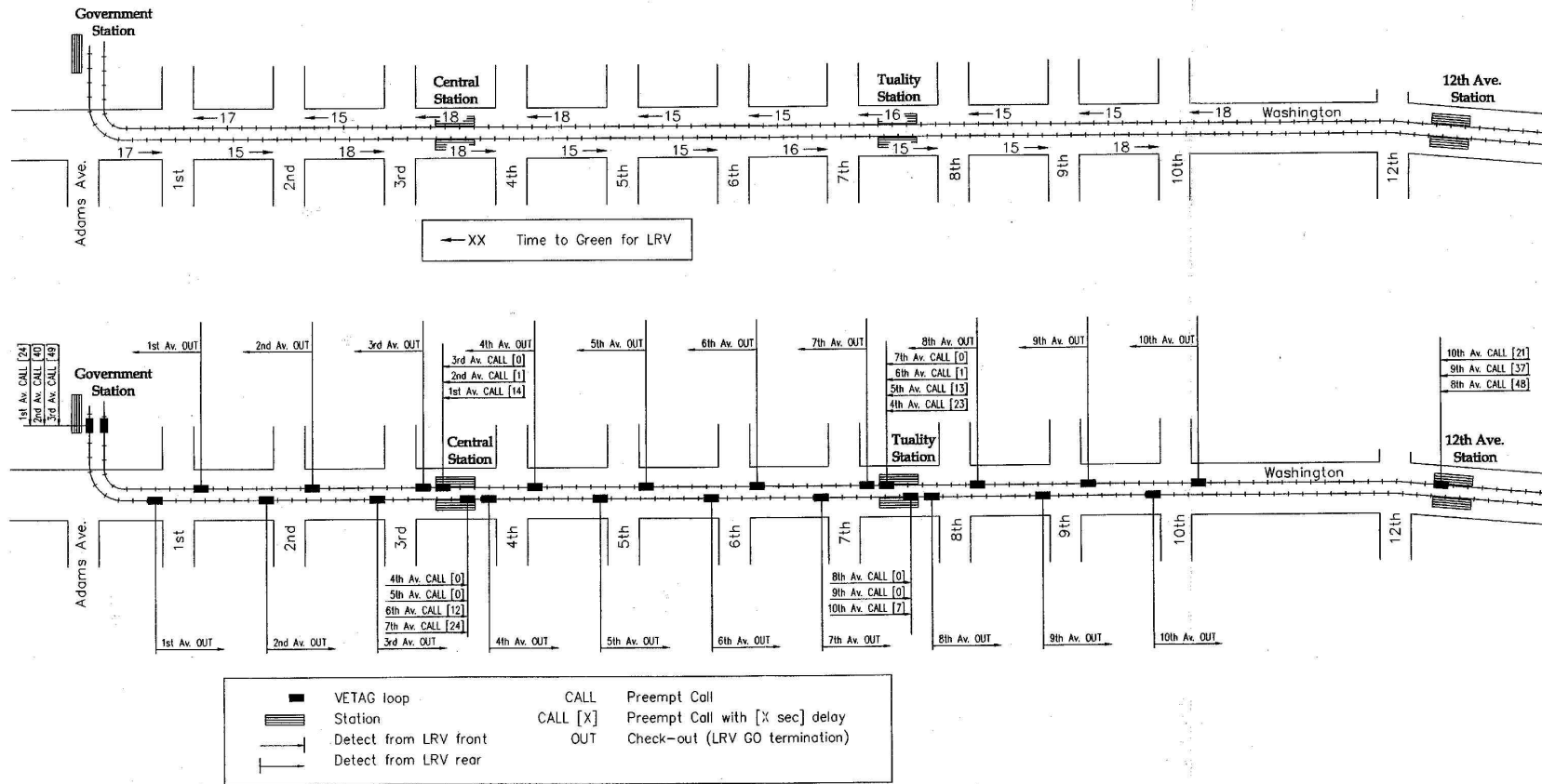
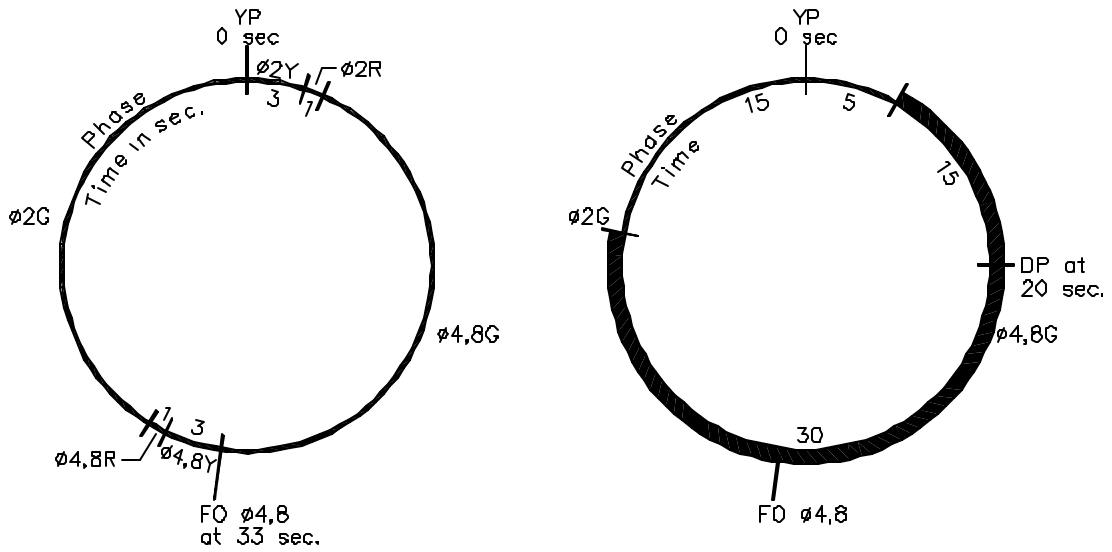


Figure 2. LRT Detection Locations and Transit Signal Priority Parameters



Washington St. at 7th St.

- C = Cycle length 65 seconds
 - YP = Yield Point (local time = 0)
 - FO = Forceoff
 - ØX = Phase numbers(s)
 - Ø2Y = Amber Ø2
 - Ø4R = Red clearance Ø4
 - DP = Dwell Point = 20 seconds past Yield Point
 - DT = Dwell Timer = 15 seconds
- If LRV checkout occurs in this area, controller rests in return phase, phase 2, until YP is reached.

Figure 3. Dwell Point Example