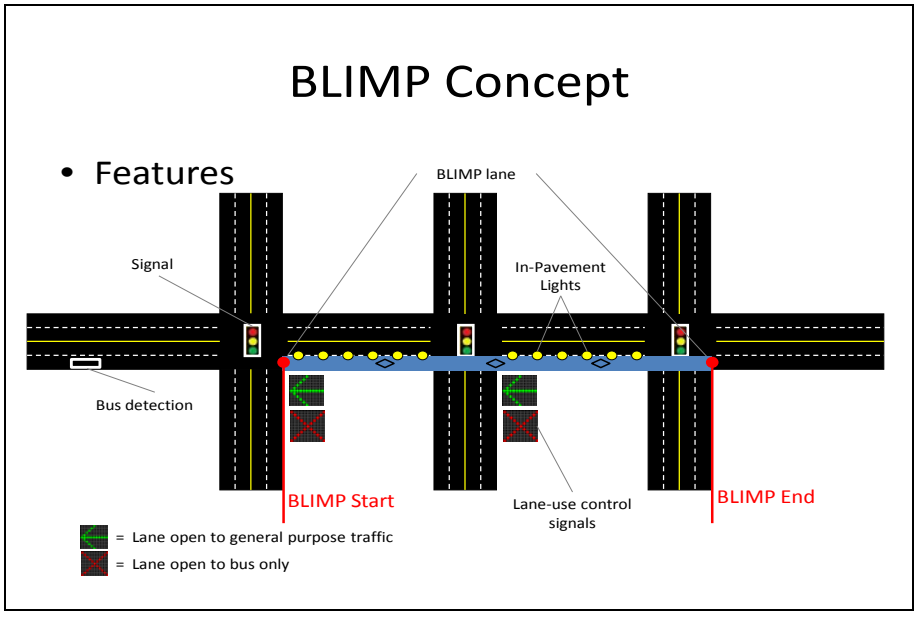
U.S. Department of Transportation
Federal Transit Administration

Bus Lane with Intermittent Priority (BLIMP) Concept Simulation Analysis

Final Report: November 2009

Report Number: FTA-FL-26-7109.2009.8



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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE November 2009	3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE Bus Lane with Intermittent Priority (BLIMP) Concept Simulation Analysis	5. FUNDING NUMBERS FL-26-7109
6. AUTHOR(S) Graham Carey, PE, AICP Thomas Bauer, PE, PTOE Karen Giese, PE	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Bus Rapid Transit Institute Center for Urban Transportation Research University of South Florida 4202 E. Fowler Avenue, CUT100 Tampa, FL 33620	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Transit Administration, Office of Research, Demonstration and Innovation (TRI) 1200 New Jersey Avenue, SE Washington, DC 20590	10. SPONSORING/ MONITORING AGENCY REPORT NUMBER FTA-FL-26-7109.2009.8
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT **Available From:** National Bus Rapid Transit Institute, Center for Urban Transportation Research, University of South Florida, 4202 E. Fowler Avenue, CUT100, Tampa, FL 33620 Also available through NBRTI web site: http://www.nbrti.org	12b. DISTRIBUTION CODE

13. ABSTRACT The Lane Transit District, in cooperation with the National Bus Rapid Transit Institute (NBRTI) at the University of South Florida, completed a preliminary implementation study to determine the potential impacts of a new and innovative transit priority treatment along a BRT corridor in Eugene, Oregon. The bus lane with intermittent priority (BLIMP) utilizes dynamic lane assignment to designate an exclusive bus lane on a temporary, bus-actuated basis. The temporary lane is designated via overhead variable message signs and in-ground dynamic lane markings.

With no existing reference, PTV America, Inc. undertook the development of a VISSIM microscopic traffic and transit simulation model for the study corridor in Eugene, Oregon. The simulation model was used to identify potential benefits and disadvantages of the BLIMP concept and to compare BLIMP to other potential BRT treatments including no-build, transit signal priority, and exclusive bus lanes. The results indicate that travel time and travel time reliability would improve upon implementation of the BLIMP concept while having minimal impact on overall intersection delay. Additionally, evaluation of movement delays indicated that concurrent movements would see improvement while conflicting movements would see minimal change with the BLIMP concept.

14. SUBJECT TERMS Bus, Intermittent Priority, Transit Signal Priority, TSP, Bus Rapid Transit, BRT	15. NUMBER OF PAGES 23
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

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Bus Lane with Intermittent Priority (BLIMP) Concept Simulation Analysis

Funded by the Federal Transit Administration

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Final Report: November 2009

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1. Executive Summary

Lane Transit District, in cooperation with the National Bus Rapid Transit Institute (NBRTI) at the University of South Florida, completed a preliminary implementation study to determine the potential impacts of a new and innovative transit priority treatment along a BRT corridor in Eugene, Oregon.

The bus lane with intermittent priority (BLIMP) utilizes dynamic lane assignment to designate an exclusive bus lane on a temporary, bus-actuated basis. The temporary lane is designated via overhead variable message signs and in-ground dynamic lane markings. This concept has been considered by many agencies but has been implemented in only two locations worldwide, with each application differing in their overall objectives and parameters. The LTD implementation would be yet again another variation and, therefore, a new concept with no existing reference for potential benefits and issues.

With no existing reference, PTV America, Inc. undertook the development of a VISSIM microscopic traffic and transit simulation model for the study corridor in Eugene, Oregon. The simulation model was used to identify potential benefits and disadvantages of the BLIMP concept and to compare BLIMP to other potential BRT treatments including no-build, transit signal priority, and exclusive bus lanes.

The BLIMP concept can be envisioned as a transit preferential technique within the continuum of measures which range from transit signal priority to an exclusive lane. The principal difference between these measures is the degree of priority assigned to the transit vehicle. With signal priority the time assigned to the transit vehicle is very small, whereas with the exclusive lane priority is continuously available. In the BLIMP concept priority is assigned only when needed; however, as the amount of priority is increased the concept starts to exhibit the characteristics of an exclusive lane. The trade off between the benefits to transit and the impacts to general traffic and adjacent property needs to be assessed on an individual basis.

Based on the various levels of priority assumed, the exclusive transit lane provides the most significant improvement in transit travel times and travel time reliability. However, the BLIMP concept evaluation did show significant improvements, especially in the peak direction of travel. The results indicate that travel time and travel time reliability would improve upon implementation of the BLIMP concept while having minimal impact on overall intersection delay. Additionally, evaluation of movement delays indicated that concurrent movements would see improvement while conflicting movements would see minimal change with the BLIMP concept.

Further evaluation of variations on the BLIMP concept indicated that a left-lane BLIMP would operate similarly to the right-lane BLIMP within the BLIMP corridor limits but the right-lane BLIMP requires no lane changes at the entry/exit and, thus, reduces/eliminates friction at these points.

Additionally, reduced driveway activity shows that the potential benefits of BLIMP approach the benefits of an exclusive transit lane as controlling ingress and/or egress at driveways provides additional improvements in transit travel times and standard deviations.

This study has demonstrated that the BLIMP concept can achieve significant benefits to transit with few impacts to traffic flow and adjacent property. LTD should continue to assess implementation of this technique. This could include further analysis of BLIMP variations, evaluation of the most appropriate treatment of driveway vehicles during BLIMP activation, and treatment at each end of the BLIMP corridor to provide the appropriate gap for the transit vehicle.

LTD could then move forward to evaluate technology available and the functional design and cost estimates.

In addition to moving forward with the implementation plan, this study also highlighted potential future research regarding the BLIMP concept, including evaluation of various corridor characteristics (traffic volumes, bus stop spacing and/or bus dwell times, bus volumes, etc) and evaluation of the ideal length of BLIMP activation preceding the bus, which may be affected by factors such as travel speeds, congestion, and/or bus stop spacing.

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2. Introduction

The National Bus Rapid Transit Institute (NBRTI) at the University of South Florida in partnership with Lane Transit District (LTD) undertook a study to determine the benefits of a new and innovative bus rapid transit (BRT) treatment concept that provides transit preferential treatment when needed called Bus Lane with Intermittent Priority (BLIMP).

Operationally, BLIMP is an exclusive bus lane that is provided on a temporary, bus-actuated basis via overhead variable message signs and in-ground dynamic lane markings. The concept also compliments this technology with active signal control intervention to better facilitate the discharge of traffic from the BRT lane in the event of an approaching bus.

Only two other similar applications exist, including an Intermittent Bus Lane (IBL) in Lisbon, Portugal and a Dynamic Fairway in Melbourne, Australia which adapts the IBL to suit the Melbourne tram system.

PTV America, Inc. undertook the development of a VISSIM microscopic traffic and transit simulation model along a potential EmX BRT corridor in Eugene, Oregon. The simulation model was used to identify potential benefits and disadvantages of the BLIMP concept and to compare it to other potential BRT treatments including transit signal priority and exclusive bus lanes.

3. Research Problem

The BLIMP concept is a new and innovative transit preferential treatment based on the concept of dynamic lane assignment. Although the concept has been discussed by many agencies it has only been implemented in two locations worldwide and each of those applications was different in their overall objectives and parameters. The BLIMP implementation for Lane Transit District would be yet again another variation and therefore a new concept that has no existing reference for potential benefits and issues.

The BLIMP concept can be envisioned as a transit preferential technique within the continuum of measures which range from transit signal priority to an exclusive lane. The principal difference between these measures is the degree of priority assigned to the transit vehicle. With signal priority the time assigned to the transit vehicle is very small, whereas with the exclusive lane priority is continuously available. In the BLIMP concept priority is assigned only when needed; however, as the amount of priority is increased the concept starts to exhibit the characteristics of an exclusive lane.

One of the key difficulties that transit agencies have had to face has been that there has not been any practical way of assessing the effectiveness of the technique. Most commonly used microscopic models have not been able to effectively simulate the logic needed to assess the technique.

Prior to implementation, LTD sought to determine the most appropriate treatment for the study corridor, which included determining the potential benefits and costs of the BLIMP compared to other likely treatments.

To quantify and compare the benefits of each type of treatment, the microscopic traffic and transit simulation model VISSIM was used. Additional scripts were developed to enable VISSIM to model and simulate real world conditions. First, a base model was built and calibrated for the study corridor. Then, specific treatments were applied and modeled as scenarios. Finally, the simulation models were run, measures of effectiveness generated, and the results compared for the treatments.

4. BLIMP Concept

The concept of BLIMP is to provide an exclusive bus lane on an as-needed basis. Therefore, the traffic lane remains open to general purpose traffic but when a bus is detected, the lane becomes a temporary exclusive bus lane. The BLIMP is dynamic in time and distance, requiring infrastructure such as overhead signing, in-pavement lights, and bus detection to detect the location of the bus and change the designation of the lane as the bus is approaching and while the bus is present. Once the bus passes through, the lane will open up to general purpose traffic again until the next bus is detected. This continues along the corridor as the bus moves and is sometimes referred to as a “moving bus lane”.

Two variations of this concept have been implemented in Melbourne, Australia and Lisbon, Portugal. Their specific operations are described below.

4.1. Melbourne, Australia

The first application of the dynamic lane concept was introduced in Melbourne Australia in 2001. This application provides transit preferential treatment for a streetcar system running along a 1.3 mile section of Toorak Road. The system is a peak period/ peak direction system on a four lane arterial with the streetcars running in mixed traffic in the inner lanes. As turning traffic (in this case right turns) is a major impediment to the operation of the street car, the traffic signal system provides additional clearance time to clear the turning vehicles before the street car arrives. Currie and Lai (1) provide a more detailed description of the operation. Whilst a thorough evaluation of the system has yet to be undertaken, preliminary results indicate that streetcar speeds have improved in both the morning and afternoon by 10% and 1% respectively.

4.2. Lisbon, Portugal

The first application of the technique using buses is on the Alameda da Universidade in Lisbon, Portugal. It consists of a 0.5 mile section of a one-way street. Using a combination of overhead variable message signs and in-pavement lights the right hand lane of the roadway is cleared for the bus. Since its inception in 2005 the system has resulted in an average increase of 20% in bus speeds, with gains as high as 50% recorded in the peak period (2).

Exhibit 1. Intermittent Bus Lane Overhead Signs and In-Pavement Lights in Lisbon, Portugal

(Photos taken from Viegas et al, 2007)

When the IBL becomes active, general purpose traffic is allowed to continue traveling along the IBL but no traffic is allowed to enter or change lanes into the IBL.

4.3. BLIMP Operations in Eugene, Oregon

The BLIMP concept that was modeled in Eugene, Oregon is a variant of the IBL implemented in Lisbon, Portugal. Similar to the IBL, the BLIMP concept will detect buses approaching specific sections of the corridor and will "activate" the BLIMP using overhead signs and in-pavement lighting. As the bus passes through, the BLIMP will be clear of most general purpose traffic. After the bus has passed, the BLIMP will open back up to general purpose traffic.

Unlike the Lisbon, Portugal IBL, traffic will be forced out of the lane when it is activated. The specific operations of the BLIMP concept implemented for this project are as follows:

1) During normal traffic operations, both lanes would be open to general traffic and neither the dynamic overhead lane control devices nor the in-pavement lights would be activated.
2) As a bus is traveling along the BLIMP lane, the overhead lane control signs and in pavement lights will be activated based on the location of the bus.
3) As the bus approaches the entrance of the BLIMP section, detectors will activate the BLIMP for 1,400 feet ahead of the bus.
4) This 1,400-foot section of activated BLIMP ahead of the bus will be cleared of general purpose traffic. Vehicles will be required to attempt to change lanes from the BLIMP lane or drive forward beyond the end of the BLIMP section.

5) Bus detection along the BLIMP section will either occur on a continuous basis or through closely spaced (100 foot) point-specific detectors.

6) In-line lane markings and overhead signs will open up each section to general purpose traffic once the bus has cleared.

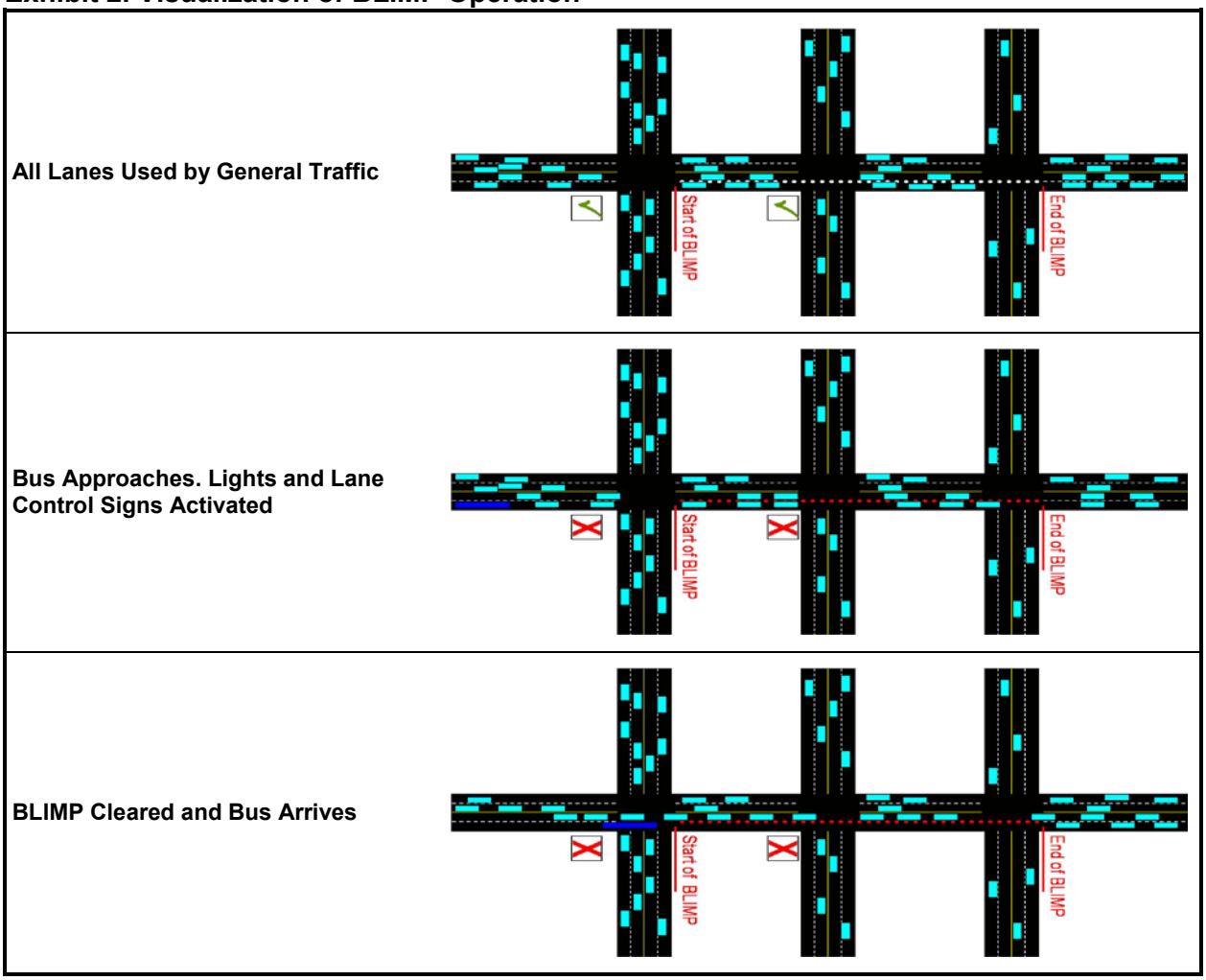
7) As the bus reaches an intersection, another 700-foot section of the BLIMP in front of the bus is activated. This allows the bus to travel with minimal impedance with BLIMP sections activated up to 1,400 feet in front of the bus.

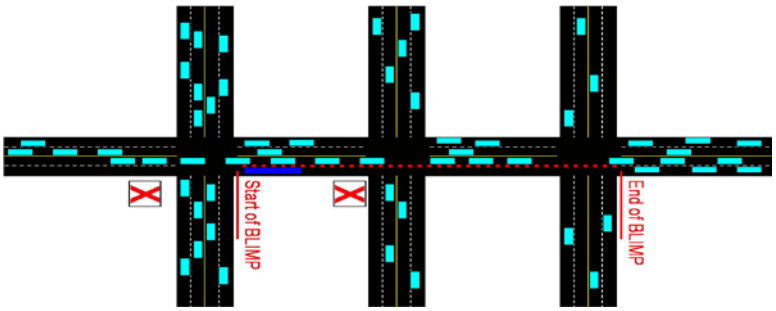
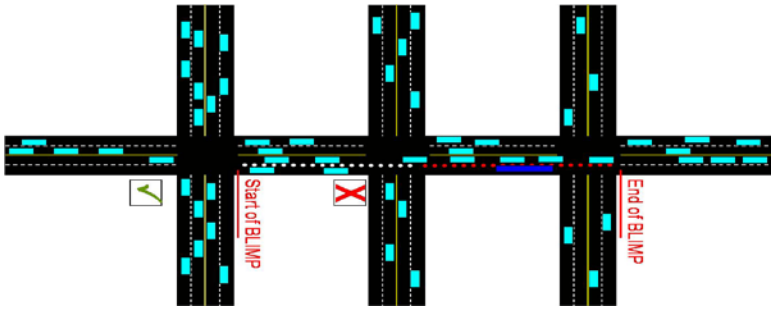
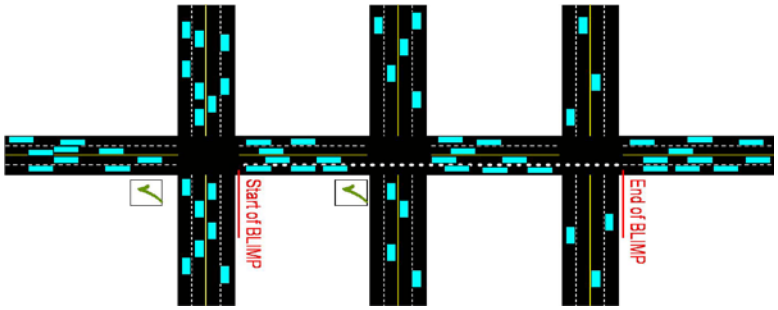
8) This continues until the bus reaches the end of the BLIMP section.

9) The BLIMP lane then returns to normal traffic operations and is open to all general traffic until the next bus enters the section.

The BLIMP operation is illustrated in the following exhibit.

Exhibit 2. Visualization of BLIMP Operation



Bus Travels in BLIMP	
Bus Passes One Block of BLIMP. One Block of BLIMP Opens to General Traffic.	
Return to Original State.	

5. Study Area

The BLIMP corridor under study is located in Eugene, Oregon along West 11th Avenue between Garfield Street and Bailey Hill Road, as shown in Exhibit 3.

Exhibit 3. Study Area

The corridor is approximately 1.2 miles and includes nine signalized intersections, as listed in Exhibit 4. It is a 5-lane cross-section with two travel lanes in each direction and left-turn lanes.

Exhibit 4. Signalized Intersection Listings

Signalized Intersection Name	Number of Approaches
Bailey Hill Road	4
Fred Meyer Access	4
Seneca Street	3
Tyinn Street	3
Oak Patch Road	3
Conger Street	4
McKinley Street	4
City View Street	3
Garfield Street	4

As shown in Exhibit 4, many of the study intersections have only three approach legs. Additionally, the study corridor is primarily commercial land uses with a high number of access driveways between each intersection and high driveway use.

6. Modeling Technique

The BLIMP concept was modeled using the VISSIM microsimulation software package and custom scripts to represent the BLIMP operations. The network was built in VISSIM using data provided by Lane Transit District for the four general categories:

1) geometry (lane configurations, turn bay lengths, crosswalks, speed limits);
2) volumes (hourly turning movements, pedestrians, heavy vehicle percentages);
3) transit (vehicle type, future BRT headway, stop locations, dwell time estimates); and
4) traffic control, including signal timing.

The model was built to represent the weekday PM peak hour for 2009 traffic conditions.

After building the base network in VISSIM, custom scripts were written in the Visual Basic language to allow the BLIMP operations to be modeled accurately. These scripts were then tied to the VISSIM simulation model through the COM programming interface. These scripts were used to a) control the lane closures as the BLIMP was activated and de-activated and b) control the 3D overhead signs for visualization. These scripts are described in more detail below.

6.1. BLIMP Corridor Operations Logic

As described above, for the LTD application, BLIMP activation requires that vehicles move out of the BLIMP lane (right lane) to allow the bus to continue with less impedance. In addition, vehicles that are turning right into a driveway or at a downstream intersection are still allowed to travel in the BLIMP lane. This was accomplished through a script that included two levels of logic: vehicle classification and dynamic lane closures.

6.1.1. Vehicle Classification

To distinguish between vehicles that are required to leave the BLIMP lane and those that are allowed to use the BLIMP lane, vehicles were classified dynamically as “BLIMP” or “Non-BLIMP” vehicles. A vehicle was considered a BLIMP vehicle if it was on a route to turn right into a driveway or at a downstream intersection. Non-BLIMP vehicles were those traveling through along the corridor and those entering the corridor from a driveway.

6.1.2. Dynamic Lane Closures

Dynamic lane closures were incorporated through the use of a series of major and minor detectors placed strategically in the network. Major detectors were placed every 700 feet in each direction and minor detectors were placed every 100 feet in each direction.

When a bus passed over the first major detector to enter the BLIMP section, the script logic used a series of lookup tables to apply lane closure to links for a distance of 1400 feet in front of the bus. The lane closure properties then closed the right-most lane to the Non-BLIMP vehicles identified above.

As the bus passed over a minor detector (every 100 feet), the preceding 100-foot section then was opened for all vehicles on all lanes. This allows the BLIMP lane to clear out ahead of the bus and allow vehicles to be able to utilize the lane as soon as the bus passes through.

6.1.3. Visualization

The script also included logic that changed the appearance of the links in VISSIM to distinguish between a "normal" section of roadway and a "BLIMP" section. Link display changed dynamically as the BLIMP lane "moves" along the corridor with a bus, which allows for a visual reference of the BLIMP dynamics through the simulation.

In addition to this visual reference, the 3D dynamic lane assignment signs were changed to reflect the open and closed status.

6.2. Model Assumptions and Limitations

In building the network model, assumptions were made based on guidance and discussion from Lane Transit District and stakeholders from the local jurisdictions. Driver behavior assumptions incorporated into the model included:

- driver population was primarily commuter drivers familiar with the corridor;
- drivers were relatively passive, especially when making a right-turn on red (RTOR) maneuver;
- pedestrians at intersections were included in the model; and
- no driveway volume data were available, therefore, it was assumed that approximately 60 ingress and egress movements occurred at each driveway.

It was also assumed, for the BLIMP scenarios, that the driver population would be educated to understand how to use the BLIMP system. Specifically, the model was built to reflect the following:

- drivers cooperated during BLIMP operations to allow vehicles to exit BLIMP lane and enter the remaining traffic lane;
- vehicles turning right into driveways and at intersections were allowed to use the BLIMP and entered approximately two blocks upstream of their turn; and
- vehicles exiting from driveways and entering the corridor during BLIMP operations entered the BLIMP lane then immediately looked for opportunity to exit the lane.

In addition to the assumptions, there were limitations to the model. Most importantly, for the BLIMP scenarios, there was no system in place to model this network after or to validate against. Therefore, operations under the BLIMP scenarios were based on anticipated behavior as listed above.

7. Scenarios

Several scenarios were modeled for comparison with Base operations as well as comparison to BLIMP operations. These scenarios were as follows:

1) Base Scenario: base conditions with no transit preferential treatments;
2) TSP Scenario: base model with transit signal priority (TSP) implemented;
3) BLIMP Scenario: BLIMP operations active with TSP; and
4) Exclusive Lane with TSP: an additional exclusive bus lane was added curbside (maintaining two general purpose traffic lanes in each direction) in both directions with TSP implemented.

It should be noted that one of the primary differences between modeled operations using a BLIMP and operations with an exclusive transit lane is related to the treatment of right turns at intersections and driveways and driveway egress. Of course any real-world implementation might differ from the operating assumptions made for this simulation analysis.

Under the BLIMP scenario, the BLIMP is still a general purpose travel lane until a bus approaches and activates the BLIMP. Therefore, if a vehicle is traveling in the right lane and the BLIMP is activated, they are able to remain in that lane and are not required to exit. To represent this, the model allows vehicles to enter and remain in the BLIMP lane for approximately two blocks upstream of their turn.

Under the exclusive transit lane scenario, the exclusive transit lane is not a general purpose lane and vehicles are not allowed to travel in this lane at all. Vehicles are allowed, however, to move into this lane to complete a right-turn movement either into a driveway or at an intersection. To reflect this more limited use of the right lane, right-turn vehicles in the model move into the exclusive transit lane approximately 100 feet upstream of their desired turn.

On the driveway egress movements, again, the BLIMP allows vehicles to utilize the lane so when vehicles egress from driveways, they enter the BLIMP lane first then, if they are in front of the bus in an active BLIMP, they exit that lane at their first opportunity. With an exclusive transit lane, vehicles are not allowed to use this lane for travel so on driveway egress, vehicles cross over the transit lane and enter directly into the right-most general purpose lane.

As LTD was also exploring variations on the BLIMP concept, four variations of BLIMP were modeled as well:

a) BLIMP in left-lane: the bus lane and associated stops were moved from curbside (right) lane to the left lane of traffic (stops would be in the median of street with buses equipped with doors on both sides of the vehicle);
b) BLIMP with No Drive Out: Egress from driveways was not allowed while BLIMP was active but ingress still allowed;

c) BLIMP with -50% drive: the number of ingress and egress maneuvers at driveways was reduced to reflect lower driveway activity along the BLIMP corridor; and

d) BLIMP with no driveway activity: ingress and egress to driveways was eliminated.

Each scenario was modeled in VISSIM and evaluated for the Weekday PM Peak Hour.

8. Evaluation

The simulation models for the four scenarios described above were run 10 times using 10 different random number seeds. The results were then averaged together and the following parameters were compared between scenarios:

- Transit Travel Time;
- Transit Travel Time Standard Deviation;
- Average Intersection Delay;
- Transit Concurrent Movement Delay; and
- Transit Conflicting Movement Delay.

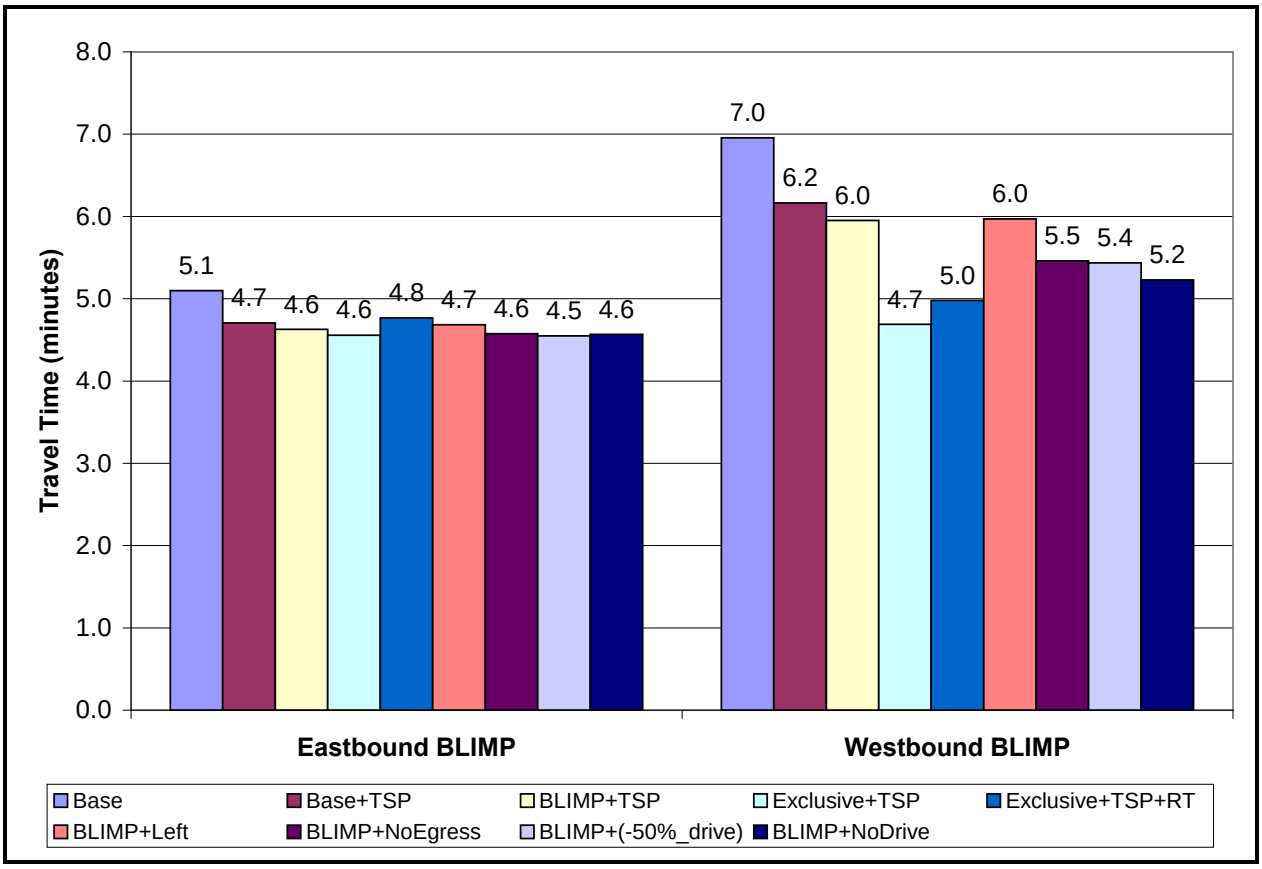
The following sub-sections highlight the results of the above analysis.

8.1. Transit Travel Time

The transit travel time is measured by computing the average travel times for the transit buses only. The travel times are reported in the eastbound and westbound directions for the length of the corridor between Bailey Hill Road and Garfield Street.

The results of the transit travel times are summarized in Exhibit 5 below with the four primary scenarios shown first followed by the variations on the BLIMP scenarios described above.

Exhibit 5. Transit Travel Times for All Scenarios



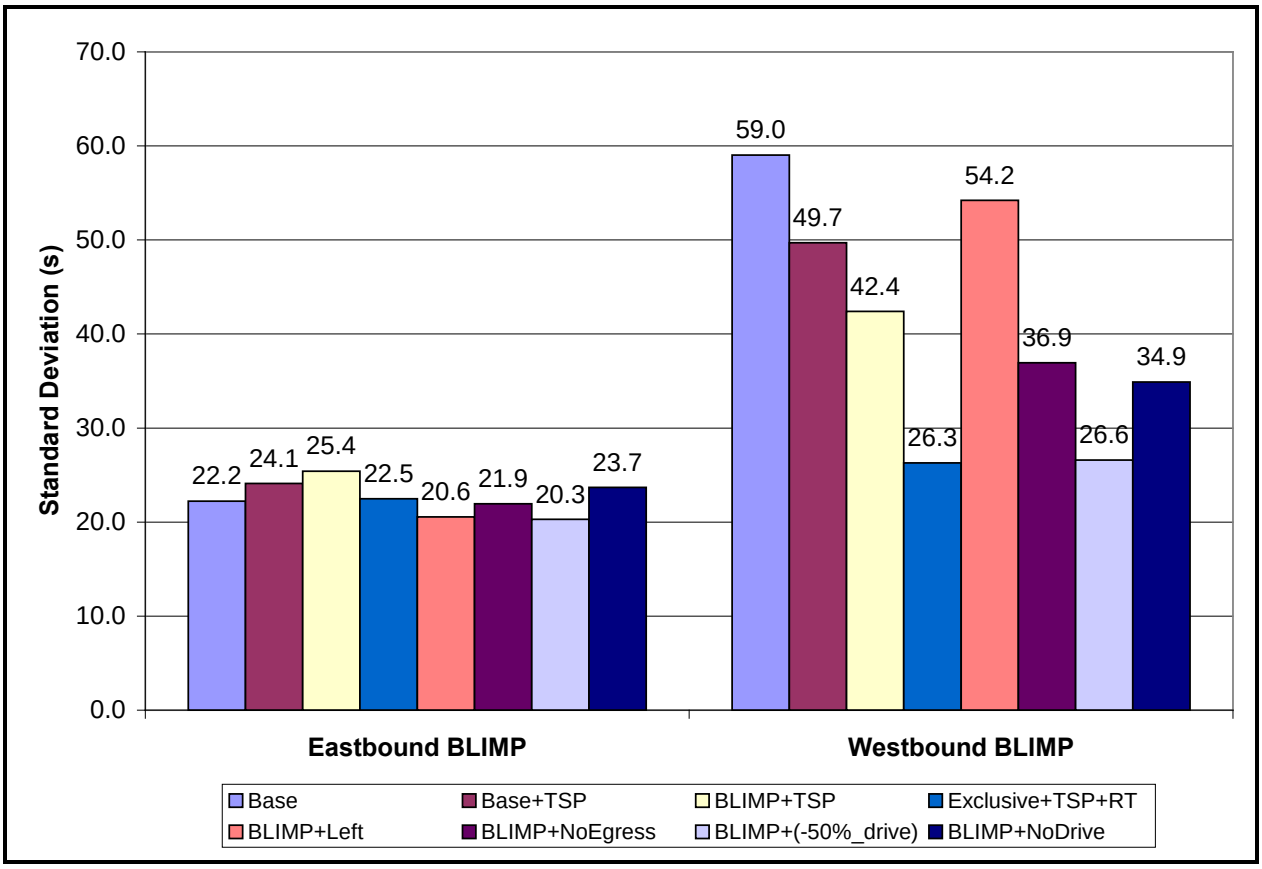
As expected, the transit travel times in the eastbound (off-peak) direction decreased slightly with the transit improvements. In the westbound (peak) direction, however, there was a significant decrease in transit travel time with each of the improvements. The addition of BLIMP results in a full minute (14 percent) reduction in the westbound travel time. The addition of an exclusive lane further decreases this travel time.

The results also indicate that changing the BLIMP to the left lane will produce similar benefits to the system as having the BLIMP in the right lane. Reducing the driveway activity or limiting it during BLIMP activation will further increase the benefits of the BLIMP to about the level of the exclusive lane scenario.

8.2. Transit Travel Time Standard Deviation

While transit improvements can decrease the transit travel time, another benefit is the potential decrease in travel time standard deviation. This is a measure of transit service reliability and is another key indicator of the effects of transit improvements. The travel time standard deviation changes for BRT vehicles along West 11th Avenue are summarized in Exhibit 6.

Exhibit 6. Transit Travel Time Standard Deviation for All Scenarios



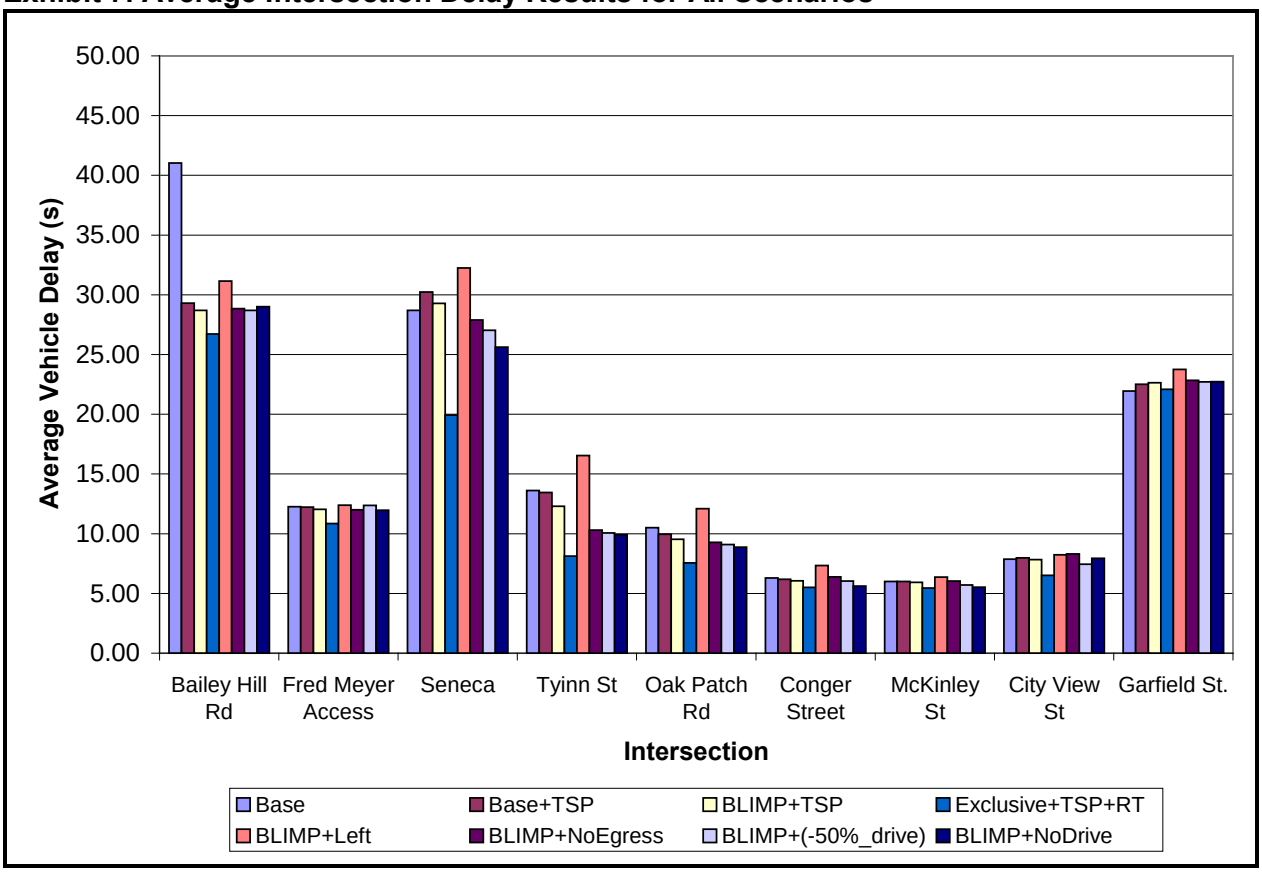
As shown in Exhibit 6, the eastbound (off-peak) direction shows very little change in the travel time reliability. The westbound (peak) direction, however, shows significant benefits with each of the transit improvements, with the exception of the scenario that operates the BLIMP in the left lane. As shown in Exhibit 5 above, this scenario has travel times consistent with other transit improvements but a higher standard deviation. This higher standard deviation in travel times is likely due to the entry treatment at each end of the study corridor as the bus must maneuver from the right lane to the left lane as it enters at Bailey Hill Road and Garfield Street and then has to maneuver back to the right lane as it exits the BLIMP corridor. Further evaluation of these entry treatments may result in a concept that would allow the BLIMP to transition between lanes more smoothly, thereby improving the reliability results for this scenario variation.

Similar to the travel times, the reduction in driveway activity also shows further improvements to the BLIMP operations, similar to those measured for the exclusive lane scenario.

8.3. Average Intersection Delay

This parameter is intended to assess the impact of the transit improvements at the intersection level. The results of this evaluation are shown in Exhibit 7 below for all scenarios.

Exhibit 7. Average Intersection Delay Results for All Scenarios



As shown in Exhibit 7 average intersection delay is generally not affected by the various transit treatments with the exception of the intersection of Bailey Hill where TSP treatment increases green time for the through movements and thus reduces overall intersection delay.

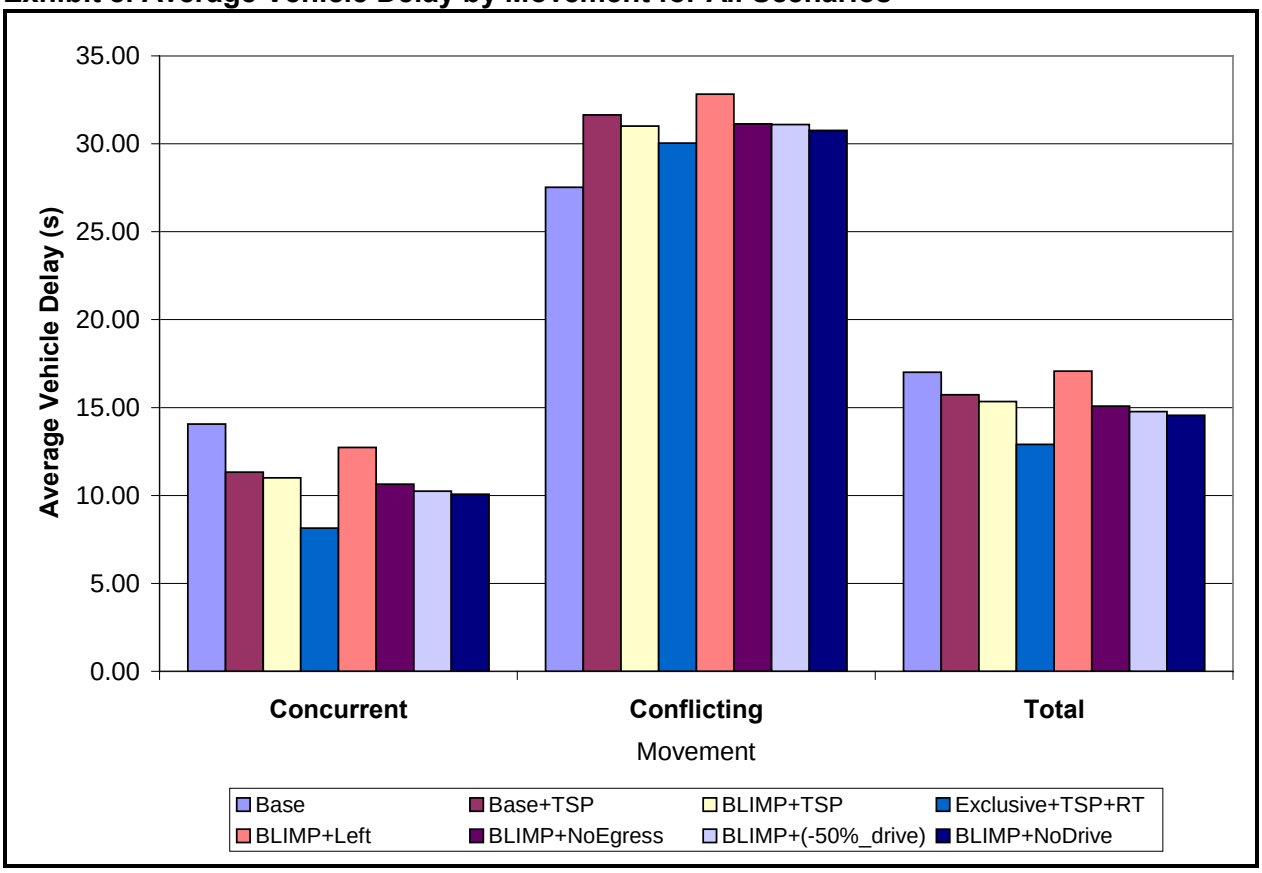
8.4. Transit Concurrent and Conflicting Movement Delay

The transit concurrent movement delay describes the benefit of the transit improvements to vehicles that move concurrently with the transit vehicles. In the case of providing TSP, as the green times increase to expedite the passage of transit vehicles, the buses as well as the traffic that move concurrently with the buses typically experience a delay reduction.

This parameter is typically one of the primary stakeholder interests regarding the impacts of transit improvements. The transit conflicting movements include all movements that cross the path of the transit vehicles. These movements primarily include the cross-streets and left-turns along 11th Avenue.

The results of both types of movements as well as the total average vehicle delay are summarized in Exhibit 8 below.

Exhibit 8. Average Vehicle Delay by Movement for All Scenarios



As shown in Exhibit 8, the concurrent movement delay decreases with the implementation of TSP and slightly more with the addition of BLIMP and the exclusive lane.

The conflicting movement delay, as expected, increases with the implementation of the transit improvements. All transit improvements include TSP which will result in a shift of green time from the conflicting movements to the concurrent movements.

Overall, it can be seen that there is very little difference in average vehicle delay between the four scenarios and the BLIMP variations.

8.5. Evaluation Summary

Based on the results above, as expected, the off-peak direction of travel (eastbound) would minimally benefit from any of the transit improvements evaluated. The more significant impact would be in the peak direction (westbound), where we see considerable improvements in travel time and travel time reliability for the transit vehicles.

The BLIMP concept, while not quite having the same effect as the exclusive transit lane, does show significant improvements especially in the peak direction of travel. This can be seen through the decrease in the travel time (60 sec / 14%) and improved reliability (17 sec / 28%)

reduction in travel time standard deviation). These impacts are further enhanced with the minimal impact on intersection delay. The BLIMP also showed minimal impact on overall delay with results indicating improvements to the concurrent movements and minimal change to the conflicting movements.

Evaluation of the variations on the BLIMP concept indicates that a left-lane BLIMP would operate similarly to the right-lane BLIMP along the BLIMP corridor. The primary difference between the two concepts is at the entry and exit of the BLIMP corridor as the right-lane BLIMP requires no lane changes and, thus, reduces/eliminates friction at these points.

The results indicate that with reduced driveway activity the potential benefits of BLIMP get close to the results of the exclusive lane scenario. As the results show, controlling ingress and/or egress provides additional decreases in bus travel times and travel time standard deviations due to the reduction in transit vehicle impedance as it travels the BLIMP corridor.

9. Conclusions

9.1. Next Steps

Lane Transit District is in the process of evaluating the results of this study and could decide to move forward with further consideration of the BLIMP. The next steps in this process could include:

- additional analysis;
- evaluating technology available;
- designing the signal interface to allow for activation of the BLIMP;
- functional design and cost estimates; and
- education and enforcement.

As part of this additional analysis, issues that arose during this evaluation should be addressed. Specifically, the most appropriate treatment of driveway vehicles during BLIMP activation and whether egress from driveways should be allowed and whether vehicles would use the BLIMP lane and/or an exclusive lane to make right turn ingress movements.

LTD could also evaluate the best treatment to implement at each end of the corridor in order to create the initial gap for the BLIMP and options for maintaining this gap along the corridor, such as disallowing egress from driveways during BLIMP activation.

9.2. Potential Future Research

The study described in the previous sections was the first study conducted to quantify the potential benefits of implementing BLIMP and to compare those benefits to the potential benefits of adding an additional exclusive transit lane in each direction. Based on the outcome of the evaluation, it may be beneficial to conduct additional research regarding the BLIMP. Potential future research includes:

- evaluation of the impacts of:
  - Traffic volumes,
  - bus stop spacing and/or bus dwell times,
  - bus volumes (e.g., headway),
  - pedestrian volumes at intersections, and
  - corridor length; and
- determination of the ideal length of the BLIMP activation in front of the bus and factors that may affect this length such as:
  - travel speeds,
  - congestion, and/or
  - bus stop spacing.

10. References

(1) Currie,G and Lai,H. Intermittent and Dynamic Transit Lanes. Transportation Research Record, No. 2072, 2008, pp.49-56.

(2) Viegas,J.M., R.Roque, B. Lu, and J. Vieira. Intermittent Bus Lane System: Demonstration in Lisbon, Portugal. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C, 2007

11. Metric/English Conversion Factors

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

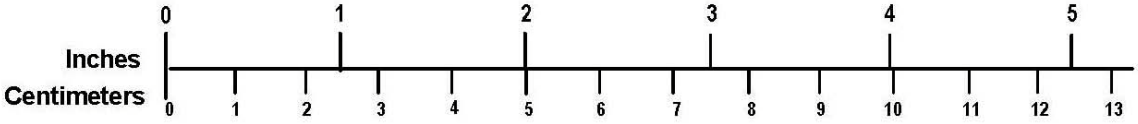
1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)

1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

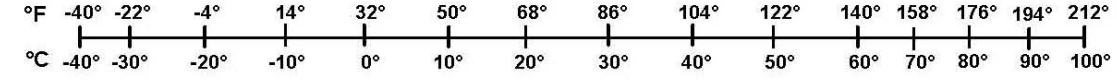
TEMPERATURE (EXACT)

[(9/5) y + 32] °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures.
Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98